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SIMPLIFIED STANDARD CELL COMPARATOR

Introduction

For use in comparing working standard cells with the potential from a "normal" or saturated cell—presumably one of a group maintained as a voltage reference—a simplified comparator is presented. Complete circuit details are given along with a description of the necessary auxiliary items.

Saturated cells, while maintaining their voltage well against time in years, must be maintained in a temperature-controlled chamber since the change in voltage with temperature is about 60 microvolts per degree Centigrade. Through the use of the Wolff formula for temperature correction and occasional cross checks at the Bureau of Standards, an independent group of saturated cells can readily maintain the volt to within 5 microvolts. The requirement for constant temperature, however, precludes the use of such cells in completely portable service, and for general use the unsaturated cell with its low-temperature coefficient is more suitable.

For standardizing the unsaturated cells in terms of the value of a "normal" saturated bank, a simple comparator of some sort is desirable.

Figure 1—Weston Standard Cell Comparator.

Saturated Cells

THE use of the saturated or "normal" form of Weston standard cell with its long life and well-maintained voltage appears to be growing. A decade ago relatively few banks of saturated cells existed outside the National Bureau of Standards. Today, however, we find numerous industries and college laboratories maintaining groups of saturated cells for the immediate availability of a high-accuracy voltage reference.

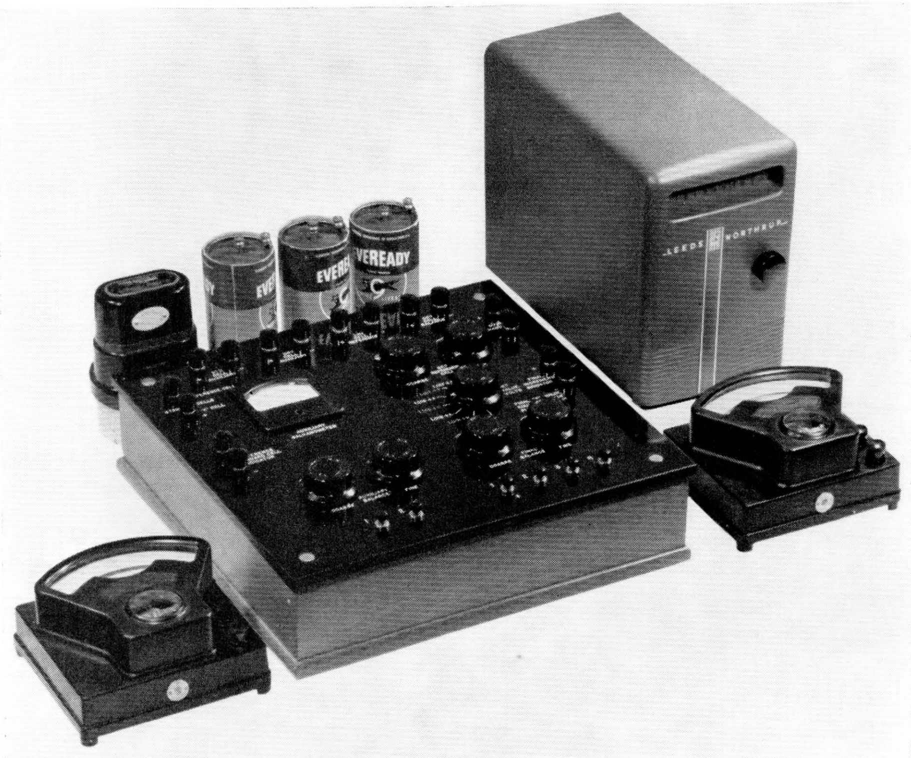

Figure 2—Auxiliary units of the Standard Cell Comparator.

Definition of a Comparator

Stated very simply, in checking a working standard cell against a reference standard, the two cells are connected in opposition, in series with a galvanometer and an auxiliary source of a few microvolts. Adjustments are made in the auxiliary source until the galvanometer indicates a null balance. The working cell potential then equals the potential of the reference cell plus, algebraically, that of the auxiliary potential. The comparator is simply a means of adjusting the auxiliary potential, indicating its value in microvolts in some manner and, possibly, with an arrangement whereby it can be added simply, accurately and with proper sign to the value of the reference cell.

The comparator designed by H. B. Brooks, and reported in Research Paper No. 586 of the Bureau of Standards, August, 1933, is a highly developed form in which readings can be made to 0.1 microvolt. Used for research and for international comparison of voltage standards, it is necessarily of high accuracy. It includes some 70 adjusted resistors and a rather elaborate calculating system.

Statement of Requirements

A useful comparator of simpler scope might have a sensitivity level of 1 microvolt with 5 microvolts per division on the indicating instrument and an over-all limit of error of 5 microvolts. On the assumption that the standard cell being checked will come within the extreme limits of 1.017000 and 1.020500 volts for a span of 3500 microvolts, we can get along with 7 coarse steps each covering 500 microvolts and the associated instrument covering the fine subdivision of each 500-microvolt step. If we assume that we are maintaining the saturated cell bank at least between 28.2 and 36.6 degrees Centigrade, then, according to the Wolff formula, the reference voltage span will be 1.017750 and 1.018250 amounting to, again, 500 microvolts and centered at 1.018000 volts.

Assembling these design parameters, the comparator illustrated in Figure 1 was built. It is assembled with the necessary auxiliary items in Figure 2, including the two milliammeters, the auxiliary standard, all three dry cells, and the main galvanometer of high sensitivity; the interconnecting wiring has been omitted for clarity. Figure 3 is a schematic diagram including all of the auxiliary items; open circles represent binding posts.

The circuit of the reference cell and the cell under test, "X," is closed to the high-sensitivity galvanometer "G" through the resistance from "A" to "B" which actually takes the form of a few feet of No. 24-ga. manganin wire wound on a skeleton Bakelite form to give about ¼ ohm per turn. A tap is made on each turn, the assembly is varnished and baked, and the sections marked "0.25" are adjusted to better than

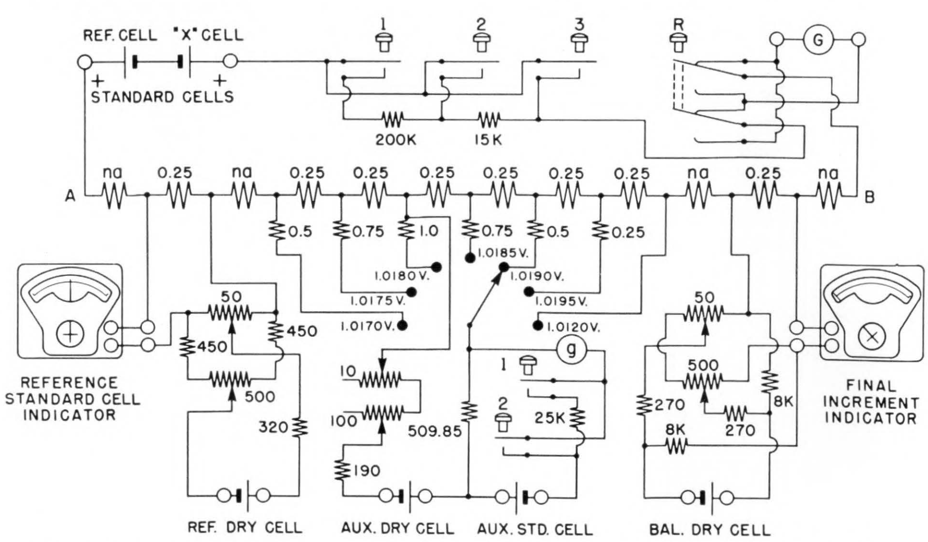

Figure 3—Schematic diagram of the Standard Cell Comparator, including all auxiliary units.

$\frac{1}{10}$ of 1 per cent or ½ microvolt in 500 when passing 2 ma. Sections marked "na" are not adjusted.

current as the range is changed.

Selection of the switch position adds or subtracts voltage in 500-microvolt steps to effectively bring the reference voltage to the values indicated at the switch points and as necessary for a coarse balance on the main galvanometer "G."

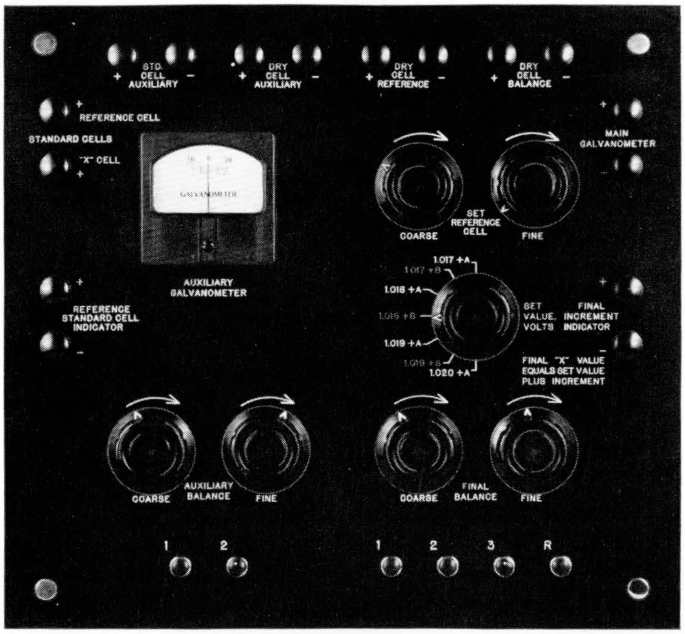

Figure 4—Panel layout of Standard Cell Comparator.

The left-hand Model 1 instrument has a range of 1-0-1 ma. Current covering this span, controlled by the associated rheostats, produces a drop in the 0.25-ohm resistor of from 250 microvolts aiding, through zero, to 250 microvolts opposing the reference cell. The instrument scale is marked, however, 1.017750 to 1.018250 volts, with 1.018000 volts at the electrical zero point. The current is adjusted so that the instrument *indicates* the actual reference cell potential at the then existing temperature; the drop of this measured current through the 0.25-ohm resistor then, added or subtracted from the reference cell, adjusts the net voltage to 1.018000 volts.

Current through the center 0.25-ohm resistor, as selected by the rotary switch, is maintained at exactly 2 ma by balancing the drop of this current through the 509.85-ohm resistor against the potential of an auxiliary standard cell through a simple galvanometer, "g," exactly as in the Brooks design. The resistors in the switch point leads, 0.5, 0.75, etc., serve to maintain constant resistance in the battery circuit on any switch position and obviate readjustment of the 2-ma current as the range is changed.

The final adjustment to balance is by means of the network at the right. When balance has been achieved, the current in this network producing the final microvolt value is measured in the right-hand instrument which, in turn, is marked 0-500 microvolts, and the indicated value is added to the value marked on the switch point in use.

The main galvanometer has a resistance of 25 ohms and its external, critical damping, resistance value of 400 ohms roughly matches the resistance of the two cells in series. One scale division deflection, 0.005 microampere, would be produced by two microvolts through 400 ohms, thus indicating the degree of resolution.

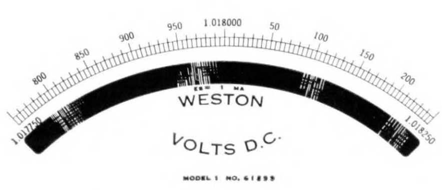

Figure 5—Scale of Reference Standard Cell Indicator. (Approximately ½ actual size.)

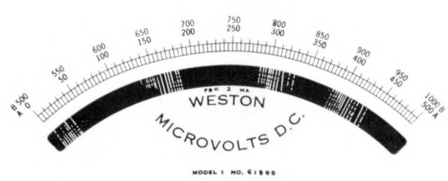

Figure 6—Scale of Final Increment Indicator. (Approximately ½ actual size.)

Accuracy of Adjustment

A brief analysis of the circuit will show that only the marked resistors in the circuit from A to B, and the 509.85-ohm resistor need be adjusted accurately; they were held to 0.1 per cent. All of the other resistors, including the control rheostats, serve adequately, if within a few per cent of the marked value. On the other hand, the values in the dry cell circuits were selected after considerable study and actual use with the instrument to give the most satisfactory manipulation under all conditions. In each case, the upper rheostat is the fine adjustment.

The device was built with full knowledge that Brooks designed an elaborate temperature-compensated galvanometer key, that he furnished a compensator for any residual thermal voltage, and that he was much concerned about various random residual potentials. It was expected that possibly copper binding posts would be required, along with other special compensation means. However, practical use in a laboratory and checking many cells as manufactured appears to indicate that if accuracy to within a few microvolts is considered adequate, no further compensation is needed. To be sure, the apparatus is left connected all of the time, and as Brooks points out, the battery drain is no more than equivalent to shelf life. Thus the apparatus reaches temperature equilibrium and is not touched in normal use except on the control knobs and the galvanometer keys which have been made of Bakelite.

In presenting this particular form of comparator with its circuit, full credit must be given to Dr. Brooks for his original paper and from which this design is abstracted. Nevertheless, since this simpler form is the result of considerable study, it is presented as a useful variant for the record.

This paper was presented on June 23, 1954, at the summer meeting of the American Institute of Electrical Engineers at Los Angeles. It has been published (without three of the illustrations) in Communications and Electronics, *Sept., 1954, and will be a part of the Transactions of the A.I.E.E. for 1954. It was also published in abbreviated form in the Oct., 1954, issue of* Electrical Engineering.

The Standard Cell Comparator has been designated Weston Model 1000.

E. N.—No. 105 —*J. H. Miller.*

WESTON INDUCTRONIC® PRODUCT RESOLVING SYSTEM

ELECTRICAL multiplication for the purpose of measurement or for functional amplification is a rather basic problem. Analog computation has developed to require product translation, and several electronic methods for multiplying two electrical inputs to form a single product function output are in contemporary use. However, the classic electrodynamometer instrument is a multiplying device of familiar usage, and is capable of a basic accuracy (better than 0.1 per cent when properly designed) that is attractive for most purposes.

The new Weston Product Resolving System uses the functional multiplication of a dynamometer mechanism as the translational device in a full feedback amplifier to produce an output current that is accurately related to the product of two input currents. In this sense, it is a product resolving amplifier that has the permanent accuracy expectancy and the frequency spectrum of a high quality dynamometer instrument.

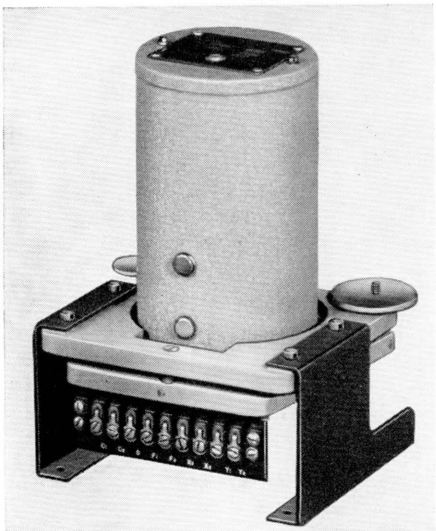

Figure 1—Model 1406 Product Resolver Unit.

The translational component of the system is a dynamometer element torque balanced against a permanent magnet, movable coil, d-c mechanism. The dual dynamometer/d-c mechanism is without mechanical restraint, and is automatically maintained in balance by sensing an incipient deflection, amplification, and feedback of a compensating current to the d-c element. The mechanical torque developed by the product of the current in the field and movable coils of the dynamometer element is thereby accurately related to the output current.

The torque of the dynamometer element is automatically balanced by the feedback system illustrated by the block diagram of Figure 4. The counter torque is developed by a d-c mechanism responding to a feedback direct current. As in any feedback system, performance is contingent upon a high resolution of error difference, which in this case is mechanical deflection of the dynamometer. The Weston Inductronic system provides this high resolution without mechanical loading of the mechanism.

Naturally the performance of such a system is conditioned to the effectiveness of deflection sensing. For this purpose, the d-c torque-balancing element is a modified induction galvanometer, wherein deflection is sensed by coupling of the coil to a 200-kilocycle-per-second alternating component of magnetic flux injected into the permanent magnetic field from the magnet. This is the method used for error detection in the Model 1411 D-C Amplifier, which has been described elsewhere (see references). The high-frequency induction pick-up has a detection resolution of a few seconds of angle, negligible time lag compared to the inertial delay of the movement, and no complicating effects such as spurious torques, fall-over effects, or added movement mass.

In operation, the high frequency induced in the movable coil of the d-c element by incipient deflection is amplified and phase rectified; and the resultant d-c feedback current is available as output. This process is entirely similar to the function of the Model 1411 D-C Amplifier, and is fully described in the article referenced.

The system comprises two basic units, the Model 1406 Product Resolver Unit, which is the primary translational mechanism, and the Model 1416 Amplifier, which is specifically designed to operate the Model 1406. The Model 1406 is illustrated by Figures 1 and 2. The dynamometer is the upper element,

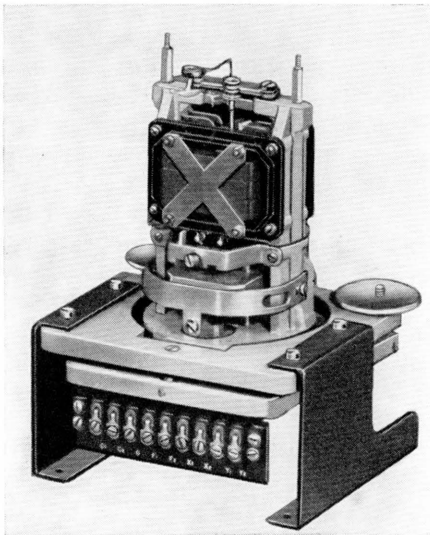

Figure 2—Model 1406 Product Resolver Unit with cover removed.

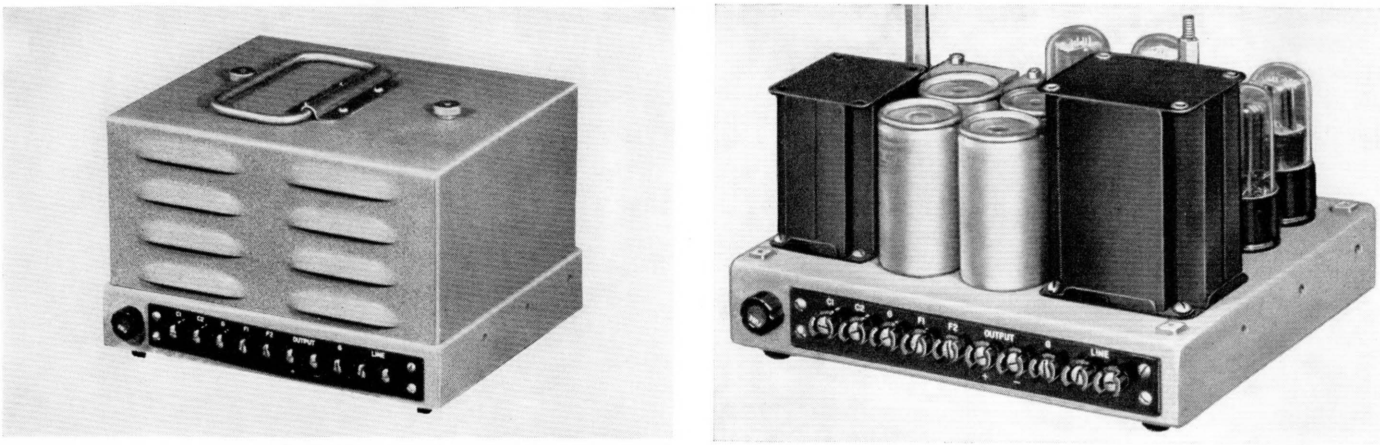

Figure 3—(Left) Model 1416 Amplifier. (Right) Model 1416 Amplifier with cover removed.

and is enclosed within a ferrite magnetic shield. The dynamometer movable coil and the d-c element movable coil are mounted on a common shaft, with the necessary four connections made through filaments having the lowest possible stiffness consistent with adequate strength. The ferrite shield surrounds the dynamometer field, but is internal to the supporting metal structure, and improves the upper frequency accuracy by minimizing the external field flux in the surrounding metal. Also, the absence of appreciable deflection allows a compacted field coil shape and somewhat better efficiency than the familiar round field coils of deflection dynamometer instruments.

Two trim adjustments are accessible through cap screws in the cover. The lower adjustment is a magnetic shunt effective upon the permanent magnet for calibration trim. The upper adjustment is for d-c balance of the dynamometer element to eliminate the reversal error on d-c. The assembly is mounted on a leveling three-point suspension, arranged for panel mounting. Two edgewise leveling nuts and a bubble level protrude through the panel for front of panel leveling. The level adjustment is not particularly critical, but is desirable and usual on dynamometer instruments of high accuracy.

The basic amplifier for operation of the Model 1406 Product Resolver Unit is the Model 1416 Amplifier illustrated in Figure 3. It comprises a 200-kilocycle amplifier strip, identical to that used in the Model 1411 D-C Amplifier, a conventional power supply section, and a single-stage capacitive-coupled amplifier section for derivative damping of the system. The power supply is somewhat more heavily filtered than the power supply in the Model 1411 D-C Amplifier, to avoid ripple beat effects when the system is used on 60 cps a-c input sources. The damping amplifier section is necessary because the Model 1406 movement

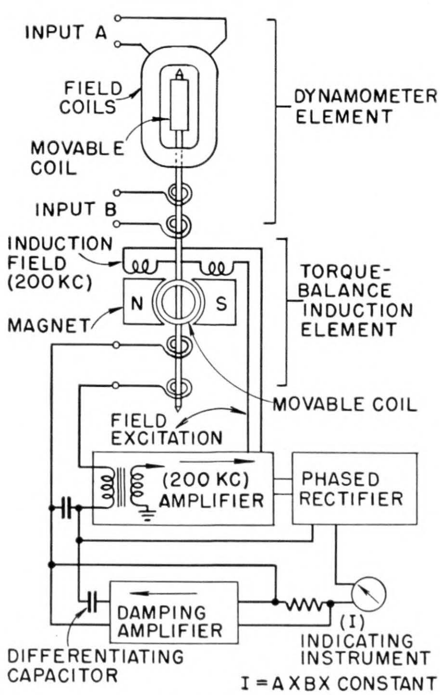

Figure 4—IPR Unit with feedback and damping amplifiers.

has a relatively high moment of inertia operating with a very high feedback stiffness, so that the normal damping effect of the d-c mechanism is insufficient. The output current has a range of 1 milliampere and will support load resistances up to 5,000 ohms (5 volts), similarly to the Model 1411 D-C Amplifier. Accessory indicating instruments should have a range of 0-1 or 0.5-0-0.5 milliampere.

Model 1482 Product Resolving Amplifier

The practical operating instrument combining a Model 1406 Product Resolver, a Model 1416 Amplifier and an indicating instrument is the Model 1482 illustrated by Figures 5 and 6. It is supplied in a steel rack cabinet as shown, but it may be removed for rack mounting with other equipment if desired.

The accuracy of the panel type indicating instrument is 0.5 per cent, whereas the accuracy of the amplifier in terms of output current is normally 0.1 per cent. The only instrument capable of matching the intrinsic accuracy of the system is the Model 5 Laboratory Standard Instrument, which can be connected externally if desired. When the Model 1482 is used as a system component, the panel instrument serves primarily as a monitor or for approximate output level indication.

Ranges

Similarly to conventional dynamometers, the full-scale input to the field requires considerably more energy than does the full-scale input to the movable coil, approximately 0.6 watt and 0.01 watt respectively in this case. The resistance presented by the field to the source is therefore much larger than the resistance presented by the movable coil for similar current ratings. Also, the field may be wound for relatively heavy currents, whereas the current level to the movable coil is limited by the capacity of the small filaments carrying the movable coil current. Shunting of the movable coil for heavier currents is feasible, but is not recommended normally because of complications involving additional temperature and higher-frequency errors.

For these reasons, the field circuit input is rated in single ranges from 50 milliamperes to 5 amperes, but the input range to the movable coil directly is 50 milliamperes only. Higher movable coil input ranges may be supplied by including an internal current transformer, which, however, excludes d-c and a-c of frequencies below 25 cps. A shunted movable coil may be used with some qualifications regarding temperature errors and upper frequency errors.

For a-c inputs, the Model 1482 may be supplied self-contained for voltage, current or power. Voltage ranges are usually 50 milliamperes full-scale demand (20 ohms/volt). Current ranges may be supplied 50 milliamperes direct, or for higher ranges with an internal or external current transformer. Watt ranges can be supplied with current inputs of 50 milliamperes to 5 amperes direct, and a potential circuit sensitivity of 20 ohms/volt.

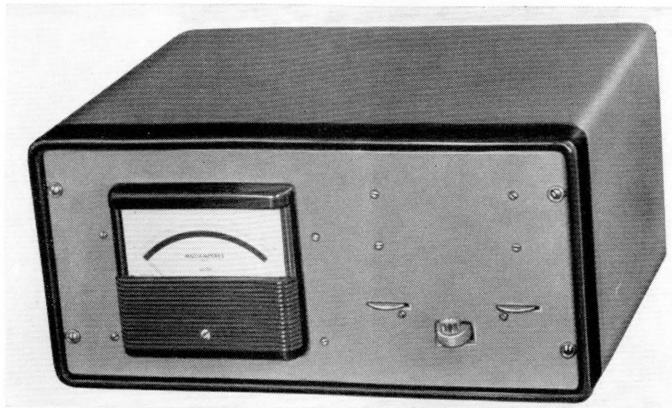

Figure 5—Model 1482 Product Resolving Amplifier.

Performance

The basic accuracy is 0.1 per cent of the input product from d-c through 400 cps. The intrinsic phase angle is about 1 minute at 60 cps, and increases to about 3 minutes through 400 cps. Above 400 cps, the low current field circuits have a somewhat poorer phase angle than the higher current field circuits because of distributed capacitance effects.

The feedback period of the entire system is approximately 20 milliseconds, and the response is considerably faster than most externally connected accessories such as indicating instruments. With an a-c product input, it must be appreciated that the response is sufficiently fast to pass through a large measure of sine product ripple, and that the first power average of the output is the true measure of the integrated input product. Accessory instruments must, therefore, be strictly average responsive as is a permanent magnet d-c instrument. For example, a thermal instrument used to measure the output current can be grossly in error because of its rms response.

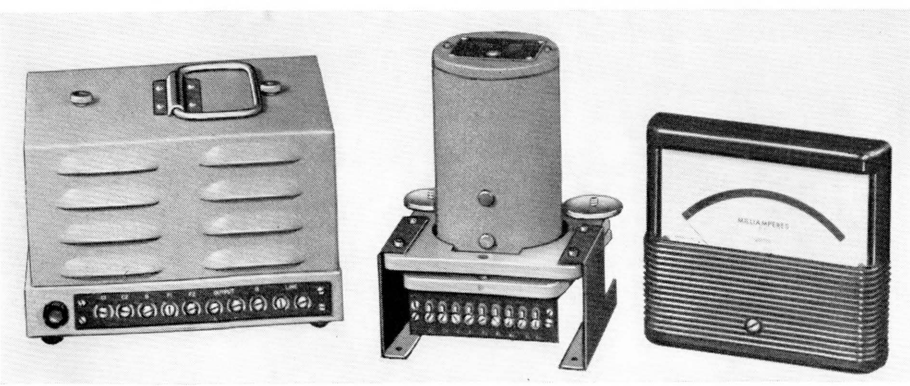

Figure 6—Component parts of Model 1482 Product Resolving Amplifier dismounted from panel.

Applications

Aside from the more obvious application to a-c measurements, the inductronic product resolving system is useful as a component for translation, computation, control, and such. Following are some broad areas of application in which this system appears unique;

—Multiplication for analog computation.
—Precise rms regulation of a-c.
—Precision telemetering of a-c.
—Automatic wave-form analysis.
—Coincidence detection or function generation.
—Data processing from analog records.

References:

"The Induction Galvanometer, a Sensitive Instrument Converter" A.I.E.E. Transactions, Volume 70, 1951.

"The Weston Model 1411 Inductronic D-C Amplifier," WESTON ENGINEERING NOTES—*Volume 6, April 1951, No. 1.*

E. N.—No. 106 —*R. W. Gilbert.*

A VECTOR-SUM AMMETER

IN THE testing of fluorescent lamps where the ballast elements are all in a potted can or box, it is difficult to separate the total lamp current—the current traveling from one end of the lamp to the other inside the glass tube—from the relatively heavy current which heats the filaments. Bipin preheat lamps are operated with a starter which opens one side of the filament at each end of the lamp when the arc current is established. Thus, the current in the arc stream is the total operating current. But with the development of lamps where the filaments are continuously connected to their respective exciting windings, it has been difficult to determine the value of all of the currents. Figure 1 shows what is involved, and it will be observed that the lamp current may flow back on either or both of the filament leads.

It will be noted that the filament current circulates from one winding of the transformer to the filament and back, whereas the lamp current either goes out on both wires or comes back on both of them depending on the relative polarity. In any event, if we let F be the filament current and L be the lamp current, and if we let K be the portion of the lamp current in one of the filament leads, we can say that one of the filament leads carries a current equal to

$$(F+KL) \text{ amperes}$$

and the other filament lead carries a current equal to

$$[F-(1-K)L] \text{ amperes.}$$

If we take a moving iron a-c ammeter and, for the coil, wind on two wires in parallel, we can connect these two parallel wires into the circuit by putting one winding in each filament lead. If we do this so that the filament currents are traveling in opposing directions in these two windings, we have a magnetic field developed proportional to the *difference* of the expressions above, or, equal to

$$(F+KL)-[F-(1-K)L] \text{ amperes.}$$

Simple algebra will show that almost everything cancels out of this expression and we have a current left which is L or the lamp current. More practically, we can simply say that the direction of the lamp current is such as to add in the two windings whereas the filament current direction is such as to cancel.

Of course, as in all differential meters, it is important that the windings be heavy enough to carry the total current without heating and that the meter mechanism be sensitive enough to operate on the differential.

At this time such a-c differential ammeters have been furnished in Weston Model 433 with full-scale values—equal to the effective *sum* of the currents in the two separate coils—of 0.5, 1.0, 1.5, 2 and 3 amperes. Note that full-scale deflection will be had with currents of half these values in each winding applied simultaneously. But the instruments will stand *double* the full-scale current in each winding indefinitely, the total instrument loss under these conditions being the order of about 2.5 watts.

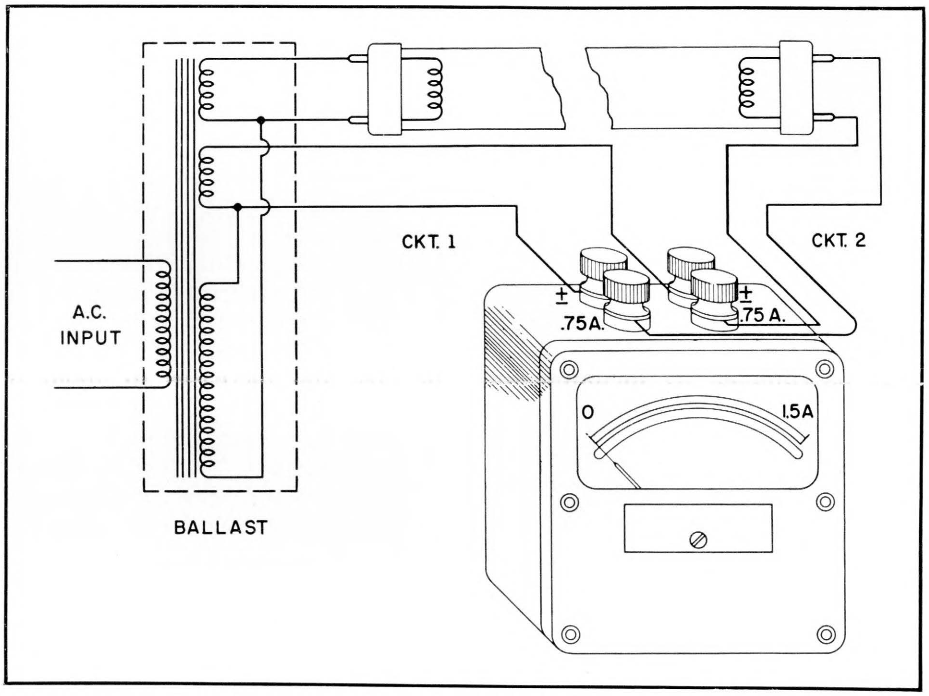

Figure 1—Connection diagram showing ballast at left supplying current to heat the two filaments at the opposite ends of the fluorescent lamp through the Vector-Sum Ammeter.

These ammeters are called "Vector-Sum Ammeters" simply because they take cognizance of the vector summation of the currents in the two filament leads and give a reading of the net lamp current.

In similar fashion where net watt readings are required of the lamp energy, independent of the filament energy, Weston Model 432 Wattmeters can be made with two current coils having independent terminals. The current coils are connected in the circuit exactly as the ammeters with the potential system of the instrument connected across the length of the tube. Since most of these tubes are for high voltage, an appropriate potential range is, of course, required. It is of interest to note that with connections made correctly to read *lamp* energy, if we then reverse *one* of the current coil connections and shift the potential terminals so that the potential system—presumably on an appropriate low voltage range—is connected across the filament, we will then be reading the *filament* energy. Similarly, if the filament watt value is taken for the filament at the other end of the tube, then the whole story is available as to the total watts in the system aside, of course, from the losses in the ballast.

And where multiple tube ballasts are used to obtain phase differences and power factor correction, this method of testing appears to be the only one which will give the true wattage in each lamp, since the method of measurement is completely independent of the relative phase of the lamp current and the filament current.

These instruments have been developed in collaboration with engineers of the Lighting Division, Sylvania Electric Products, Inc., as well as engineers of the Champion Lamp Works. Credit for the initial analysis of the problem of measuring arc current must be given to these men.

E. N.—No. 107 —*J. H. Miller.*

"Westonia"

"Sometimes nowadays people are inclined to feel that the Doctor's work in the plating field could not have been very important since he really made his mark in the measuring instrument business. But apparently he was one of the first to use a buffer in a nickel bath." E. F. Weston was holding forth again at luncheon about his father.

"It seems that when he was the expert for a nickel plating company back in the seventies, he was faced with a situation where the plating started to peel off. He reasoned that the solution was corroding the base metal before a good, tight adherent coat of nickel could get a good start. So, from his knowledge of chemistry and an understanding of chemical combinations far in advance of the times, he put some boric acid in the bath and the trouble stopped. Of course the use of buffers of various kinds is common today but it seems to have been new when the Doctor figured it out. Take a look at the old Scientific American reference book under the general subject of nickel plating."

So, from the library we obtained "The Scientific American Cyclopedia of Receipts, Notes and Queries," Munn & Co., 1892, and donated to the Weston Library by John Miller from the collection of his father, a consulting engineer of Chicago. From page 190, Formula No. 2 for nickel plating solutions is copied verbatim:

Double sulphate of nickel and ammonium.....	10 parts
Boric acid (refined)...2½ to	5 parts
Water...............	150 to 200 parts

(Weston's solution). The superiority of this solution is generally acknowledged. The deposited metal, as previously remarked, is almost silver-white, dense, homogeneous and tenacious, and the solution maintains its excellent working quality very uniformly in long-continued service.

Thus, in 1892, the formula was well established. From the biography of Doctor Weston we find that he apparently developed this combination in 1871, when he was just 21 years of age and had already established a reputation in New York City as the top technical expert in the entire electroplating field.

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WASHINGTON 11, D. C.—Weston Electrical Instrument Corp., 6230 Third St., N. W.—TUckerman 2-2414

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