ELECTRICAL SECTION.

Stated meeting held Tuesday, April 24, 1900.

ELECTRICAL MEASURING INSTRUMENTS.

BY J. FRANKLIN STEVENS.

In attempting a brief discussion of so broad and comprehensive a subject as that assigned me for this evening, I have been principally concerned in trying to decide just what portion of the general subject I should touch upon and in what manner I could treat that portion briefly, for I cannot hope to be comprehensive, and yet have my remarks present a semblance of coherence.

Since we have available a very extensive literature bearing on the subject of laboratory testing instruments, in which can be found descriptions of the instruments employed, their construction, application and approximate laws, I shall pass over that portion of the subject and confine myself to commercial direct reading indicating instruments, such as are to be found in every-day use.

The history of the art embodied in the commercial manufacture of indicating instruments is extremely interesting, but shows many analogies to the development of other branches of electrical engineering, with the single exception that practical data in published form is extremely scarce. Every one entering this field is compelled to master some of the most intricate problems known to the profession, and must learn for himself how best to apply theoretical deductions to practical mechanical devices. Until very recent years, our sole guide has been the study of early and primitive types which in their time were useful and valuable, but which to-day fail to reach the high standard we have learned to demand of an instrument whose function is to indicate the input or output of our many and varied electrical devices. Every new device put before the public has meant a new condition to be met by the instrument manu-

facturer, requiring of him a new design or modification of an existing design. Two rather recent examples of this occur to me: one, the increasing tendency to employ high voltages in commercial work, reaching frequently 12,000 volts in the case of series constant-current arc light systems and 33,000 volts in long-distance power transmissions; the other, the rapid development of the electric automobile, which requires a volt-ammeter of as high a degree of accuracy as the portable laboratory instrument, yet able to withstand the roughest usage ever accorded an instrument of precision, coupled with restrictive specifications as to size and weight. In every instance instrument manufacturers have met the demands made upon them better, I think, than many of our fellow-workers have in some other lines. Much yet remains to be done, and much, I am confident, will be done in the matter of perfecting existing instruments in the near future. Gradually inefficient or unreliable types are being relegated to oblivion, and the remaining ones brought closer and closer to standard uniform construction.

The greater number of measurements required to-day can be made with a voltmeter, ammeter and wattmeter, and, while it might be thought that the wattmeter is merely a combination of the voltmeter and ammeter mounted in one case, this is not true in all classes of measurement. While it is true that the reading of the wattmeter represents the product of the readings of the voltmeter into the ammeter in the case of direct current measurements, it is not true in the case of alternating current measurements, save in the very exceptional case of a circuit possessing neither capacity nor inductance or a balance of the two. When either inductance or capacity exist there is a consequent lag or lead of the current wave relative to the pressure wave, and, since the instantaneous readings of the volts and amperes represent the mean effective or virtual values, that is, the square root of the mean square, their product differs from the reading of the wattmeter, which indicates the integrated values of two curves, the maximum and minimum values of which occur at different times. To obtain an agreement

between the values obtained by volt-ampère readings and watt readings, it is necessary to multiply the volt-ampère readings into the cosine of the angle of lag or lead, so that the ratio of the watt readings, as given by a properly constructed wattmeter, to the volt-ampère readings gives us the power factor of the circuit, and from the two sets of readings we can readily determine the angle of lag or lead and the so-called wattless current. Probably this is well known to all of you, yet scarcely a week passes but I have to explain the matter to one or more customers who cannot reconcile the difference in the two sets of readings and are inclined to believe that some, if not all, of their instruments are indicating erroneously.

Before touching on the different types of indicating instruments which are most commonly found in commercial use, let us consider for a moment the essential requirements of a practical and satisfactory instrument for measuring voltage, current or power. To start with, the instrument must be direct reading. We have no time to-day to convert angular deflections into true values by means of tables of constants, but insist that the pointer shall indicate directly in definite units the value of the passing load or the impressed electro-motive force. We must next be assured of the accuracy of the calibration, and for that depend principally upon the reputation of the maker or check the indications by comparison with a secondary standard. Beyond this we must know that the accuracy of the indications is not affected by the influence of ordinary external fields or by normal variations of temperature, due either to heating within the instrument, by means of the passage of the current to be measured, or to variations in the temperature of the room in which they are installed. All instruments should be mounted in dust-proof cases, and the systems carried in jewelled bearings; the movement of the pointer should be aperiodic or dead-beat, and, so far as possible, the system should contain nothing subject to change or deterioration, and should be constructed so that it will withstand successfully the ordinary rough usage liable to be accorded it in practice. The question of gradual change of accuracy,

due to the change in some constituent part of the system, has led me to strongly advocate the use of electro-magnetic instruments with gravity control for switchboard use whenever the conditions render them applicable, and I fully expect to see this type of instrument become more popular as its advantages become more widely appreciated. Such a system is not applicable for portable instruments, save the dynamometer system for alternating currents, and even then a spring control must be used; nor is the series electro-magnetic ammeter practical above about 1,500 ampères, due to the structural difficulties involved in carrying the bus bars directly to the instrument terminals. The one objection most commonly urged against the electro-magnetic instrument for direct current switchboard use is the unequally divided scale, for, as a rule, the scale only covers a range starting at 10 per cent. of the total up to maximum. In most cases, however, this objection is purely captious, for a switchboard voltmeter is seldom used to indicate more than 10 per cent. above or below the normal voltage, and the ammeter indications are of principal importance in the higher ranges to prevent a possible overload of the circuit or generator. In alternating current circuits an equally divided scale is an impossibility, so why should we sacrifice constancy in direct current measurements for the sake of an equally divided scale when the lower registers are so seldom used? In portable direct current instruments the proposition is somewhat different, as we desire to cover the maximum limits of possible measurement on a single scale instrument; therefore, an equally divided scale is desirable and practically necessary.

Taking up now the different types of instruments which are in most common use, we find they may be roughly divided into six classes, depending on the principle by means of which measurements of voltage, current or power are made: (1) the hot-wire; (2) the tangent galvanometer; (3) the electro-static; (4) the dynamometer; (5) the D'Arsonval galvanometer and (6) the electro-magnetic.

The hot-wire instrument is designed to operate by the expansion of a fine wire or strip of conducting material

due to the heating produced by the passage of the current to be measured, and, therefore, the indications are proportionate to the square of the current. This type of instrument possesses the advantage of indicating with equal accuracy the current flow on either direct or alternating current circuits and is independent of the frequency of the circuit or of the shape of the current wave; it is, further, unaffected by the presence of external fields. These advantages, however, are all that can be claimed for this system, and to offset them are many serious disadvantages. Since the instrument operates by virtue of temperature differences, it is extremely susceptible to variations of external temperature, and such variations must be compensated either by mechanical means, which provide for bringing the pointer to zero by increasing or decreasing the tension on the working wire, or by providing auxiliary heating strips which are supposed to automatically adjust the tension of the working wire on the general principles of a thermostat. This may seem a small matter to most observers, but to me it signifies an error in principle, and reminds me of one of our early types of arc dynamos which, by reason of incorrect construction, was found to spark badly; so, in place of correcting the design, an air blast was provided to blow out the spark. Another point of objection is the constant change of zero, due to the fact that until the wire has been stretched to its elastic limit it will fail to return to the same point after having been stretched by the heat applied and will always show a slight residual strain. To attempt to correct this prior to installation in the instrument means, judging by my own experience, that at least 90 per cent. of the wires will break during the preliminary stretching process, and the remaining 10 per cent. will stand but a very slight overload in service. As overloads are quite common, this would constitute a serious objection, for it means the return of the instrument to the manufacturer for the insertion of a new wire and recalibration. Another very serious objection is the amount of current required to operate the instrument. The average resistance of a modern hot-wire voltmeter is 4

ohms per volt, which means a current flow of .25 ampère. This low resistance effectually bars this type of instrument for accurate testing, since the amount of power abstracted from the circuit to be tested vitiates the accuracy of the results obtained and introduces serious errors, which must be allowed for in all calculations. Recently an attempt has been made to introduce the hot-wire instrument as a shunt ammeter, particularly for alternating current measurements. As a shunt ammeter, the hot-wire instrument is a distinct failure, for, while the manufacturers claim it can be operated on a drop of .3 volt for full scale, my personal experience has shown a drop of 6 volts to be necessary. On the makers' figures, 300 watts would be required to operate a 1,000 ampère ammeter, nearly .4 horse-power per instrument, while on the sample I have tested 6,000 watts, or 8 horse-power, would be required. Again, it has been shown that these ammeters when calibrated on direct current are not accurate within 10 per cent. when used on alternating currents, unless the reactance in the shunt is exactly equal to the reactance in the instrument, a condition almost impossible to obtain, even with the most careful design.

A modification of the hot-wire system has been proposed, consisting of an enclosed chamber containing a fixed resistance wire, one end of the chamber, which is made air-tight, consisting of a flexible diaphragm operating the pointer through a system of levers. In this case, the heat supplied to the wire by the passing current causes the air in the enclosed cylinder to expand and, consequently, puts the diaphragm under tension, very much on the principle employed in the aneroid barometer. I find by actual experiment that such a system could be applied to voltmeters, and could be so made that it would be accurate in its indications and would possess a reasonably high resistance. The feature, however, which renders this system impracticable is the slowness with which the readings can be taken. The pointer will not come to rest until after the heat supplied the air enclosed within the chamber is equal to the heat radiated by the walls of the enclosing chamber, and from

one and a half to two minutes are required before the pointer will come finally to rest at the part of the scale marked to indicate the impressed E.M.F. This is true no matter how small the air chamber is made; and while it is possible to shorten this time by carefully covering the sides and one end of the cylinder by a heat insulating jacket, still it cannot be constructed so as to give an instantaneous reading, and every attempt to shorten the time by covering the walls of the chamber results in a corresponding increase of the time required for the pointer to come back to zero after current has been shut off. In other words, the instrument is similar in its action to an ordinary thermometer, which, as you know, cannot be made to respond instantly to changes of temperature.

Electro-static instruments, which depend for their action on the mutual attraction of two plates connected to the opposite sides of the line, are still used, but not extensively, for high tension measurements. They will indicate correctly on either direct or alternating current circuits, but are limited to measurement of voltage. It is impossible with this type of instrument to obtain a low reading, as the attraction of the plates toward one another varies approximately with the square of the potential difference between them. I say "varies approximately" advisedly, as the capacity of two plates varies directly with the square of the voltage only when the distance between the plates is maintained constant, which in this case is an obvious impossibility. As a rule, these instruments cannot be made dead-beat without introducing elements liable to seriously interfere with their accuracy; and, while there are no errors due to temperature changes, and while they are also extremely efficient, requiring no current flow at all, they are affected very considerably by external influences, particularly by static charges, which are almost invariably present in power stations or dynamo rooms, and, as you probably know, it is practically impossible to provide a shield for static effects.

Instruments employing the principle of the tangent galvanometer are still employed, and for certain classes of

measurements are extremely useful. They can be particularly recommended for use as ground detectors or differential voltmeters, where the actual value of the indicators is of small moment, the particular object being to show a balance of two opposing voltages or the presence of a ground by deflection. In this system the magnetized needle is suspended vertically, and is acted upon by two equally and oppositely wound solenoids; that is, the solenoids are wound with two wires in multiple and then cross-connected, so that we have two circuits equal in effect but opposite in action. I might say in passing, that if the proper proportions of solenoids to magnetized needle are employed, and the length of the magnetized needle properly proportioned to its area, the tangent galvanometer instrument may be made extremely accurate and also quite permanent. Care must be taken, however, that under no conditions can the direction of the lines generated by the solenoids oppose the lines existing in the magnetized needle, otherwise the value of the calibration is almost instantly destroyed.

For measurements of alternating current voltage, and also for the measurement of the watt output of any alternating current source of energy, the dynamometer system, in one of its many modifications, is unquestionably the best type of instrument that can be used. This instrument indicates directly the mean effective voltage of the line to which it is connected, and is equally accurate for direct current measurements, provided readings are taken with the direct current flowing through the instrument in one direction, then the direction of the current flow reversed and a second reading taken, the mean of the two readings being the correct value of the impressed electro-motive force. This for the reason that the instrument is extremely susceptible to the influence of external fields. Further, the dynamometer type of instrument is only properly adapted for use in portable instruments. The fact that two readings are necessary on direct current prohibits its use as a switchboard instrument on direct current circuits, and its delicacy, coupled with its field of low intensity and its sus-

ceptibility to error, due to the presence of iron in its immediate neighborhood, whether used on direct or alternating current circuits, renders it impracticable as a switchboard instrument for alternating current circuits. As an ammeter, it cannot be successfully employed for measurements above .5 ampère, due to the difficulty of providing perfectly flexible contacts capable of carrying large currents. When you attempt to convey a current into a moving coil beyond the carrying capacity of a flexible conducting spring, recourse must be had to mercury contacts, and a mercury contact should never be employed in a portable or enclosed type instrument. In the dynamometer instrument great care must be taken to have the moving coil as light as possible; and to render the instrument aperiodic, or dead-beat, an aluminum air vane, moving in a partially enclosed chamber, must be employed. Manually operated brakes acting on the delicate moving system should be avoided, as their continued use results in a serious derangement of the moving parts.

Instruments based on the principle of the D'Arsonval galvanometer are very extensively used to-day for both switchboard and portable instruments on direct current circuits; they can be calibrated so as to show an equally divided scale, and, if properly constructed, are an extremely efficient instrument. Further, they are very well adapted to the measurement of resistances and grounds. In the construction of this type of instrument the important factor is the permanency of the permanent magnet fields employed. It is essential, in the first place, that the proper grade and quality of steel shall be employed, which means a steel possessing high permeability and a high degree of retentivity; then this steel must be carefully worked within definite limiting temperatures and must be treated with great care and skill in the processes of magnetizing and ageing. Further than this, the moving coil should be extremely light and the whole system carefully shielded from the influence of external fields, and yet so shielded that the moving coil will not be robbed of an appreciable number of lines of force, due to the presence

of the shielding iron. The greatest field for this type of instrument is in the measurement of heavy currents; that is, for currents of 1,000 ampères and upwards, due to the fact that it can be operated as a shunt instrument, requiring an extremely small drop of potential, full scale being obtained with a drop of from '03 to '05 volt. This means a relatively high efficiency, and, while the instrument does not possess all of the advantages of a series ammeter, yet it is far easier to install, and, where a high degree of accuracy in current indications is not demanded, will be found very satisfactory in practice.

Further than this, the D'Arsonval instrument, which gives deflections directly proportionate to the current flow, lends itself readily to a large variety of measurements, such as determining resistances and measuring the drop of potential from which resistances and grounds may be readily computed. It is, however, a type of instrument which should be handled with great care, as rough handling or the presence of powerful external fields will permanently destroy the accuracy of its indications. Further, since it depends primarily for its continued accuracy on the maintenance of a field of uniform strength, as supplied by its permanent magnet field, instruments of this type should be frequently checked to ascertain whether the permanent magnets have maintained their initial strength.

A great deal might be said on the subject of the last type under consideration, namely, the electro-magnetic system, for there are probably more variations in practical construction contained in this type than in all the other types put together; some are good, many very bad. It is, however, unfair to adopt the policy of certain engineers, who unqualifiedly condemn every electro-magnetic instrument, solely and entirely on the grounds that they contain a moving mass of iron, which, in their opinion, must render the instrument subject to errors of lag and hysteresis. My practical experience with this type of instrument, covering a great many years, has taught me that it is perfectly possible to so construct an electro-magnetic instrument containing a mass of moving iron that errors of lag and hysteresis,

if they are present, are so small as to be negligible. In order to achieve this result it is necessary, first, to proportion every part of the instrument with reference to all other parts; to carefully shield the instrument from the influence of external fields, and this by means of a shield that will not introduce errors due to its own retentivity. The iron employed should be very small and very light, and should be selected, after careful test, for purity and absence of retentivity. It should then be formed up with care, and so treated that oxidation is practically impossible. The field due to the actuating solenoid should likewise be carefully studied, and should be designed so that the moving iron will at no time be completely saturated, and yet of sufficient strength, in conjunction with the shield employed, as not to permit the indications of the instrument to be seriously influenced by external fields. In no case should two masses of iron be employed, as is common in some types of instruments, which depend on the repulsion of a moving vane by a fixed vane of similar polarity, both being energized by the actuating solenoid. It is almost impossible to free double vane instruments from errors of lag or hysteresis, and there is a further tendency for the pointer to stand off zero, due to the residual magnetism mutually induced in the two vanes.

The fact that the instruments constructed on the electromagnetic principle contain no material subject to change or deterioration, coupled with the fact that they can be built solidly and substantially, and controlled by gravity in place of a spring or springs, renders them exceedingly reliable in practice. If their calibration is correct when first installed, there is no reason why the calibration should change with time.

In the above brief description of the most common types of indicating instruments, it may be noted that there is no one type which is universal, that is adapted for both switchboard and portable use for either direct or alternating current measurements. While we can very readily dispense with the hot-wire and electro-static instruments, the other four types are essential for some class of measurement, and

for any particular line of measurement the most suitable system should be selected. It is possible that some day a universal system may be found, but, until that time, the user must select from existing types the one which in principle seems most applicable, not only to the character of electrical energy to be measured, but, also, to the conditions under which measurement must be made.

There is no one line connected with the electrical industry in which so much attention must be paid to details as in the manufacture of electrical indicating instruments. A very prominent engineer remarked to me recently that he had examined the construction and operation of a great many different types of indicating instruments, and, while a number of them bore evidence of similarity in design and construction, yet, in some cases, the manufacturer seemed to have acquired the "trick" of proportioning, manufacturing and calibrating, while others utterly lacked the "trick." As a matter of fact, it is not altogether a case of acquiring the proper "trick," but is a case of studying the theory and design of instruments for a number of years, backed by a large and varied experimental experience, which marks to-day the difference between the successful and unsuccessful instruments in the various types commercially exploited. Account must be taken of the most petty details of construction, the most careful and skilled labor must be employed in each department, and every particle of material entering into the instrument must be carefully selected and tested with reference to its particular function.

Personally, I have seen the experiment tried of taking a finished and efficient instrument and placing it in the hands of a careful and skilled mechanic for duplication; every wire and every part would be, apparently, an absolute copy of the original, and yet the results obtained would be totally different. It follows, therefore, that it is always wise in placing orders for electrical instruments to select a house who have publicly demonstrated the fact that they have learned the necessary "trick" or "tricks" of their profession.

In no line does reputation count for more than in the

manufacture of indicating instruments, nor is there any line in which I have been brought in contact where it takes so long a time to establish a reputation. Further than this, there is no line in which a greater amount of patience is required by the manufacturer. The average purchaser is totally ignorant of the laws or principles embodied in the instrument he is using, and, without regard to the fact that he may have selected the wrong type for the particular class of measurement he wishes to make, unhesitatingly blames the manufacturer for not having known what he wanted and for not having supplied him with the proper type of instrument by pure intuition.

Another obstacle which is commonly met by instrument manufacturers is the fact that for the average installation he is required to furnish instruments delivered to the switchboard contractor, who may or may not handle the instrument properly. It is true that most instruments are sealed, yet it is perfectly possible to utterly ruin the calibration of almost any type of instrument by improper handling without destroying the seal or opening the case. For instance, if a D'Arsonval instrument is laid upon the frame of an actively excited dynamo or motor, its entire calibration will be almost instantly changed, and yet no external evidence is presented to show exactly what has happened. Rough handling and an occasional fall, or improper packing for delivery to the plant, may further operate to destroy the accuracy of the calibrated instrument; yet the manufacturer is expected to provide instruments which will stand such usage and which, after they have been installed, may be subject to the influence of such strong external fields or such high external temperature as to make their correct indications impossible; and, after all of this, must have his instruments accepted or rejected by the consulting or supervising engineer, who, on the day of the test, carefully checks them with his personal portable instruments, which are usually kept in almost ideal condition and seldom or never leave his immediate possession. Some day I trust these conditions may be modified to the extent that the engineer in charge will test and check the instruments, if

he doubts the accuracy of the maker's calibration, before the instruments are shipped; or else issue instructions that the switchboard shall be drilled from template and the instruments set in place by the engineer's own assistants. In several cases I have succeeded in having the latter course adopted, with the result of mutual satisfaction on part of the owner, engineer and ourselves.

If arrangements could be made to have all instruments installed under the supervision of the engineer in charge, it would then be quite sufficient to have the specifications state the limit of error allowed in the indications of the voltmeters and ammeters; and this information, coupled with a specification covering the style of case, character of scale, range and class of measurement to be made, would enable the manufacturer to make an intelligent tender for the instruments required in any installation.

While a high degree of accuracy is desirable in all indicating instruments, it is particularly important that the voltmeter should be right within at least 1 per cent., since a variation of 1 per cent. in voltage means a corresponding variation in the candle-power of every incandescent lamp which may be in circuit. It is quite well known that the candle-power of any incandescent lamp varies directly with the voltage, the variation being approximately 1 candle-power for every volt increase or decrease from the normal voltage of the system.

Further than this, a variation of 1 per cent. from normal voltage on a system carrying incandescent lamps means a variation of about 16 per cent. in the life factor of the lamp and about 3 per cent. in the watt consumption per candle-power. Errors in the indications of ammeters do not produce such serious results, yet it is desirable that they should be accurate in order to obviate the danger of overload on circuit, translating device, or generator; and in the case of test instruments, as high a degree of accuracy should be demanded as is required in the voltmeter.

While on the subject of accuracy of indications, I would like to impress upon you the fact that, while we have three electrical units in common use, namely, the volt, ohm and

ampère, the ohm and ampère are the only two fundamental units, the volt being a derived unit. The absolute ohm may be quite readily obtained, and, as you probably know, is defined by law as the resistance offered to an unvarying electric current by a column of mercury at the temperature of melting ice, 14.4521 grams in mass, of a constant cross-sectional area, and of the length of 106.3 centimeters. The ampère is likewise defined by law as the practical equivalent of the unvarying current, which, when passed through a solution of nitrate of silver in water in accordance with standard specifications, deposits silver at the rate of .000118 gram per second. The volt is defined as the electro-motive force necessary to send 1 ampère through 1 ohm. This, as you will note, gives us fundamental values for the ohm and ampère and defines the volt as a derived unit, and I am laying stress on the matter for the reason that the average electrical writer defines the volt as a fundamental unit equivalent to $\frac{1}{1.434}$ of the potential at the terminals of a standard Clark cell, and then defines the ampère as that current which 1 volt will cause to flow through a resistance of 1 ohm. As a matter of fact, the Clark cell is a secondary standard, exceedingly useful in practice, but not designed for use as a fundamental standard, due to the fact that Clark cells will vary among themselves and will give a gradually decreasing voltage at their terminals after they have been in service any length of time. It is, further, impossible to take 1 ampère from a single Clark cell without permanently ruining it; and, as a matter of fact, the potential of a Clark cell is only correct when the cell is used on open circuit.

It has been rather difficult for me to understand why the absolute ampère has been so little used or so seldom referred to, when it is a unit more readily verified than is possible with the volt. It is true that the fundamental method of determining the ampère is rather slow and tedious, but it is extremely easy to obtain the absolute ampère in c. g. s. units by the use of the tangent galvanometer. Defined in c. g. s. units, the ampère is such a current that, passed through a conducting wire bent into a circle of the

radius of 1 centimeter, will attract a unit magnetic pole held at its center with a force of one dyne; and this method applied to the tangent galvanometer gives the very simple formula of current equals galvanometer constant into the tangent of the angle of deflection of the polarized needle, the galvanometer constant being readily determined from its dimensions and the number of turns of wire, in connection with a determination of the value of the horizontal component of the earth's magnetism. Having once determined the absolute c. g. s. value of the ampère, we know that the practical ampère is $\frac{1}{10}$ the value of the c. g. s. unit. Having obtained the absolute standards of current, expressed in ampères, and resistance, expressed in ohms, the standard volt is readily determined from the relations given in Ohm's law. With the primary units once determined, all others, such as the farad or coulomb, can be readily obtained.

To obtain absolutely correct standards of voltage and current for alternating current calibration, it is only necessary to calibrate a dynamometer voltmeter and a dynamometer ammeter in true volts and ampères, as determined by fundamental standards; then, as a dynamometer measures directly the square root of the mean square, it will indicate correctly the virtual voltage or current in an alternating circuit. In calculating resistance in alternating current instruments, it is necessary to modify Ohm's law to the extent of substituting impedance for resistance. Since impedance is the vector sum of the ohmic and inductive resistances, it is readily obtained by triangulation when the two resistances are known, or when one is known and the angle of lag can be ascertained.

While the design, workmanship and material entering into the construction of an instrument are of vital and fundamental importance, the actual calibration is equally important. Assuming the manufacturer has reliable standards of voltage, current and resistance, trained observers are necessary who should be instructed not only to properly mark the scale, but to check it; and should also be instructed to carefully test the instrument for errors due to

reversal, to lag or hysteresis, and for errors introduced by the presence of external fields, or by the variations of internal or external temperature. Certain definite limits must be set for errors allowed, and no instrument permitted to go out until it has fully come up to the standard so set. In the company with which I am associated, we not only make all of these tests and check readings, but, likewise, provide an additional check on the calibration by plotting the calibration curve at the time the scale is made by the draughtsman, and if errors or irregularities are observed in the curve showing a departure from the standard curve applicable to the type of instrument under construction, the instrument is promptly returned to the calibrating room to have its readings checked, or to hunt for and remove the defect which caused the irregularity. It is a known fact that for every type of system there is a characteristic scale, following a more or less complex law, and any variation of the calibration from the normal indicates immediately that there is something wrong, either in the construction of the instrument or of some of the elements entering into it; or else it was inaccurately calibrated. I, personally, attribute a great deal of our commercial success to this intermediate checking in the drawing-room, and you can put it down as a settled fact that any manufacturer who produces instruments of any particular type the scales of which for corresponding ranges vary greatly from one another has not yet mastered the proper design or construction of his instrument.

It would be impossible to detail the many different kinds of measurements which can be made with the proper type of voltmeter, ammeter and wattmeter. In general, however, the possession of these three instruments enables one to measure not only voltage, current and power, but, likewise, capacity, inductance and resistance; and from these various measurements may be obtained data covering the performances of almost any type of generating or translating device.

There are many special forms of indicating instruments designed to indicate directly some of the various measure-

ments most frequently employed, two of which, at least, are so universally used at the present time that they deserve, at least, passing mention. One is a voltmeter designed for use on constant current arc light circuits, capable of indicating directly the total electro-motive force of the dynamo, and so connected by means of self-contained switches that not only can the total voltage of the dynamo or circuit be read, but, likewise, the presence of a ground indicated and its actual value in volts directly determined. This involves an arrangement of connections so that the voltmeter can be connected directly across the terminals of the circuit and then connected successively from the plus and minus side of line to ground. From the three readings thus obtained the number of lamps burning can be directly ascertained, the presence of the ground shown and the ground itself can be absolutely located by a very simple calculation. By employing, in addition to this, the known resistance of the instrument, the actual resistance of the ground in ohms may be obtained, thus defining its character.

An instrument of this character was brought out by my company some few years ago, and has met with almost universal favor, due largely to the growing tendency to measure resistances under full working potential. Such an instrument will show grounds which would not be shown by the ordinary galvanometer and bridge method of testing, and further enables the switchboard attendant to locate grounds while the line is in operative condition.

Another instrument which, for a time, fell into disuse, but which to-day is being used more extensively than ever, is the differential voltmeter, designed primarily to show the difference in potential between the bus bars and any dynamo which has to be connected to the bus bars in parallel with dynamos already operating. It is rather a curious fact that the average dynamo tender places implicit confidence in the indications of his differential voltmeter. The mere fact that he can see the pointer come back to zero when the free dynamo is being brought up to voltage, and the knowledge that when the pointer does stand at zero he

can throw the free dynamo into circuit without danger of trouble, impresses him with the idea that the instrument is essentially reliable and accurate, and he is ready to condemn any or all of his regular switchboard voltmeters which fail to agree with it in indication. This tendency has led my company to devote special attention to the calibration of differential voltmeters and to furnish them with a full scale which indicates the exact voltage of the bus bars, in place of furnishing instruments which give full scale deflections for 10 per cent. or 20 per cent. of the normal voltage.

In closing, I would say that I know of no subject connected with electrical engineering which promises such rich rewards for investigation as the subject of electrical measuring instruments, and if my hasty and very general review of the subject will influence any one to pursue the subject thoroughly and scientifically, I shall feel more than repaid. I have confined practically my entire time and attention to this line for a number of years and find the subject grows more interesting the further I investigate it, and I hope the time is not far distant when the literature on this subject will be as complete and as comprehensive as that now available in allied branches of electrical engineering.

THE FRANKLIN INSTITUTE.

Stated Meeting, April 25, 1899.

ELECTROMAGNETIC MECHANISM, WITH SPECIAL REFERENCE TO TELEGRAPHIC WORK.

BY R. A. FESSENDEN.

(Continued from vol. cxlix, p. 470.)

Any motion which reduces the energy must have a force. Thus, since the energy would be reduced by enlarging the size of the plate of the condenser, keeping the charge constant, the plates of a condenser tend to stretch themselves out sideways if they are prevented from coming together. Thus we can make a nice little electrometer by taking a