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In This Issue

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THE WESTON CORE MAGNET SYSTEM

AS WITH many of our scientific components which have been brought to a high degree of refinement, the basic direct current electrical measuring instrument has been most advanced since the turn of the century by parallel advances in materials. And of these, we must necessarily count the improvements in permanent magnet materials as the most important in the last few decades.

Early Developments

Some 60 years ago, Dr. Weston showed the way to make a truly permanent magnetic system which could be used as the basis for an electrical measuring instrument. His fundamental finding was that a nominally permanent magnet system could be made truly permanent if proper dimensional relations were maintained. These relations were studied and placed in more concrete form by Mr. R. O. Heinrich, an engineer in the Newark Laboratory of the Weston Company in 1895. Mr. Heinrich was sent to Berlin by Dr. Weston to establish a European branch of the Weston Company in 1896, and later, with Mr. D. Berkowitz, published a paper on Weston instruments in "Handbuch der Elektrotechnik," Volume 2, parts 4-6, page 26, entitled "Weston Instruments." In this paper, Mr. Heinrich pointed out that the length to cross-section ratio of the magnet should bear a certain minimum over-all ratio to the cross-section to length ratio of the working gap, since the magnet produced the flux and the gap became the load. If the length-section quotient of the magnet for a given material were greater than some factor of the section-length quotient of the gap, a permanent system resulted.

But all of this work was predicated on those steels available at the time, high carbon steel and tungsten steel being among the best; chrome steel came quite a bit later. With any of these, and a flux density in the steel in the 10,000 gauss bracket, and coercive force in the 50-60 oersted vicinity, the minimum factor referred to was about 100. Using a somewhat higher value for the Model 1 instrument to obtain a high safety factor, it works out that a tungsten-steel magnet some 12″ long is required. This length had to be wrapped around the outside of the system in some manner and the conventional horseshoe magnet was the natural form it took.

Designers wished for better steels to allow the use of smaller magnets, but it was not until cobalt-magnet steel became available in 1918-1920 that there was much improvement.

An equivalent magnet in cobalt steel could be about one-half the size of the older tungsten or chrome-steel magnet for the same output. Alternatively, more flux could be obtained from the same volume of cobalt steel, and interest began to grow in the use of magnetic systems giving much higher flux densities in the air gap. However, no radical changes appeared in the form of the magnetic systems, although there was much experimentation along new lines.

Introduction of Alnico V

Around 1930, the precipitation hardening aluminum-nickel steels were available for experimentation, with their increased coercive forces and only mildly reduced flux densities. And in the middle of World War II, heat treatment of certain varieties of these steels in a magnetic field produced a totally new sort of magnet having an energy product several times anything which had ever been visualized previously.

This material, Alnico V and its variants, made it possible to reduce to practice a dream of many instrument engineers; that of making the core inside the moving coil of a Weston-type mechanism the actual magnet. We seem to find references to this sort of thing as early as the disclosure of D'Arsonval in 1870, although with the addition of the outside magnet. Mr. K. M. Lederer of the Weston Company made a core magnet mechanism in 1935, experimentally, but put the design in the museum as the available flux density in the gap was almost too low to be useful and the stability of the system was questionable even with the best steels then available.

A system of this sort, where a moving coil surrounded the magnet, has been used in the telephone art as a relay since about 1935. Here, a very long coil was not detrimental to performance and allowed for a long magnet for a reasonable degree of permanence. So the art develops.

Design and Application

With the advent of this material, those involved in basic direct current instrument design in the Weston Engineering Department began a study of the possible use of these steels as core magnets. Prior patent disclosures showed such structures, but there had been no reduction to practice in measuring instruments with long uniform scales. It is probable that Mr. K. M. Lederer, alone of the group, visualized at that time the possibility of making a stable system which would give a uniform field over an adequate arc, and that it would be possible to manufacture it economically.

After many studies and experiments, the final structure evolved is shown schematically in section in Figure 1. It will be noted that the length of the active portion of the magnet is uniform, giving uniform magnetomotive force to the magnetic circuit. The magnet bulges on its sides and the material in these bulges essentially supplies the leakage flux of the sides of the system. The pole piece horns extend outward to furnish a uniform field of flux into the air gap far around the sides of the magnet itself; this is accomplished by the degree of taper, both of the pole tips as well as of the air gap between the pole tips and the magnet. Obviously a design of this kind must of necessity be a co-ordinated whole in order to secure a resulting instrument having a uniform field of flux over a deflection angle of some 125 degrees.

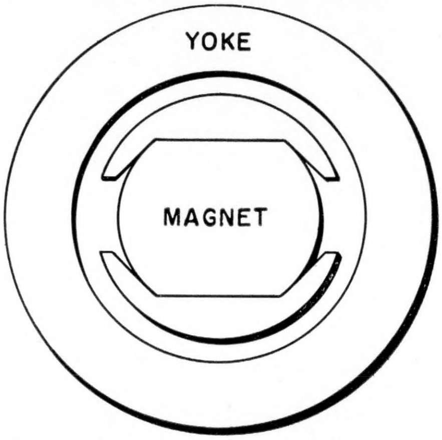


Figure 1—Schematic diagram of the Weston Core Magnet Mechanism.

The system has been reduced to practice in a design which is now being used in the Weston Model 931 portable direct current instrument, the interior of which is shown in Figure 2 with particular regard to the mechanism. In addition to the advantage of less weight for a given torque and moving element, the system has the advantage of very excellent shielding against the effect of external fields, this shielding being inherent and implicit in the design.

Special Shielding

To gain some picture as to degree of shielding, a 5-oersted field, commonly used for testing, is obtained at a distance of about 16″ from a conductor carrying 1,000 amperes. Such a field will affect an unshielded instrument, such as a Weston Model 430 of conventional type, varying amounts up to 2% if the field is applied in the most effective direction. It will cause no permanent error. By shielding, as in the Model 622, or through the use of the core magnet principle, the effect of a 5-oersted external field cannot be seen.

Taking another step, let us assume a 50-oersted field which is obtained 16″ away from a 10,000-ampere conductor, or approximately 7 feet from a 60,000-ampere conductor which is quite common in the aluminum reduction industry. In such a field, 50 oersteds, the unshielded conventional instrument, depending on its detailed design, will be in error from 25 to 50% and may have a permanent change caused by this field anywhere from 2 to 5%. However, either a well-shielded conventional mechanism, as in Model 622, or the self-shielded core magnet mechanism will show less than 1% transient error and a negligible permanent error.

Special shielding around a magnetic system is always costly in several ways. There is the simple cost of the parts. There is the extra weight of the shield, and the extra

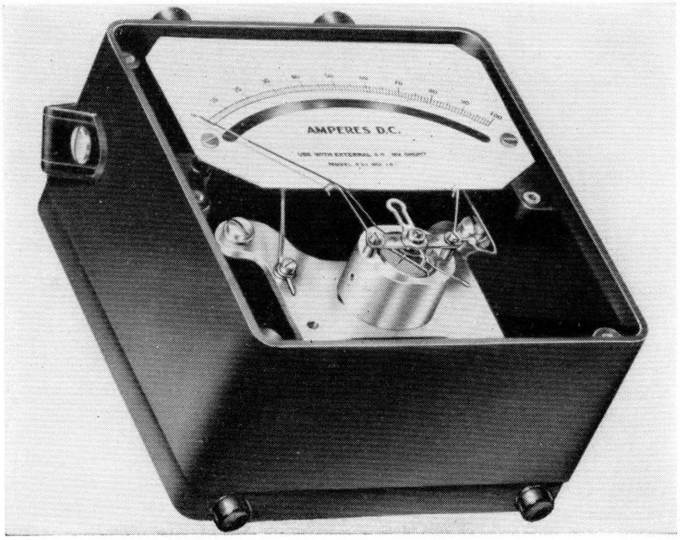


Figure 2—Interior view of the Model 931 Portable Direct Current Instrument showing the Core Magnet Mechanism.

space it takes. But even worse is the fact that the shield necessarily reduces the available flux in the air gap if it is at all effective and of reasonable dimensions. With this new core magnet mechanism, the shielding effect is obtained without increasing cost, without increasing size or weight, and without loss of flux!

Perhaps a word should be said here about permanence. The very fact that the instrument is relatively immune, inherently, to the effect of external fields means that it is, by the same token, very stable magnetically. Jolts and jars which might affect conventional magnetic systems have absolutely no effect on the core magnet system.

Fabrication requirements for a design of this sort are somewhat involved. As experience is gained in manufacturing the system to the required tolerences, and consistent with complete suitability to the end requirement, it seems quite possible that the core magnet system will see widespread use in years to come.

E. N.—No. 59 —*John H. Miller*

ORGANIZING AN ELECTRICAL INSTRUMENT STANDARDIZING LABORATORY

PREVIOUS articles appearing in WESTON ENGINEERING NOTES, Volume 2, Numbers 3 and 4, discuss the general problem of establishing an instrument standardizing laboratory and the use of potentiometers for the laboratory testing of electrical instruments.

Where the highest precision standards are required, a potentiometer and galvanometer, with a group of at least three Weston Standard Cells (for intercomparison), a volt box for voltage measurements, and a selection of shunts for current measurements will be necessary. The accuracy obtainable with such standards will be from 0.02 to 0.05 per cent depending on the type of maintenance and the skill of the operator.

If the instruments to be standardized are used in production testing where only nominal accuracy established by production tolerances is required, instruments having a higher order of accuracy can be used as the primary standards in place of the potentiometer.

Direct Current Measurements

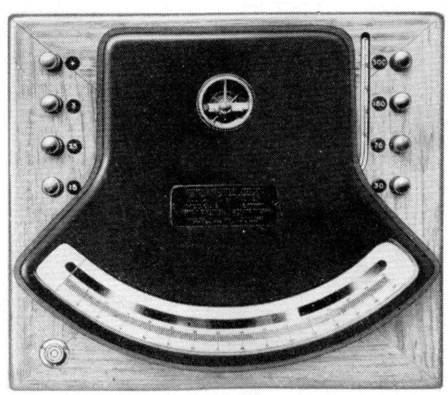
Instruments of the ½, 1 and 2 per cent accuracy class can be standardized by using ¼ per cent accuracy instruments such as the Weston Model 1. Instruments of the ¼ per cent class require standardizing by comparison with instruments in the 1/10 per cent accuracy class. Laboratory Standard Instruments, such as the Model 5 for direct current measurements and the Model 326 for alternating and direct current use, have been designed particularly for standardizing purposes. They are large, long-scale, direct-reading instruments, convenient and simple to use with a minimum of auxiliary equipment to maintain and operate. The scales are hand drawn into 100 or 150 divisions, as required, with each division subdivided into fifths for maximum accuracy and readability. The laboratory which expects to develop some prestige for the quality of its work would do well to select 1/10 per cent accuracy class Laboratory Standard Instruments as the principal standards and ¼ per cent accuracy class instruments for the less frequently used ranges.

The Weston Model 1 D-C Voltmeter.

In general, the ranges of the standard instruments, whether of the ¼ per cent or 1/10 per cent accuracy class, should be selected so that they will provide a suitable span to cover the work required. The ranges should overlap with a top mark ratio not greater than 2.5, such as a ¼ per cent accuracy class voltmeter with ranges of 1.5-3.0-7.5-15-30-75-150-300-750 volts. Some of these ranges could be omitted if no use can be foreseen for them, and if required later they could be obtained by using a multiplier, provided there is a lower range, or the instrument could be changed by the manufacturer.

The standard instrument for testing direct current ammeters should consist of a millivoltmeter of the necessary accuracy class and a suitable selection of external shunts. Such a group of shunts could be 1-2-5-10-20-50-100-200-500 amperes. For convenience, a group of shunts in one combination may be obtained such as a series switch-type shunt. This type of shunt, however, has one disadvantage in that, if one range is damaged all of the ranges are affected and put out of commission.

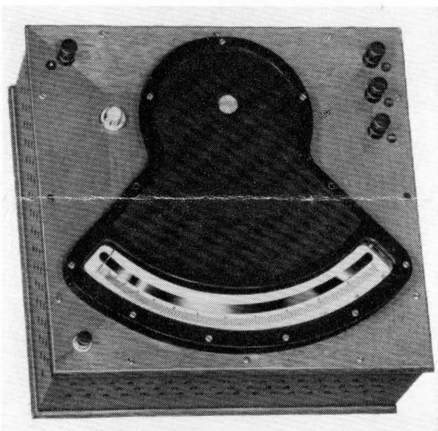
Milliammeters and microammeters with single or multiple ranges should be procured if required. Such small currents are also frequently measured by using a voltmeter or potentiometer to measure the potential applied to the instrument under test plus an external known series resistance. The current is then determined by Ohm's Law. For example, a 1.5-milliampere instrument measuring 143 ohms should


The Weston Model 5 D-C Voltmeter.

have an accurate resistance of 99,857 ohms connected in series with it to produce a total circuit resistance of 100,000 ohms. Applying 150 volts to this combination will cause a current of 1.5 milliamperes to flow through the instrument which can then be checked proportionately at any part of the scale by varying the voltage. The series resistance must be accurate, constant, and capable of carrying the current without changing its value due to heating.

A-C Voltage and Current Measurements

The standard instruments required for alternating current voltage and current measurements are determined by the type of instrument to be tested. If the instruments are in the ½, 1 and 2 per cent accuracy class, satisfactory standards would be ¼ per cent class electrodynamometer instruments. If the highest precision is required or if ¼ per cent accuracy class instruments are to be tested, Laboratory Standard Instruments such as the Model 326 should be used as standards. The ranges should overlap with a top mark ratio not greater than 2.5, such as 75-150-300-750 volts. Lower range alternating current voltmeter standards can be secured with full-scale ranges as low as 1.0 volt, but they are not as satisfactory as instruments having higher voltage ranges. A special low voltage standardizing transformer, such as the Model 311, which operates with a standard 150-volt instrument, is recommended. Additional information on this transformer will be found in ENGINEERING NOTES, Volume 3, Number 5. This transformer is very useful for establishing low alternating current potentials varying from 0.2 to 30 volts with an accuracy within 0.1 per cent in addition to the accuracy of the standard. The transformer may be used on frequencies from 25 to 1,000 cycles without additional error.

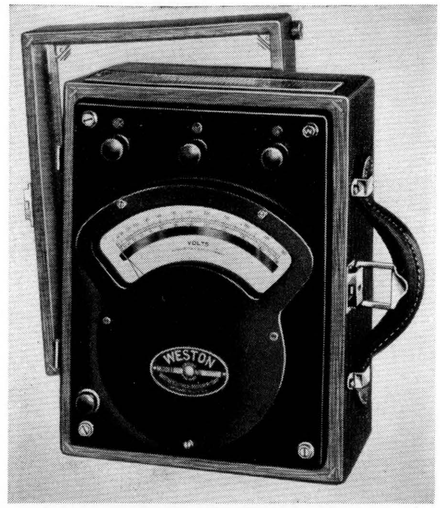


The Weston Model 326 A-C and D-C Voltmeter.

The Weston Model 311 Potential Transformer.

The standard instrument for testing ammeters should be ¼ or 1/10 per cent accuracy electrodynamometer ammeter with ranges of 0-2.5 and 0-5 amperes. For currents lower than 1.0 ampere, a double-range ammeter with ranges of 0-0.5 and 0-1.0 ampere or a Model 461 Current Transformer with a standard 5-ampere instrument is recommended. For currents greater than 5 amperes a high grade multiple-range current transformer having ranges of 10-20-50-100-200-300-400-600 and 1200 to 5 amperes should be procured.

The greater majority of alternating current instruments are designed for and used on circuits of 25 to 60-cycle frequencies. There are some special requirements for instruments to operate on higher frequencies. The electrodynamometer instruments can usually be compensated on order by the manufacturer to operate over frequency ranges of 25 to 2,500 cycles accurately and without excess current consumption although some modification of the ranges may be necessary.



The Weston Model 341 A-C and D-C Voltmeter.

The Weston Model 622 Thermo Milliammeter.

The measurement of voltage and current at radio frequencies requires thermocouple instruments. Good thermocouple instruments are as reliable and accurate as other alternating current instruments within their proper range of frequencies. Thermocouple ammeters indicate accurately at frequencies up to 50 megacycles. Single-range vacuum thermocouple milliammeters are accurate at frequencies up to 2 megacycles. Multi-range vacuum thermocouple milliammeters of the shunted type are accurate up to 15 kilocycles. Voltmeters of the vacuum thermocouple type are accurate on frequencies up to 5,000 cycles normally and 15,000 cycles by special design. In general, thermocouple instruments inherently develop considerable error due to temperature influence. This effect can be partially compensated by a suitable network, but a correction factor must be applied to readings when the ambient temperature differs widely from that at which the instrument was standardized.

The basic electrical standards are direct current standards and it is necessary to have an instrument which indicates with equal accuracy on alternating and direct currents in order to derive an alternating current standard from them. Such an instrument is known as a transfer standard since it may be standardized on direct current and used on alternating current with the same accuracy. Although both the electrodynamometer type and the thermocouple-type instruments can be used as transfer standards, the electrodynamometer type is preferable for precision measurements at the lower frequencies. Moving iron instruments, although very useful on alternating current, are not accurate on direct current and are therefore not suitable for transfer instruments since they cannot be checked accurately directly against a potentiometer and standard cell.

E. N.—No. 60 —*J. B. Dowden*

Reference: *Instruments*, September, 1948, Electrical Instrument Calibrating for Industry by William L. Kinsell.

USE OF PRECISION A-C INSTRUMENTS AT AUDIO FREQUENCIES

FOR general measurements, such as testing in the audio frequency spectrum, the 5% rectifier type of instrument is the most convenient where its accuracy and average value response permits. When somewhat better accuracy and an rms response is necessary the thermal type of instrument is considered the logical alternate, and is generally to be recommended whenever its accuracy as a class is sufficient. For still higher orders of precision such as ½% or better, the only acceptable class of instrument is the electrodynamometer which is available up to accuracies of 1/10%. Typical of these are the Weston Model 370, one-quarter per cent, and the Weston Model 326, one-tenth per cent accuracy. Unfortunately the dynamometer-type instrument has a relatively high-internal inductance which must be evaluated at the higher frequencies for most applications.

As an example of the direct use of an electrodynamometer, a Model 370 milliammeter with a range of 50 ma is used with a 1,000 cycle source as a standard for the calibration of all VU meters in the Weston laboratories. The 1,000-cycle current to the accurately adjusted 600-ohm attenuator is held to 40.82 ma, representing 1 watt in 600 ohms, with the result that high accuracy is available for calibration of VU meters.

While the dynamometer-type instrument is usable without qualification at service power frequencies, and the inductance does not complicate matters materially at 1,000 cycles, this inductance does complicate the use of the instrument on higher frequencies in the audio band. To at least partially offset this limitation, built-in frequency compensation for voltmeters has recently been made available up to 2,500 cycles per second in ranges over 30 volts. However, such broadly compensated instruments are limited in top frequency, whereas, compensation of special form for a single frequency can be made quite accurate at that frequency and with minimum reactive burden. It thus is of interest to determine what can be done toward offsetting the effect of internal inductance in specific cases where a single frequency magnitude only is to be measured, or where special conditions indicate that standard built-in compensation is not the most effective.

In the straight series connected electrodynamometer current instrument, the internal inductance is the sum of the self-inductances of the field and moving coils plus the mutual inductance between the coils. For the same structure the inductance is roughly inversely proportional to the square of the instrument range. When used as a voltmeter by the addition of series resistance it introduces reactance that raises the total circuit impedance with increasing frequency, causing a low reading error. When used directly as a current instrument the inductance of itself causes no error, but adds a reactive burden to the measured circuit that becomes prohibitive at high frequencies. For example, a typical 150-milliampere Model 370 would have a resistance of about 20 ohms, but at 5,000 cycles the reactance would be in the order of 300 ohms which at full scale would cause an insertion drop of 45 volts.

In this connection, it should be noted that inductance in itself is a cause rather than a source of error, the error if any being caused by reactance in the associated circuit. The dynamometer effect, or the force reaction between currents, is fundamental and is a function of the current and not the reactance. In fact, special versions of the electrodynamometer instrument are used at radio frequencies without fundamental error, but with a special technique required to accommodate the unavoidable inductive reactance.

The basic series connected electrodynamometer instrument may be visualized in the equivalent circuit of Figure 1. The inductance (L) varies with the deflection angle because of the changing mutual between the coils. The variation is approximately as shown in the curve of Figure 2, in which the inductance is expressed relative to the

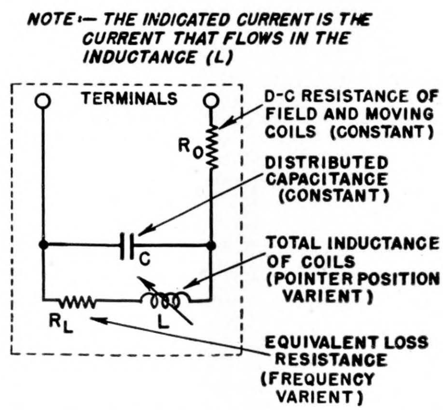


Figure 1—Equivalent internal electrical network for electrodynamometer instrument.

full scale inductance for a particular design. The inductance also drops slightly with increasing frequency due to eddy current reactions, but the change is only about 2% at 6,000 cycles and for practical purposes the frequency variant component of inductance may be neglected.

In Figure 1 the resistance (R_o) represents the d-c resistance of the coils, which will vary from instrument to instrument approximately inversely as the square of the current range.

It is customary to indicate the inductance and resistance values on the certificate accompanying precision electrodynamometer instruments, with the inductance usually stated for full scale and half scale deflections.

The resistance (R_L) represents a loss resistance that is completely frequency variant, being zero at 0 frequency (direct current) and becoming larger than the d-c resistance at higher audio frequencies. It is the composite loss due to inductive coupling to the instrument shielding and other internal conducting structural parts. It varies approximately as shown in the curve of Figure 3, in which the loss resistance is expressed relative to the d-c resistance (R_L/R_o) at room temperature; note the loss resistance is the order of the coil resistance at 4,800 cycles, thus doubling the I^2R loss.

In addition, the coils include an unavoidable distributed capacitance which is represented as a lumped shunt capacitance (C_s). Note that this is the only shunt parameter and consequently is the only current path alternative to that through the moving coil. But fortunately it is small and represents a shunt reactance that is large in comparison to the coil reactance except at the higher audio frequencies.

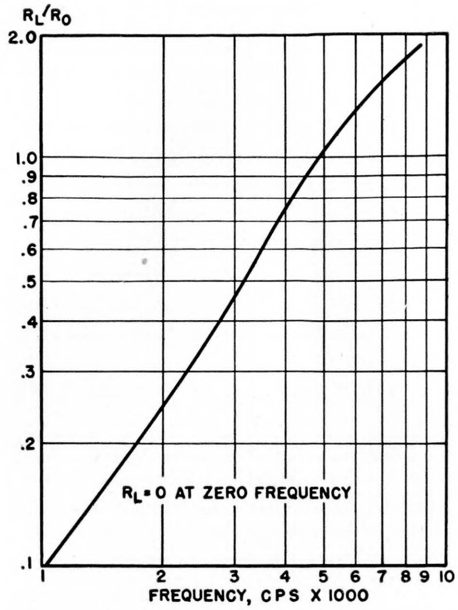
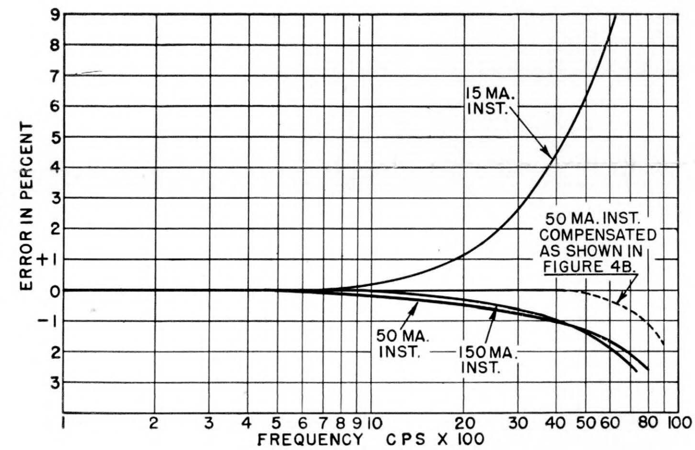


Figure 3—Variation of loss resistance with frequency of a typical series-connected electrodynamometer.

Note that C_s in addition to being a shunt path, which produces a low reading error, may resonate with L to produce a high reading error. The former condition predominates in higher current range instruments and the latter in lower current range instruments. This is illustrated in Figure 4a wherein the 15 milliampere instrument has a positive error, but the higher ranges show a negative error. Also, the magnitude of this positive error indicates that the more sensitive instruments are basically unsuited to the higher frequencies.

This condition of reversing error indicates that an instrument of some median sensitivity should have a minimum error, or conversely a less sensitive instrument may be compensated by the addition of shunting capacitance. In practice this is done as shown in Figure 4b, wherein a series connected capacitor and resistor are shunted across the instrument. For illustration, a typical 50-milliampere instrument error curve is compensated by the specific values of capacitance and resistance shown in Figure 4b.

Figure 4a — Frequency error due to distributed capacitance for some typical instruments.



Unfortunately specific values of compensating capacitance and resistance cannot be recommended because of manufacturing variations between instruments. In each case, it is therefore necessary to experimentally determine the values for optimum compensation, using for example, a thermal instrument, which need not be accurate, as a comparator between a low frequency and the frequency range of interest.

The internal equivalent inductance (L) can be readily compensated by the addition of an external series capacitor to series resonate the combination at the applied fre-

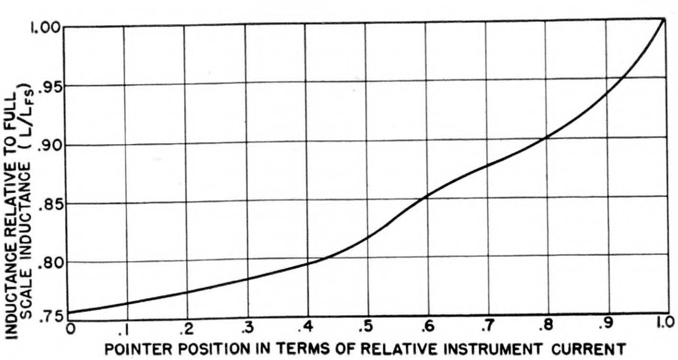


Figure 2—Variation of inductance with pointer position of a typical series-connected electrodynamometer, measured at 2,000 cps.

quency. When resonant, the reactance of the internal inductance and the external capacitor exactly

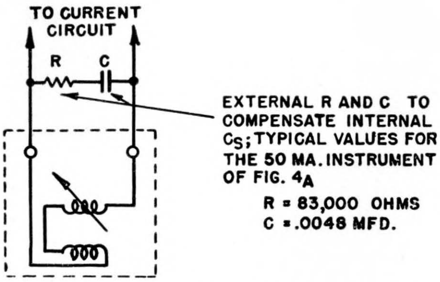


Figure 4b—Compensation of distributed capacitance.

cancel, leaving only the resistive parameters R_o and R_L. This is illustrated for the case of a current instrument in Figure 5. The circuit may be resonated experimentally by adjusting the series capacitor to produce the lowest insertion voltage drop, which can be indicated by a shunt voltmeter such as a 1,000 ohms per volt rectifier-type voltmeter, which must be removed before taking a reading. Because of the equivalent inductance variation with pointer position, the capacitance for exact resonance will vary somewhat with the indicated current, and must be readjusted for minimum circuit burden. But if the circuit is sufficiently tolerant toward burden it may be resonated at the optimum mean inductance, which has been determined as occurring at about 87% deflection in terms of current.

On higher current range electrodynamometers it becomes impractical to pass the full current through the moving coil, so instruments above about 750 milliamperes are normally supplied with an internal resistance shunt across the moving coil. As this is reactance shunted by resistance, the frequency error becomes high at the higher frequencies and instruments having a range of 1 ampere or higher can, in general, be internally compensated effectively at frequencies only up to about 2,500 cycles.

When the basic current instrument is combined with series resistance to measure voltage, inclusion of series capacitance to resonate the inductance is equally effective. But in this case the residual resistive parameters R_o and R_L must be evaluated and included as a portion of the total series voltmeter resistance, and the series resistor must be readjusted with changes in frequency to correct for the corresponding change in R_L.

If the instrument is a self-contained voltmeter the junction between the coil circuit and the series resistor will not be available externally, so tuning by observing the developed voltage as shown in Figure 5 is not possible.

An alternative method applicable to the self-contained voltmeter is to tune for maximum current (minimum impedance) by holding the applied voltage constant and adjusting the capacitor to produce the

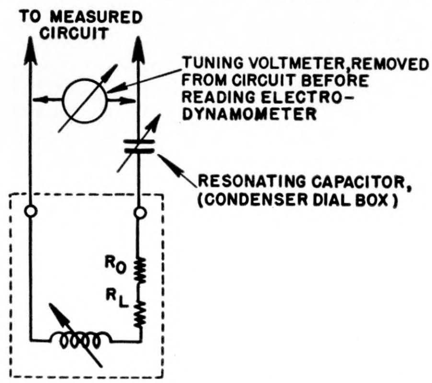


Figure 5—Compensation of the reactive burden component by resonating.

highest reading. However, this method is relatively insensitive and the indication must be observed closely during the tuning process; any mistuning is a direct error in terms of the equivalent deviation from the true maximum deflection.

Also, in the case of self-contained voltmeters, the series resistance is not adjustable for correction of the R_L factor, and the reading will be low and should be raised by a multiplication factor that is somewhat larger than 1, or:—

$$\text{Correction factor} = \frac{R+R_L}{R}$$

Wherein R is the total d-c resistance of the instrument.

The coil resistance (R_o) is already included in R and need not be considered.

When the waveform is complex or non-recurrent the resonating capacitor naturally cannot be completely effective. But its use is still a major improvement over the uncorrected instrument. In such cases it is suggested that the tuning voltmeter of Figure 5 be a peak responsive vacuum-tube voltmeter, and the capacitor be readjusted simply for minimum peak burden.

In regard to the curve data presented in Figures 2 and 3, it should be realized that the values are the approximate mean of a number of instruments, and do not imply that all instruments will follow closely. But they represent a rather small order correction and may ordinarily be applied with fairly good results. However, if the maximum precision is desired it is recommended that the factors, particularly R_L, be determined experimentally for the specific instrument involved.

E. N.—No. 61 —*R. W. Gilbert*

THE WESTON MAGNETO-GENERATOR

The following article deals briefly with the history of the early development of a tachometer-generator. A supplementary article discussing the present-day designs of both a-c and d-c tachometer-generators will appear in a subsequent issue of WESTON ENGINEERING NOTES.

IN THE year 1883, Dr. Edward Weston invented the so-called "magnetic drag type" speed indicator for which he was granted U. S. Patent 277179.

This is the type, known popularly as the speedometer, which has been used on automobiles since their inception, for indicating speed. In this instrument, a permanent magnet is attached to a shaft driven from a wheel or the transmission shaft of the automobile, and revolves with it. A metallic disc or cup, to which the pointer is attached, is independently pivoted so as to move freely under the control of a spring, near the permanent magnet and cause the pointer to pass over a scale. When the magnet rotates it tends to "drag" the disc with it as a result of Foucault currents induced in the disc until the "drag" is balanced by the spring. With this construction, it is obvious that the indicating member must be in relatively close proximity to the rotating shaft, the speed of which is to be measured.

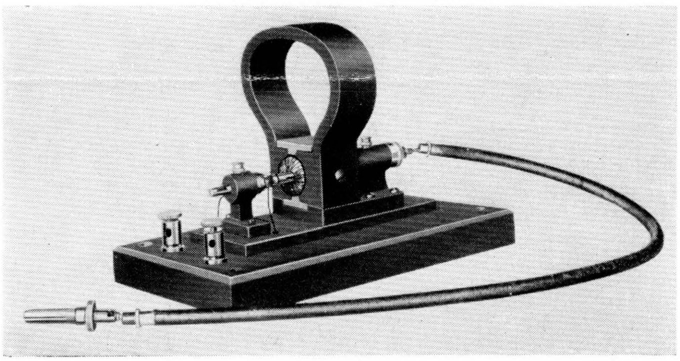
About the year 1896, Dr. Weston made it possible to measure speeds entirely electrically by the development of the magneto-generator. By this new method, an electrical indicating instrument could be placed at any distance from the rotating shaft and connected electrically to the magneto.

He had developed and commercialized his electric lighting generator around the year 1882, known then as the Weston Dynamo, which incidentally was the first generator to have laminated armature and field cores. From his experience with these generators he knew that when the magnetic field was constant, the emf developed was directly proportional to the speed of the armature. Also from his experience with permanent magnet instruments, which he placed on the market in 1888, he knew that permanent magnets produced a constant magnetic field. By making use of this knowledge, he combined the armature and the permanent magnet to make a magneto-generator. This consisted of a magnet and pole pieces similar to those used in the Weston Model 1 Voltmeter, in which an armature, secured to a shaft mounted in bearings, replaces the movable coil.

Until the year 1905, a smooth laminated armature core was used in the magneto. This necessitated winding the wire in the air gap space between the armature core and the pole pieces. The smallest diameter wire then available was used to obtain the required number of turns in the necessarily restricted air gap. This resulted in an armature resistance of about 150 ohms and an emf of about 2.7 volts per 1,000 rpm. The commutator and brushes were made of phosphor bronze.

As the measurement art progressed, increasing accuracy in measurements was demanded. It was found that errors in the use of the magneto, as then designed, resulted from three causes: (a) the electromotive force was so low, relative to the armature resistance that, with voltmeters then available, sufficient series swamping resistance could not be used to prevent rather serious temperature errors; (b) for the same reason, the contact resistance of the brushes on the commutator was also effective in producing appreciable errors; (c) the wear between the phosphor bronze brushes and commutator produced a fine metallic dust which is a poor electric conductor. This introduced a relatively high and variable resistance into the circuit.

In the year 1905, the magneto was redesigned by the writer. The armature was changed to a slotted type in which the wire coils were wound in circular slots. This construction permitted larger wires, and more turns to be used by which the resistance could be reduced, and the electromotive force increased. The air gap could also be reduced to the minimum required for clearance, without having to provide space for windings between the armature core and the pole pieces.



First Model of the Weston Magneto-Generator, made in the year 1896, and used as a Tachometer.

By this means, the magneto could be designed to have almost any reasonable values of electromotive force and resistance, and many values were tested.

An extensive investigation was also made to determine the best metals or alloys for the commutator and brushes. Many combinations were tried including platinum, gold, silver and their alloys, steel in various degrees of hardness, nickel copper, nickel steel and many other alloys, all compared with the phosphor bronze then used. All of these metals except some of the silver alloys seemed to produce a metallic dust having a high electrical resistance. The silver alloys gave the best results in other respects as well, and definite alloys were adopted, one for the commutator and one for the brushes.

Tests were then made to determine the best voltage to be used. At first thought, one would surmise that the higher the voltage, within reason, the better the results would be, but this was not found to be the case. When higher voltages were tried, for example, of the order of 20 to 25 volts per 1,000 rpm, the slight and almost invisible arcing was sufficient to wear the commutator and brushes in a relatively short time, and produce uneven and high-resistance spots. These caused not only high-resistance contacts, but resulted in diminishing the contact time, which affected the average electromotive force produced. Furthermore, as the voltage was increased, the armature resistance increased at a greater rate, since the number of turns and, consequently, the length of the wire increased proportionally, but the diameter of the wire necessarily decreased as a result of constant slot area. This disproportionate increase in resistance resulted in an undesirable temperature error.

On the other hand, when the electromotive force was made low, for example, one or two volts or lower, contact resistance and temperature errors resulted. As a result of the long series of tests, it was found that an emf of six volts per 1,000 rpm gave the best all around results and this value was adopted.

The commutator originally used had the customary solid insulation between the commutator bars. It was found that metallic dust would bridge across the bars and cause errors. To correct this, a squirrel cage construction was adopted with air spaces only between the bars.

E. N.—No. 62 —*W. N. Goodwin, Jr.*

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