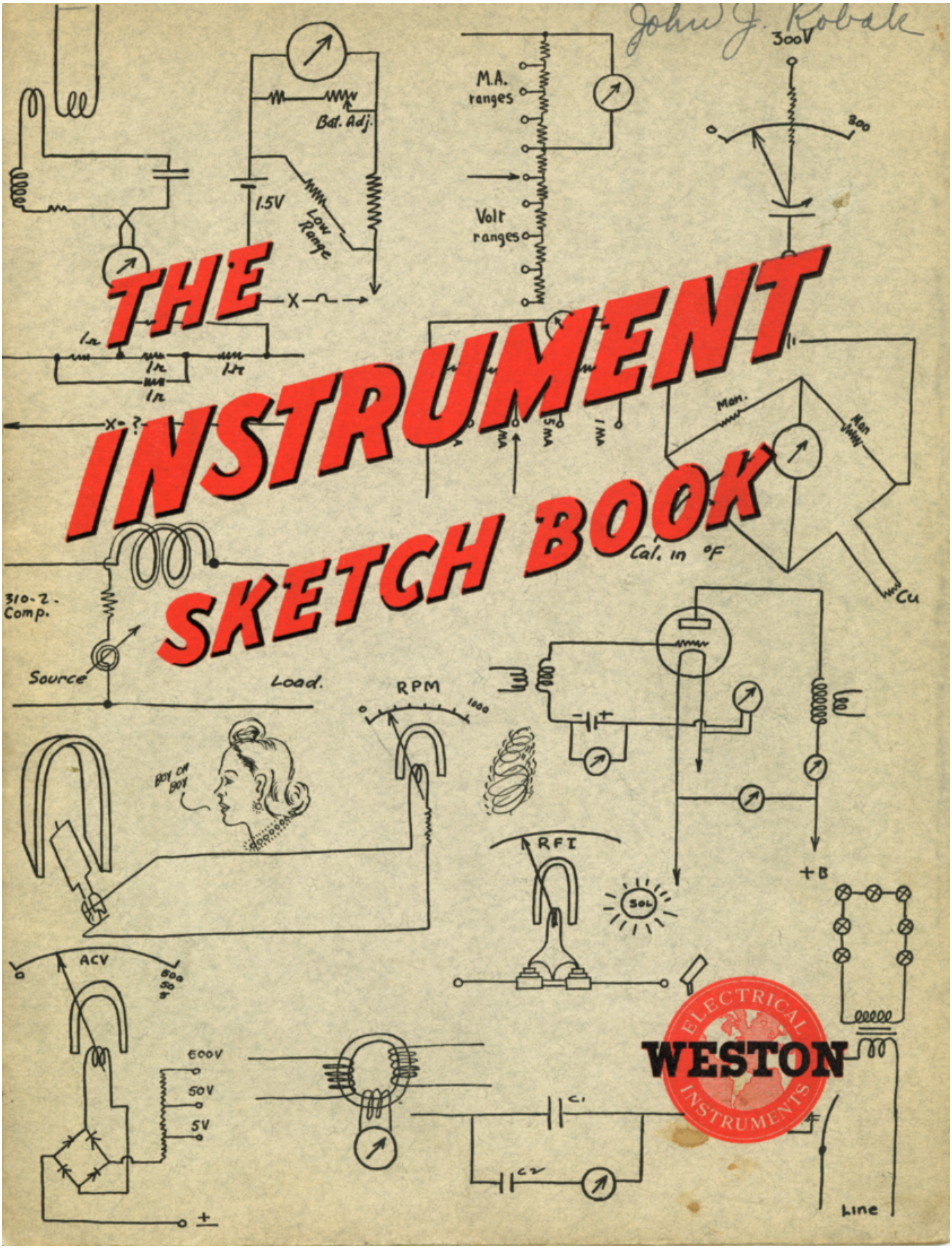
THE INSTRUMENT SKETCH BOOK



The
Instrument Sketch Book

..............being a series of sketches of instrument mechanisms, together with some data, arranged to be used in connection with Weston lectures on Indicating Electrical Instruments.

Printing has been limited to one side of the sheet making this material usable in any more elaborate notebook on the subject. The inside covers and the margins provide space for additional notes.

JOHN H. MILLER
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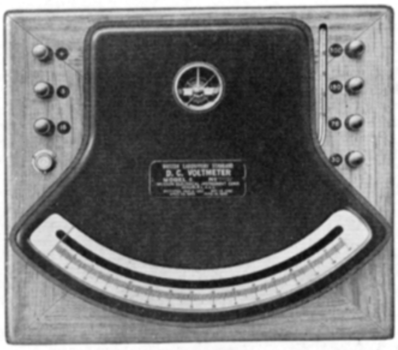
Available to Electrical, Physics and Science Instructors on request to the Publicity Department.

WESTON ELECTRICAL INSTRUMENT CORP.

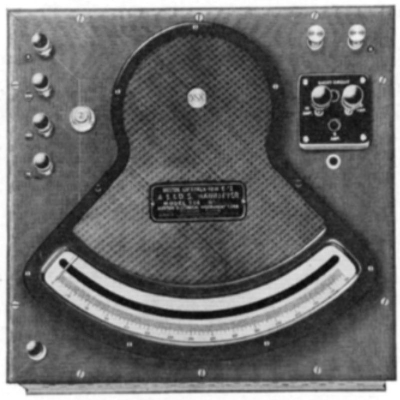
NEWARK • N. J. • U. S. A.

TYPICAL PRESENT DAY ELECTRICAL INDICATING INSTRUMENTS

Precision Types



Model 5



Model 326

Model 1

Model 370

TYPICAL INSTRUMENTS are shown on this and the next page in which the basic theory and the mechanisms shown later are incorporated to make complete devices for specific uses. The instruments shown are indicative of the great variety used in laboratories and industries throughout the world—space does not permit the showing of all of the individual variations.

LABORATORY STANDARDS such as Models 5 and 326 represent instruments of the highest accuracy available—international standards of comparison against which other instruments may be calibrated and checked. The Model 5 for DC measurements of current and voltage is of the permanent-magnet moving-coil type. The Model 326 using an electrodynamometer mechanism operates on AC and/or DC to indicate current, voltage, or power. Each instrument has a long mirror scale and is accurate within 1/10 of 1%.

PRECISION PORTABLES like the Model 310 and the Model 1 are used where high accuracy instruments must be taken to the job. They are frequently used as reserve check instruments and often as standards in the smaller laboratories. Instruments similar to the Model 310 are available as Voltmeters, Ammeters and Wattmeters, AC and/or DC, (¼%), Polyphase AC Wattmeters, (½%), Power Factor Meters (½%), Frequency Meters (½%), Microfarad Meters (½%) and Phase Angle Meters. All are of the electro-dynamometer type. Precision DC voltmeters and ammeters are available in the Model 1 which is of the permanent-magnet moving-coil type.

THE WESTON STANDARD CELL was developed by Dr. Edward Weston in 1893 to provide a working standard of the volt, as well as a purely reference standard. Since 1908 the Weston normal cell has been the international standard of the volt. These cells consist of H shaped glass jars filled with mercury, cadmium and their sulfates and will generate an unbelievably constant voltage throughout their lives. The basic voltage standard for this country consists of a group of these cells maintained at constant temperature in the Bureau of Standards, Washington, D. C. A similar group is maintained by Weston for calibration purposes.

Model 310

Model 329

Model 4

TYPICAL PRESENT DAY ELECTRICAL INDICATING INSTRUMENTS

Portable Testing and Switchboard Types

Model 430

Model 280

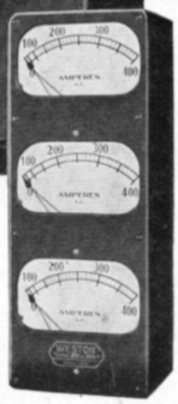
Model 45

SWITCHBOARD INSTRUMENTS are available in a wide range of sizes and shapes as are required by the various communication, industrial and utility needs. In general, switchboard instruments are built with scales and pointers that can be read at a distance and to an accuracy of 1%.

PANEL INSTRUMENTS might be considered as small sized switchboard instruments, generally flush mounted in some piece of built-up equipment such as a radio transmitter, an electric welder, or a piece of service equipment. Size and cost being important factors these instruments are generally built to an accuracy of 2%. The Model 301 is typical of such instruments.

PORTABLE INSTRUMENTS vary over a wide range as to size and accuracy due to the very broad use made of these devices. The simplest portables are made by mounting panel instruments in portable mounting bases giving an assembly such as the Model 375. Small sized assemblies are represented by the Model 280 which incorporates a number of ranges in a very compact arrangement convenient for carrying. Portables for general testing in industry and in the laboratory are represented by the Models 430, 45, 155 and 622. These instruments vary in their size and sensitivities to meet field requirements. Portable instruments in general are made in accuracies of ½ to 1%.

Model 502



Model 501

Model 301

Model 271

Model 375

Model 155

Model 622

ADAPTATIONS OF PRINCIPLE

The equipment shown below uses basic indicating mechanisms arranged to perform special functions.

Model 715
Exposure Meter

Model 633
Clamp Ammeter

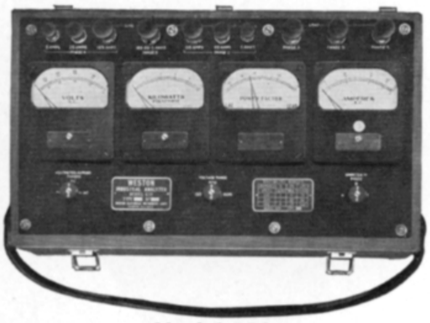
Model 534
Relay

Model 785
Industrial
Analyser

Adaptations of Principle are found in many devices built for special functions in which the indicating mechanism is a part of the complete apparatus. Simplest of these adaptations is the sensitive relay which is an indicating mechanism arranged for control rather than indication. The exposure meter is a complete device in itself arranged to indicate light brightness in terms that can be converted by a calculator into camera settings. More complicated apparatus is represented by the analyzers—devices arranged to take a variety of readings under many different conditions on one or more instruments.

The number of adaptations possible is infinite and is limited only by the user's understanding of the basic principles of these indicating mechanisms.

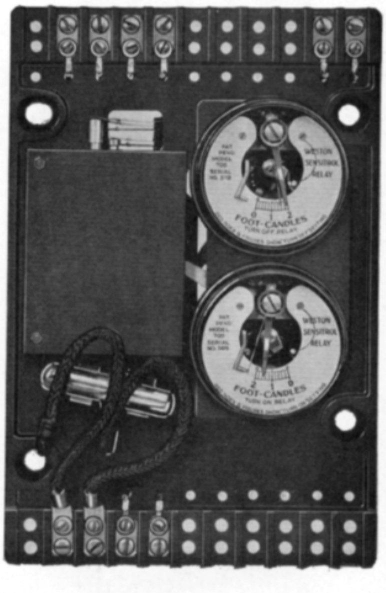
Model 705
Sensitive Relay



Model 639
Industrial Analyser

Model 614
Foot Candle Meter

Model 602
Aircraft Instrument



Model 709
Illumination Control

The Polarized Iron-Vane Mechanism

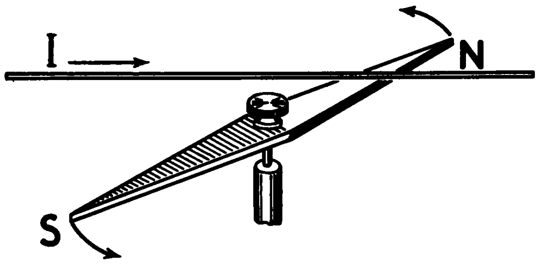


Fig. 1

The original electrical indicator—Oersted—1819

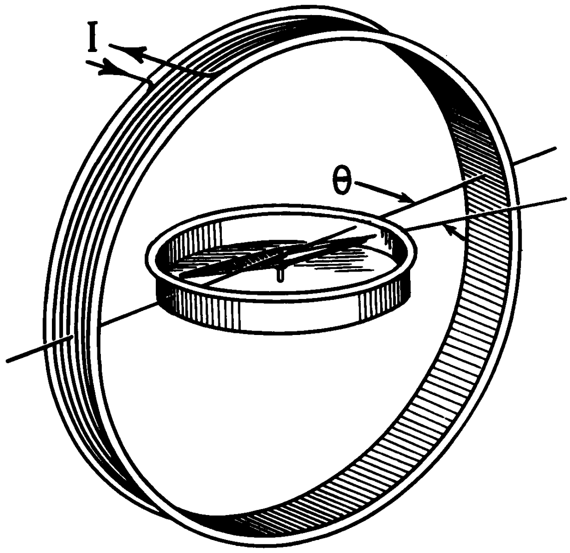


Fig. 2

Tangent Galvanometer, $I = \frac{10\ Hr.}{2\pi\ N} \tan\theta$ amperes.

r	radius of coil.
H	horizontal component of earth's field in gauss.
N	number of turns.

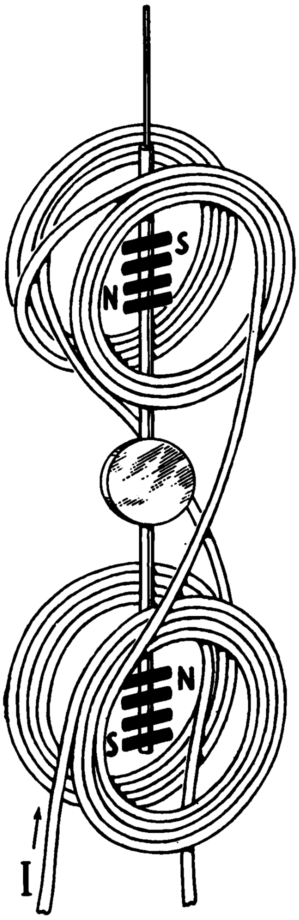


Fig. 4

Early type astatic galvanometer—Kelvin—1858.

Used on early trans-Atlantic cable circuits. Note lower set of needles has reversed magnetic polarity from upper set, thus reducing the restoring force of the earth's field and increasing the sensitivity.

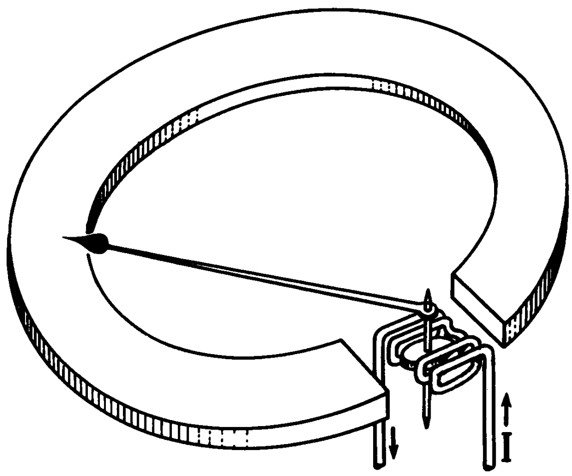


Fig. 3

Simple polarized iron vane mechanism.

Pointer is driven by an iron vane governed by the resultant field of the permanent magnet and that of the current in the coil.

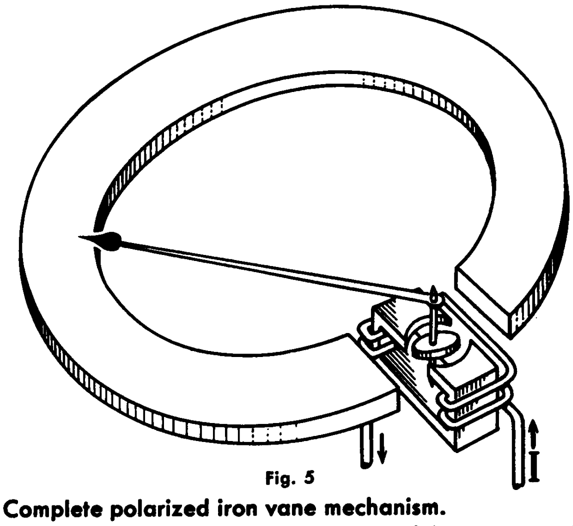


Fig. 5

Complete polarized iron vane mechanism.

Soft iron core adds to sensitivity and improves scale characteristics. Weston prototype—Model 354.

The Moving Iron-Vane Mechanism

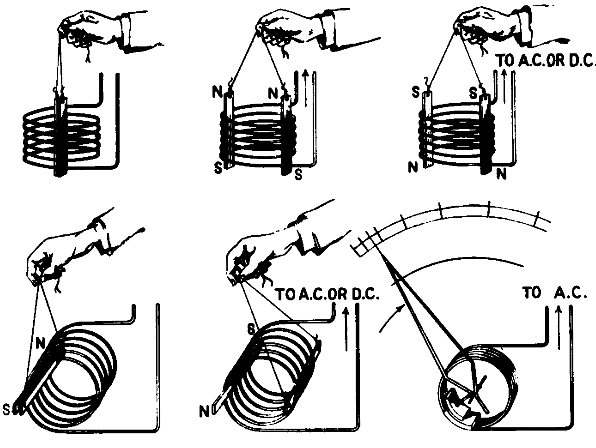


Fig. 6

If two similar adjacent iron bars are similarly magnetized, a repelling force is developed between them which tends to move them apart. In the moving iron vane mechanism this principle is used by fixing one bar in space and pivoting the second so that it will tend to rotate when the magnetizing current flows. A spring attached to the moving vane opposes the motion of the vane and permits the scale to be calibrated in terms of the current flowing.

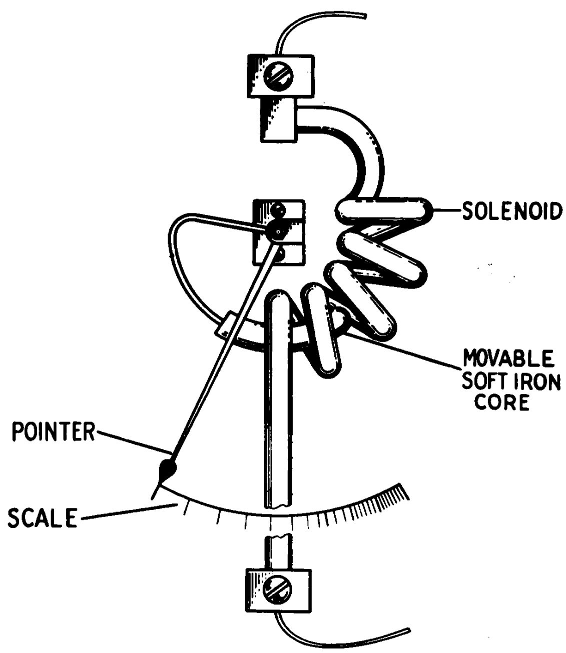


Fig. 8

Early magnetic vane mechanism of the suction type.

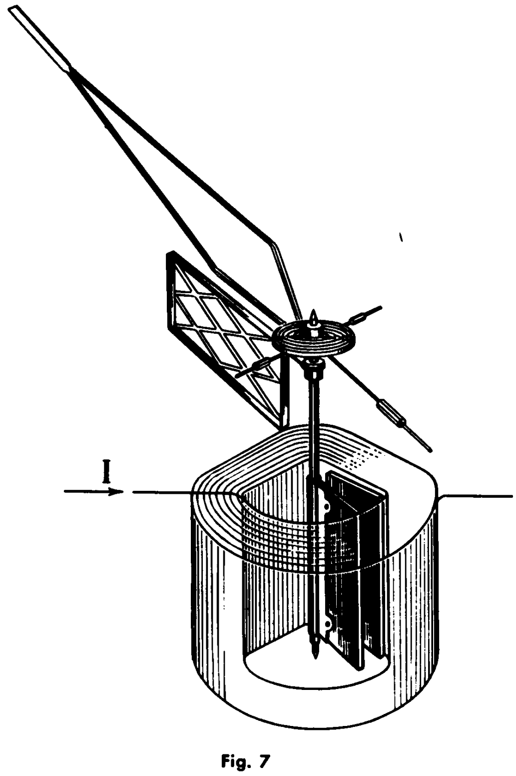


Fig. 7

Radial vane mechanism—most sensitive—most linear scale—requires better design and better magnetic vanes for good grades of instruments. Note the aluminum damping vane, attached to the shaft just below the pointer, which rotates in a close fitting chamber to bring the pointer to rest quickly.

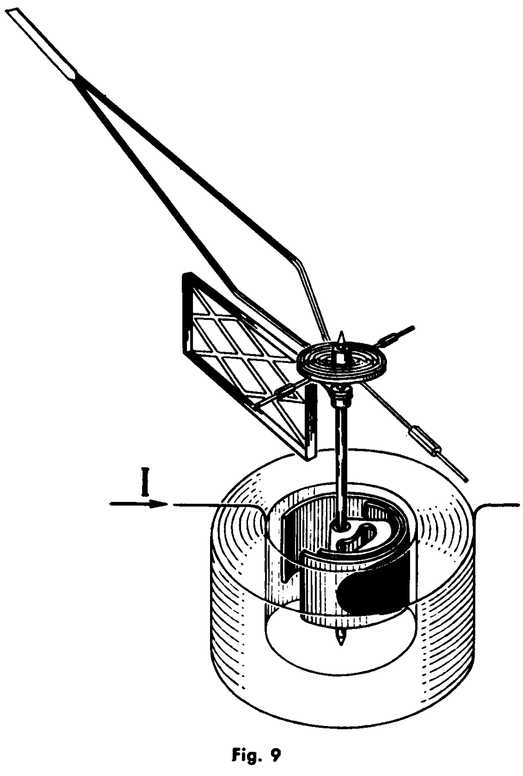


Fig. 9

Concentric vane mechanism—less sensitive—square law scale characteristics—shorter magnetic vanes resulting in smaller DC reversal and residual magnetism errors. With this mechanism it is also possible to shape the vanes to secure special scale characteristics.

The Electrodynamometer Mechanism

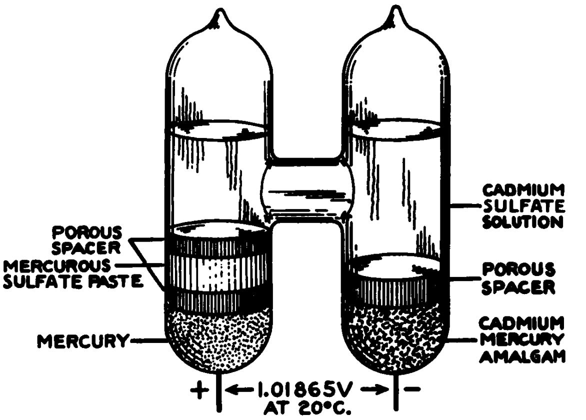


Fig. 10

The Weston Standard Cell is made in two forms, the normal cell containing a saturated cadmium sulfate solution and the type used as a working standard in which the solution is less than saturated. The saturated cell is the basic standard, being reproduceable to a very high degree of accuracy, but its temperature coefficient must be taken into account for accurate measurements. The unsaturated cell is not exactly reproduceable, its potential value must be checked against a normal cell, but its temperature coefficient is negligible, and it is, therefore, a much more practical working standard.

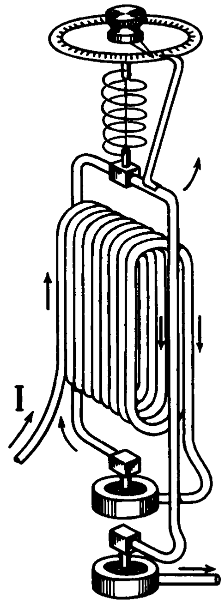


Fig. 12

Early electrodynamometer in which the moving coil was returned to its initial position and the deflectión of the spring measured.

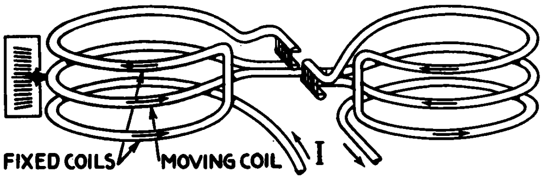


Fig. 11

Current balance—Lord Kelvin—1883.

Like fields repel, unlike attract—thus current can be weighed. This is a simple form of an electrodynamometer mechanism.

Electrodynamometer mechanisms are the most fundamental of all of the indicating-devices now used. Form factor variations do not occur because of the complete absence of magnetic materials such as iron, and the indications are of true rms values. This mechanism is current sensitive—the pointer moves because of current flowing through turns of wire. It is the most versatile of all of the basic mechanisms since the single coil movement as shown can be used to indicate current, voltage, or power, a-c or d-c, while crossed coil movements can be used for power factor, phase angle, frequency and capacity measurements. Arrangements for these uses are shown on page 27

Perhaps the most important use of the mechanism is that of a transfer instrument between the basic standards of E, I and R, all of which are d-c, to a-c circuits in which most of the power of the world is generated, sold and used.

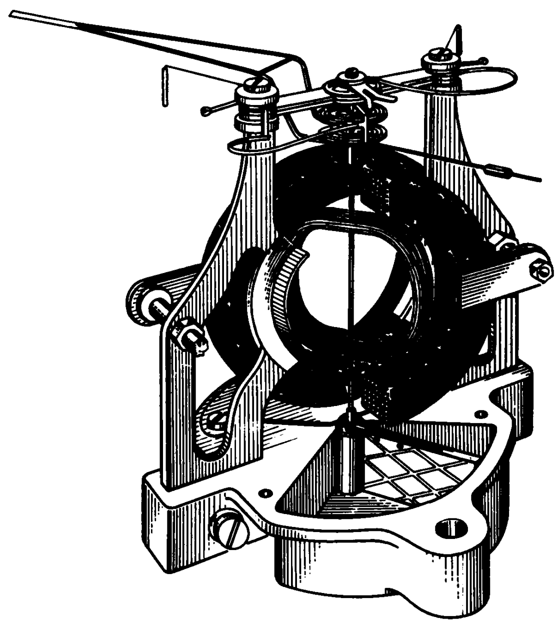


Fig. 13

The Weston Electrodynamometer mechanism shown above is that used in Model 310 wattmeters, Model 341 voltmeters and Model 370 ammeters. With a longer pointer and other minor changes it is the mechanism used in the Model 326 laboratory standard. With the further modification of crossed moving coils, shown schematically on page 27, fundamentally the same mechanism is used for measurements of power factor phase angle and capacity

The Hot-Wire Mechanism

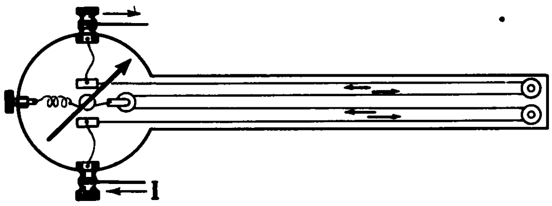


Fig. 14

Cardew voltmeter—earliest hot wire instrument—consisted of a platinum silver wire of small diameter and long enough to connect directly across circuit being measured which was looped over pulleys arranged to cause rotation of a pointer as the wire expanded due to current flow.

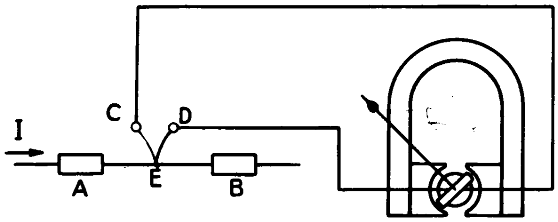


Fig. 15

Basic type of heating element and permanent-magnet moving-coil mechanism for the indication of d-c, a-c and rf A potential is generated in the junction E of the dissimilar metals ED and EC as the temperature of E is increased over that of the junctions C and D by current flowing through the wire AB. This potential causes a d-c current to flow through the indicating mechanism, which is a function of the heating current in AB. This arrangement provides no compensation for ambient temperature changes.

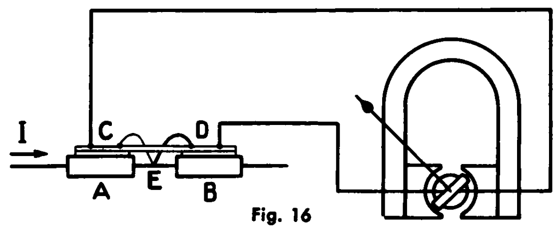


Fig. 16

The Weston compensated heating element produces a thermo-electric voltage in the couple CED which is a function of the current which flows through the circuit AB and causes a temperature rise at point E. Since the couple voltage developed is a function of the temperature difference of its hot and cold ends this temperature difference must be caused only by the current being measured. For accurate measurement, then, points C and D must be at the mean temperature of point A and B. This is accomplished by attaching the couple ends C and D to the center of separate copper strips whose ends are thermally in contact with A and B but which are electrically insulated from them. See the diagram above for greater details.

The scale of the indicator can be calibrated with evenly spaced divisions in terms of I^2 or with a square law arrangement of divisions—cramped at the left—in terms of I in AB since heating is a function of the square of the current producing the heat

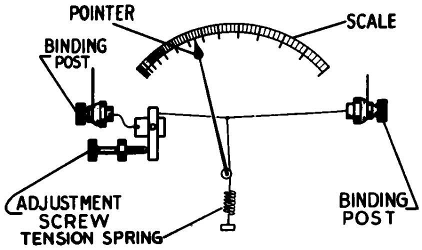


Fig. 17

In the hot wire ammeter the current being measured caused a wire through which it flowed to heat and thus expand or increase in length approximately in proportion to I^2 The change in length or sag of the wire was amplified mechanically and arranged to drive the pointer Instability due to wire stretch and lack of ambient temperature compensation have made this mechanism obsolete.

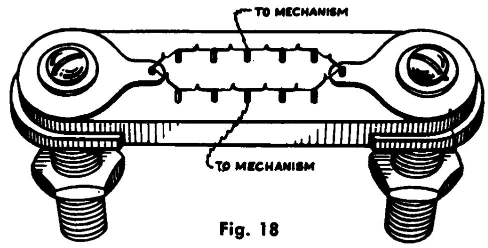


Fig. 18

Bridge type heating element used for currents from 1 to .75 amperes. In this arrangement the voltage generated by a number of junctions is used to drive current through the indicator Ranges .002 to 1 ampere use simple heating elements in small vacuum containers.

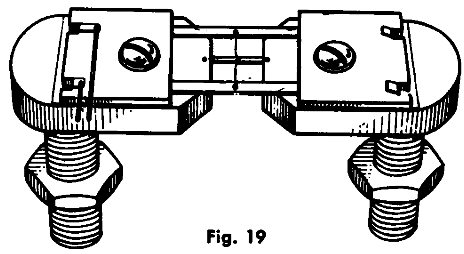


Fig. 19

Weston compensated heating element as used commercially .5 to 20 amperes for self-contained instruments. Higher ranges are of similar construction except that the heating element is supplied external to the indicator and the connecting lugs are in line with the heating wire or element. Ranges over 60 amperes are provided with air cooling fins. The heating wire .5 to 3 amperes is solid—above 3 amperes it is tubular to reduce skin effect errors.

Hot wire mechanisms are now obsolete as such, being replaced by the more sensitive, more accurate, and better compensated heating element—permanent-magnet moving-coil combination.

Thermo instruments measure the effective value of the current flowing; can be used on d-c, a-c, audio or radio frequency; and are used extensively where wave forms or frequencies encountered are such as to cause errors in other types of indicators.

No standard ampere at radio frequency being available, thermo instruments are generally calibrated at 60 cycles, sine wave. Instruments giving excellent performance up to 100 megacycles are available.

The Electrostatic Mechanism

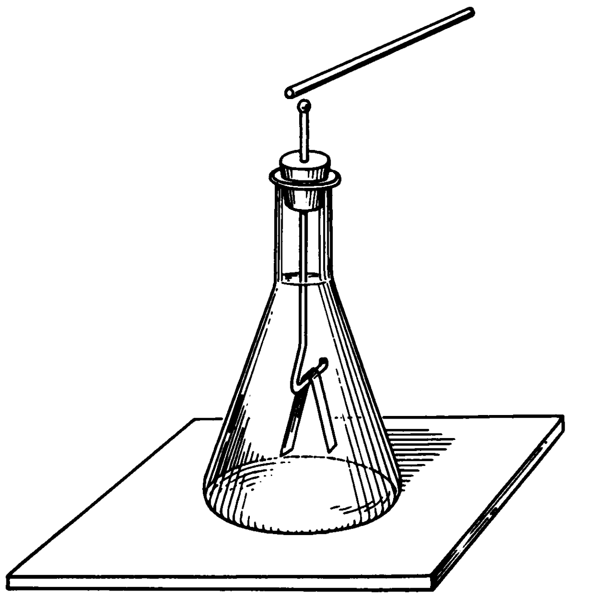


Fig. 20

Gold leaf electroscope—like charges on the ends of the leaf cause a separation of the ends. A very sensitive indicator but not an instrument.

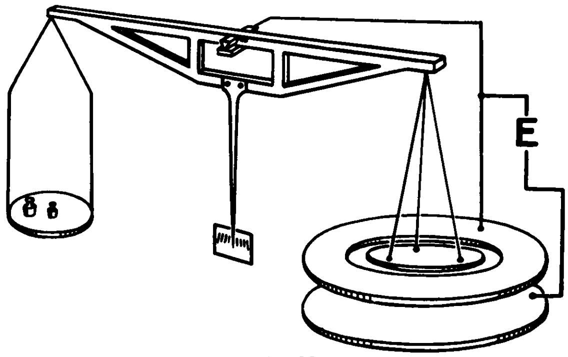


Fig. 22

The figure shows a form of the attracted disc electrometer as devised by Sir William Snow Harris in 1834. Note the guard ring around the disc to prevent any non-uniformity in the electrostatic lines of force.

A very large example of the attracted disc electrometer mounted in a shielded cage and using quartz pillar supports is used at the National Bureau of Standards for voltage standardization up to 300,000 volts. Using this high voltage electrometer, the ratio of transformation of high voltage potential transformers has recently been checked for the first time by an independent method.

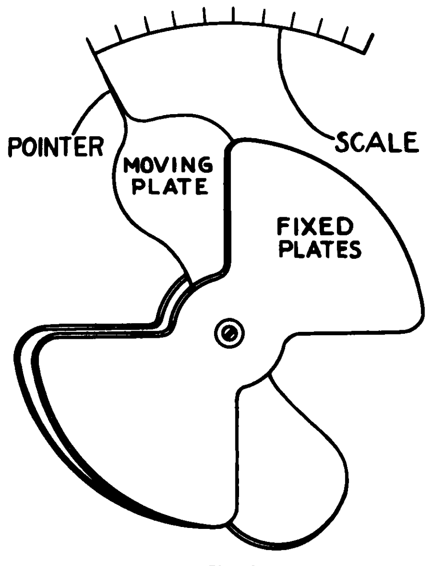


Fig. 21

Simple early electrostatic mechanism—Lord Kelvin—1887

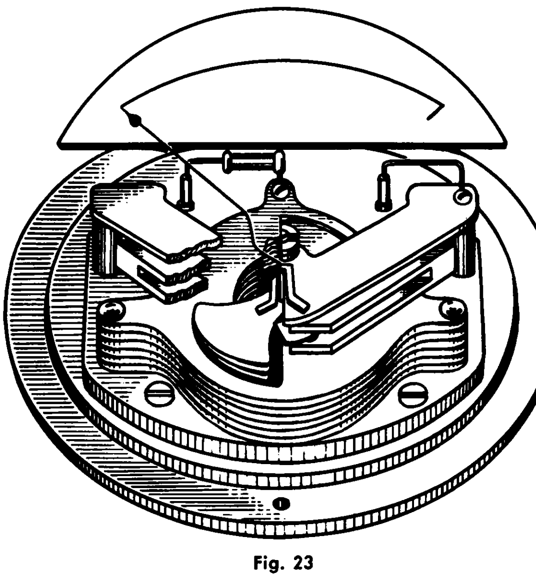


Fig. 23

Electrostatic voltmeter as made commercially by Ferranti, England. Available in 3½" panel size, 300 to 3500 volts.

The electrostatic mechanism is the only one of those used for electrical indications that functions because of the presence of a voltage. All of the other mechanisms are current sensitive producing pointer movements due to current flowing through the instrument circuit.

The torque useful in driving the pointer of an electrostatic instrument is a function of the voltage, the area of the plates and inversely as the distance between them. As the voltage increases the distance between the plates must be increased so that these factors cancel; as the plate areas are increased so is the weight of the moving system thus requiring more area; hence, a good compromise is very difficult to obtain and the resulting design generally has far too little torque to successfully overcome resulting pivot friction in most industrial applications.

The electrostatic voltmeter is particularly useful on a-c circuits where the current taken by other mechanisms would result in distorted conditions. A protective resistor is normally placed in series in the circuit of these instruments to limit current flow in the event of a short between moving and fixed plates. The presence of this resistor must be recognized under certain operating conditions.

The Permanent-Magnet Moving-Coil Mechanism

Many persons over a period of more than 130 years have contributed to the permanent-magnet moving-coil mechanism as it is used today. Oersted (1819) discovered the relation between current and magnetism; Faraday (1821) learned that a current carrying conductor would rotate in a magnetic field; Ampere (1821) worked out the laws governing the strength of currents; Sturgeon (1836) first suspended a coil in a magnetic field forming a moving coil galvanometer; Kelvin (1867) placed a soft iron core in the center of the coil shortening the air gap, increasing the sensitivity of the device and improving the scale characteristics; D'Arsonval (1881) patented an instrument of this type; Weston (1888) discovered that the factors governing the permanency of a magnetic circuit lay in the circuit rather than in the magnet, added the soft iron pole pieces and current carrying control springs, and made the first commercial permanent-magnet moving-coil instruments as such.

Since 1888 there have been no changes in basic theory or design, but numerous changes in materials and technic have increased available sensitivities by 125,000 fold. Few devices in any field can show this improvement; 10 Milliamperes full scale (12500 microwatts) in 1888, .005 milliamperes (.1 microwatt) in 1933, each on a scale of 5.2"

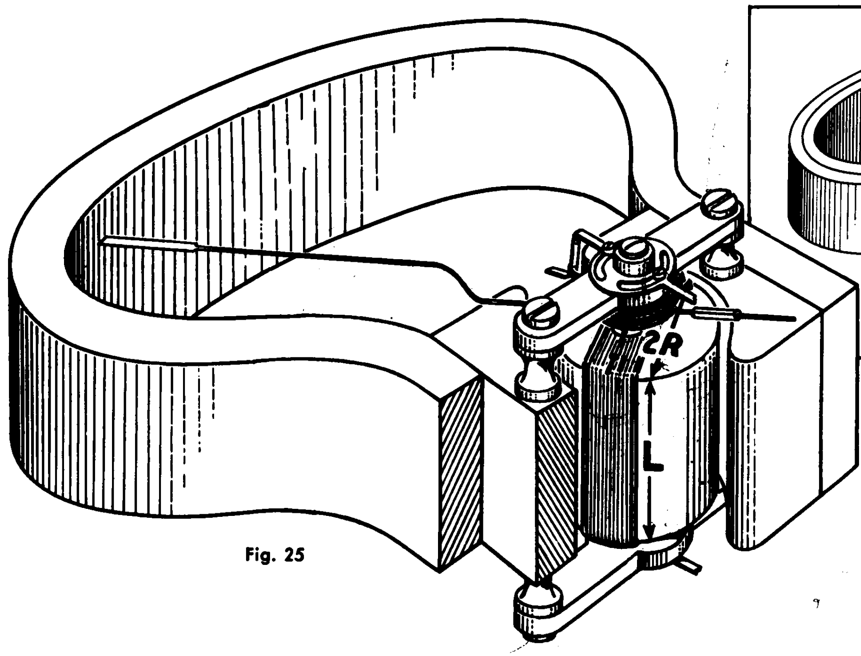


Fig. 25

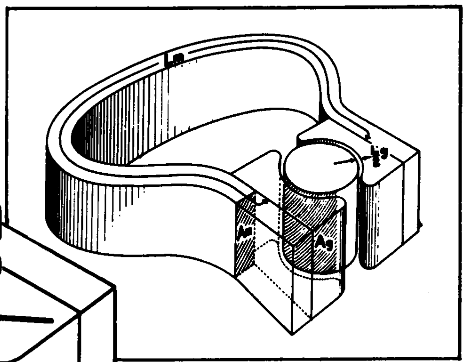


Fig. 24

The torque, developed by current flowing through the moving coil, is given by

$$T \quad \frac{B2RLIN}{10} \quad \frac{BAIN}{10}$$

where T torque in dyne centimeters.
B flux density, lines/square centimeter in the gap.
A coil area in square centimeters.
I moving coil current in amperes.
N = turns of wire in moving coil.

An average Model 1 develops approximately 200 dyne centimeters/radian in a movement weighing 1 9 grams while an average Model 301 develops approximately 10 dyne centimeters/radian for a weight of 200 milligrams.

The generally accepted criterion for the permanency of a permanent magnet is

$$K \quad \frac{Lm.Ag}{Am.Lg}$$

where K permanency constant
Lm effective length of the magnet
Ag area of the gap
Am cross sectional area of the magnet
Lg length of the gap (sum of the two sides)

The value of the permanency constant is associated with the various grades of magnetic materials and may be roughly considered as 100 for tungsten steel, 30 for cobalt steel and 12 for Alnico, all presumably properly heat treated, magnetized and aged. Small changes in steel analysis as well as leakage factors in specific designs may modify the above criteria and for best design a rather complete knowledge of all factors is required.

The Permanent-Magnet Moving-Coil Mechanism

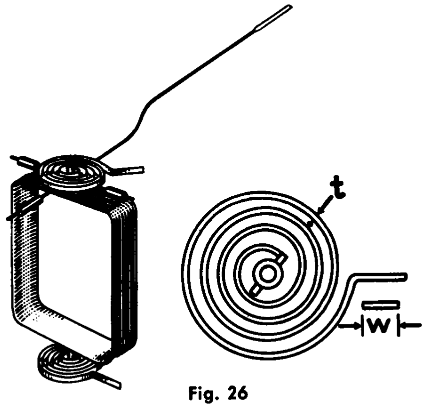
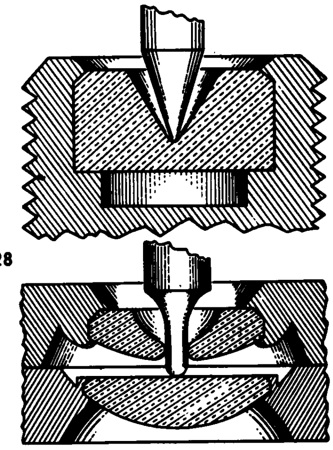


Fig. 26

A typical moving coil for a permanent-magnet moving-coil system. Most voltmeter coils have metal frames for damping—a short circuited turn in a strong magnetic field; most ammeter coils are frameless—the turns themselves being shorted by the shunt. One spring normally unwinds while the other winds with rotation of the pointer; both are normally equal in strength and both normally contribute equally in opposing the electrical torque developed by the movement Each coil carries top and bottom, a pivot base and removable pivot. The entire moving system is statically balanced for all positions of the axis by means of three balance weights.

The spring's tension, by just balancing the moving system's twist, is the part that is actually calibrated in the indicating instrument. Its constancy of performance is essential to the instrument's sustained accuracy. The torque of a spiral spring is directly proportional to spring width, to the cube of its thickness, and inversely to its length. For deflection of the order of 90° the length must be greater than 1500 times the thickness to avoid permanent set in good phosphor bronze spring material.

Fig. 28



For instrument bearings the ring jewel produces entirely too much friction and the V jewel as shown is almost universally used. The pivot may have a radius at its tip from .0005″ to as high as .003″ depending upon the weight of the mechanism and the vibration it will encounter The radius of the pit in the sapphire is somewhat greater so that contact is in the form of a circle a fraction of a thousandth across. This type of bearing, operated dry, has probably the lowest constant friction value of any known type of bearing.

Jeweled bearings for fine mechanisms and particularly clocks and watches were invented by Nicolas Facio, a Swiss watchmaker, about 1705. Such bearings in timepieces were used because of their low friction, but their form must be such as to keep the tiny teeth of the gears constantly in mesh. A ring jewel is, therefore, necessary to maintain the alignment with the table jewel for end thrust. The jewels are mounted in the watch plates as shown.

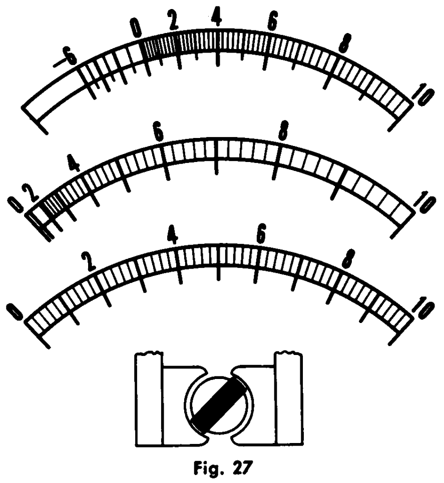


Fig. 27

The conventional permanent-magnet moving-coil mechanism is supplied with core and pole pieces having concentric faces. Such mechanisms produce the scales shown. The lower scale is that of the mechanism itself showing linear placement of the divisions with linear increase in current in the moving coil. The center scale shows square law distribution resulting from the use of a heating element with standard mechanism. The top scale shows logarithmic distribution resulting when this movement is used for DB measurements. Because of cramping at the left, the upper two scales are difficult to read at the lower values.

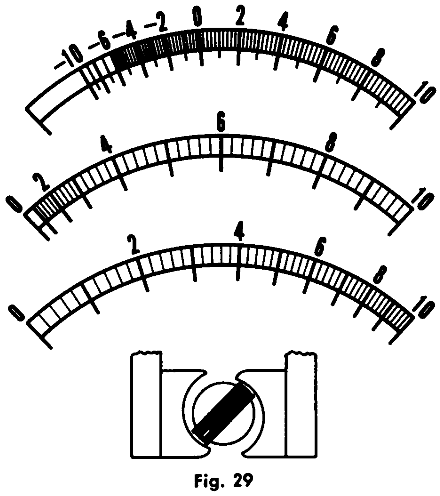


Fig. 29

The permanent magnet-moving coil mechanism may be supplied with specially shaped or eccentric pole pieces resulting in uneven flux distribution in the air gap and a non-linear relation between current in the moving coil and pointer movement. The lower scale shows the effect of the eccentricity illustrated. When used with square law heating elements the resulting scale, center, becomes more linear The top DB scale is not only more uniform but is readable over a longer portion of the arc. Such special pole pieces and/or cores, though expensive to produce, are useful in adapting this mechanism to special applications.

Series Resistors and Shunts

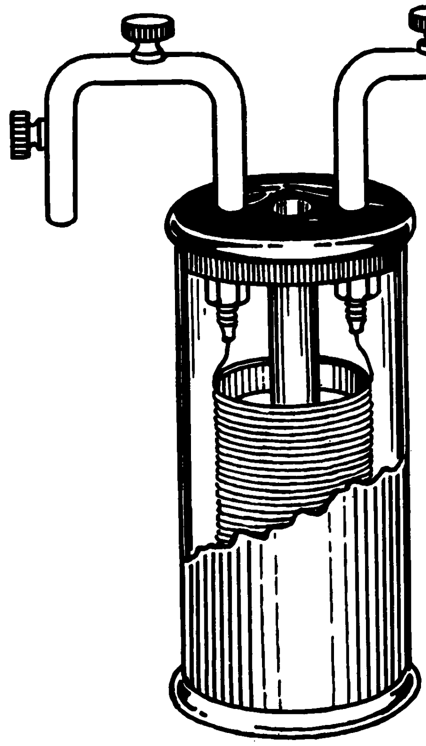


Fig. 30

Resistors used as basic standards in values above 10 ohms are built in the form shown above as designed by the National Bureau of Standards. Carefully heat treated manganin wire is wound on an oiled silk insulated brass cylinder and shellacked to fix its position. Separate connections are provided for input and potential leads. After extended baking to insure dryness the assembly is placed in moisture free oil and sealed in its brass case. Below 10 ohms the construction is the same except mechanically larger Such units, properly handled and used, maintain their accuracy within 10 parts per million for long periods of time.

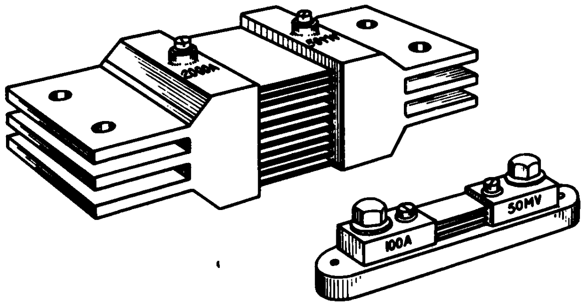


Fig. 31

Shunts for d-c instruments are usually self-contained for the lower current ranges. On the higher ranges where the shunt becomes physically large and the heat generated in it more than a few watts, external shunts are required. Small or large, the shunt (British for railroad siding runaround) consists of a manganin conductor terminating in copper terminals. The manganin is usually adjusted to give a drop of 50 mv for full load current—the copper terminals are provided with separate connections for the instrument to avoid errors.

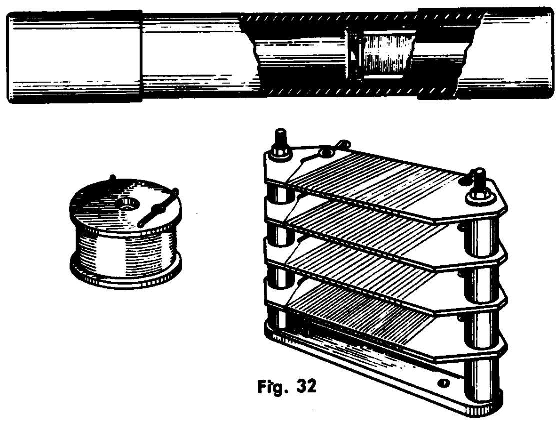


Fig. 32

Series resistors for voltmeter use take various physical forms depending on the application. Self-contained ranges use small compact spools for the more sensitive mechanisms and larger "cards" for those requiring more current. All series resistors in which the heat generated is more than the instrument case can radiate must be external. The special tubular resistor shown at the top is wax filled, hermetically sealed, and electrostatically shielded to insure long life at high voltages in humid or salt atmospheres.

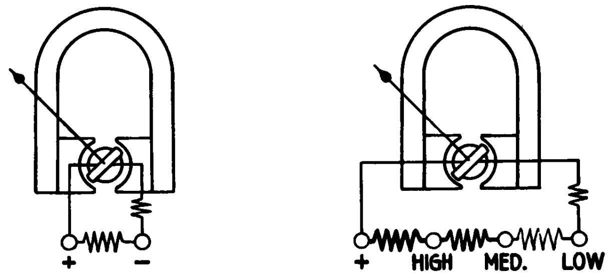


Fig. 33

Shunts, are usually made to produce definite potential drops across their terminals; the associated d-c mechanism is built to give full scale deflection on a slightly smaller potential; and the two adjusted to each other by means of a small series resistor Wherever possible, multi-range shunts should be connected as shown thus avoiding the use of a switch, and the resulting variable contact resistance, between the mechanism and the shunts.

Only small amounts of current, approximately 50 ma maximum, can be taken into the moving coil through the springs hence, external shunts are needed for the higher ranges.

Likewise, the resistance of the moving system, including the springs, is low and series resistance is needed for voltmeter ranges.

A permanent-magnet moving-coil mechanism is not independent of temperature by itself but may be made so by the appropriate use of proper series and shunt resistors of copper and manganin. Magnets and springs decrease in strength and copper increases in resistance with increase in temperature. The changes in the magnet and the copper tend to make the pointer read low on fixed voltage impressed while the spring change tends to cause the pointer to read high. The effects are not identical, however, with the result that an uncompensated mechanism tends to read low.

Copper-Oxide Rectifiers...Photronic Photoelectric Cells

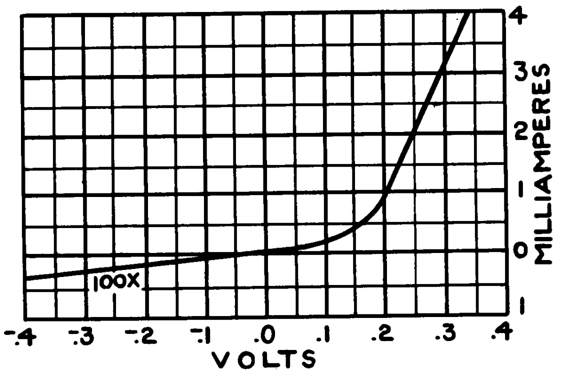


Fig. 34

Copper-oxide rectifiers as used with indicating instruments have current-voltage characteristics as illustrated above. Note that the curve to the right of zero volts is not linear which accounts for the scale characteristics found on low range voltmeters and the inability to track low and high ranges on the same distribution of divisions.

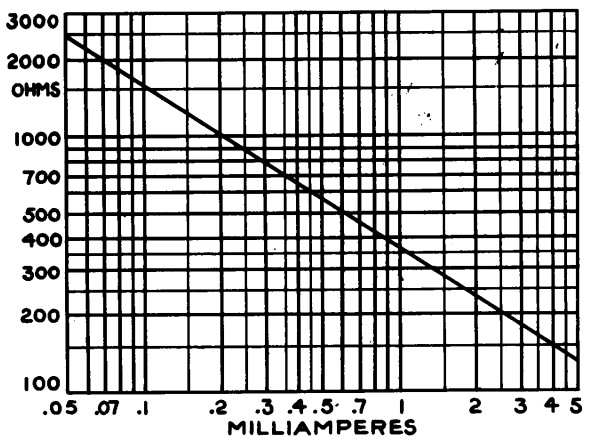


Fig. 35

The current-resistance relation in any given rectifier is logarithmic over its usable forward conducting range. The curve above shows this characteristic for one size of instrument rectifier This rectifier is used with instrument ranges from 1 to 5 milliamperes.

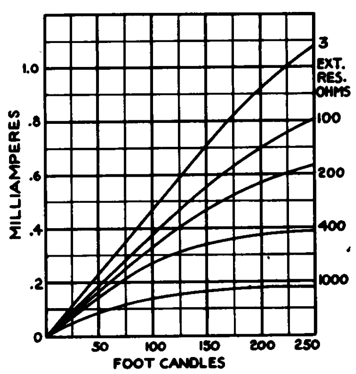


Fig. 36

The Photronic photoelectric cell may be considered as a converter of energy—light to electrical. The curves above indicate current output of a standard Photronic cell at various light values and show the effect of external circuit resistance upon linearity

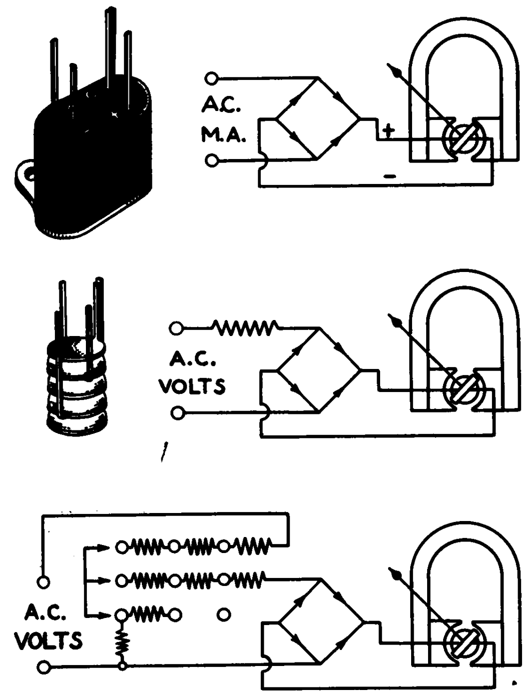


Fig. 37

The copper-oxide rectifier as used by Weston is shown approximately full size above. The assembly of discs is hermetically sealed in the bakelite housing to insure constancy of performance with time. The current ranges of a rectifier instrument are, except in special applications, limited to the current that the rectifier can safely pass. Shunting is not practical because of frequency errors in the branch circuits so formed. Above approximately three volts rectifier voltmeters are practical and ranges above 10 volts will usually track on the same scale divisions. Constant impedance voltage measuring circuits, such as are required in many DB and VU applications, are arranged as shown in the lower diagram.

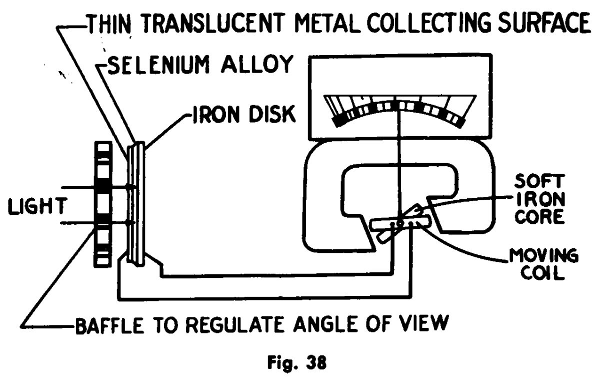


Fig. 38

The photographic exposure meter indicates scene brightness. Having a figure representing the film speed and a reading of the scene brightness, the calculator discs are set to these values. The lens opening and exposure time are then indicated for a well exposed picture. Note the shaped pole pieces on the d-c instrument which, in conjunction with the cell characteristics, give a wide coverage of light values on a nearly logarithmic scale.

Temperature Measuring Devices

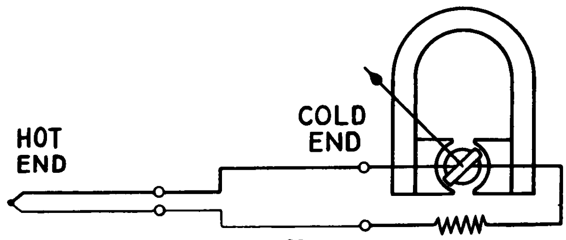


Fig. 39

Two of the principles used in the electrical measurement of temperature are shown; the thermocouple pyrometer above and the resistance thermometer at the right.

As shown in the diagram, the thermocouple pyrometer circuit is relatively simple and possesses the advantage of operating without any external source of energy It is generally useful only where large temperature differences exist between the hot and cold ends of the couple; it must be noted that this device does not measure absolute temperature, but simply temperature difference between the hot and cold ends. In general this temperature difference should be greater than 200° for the satisfactory application of a direct reading instrument.

The resistance thermometer on the other hand requires a source of energy, frequently a battery of a few dry cells, and measures absolute temperature in terms of the resistance contained in one of the arms of a Wheatstone bridge. A relatively high sensitivity can be obtained, and it is useful for measuring moderate temperatures, say between —200° and +300° F Ambient temperature variations can be fully compensated.

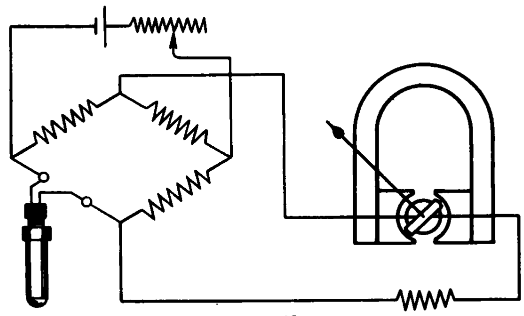


Fig. 41

Used with a conventional instrument, a constant battery voltage is required; used with rather special ratio type indicators a correct indication of temperature will be had with battery voltage variations as high as 50%

Basic temperature measurements are made with the null balance bridge wherein the resistance of the temperature sensitive arm is accurately measured and a conversion table used to determine corresponding temperature. The temperature limits of this method are the resistance-temperature linearity limits of the material used in the variable arm of the bridge. The method is fundamental and the resistance of pure platinum is used as the tie between the basic gas thermometer and ranges of temperature beyond which the gas thermometer cannot be used.

Ratio Indicating Mechanisms

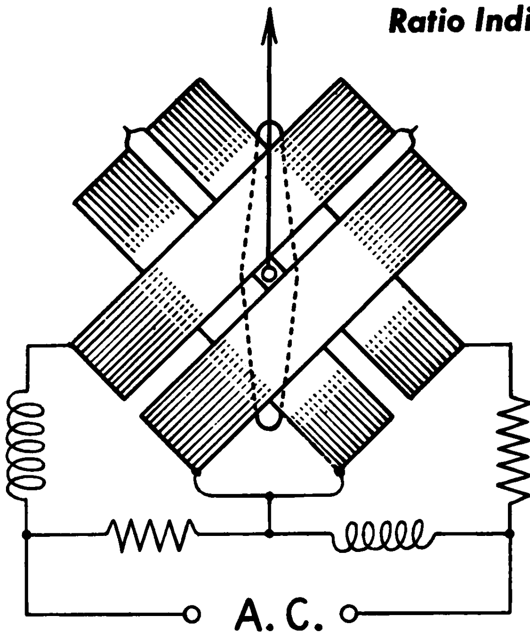


Fig. 40

The mechanism shown above is typical of the crossed coil iron vane ratio group. As shown the circuit is arranged to be frequency conscious and is that of a Model 339 Frequency Meter Note that in this case the relative strengths of the two fields are governed by the reactor-resistor combinations and that the iron vane has no control spring or zero as such. When not connected to the circuit the pointers of such instruments may stand at any point on their scales.

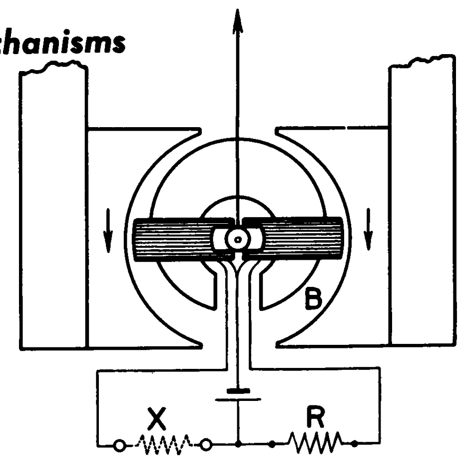


Fig. 42

Another distinct type of ratio meter is that shown above in which two independent coils rigidly mounted on opposite sides of a common axis each move in an eccentric air gap. No control springs are attached to the moving system, the current being fed to the moving coils through fine filaments. The ampere turns—or flux —developed by each coil reacts with the flux in its gap causing the pointer to move until a balance is reached at which point the product ampere turns X gap flux will be equal on each side. Such a system will not function with concentric air gaps.

The circuit as shown is arranged to indicate the value of the resistance X; the indication is actually that of the ratio of X to the standard resistance R.

Ratio meters of this type can be used for any indication that can be arranged to change one arm of a bridge circuit with reference to another

Transformers

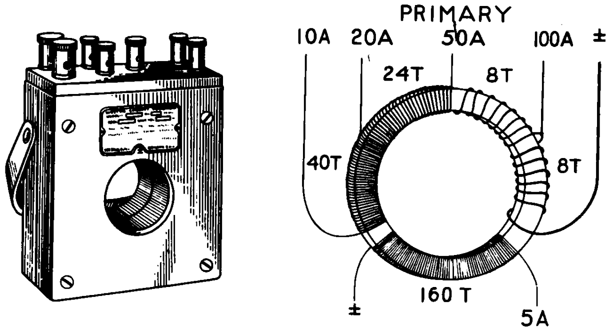


Fig. 43

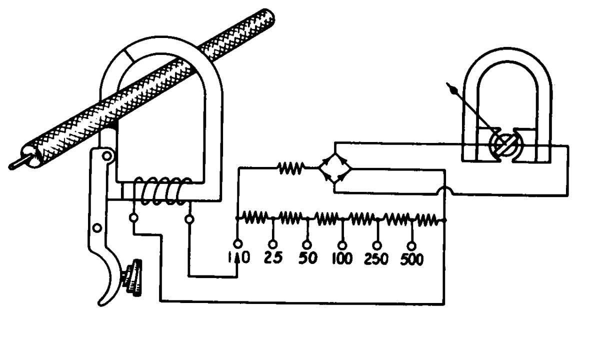


Fig. 45

Current and potential transformers extend the ranges of a-c instruments in the same way as shunts and series resistors work for d-c instruments. Taps on the windings permit a single transformer to operate over a very wide range. Basic instrument ranges for transformer use are usually 5 amperes and 115 volts.

The chief errors in instrument transformers are due to ratio and phase angle both of which are controllable in design by using proper flux densities for the magnetic material involved and appropriate construction.

The circuit of the Model 633 clamp ammeter is shown above. A small proportional current is derived from the line current through the use of the hinged core current transformer This secondary current is then connected to a suitable tap on the multiple range rectifier type milliammeter to give the reading. Note the use of the rectifier meter made into a multiple range device through the use of the multi range series shunt. Thus we have here the current transformer, the series shunt, the rectifier meter principle and the fundamental d-c mechanism, all to secure the single result of reading the current in a conductor without making a connection to it

Composite Application

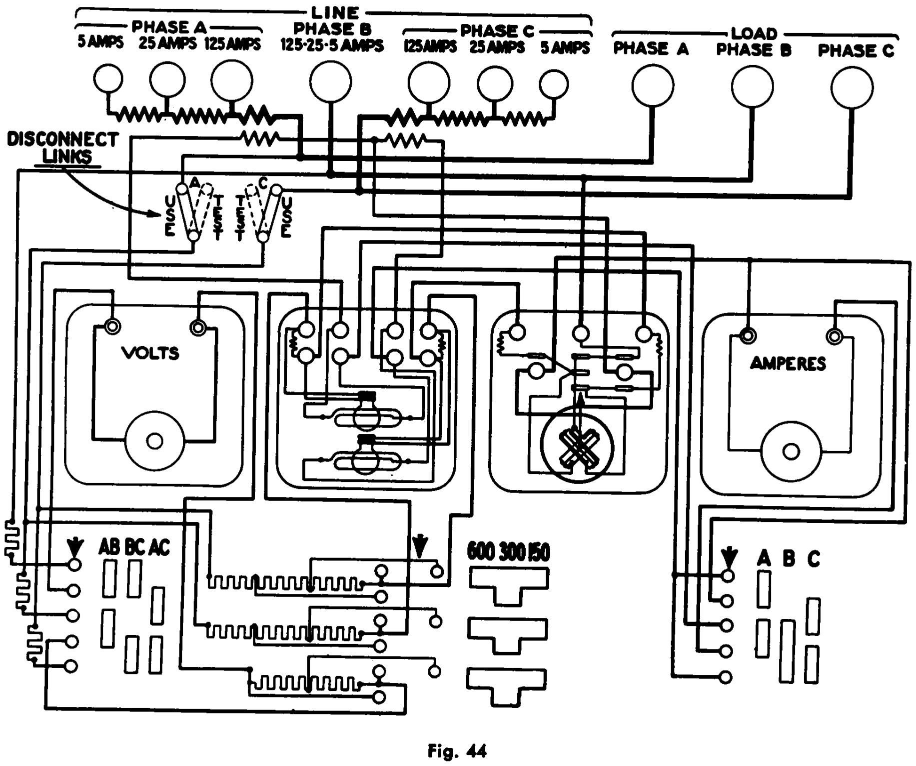


Fig. 44

The Model 639 Industrial Analyzer pictured on page 4 is typical of devices consisting of an assembly of instruments and accessories arranged to conveniently perform a certain measurement or group of measurements. The circuit of this device, shown above, consists of two current transformers, connected to the line side, followed by the voltmeter, wattmeter, power factor meter, and ammeter in a circuit containing the necessary switching. Note that the composite assembly permits the common use of certain series resistors by more than one instrument.

Coil Arrangements in Electrodynamometer Mechanisms

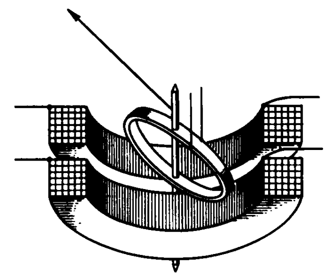


Fig. 46

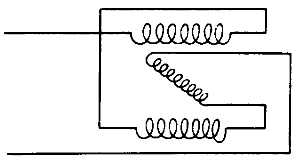


Fig. 47

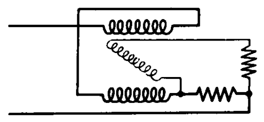


Fig. 48

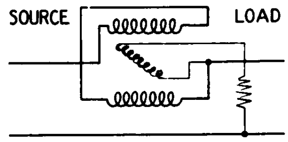


Fig. 49

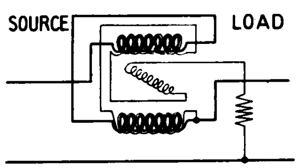


Fig. 50

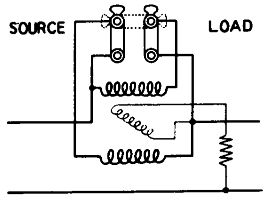


Fig. 51

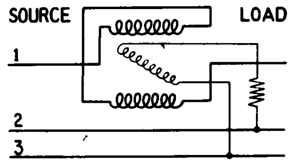


Fig. 52

Fig. 46—Physical arrangement of coils in single element electrodynamometer.

Fig. 47—With fixed coils of fine wire in series with moving coil, for low range milliammeters and for voltmeters when used with series resistors.

Fig. 48—With fixed coils in series with a shunt resistance across which is connected the moving coil, for current measurement.

Fig. 49—With fixed coils in series with the line and moving coil in series with resistance across the load as a simple direct connected single phase wattmeter.

Fig. 50—As above but with compensating winding cancelling the effect of the potential system current so that only true power in the load is indicated. Usually used only in moderate range portable standard wattmeters.

Fig. 51—Arranged with links to place fixed coils in parallel or in series thus producing a wattmeter with a double current range.

Fig. 52—In a 3 phase 3 wire circuit with fixed coils in one line and potential coil connected across the other two lines this instrument reads reactive volt-amperes instead of watts. This arrangement can be applied to a two element system for a more accurate reading of volt-amperes irrespective of load balance. Other schemes may also be used for securing the quadrature current in the potential system. Much used by Utilities to measure reactive KVA.

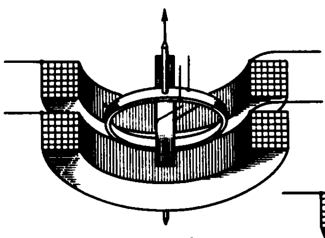


Fig. 53

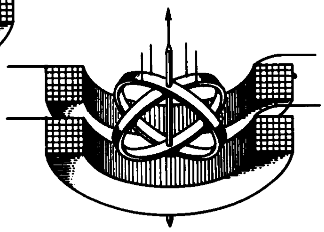


Fig. 54

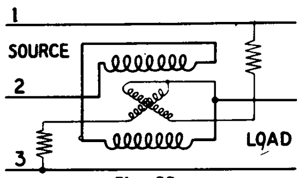


Fig. 55

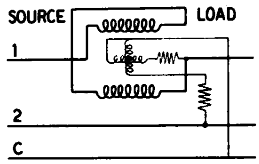


Fig. 56

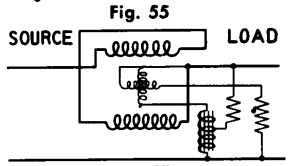


Fig. 57

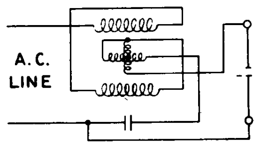


Fig. 58

Figs. 53 and 54—Physical arrangement of coils in electrodynamometer with crossed moving coils for power factor measurement; used also as an a-c ratio device for measuring other quantities.

Fig. 55—With crossed coils connected to opposite legs of a three phase system and with filaments rather than springs on the moving element, the moving system takes up a position dependent on the phase angle or power factor of the circuit. This is the conventional three phase power factor meter.

Fig. 56—For two phase systems a somewhat different arrangement of the moving coils is used, but the result is the same; the pointer indicates the power factor of the system.

Fig. 57—For single phase power factor measurement a two phase mechanism is used with the current in the vertical moving coil lagged full 90° by the reactance-resistance network.

Fig. 58—Used as a ratio meter the two phase power factor mechanism measures the capacitance of the condenser shown in dotted lines by comparing the a-c current through it with that through the standard condenser. The scale is marked directly in microfarads.

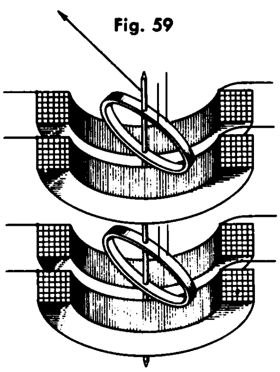


Fig. 59

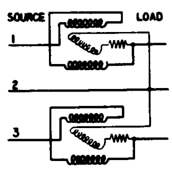


Fig. 60

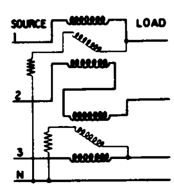


Fig. 61

Fig. 59—Physical arrangement of coils in two element electrodynamometer mechanism used largely in polyphase circuits.

Fig. 60—In any polyphase system Blondel's Theorem states that true power is indicated by one less wattmeter than the number of wires; in a 3 phase 3 wire system the two element mechanism connected as shown at left indicates true power for any condition of unbalance.

Fig. 61—In a 3 phase 4 wire system a three element wattmeter would be required for true power; three element instruments are unduly expensive, however and the so-called 2-½ element instrument shown at left reads correctly if the voltages are in balance and undistorted even though the current be unbalanced. Note current in line No. 2 passes through both the upper and lower elements but is displaced in phase by 60°; the component in phase with the moving coil current is therefore half of its actual value, and the summation in the two elements gives the correct result.

THE PERMANENT-MAGNET MOVING-COIL MECHANISM

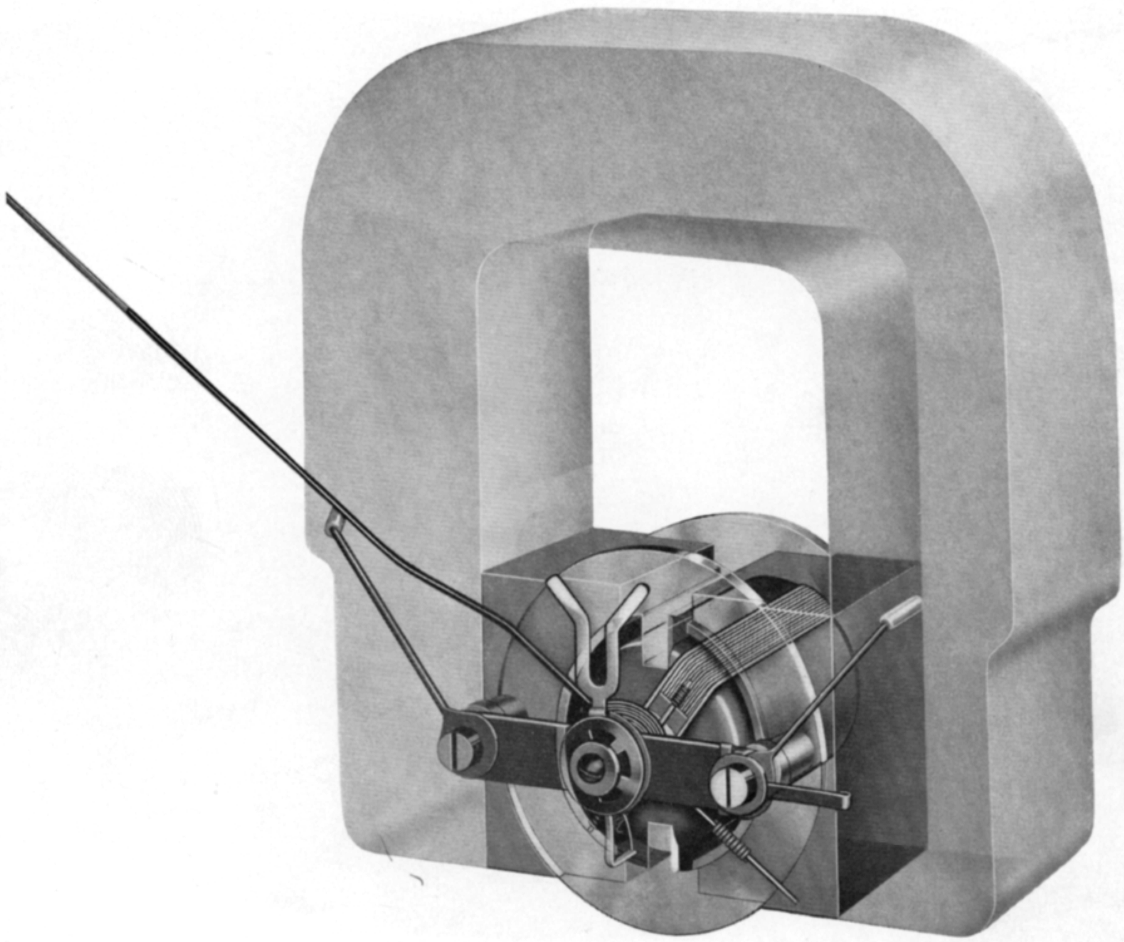
As reduced to practice in the Model 430

In the manufacture of a device as finely integrated as an electrical measuring instrument the actual fabrication of the parts and their assembly is fully as important as the optimum selection of materials and the best of design.

Fabrication of materials in the Weston plant goes back to fundamentals and in the case of important items such as control springs, the actual alloy is made in our metallurgical department and processed through completely to the final spring. Several large batteries of screw machines allow for the maintenance of the necessary accuracy in small parts. Many of the punch press items are punched and then sheared to size to get the necessary exactness.

Coils are wound from carefully inspected wire, and in many cases are bakelized in an autoclave to produce a solid structure of great rigidity

Below is the mechanism of the Model 430 shown above—a typical permanent-magnet moving-coil system.



THE MOVING-IRON VANE MECHANISM

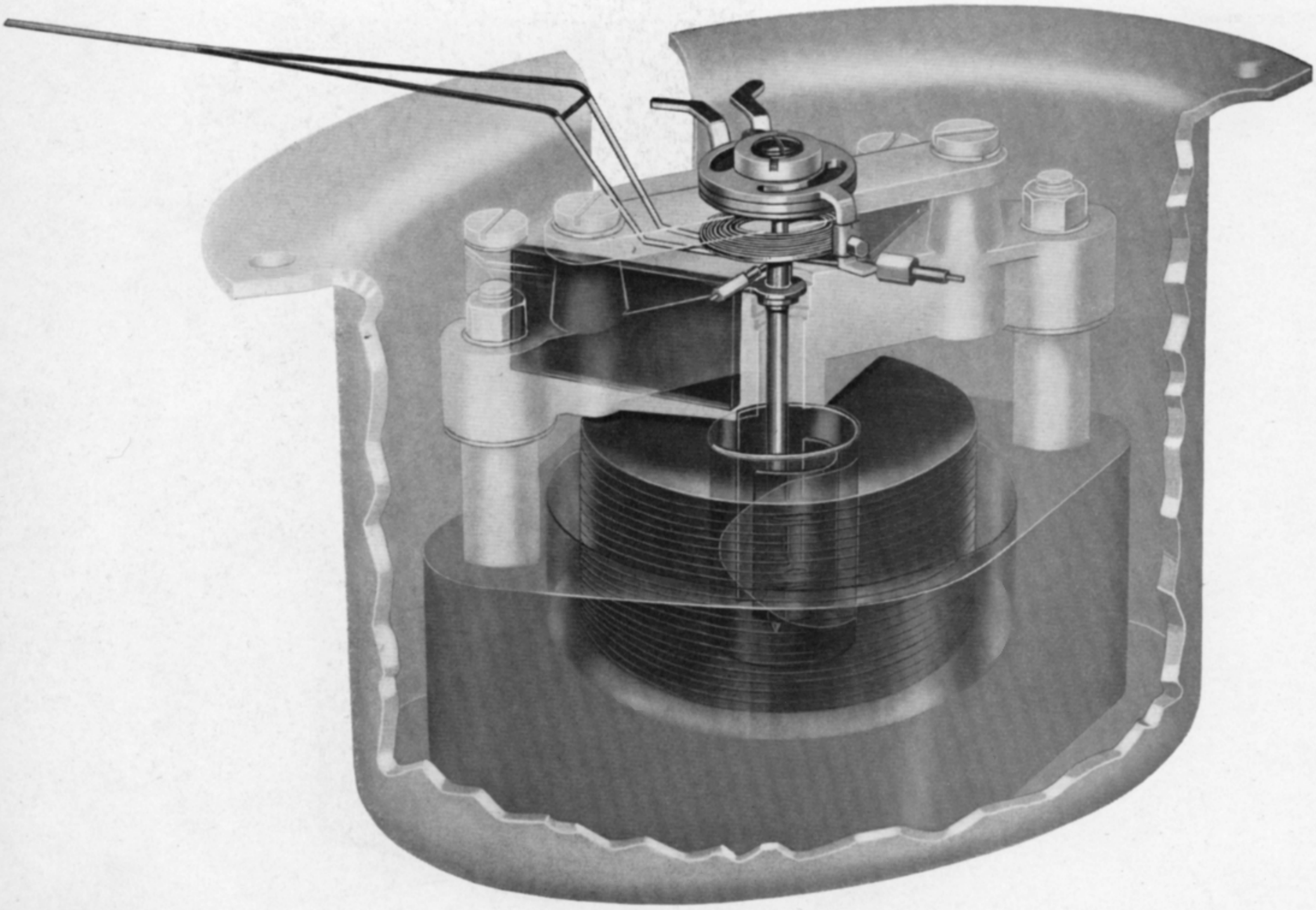
As reduced to practice in the Model 433

and permanence of form. The winding of 1 mil wire on a production basis is a feat rarely attempted but is considered in the Weston plant as just another problem in the production of high sensitivity instruments.

Instrument assembly proceeds in a rapid and straightforward manner through the use of assembly fixtures for every possible operation which can be expedited and refined by their use. Calibration is against standards always at least five times as accurate as the requirement for the instrument itself, and the standards are all kept in condition by a laboratory charged with this specific job and reporting directly to the Vice-President in charge of Engineering.

But even the development of equipment to function with materials of proper selection and fabrication will not necessarily result in the best product, and it is perhaps to the personnel and their skills which have been developed over a long period of time to which the reputation of Weston instru-

The concentric vane mechanism shown below is used in the Model 433 shown above and is typical of such systems.



THE ELECTRODYNAMOMETER MECHANISM

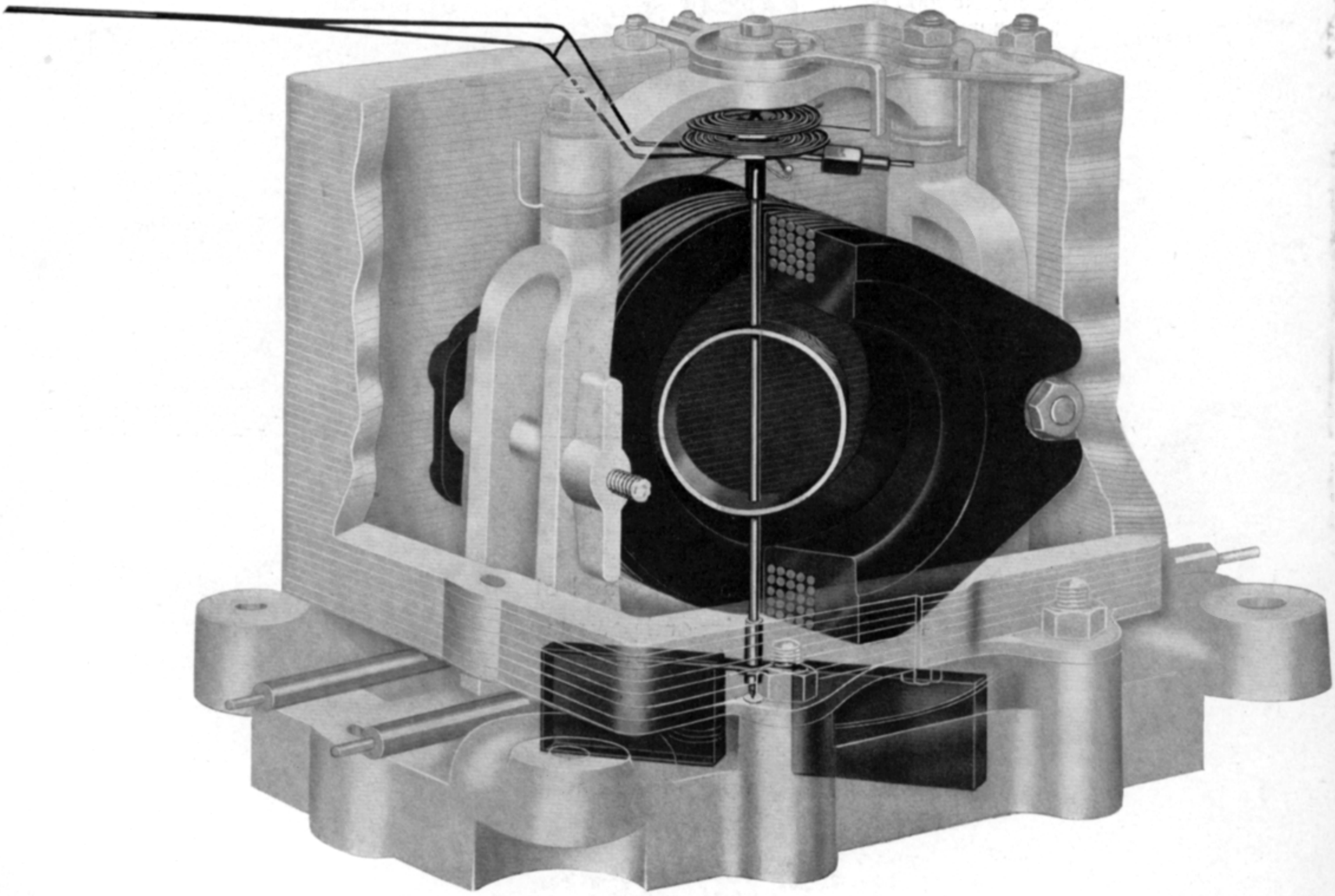
As reduced to practice in the Model 432

ments is due. The great majority of operators have a personal pride in the production of instruments which exceeds their required accuracies in terms of both the final electrical result as well as in the tolerances established for the detail parts.

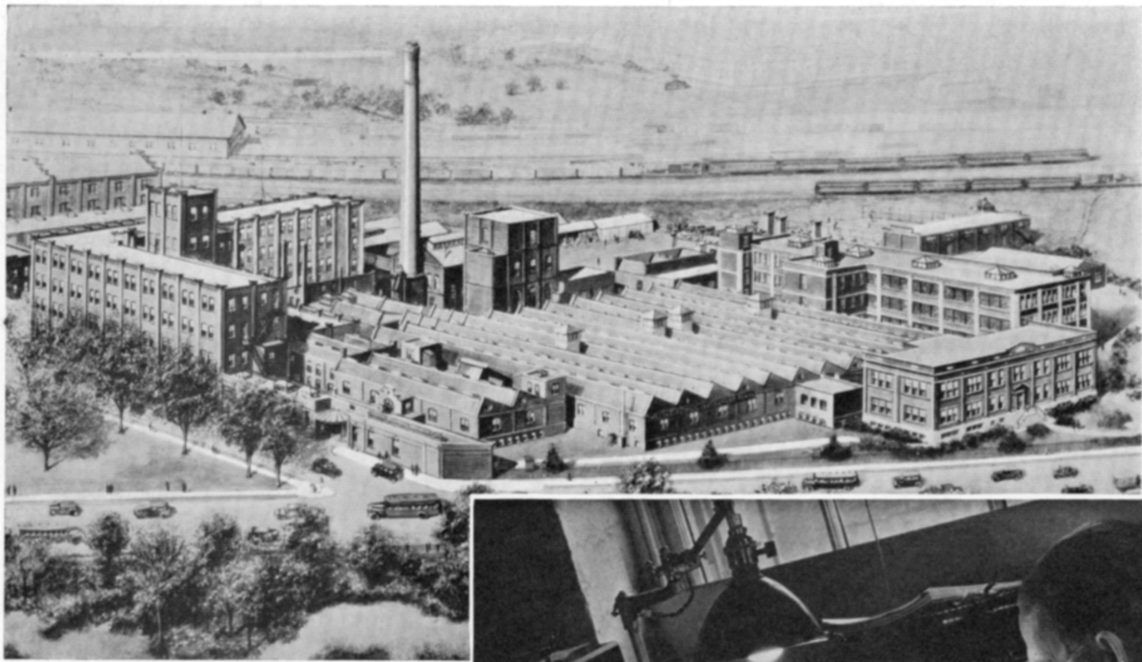
A thoroughly satisfactory instrument must, therefore, be considered as the composite product of the proper materials to start, fabricated with care and accuracy to the optimum designs and assembled and adjusted by a group of people who are honestly endeavoring to make the final product fit the requirements.

Weston has no yearly models and Weston engineers may spend years developing a new instrument. Changes in existing designs are to be avoided rather than encouraged since each change introduces new variables the magnitude of which is not known until years of field experience are passed.

The Model 432 above uses the electrodynamometer movement below which is representative of such systems when arranged for single phase, single moving coil.

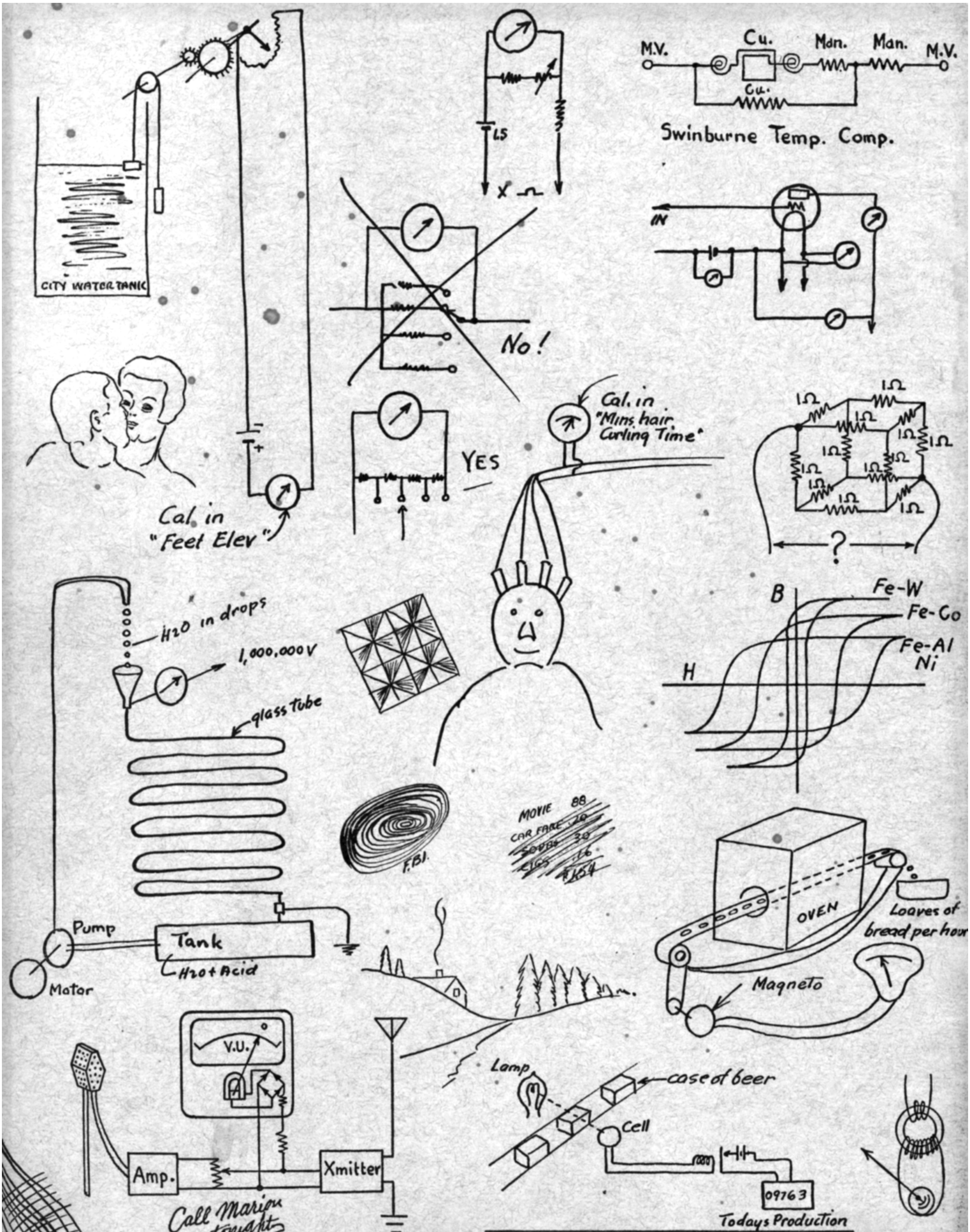


WESTON FACTORY FACILITIES



Weston Factory, Newark, N. J., U. S. A. 15 Buildings, 12 acres, 250,000 square feet factory space. 1500 employees, normal average.

Repair Service Facilities are maintained at the factory where original specifications, parts, tools, jigs and personnel are available to restore the damaged instrument to its original condition. It should be recognized that, while field repair stations are desirable from a convenience standpoint, they are of necessity limited to simple and emergency work due to the non-availability of complete tools and jigs.


CITY WATER TANK
Cal. in "Feet Elev"
X Ω
M.V.
Cu.
Mdn.
Man.
M.V.
Cu.
Swinburne Temp. Comp.
IN
No!
YES
Cal. in "Mins. hair Curling Time"
1Ω
?
B
H
Fe-W
Fe-Co
Fe-Al Ni
H2O in drops
1,000,000V
glass tube
Pump
Tank
H2O + Acid
Motor
F.B.I.
MOVIE 88
CAR FARE .20
SODAS .30
CIGS .16
$1.54
OVEN
Loaves of bread per hour
Magneto
V.U.
Amp.
Xmitter
Call Marion tonight
Lamp
case of beer
Cell
09763
Todays Production