NORTHERN ALBERTA INSTITUTE OF TECHNOLOGY
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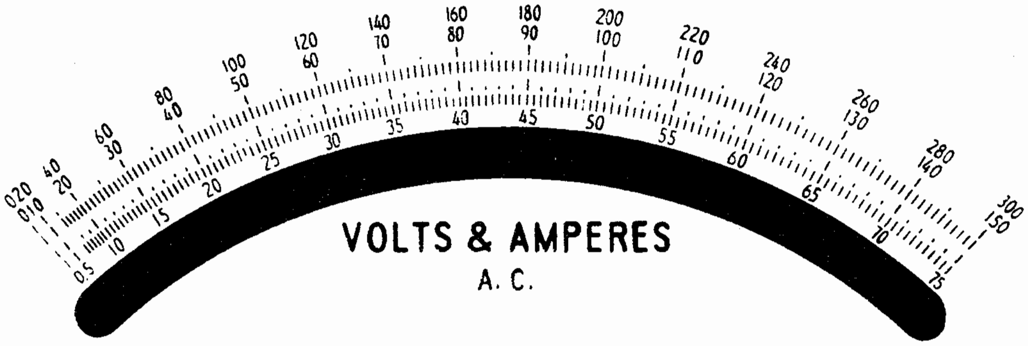
ELECTRONICS DEPARTMENT



ELECTRICAL MOVEMENTS

There are five basic, common electrical "movements"—devices which move when an electrical voltage or current is applied to them. Every metrologist (i.e., every scientist, engineer or technician who measures what he is doing) should know the principles and applications, advantages and limitations of these five electrical movements. Four are still in common, everyday use.

The five (Figure 1) are:

A. PERMANENT-MAGNET MOVING-COIL (also called PM/MC or D'Arsonval movement).
B. ELECTRODYNAMIC (also called dynamic or dynamometer movement).
C. MOVING IRON (also called moving iron vane).
D. MOVING MAGNET (also called polarized iron or polarized iron vane).
E. ELECTROSTATIC.

Of the five, only the electrostatic uses the attraction or repulsion forces between charges; the other four use the forces due to the interaction of currents and magnetic fields, created by magnets (in PM/MC or moving-magnetic types) and/or currents in coils (dynamic or moving-iron types).

PRINCIPLES

As shown in Figure 1, the motion of each movement is caused by forces due to the interaction of currents and fields, as follows:

TABLE I—COMMON ELECTRICAL MOVEMENTS

	POLARIZED IRON	MOVING IRON	DYNAMOMETER	D'ARSONVAL	ELECTROSTATIC
Principle	Fixed coil; moving magnet. Magnet moves due to the field in coil	Fixed coil; moving piece of iron. Iron vane moves in field of coil	Fixed coil; moving coil. When current flows in both coils, one moves	Fixed magnet; moving coil. Coil moves in field due to magnet	Repulsion or attraction of electrodes due to charges on the electrodes.
Types	Either earth field or magnet can be used as "reference field"	Attraction (iron into solenoid); repulsion (between two iron pieces); attracting-repulsion type combines effects	1. Single element 2. Double element 3. Crossed coils, single or double	External or core magnet; jewel or tart-band suspension	
Use	DC; inexpensive indicator for DC	DC; AC to 125 Hz, self-contained; inexpensive indicator for AC; can be used to 1100 Hz as ammeter.	DC or AC (to 200 Hz); transfer standard. Single coil type measures current, voltage or power; crossed-coil mount measures power factor, phase angle, frequency and capacity	DC; with rectifier, for AC to 10 kHz (average reading); with thermo - couple to MHz (RMS)	High voltage AC or DC, over 10 volts
Response (Scale)	Arc tangent θ (linear at low-end, compressed at high end)	Square-law scale (RMS reading) compressed at low end; can be made linear or shaped by shaping vanes	Square-law compressed at low end (unless constant current flows in one coil)	Linear	Square law
Comments	First type historically; movement used in automobile ammeters; can be made astatic by using magnets with reversed polarity; not used for accurate instrumentation	Radial - vane - type scale more linear than concentric-vane type. Vanes must be large to achieve adequate torque. Field coil requires from 0.25 to 3 watts power	Most fundamental of all movements—uses no magnetic material or iron: available at 0.1% accuracy; coils require about 0.5 to 1w power, higher on voltmeters and multirange instruments	Economic; available with 0.1% accuracy. Moving coil requires only from 0.1 μw to 400 μw (highest sensitivity of any mechanism)	Accuracy: 1%, 0.5%

1. PM/MC—moving coil in a magnetic field produced by a stationary magnet; torque is proportional to current because the magnetic field is constant.

2. DYNAMIC—moving coil in a magnetic field produced by a current in a stationary second coil. Torque is proportional to the square of the current because the current flows in both coils.

3. MOVING MAGNET—moving magnet in a field produced by a stationary coil (although a fixed magnet also might be used). Torque is proportional to the first power of the current.

4. MOVING IRON—fixed coil surrounding a fixed iron vane and a movable iron vane. Since (1) the strength of the field and (2) the induced magnetism in the iron both depend on the current, reaction force (torque) depends on the square of the current.

5. ELECTROSTATIC—torque is proportional to applied voltage, which produces charges on fixed and moving plates. Since energy $= \frac{1}{2}\,CV^2$, device is square-law device.

All the common movements must be calibrated because none are "absolute instruments"—i.e., their sensitivities cannot be calculated from their physical dimensions without knowledge of the properties of the particular materials from which they are constructed—and all are thus called secondary instruments. Let us now examine each of these five basic types in detail.

THE POLARIZED-IRON (MOVING-MAGNET) MECHANISM

The original electrical indicator (Figure 2) can be called a polarized-iron movement (note: polarized iron is simply an elegant name for "magnet"). A magnetic field surrounds every current-carrying conductor, and a freely-suspended magnet will

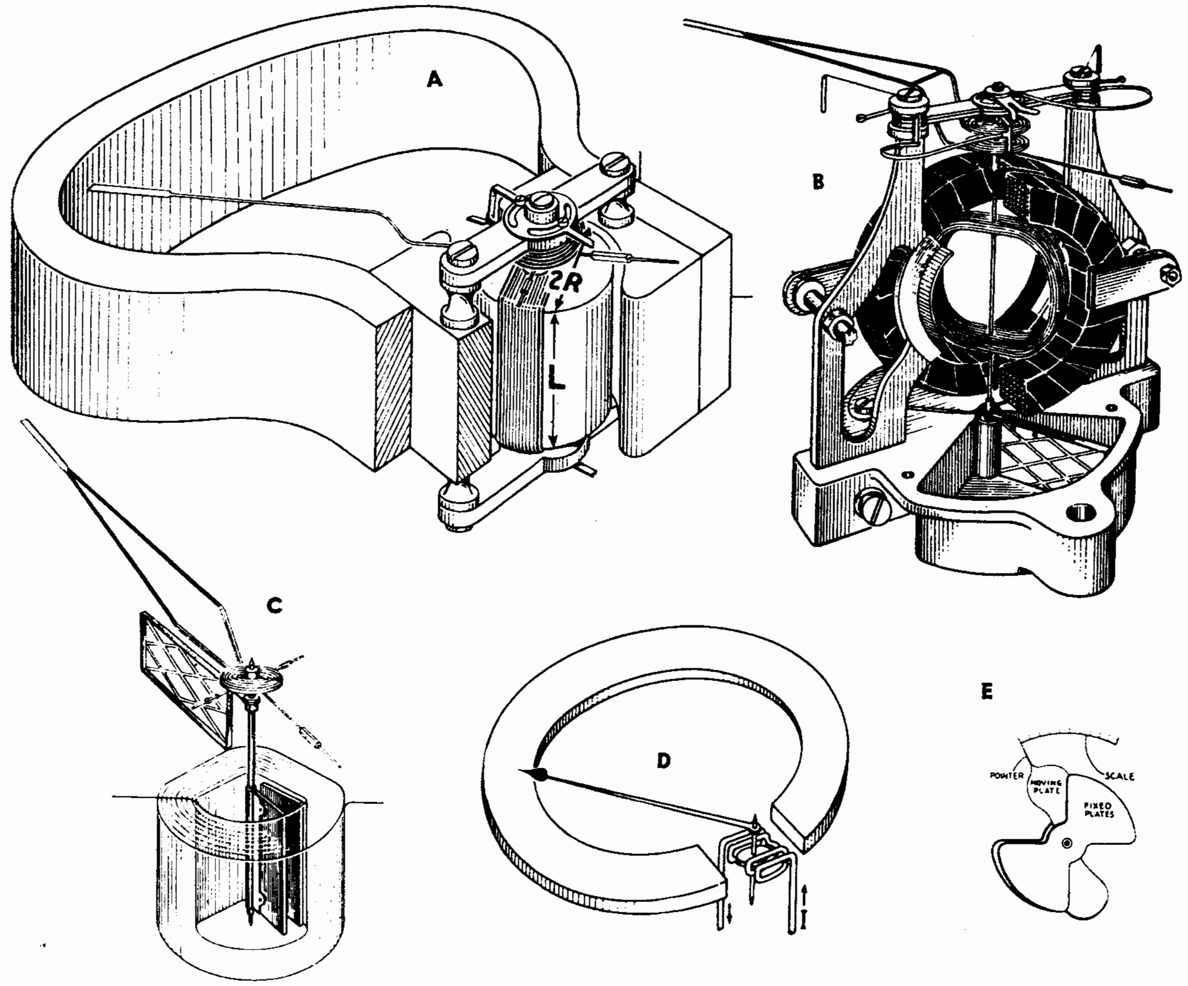


FIGURE 1. *The five basic electrical movements—(A) permanent-magnet moving-coil, PM/MC; (B) electrodynamic, (C) moving iron, (D) polarized iron, (E) electrostatic.*

attempt to align itself parallel to local lines of magnetic flux. Thus a magnet on a pivot is all that is needed to detect the presence of a current. The original electrical indicator, used by Oersted in 1819, is shown in Figure 2.

The tangent galvanometer (Figure 3) uses a small magnetic needle suspended at the center of a large coil of radius r. The coil is large so that the field at the center of the coil is uniform and horizontal.

With no current flowing in the coil, the needle will align itself along a magnetic meridian (lines of magnetic flux due to the earth's magnetic field). That is, it will point "north." The plane of the coil is placed vertical and parallel to the local magnetic meridian, so that with no current, both coil and needle are parallel to the local magnetic meridian (i.e., north-south).

Current in the coil sets up a magnetic field which, at the center of the coil, is horizontal and perpendicular to the plane

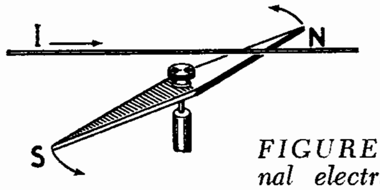


FIGURE 2. *The original electrical indicator (Oersted,* 1819).

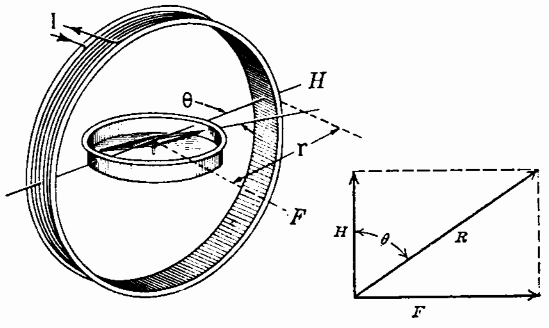
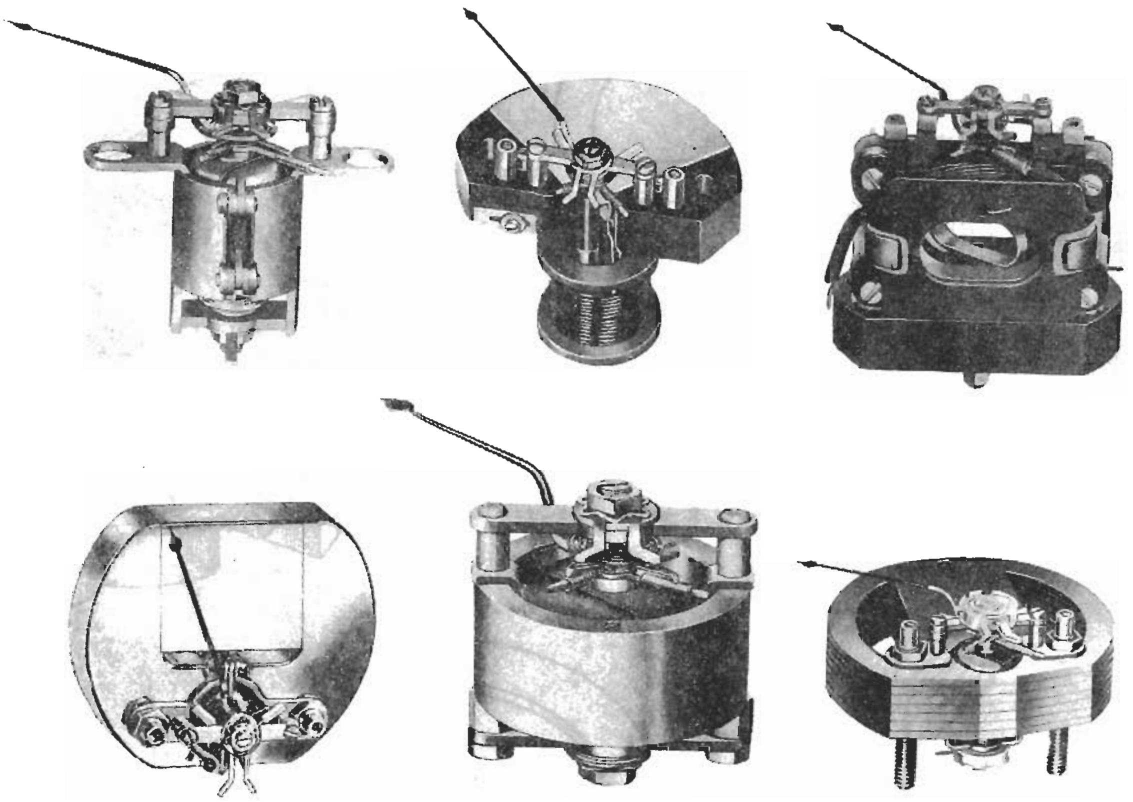


FIGURE 3. *Tangent galvanometer, an absolute indicator, is polarized-iron (moving-magnet) movement.*



Movements of Simpson Electric Company include (left-to-right, top): external-magnet D'Arsonval (show without surrounding magnet); moving-iron, available with both air damping (shown) or magnetic damping; dynamometer (2½" panel wattmeter is shown); bottom—external-magnet D'Arsonval, complete; core magnet (center); self-shielded, ruggedized annular-magnet D'Arsonval.

of the coil. This field tends to turn the needle in an east-west direction. The needle assumes a position in the direction of the vector sum of H (the horizontal component of the earth's field) and F (field due to current I). As shown in Figure 3, the needle will turn until it reaches an angle θ such that

$$R \cos \theta = H$$

$$R \sin \theta = F$$

$$\therefore \frac{F}{H} = \frac{\sin \theta}{\cos \theta} = \tan \theta$$

$$F = H \tan \theta$$

The field F is given by

$$F = 2\pi nI/r$$

where n is the number of turns in the coil, r = the mean radius of the coil, and I is the current (in absolute units).

Thus the relationship between I and θ is:

$$F = 2\pi nI/r = H \tan \theta$$

$$I = \frac{H \tan \theta}{2\pi n/r}, \text{ in absolute units}$$

$$= \frac{10H \tan \theta}{2\pi n/r}, \text{ in amperes}$$

The term $(2\pi n/r)$ is the field strength at the center of a coil due to unit current in the coil. It is called the galvanometer constant, G. Note that, since the current indicated depends on tan θ, the scale is linear at low end and compressed at high end.

ASTATIC GALVANOMETER

The next development, historically, was to make the moving-magnet galvanometer insensitive to position with relation to the earth's field. This was done by using sets of magnetic needles, with reversed polarity.

Figure 4 shows an astatic galvanometer used on an early trans-Atlantic cable. The poles of the lower set and the upper set of needles are oriented oppositely; thus the effect of the earth's field on one set is countered by that on the other set, and the movement is astatic—i.e., position insensitive.

The polarized-iron-vane (moving-magnet) mechanism is shown in Figure 1D. Instead of relying on the earth's field, a magnet is used to create a large (relative to the earth's) field that establishes the no-current position of the magnetic needle, which now has a pointer attached to it. Current in the coil establishes a field which causes the needle to turn so that its final position is the resultant (vector sum) of the two fields, one created by the magnet, the other created by the current.

In the modern version (Fig. 5), a soft-iron core increases the sensitivity, requiring fewer turns of wire and improving scale sensitivity. This type of indicator, used in automobile ammeters, is inexpensive, but incapable of great precision—and thus not in general instrumentation use.

MOVING-IRON MECHANISM

The moving-iron mechanism (Figure 1C) is in general use for AC voltage and current measurements. Although it works with DC or AC it is seldom used for DC measurements because other DC movements provide better sensitivity and accuracy. Unless specially made for DC, it will have errors due to hysteresis effects. This is why reverse-reading technique is used when measuring DC. A scale from a moving-iron movement (Hallmark SPFB-13R) is shown on the first page of this discussion.

The popularity of the moving-iron movement for AC measurement stems from the fact that three of these basic movements are directly operable with AC (i.e., without rectifiers, thermocouples or other auxiliary means for converting AC to DC): (1) moving-iron, (2) electrodynamometer and (3) electrostatic. Since the moving-iron movement is less expensive than the electrodynamometer, it is used wherever the higher accuracy of the dynamometer is not required. Moving-iron meters are available at accuracies of 0.5%, sufficient for many measurement situations. Their applicability is limited also by relatively high power consumption.

The moving-iron mechanism is made in three basic forms—attraction, repulsion, and combinations of the two, called attraction-repulsion. The attraction type uses the attraction of unlike polarities; the repulsion uses the repulsion of like polarities; the attraction-repulsion uses both. The attraction type (Figure 6) uses the attraction of an iron armature into the magnetic field due to a solenoid; the repulsion type (Figure 7) de-

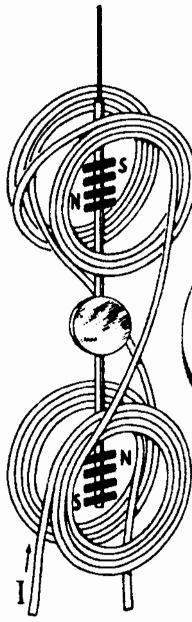


FIGURE 4. Early astatic galvanometer (Kelvin, 1858). Suspension provides restoring force.

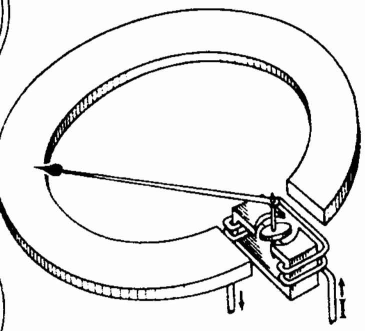


FIGURE 5. Modern polarized-iron (moving-magnet) movement has soft-iron core to increase sensitivity; compare with Figure 1D.

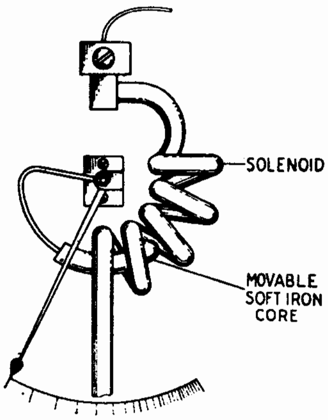


FIGURE 6. Attraction-type moving-iron movement responds to DC or AC.

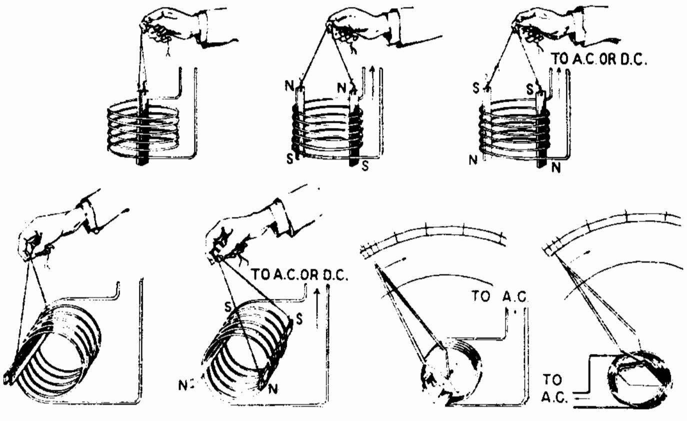


FIGURE 7. Repulsion-type moving-iron movement also responds to DC or AC.

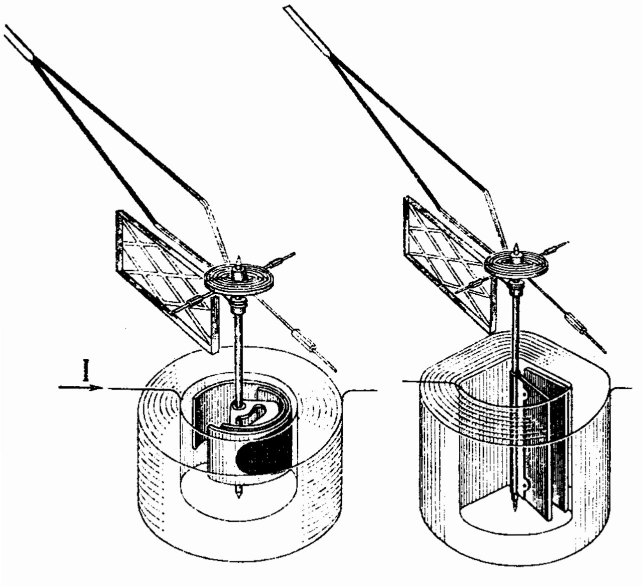
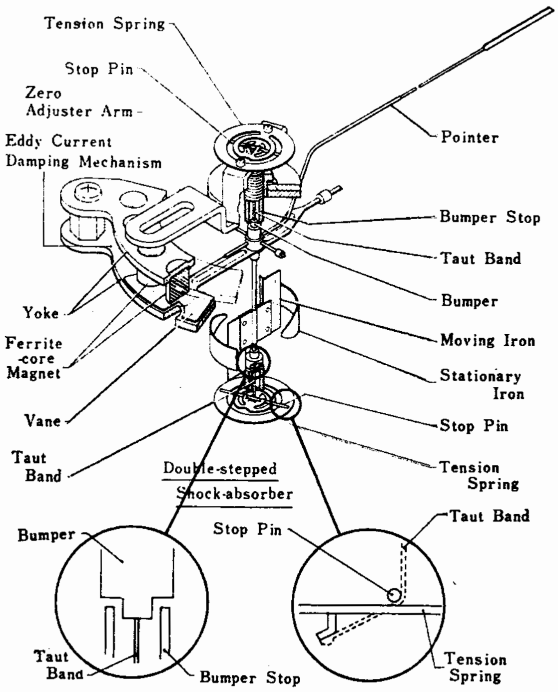


FIGURE 8. Moving-iron movements are made in concentricvane (left) and radial-vane types.



Construction of Hallmark Standards moving-iron instrument with taut-band suspension. Note special calibration adjustment feature: a magnetic shunt that can be adjusted to compensate for changes in sensitivity in the field.

pends on the repulsion that results when two parallel iron armatures are similarly magnetized by a current-carrying coil. In the moving-iron-vane mechanism this principle is used by fixing one bar and permitting the second 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 current flowing.

The torque developed is proportional to the product of (1) the current within the solenoid and (2) the strength of the pole induced in the iron, which also is approximately proportional to the current. Thus the torque is approximately proportional to the square of the current—until the iron is saturated, after which the torque becomes proportional to the first power of the current (the pole strength being constant). The net result is that the scale is compressed (square-law) at the low end, becoming more linear at the high end.

There are two constructions of moving-iron-vane mechanisms—concentric vane and radial vane (Figure 8). The concentric-vane mechanism, in which vanes slip laterally under repulsion, is only moderately sensitive, has square-law scale characteristics, and small direct-current reversal and residual magnetism errors (due to short magnetic vanes). It is also possible to shape the vanes to secure special characteristics, such as scale expansion, where needed.

The radial-vane mechanism opens up like a book under repulsion. It is more sensitive and has a more linear scale than the moving-iron-vane type, but requires better design and larger magnetic vanes for good grades of instruments. The aluminum damping vane (attached to the shaft just below the pointer) rotates in a close-fitting chamber to bring the pointer to rest quickly.

As shown in Table 1, the moving-iron mechanism can be used up to 125 Hz as a voltmeter (with series R) without compensation; the inductance of the coil causes error above this frequency. It can be used to 1100 Hz as an ammeter, above which both L and eddy-current losses cause error.

As current does not go through the spring, high-range ammeters are possible, and this movement is especially suitable for ammeters; meters with range to 500 amps have been made, without shunts or transformers. To measure watts, the only auxiliary required is the voltage-multiplying resistor.

With compensation, the frequency rating can be increased to 2500 Hz. Lowest practical range is about 10 ma; highest (self-contained) is about 50 amps. Voltmeter

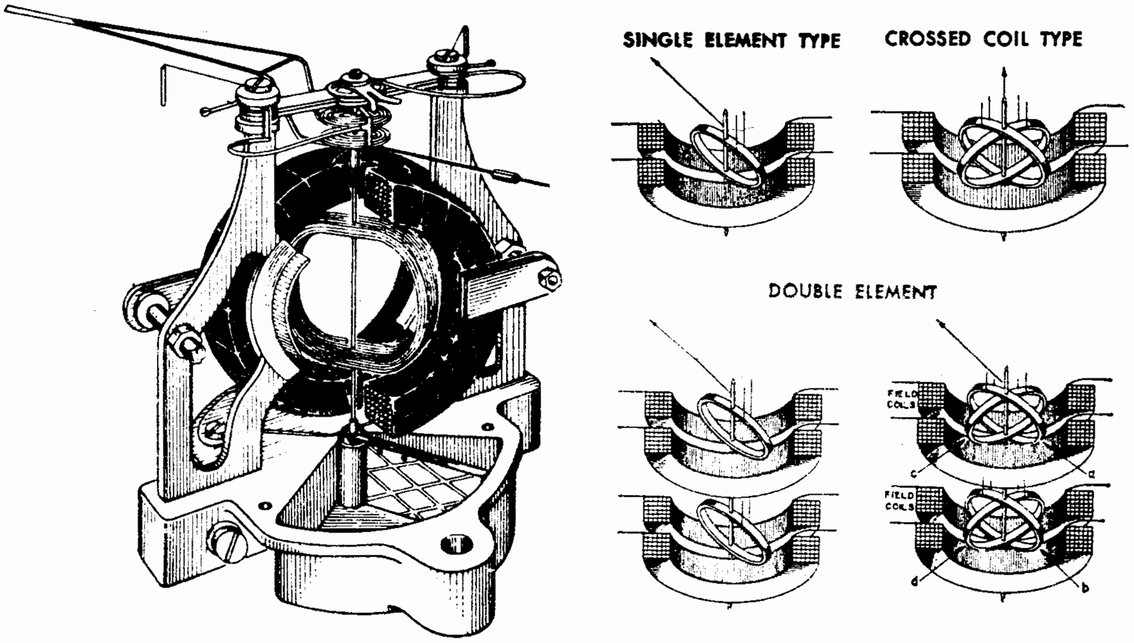


FIGURE 9. Electrodynamic movement, using one fixed and one movable coil, is the most flexible and accurate of the electrical movements. Note that crossed-coil type is available in both single-element and double-element types.

ranges are about 1 v to 750 v, self contained. Current and potential transformers are recommended to extend these ranges.

The scales are not the same for AC and DC. When measuring DC, the direction of current through the movement should be reversed and the average of the resulting "reversed" readings taken, for maximum accuracy. Accuracy on DC is not as good as on AC.

The power taken by the field coil is from 0.25 w to 3 w, much higher than that required by the PM/MC movement, but about same as that required by the electrodynamometer.

ELECTRODYNAMOMETER

Table 1 lists the principle and elements of the five common electrical mechanisms. Note that only the electrodynamic (also called dynamometer or electrodynamometer) mechanism employs no magnetic material (iron) as a basic component. It is inherently the most versatile and most accurate of the common movements because it employs no magnetic materials.

As shown in Figure 9, the basic electrodynamometer movement comprises two windings, one fixed and one movable. The current to be measured flows* through both, the field of each winding interacting with the current flowing in the other. The torque is proportional to the square of current because the current produces fields in both coils. Thus the scale is square-law, compressed at the low end. The fixed field-winding is made in two sections to produce a more uniform field in which the armature (moving coil) is located.

Electrodynamic mechanisms are the most fundamental of all of the indicating devices now used. Form-factor** (shape of magnetic circuit) variations and nonlinearity do not occur because of the complete absence of magnetic materials such as iron, and the indications are true mean-square 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 because the single coil movement can be used to indicate current, voltage, or power, AC or DC, while crossed-coil movements can be used for power factor, phase angle, frequency and capacity measurements.

An important use of this mechanism is

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*If a constant current is maintained through one coil, then the movement is not RMS reading, of course.

**When used as a voltmeter (with series R), then the coil inductance causes error, as in the moving iron. It should be noted that the 250° models (GE, Westinghouse), do have magnetic materials in their construction.

as a transfer instrument between the basic standards of E, I and P (all of which are defined for direct current only), to alternating current, in which form most of the power of the world is generated, and used.

The torque produced in the moving coil is proportional to the product of the IN-PHASE components of the currents in the field and armature windings. As the mechanism measures products, it can be adapted to many interesting measurements involving products and ratios.

With the crossed moving coils, the same mechanism is used for measurements of power factor, phase angle and capacity. In this form, or with crossed field coils, this mechanism measures ratio by balancing two torques.

Damping vanes similar to those used in moving-iron instruments rotate in close-fitting chambers to provide proper damping for the pointer motion.

If two (or more) complete field coil systems are arranged one above the other, each including and acting upon its own moving coil, and the moving coils are attached to a common shaft which carries the pointer, the mechanism can be used to measure the total power in a polyphase AC system.

The frequency range of the electrodynamometer is about the same as that of the moving-iron movement, and the power required to operate the movement is about 0.5 to 1 watt; when resistance is added to make it a voltmeter, the power required is about 3 watts, more on higher ranges.

SINGLE-ELEMENT DYNAMOMETER

The single-element type (Figure 10) is used as either ammeter, voltmeter, wattmeter, compensated wattmeter, or single-phase varmeter, as shown. Without any accessories, or resistors, this unit is a milliammeter (A). For use as a voltmeter, a series resistor is added (not shown) as is done to convert any current meter into a voltmeter.

For use as an ammeter (B), a series resistor is added which acts as a shunt for the moving coil, so that the current in the moving coil is limited to a safe value. Figure E shows a wattmeter with double current ranges by connecting field coils either in series or parallel.

For use as a wattmeter (C), the fixed field coils carry the full load current, so that the field is proportional to load current, but a resistor is used in series with the moving coil so that its field is proportional to line voltage. Torque depends on EI cos θ, or active power. As the moving coil is connected across the load (as shown), the reading is load power plus the small power of the moving-coil circuit. (If the moving-coil were connected across the source, it would read the load power plus the fixed-coil circuit power.) Replacing the moving-coil resistor of the wattmeter with a reactor shifts the moving-coil current 90° with respect to the line voltage; the instrument reads "imaginary power" in vars (volt-amps reactive), and is known as a varmeter.

To cancel the effect of the moving-coil current, the compensated wattmeter shown in D is used. The fixed coils have an extra winding, connected in series with the moving coil, which cancels the effect of the moving-coil current. The result is load-power reading.

A 3-phase varmeter is shown at F. The hookup is the same as for the wattmeter (C) but the current in the moving coil lags the applied voltage by 90°. Hence only out-of-phase power (volts-amps-reactive) is measured. Torque is EI sin θ.

CROSSED-COIL DYNAMOMETER

The single-element crossed-coil electrodynamometer is used primarily in power-factor meters (Figure 11). It is a combination of wattmeter (Figure 10C) and varmeter (Figure 10F). That is, one moving coil is connected as in a wattmeter, the other measures a phase-shifted signal, as in a varmeter. This is equivalent to mounting a wattmeter and a varmeter on a common shaft so that torque is a function of the ratio of vars to watts. As this ratio varies as the phase angle, the scale is calibrated in terms of the cosine of the phase angle (power factor) of the circuit.

A power-factor meter for a 2-phase circuit is shown in Figure 11B. This is the same as the single-phase instrument except for the reactor, which is replaced by a resistor, and connected to phase 2. This provides currents in the moving coil which are displaced by 90° to each other, as in the single-phase power-factor meter (Figure 11 C).

A power-factor meter for a 3-phase circuit is shown in Figure 11A. The fixed coils are connected in series in the line used as the common for the moving coils. The latter are connected like wattmeters in opposing legs. The final position depends on the power factor of the circuit—if the loads and voltages are balanced.

A crossed-coil mechanism arranged to meas-

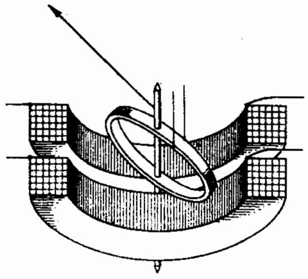


FIG. 10.

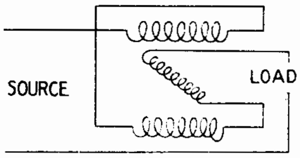


Fig. **A**

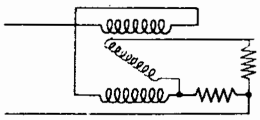


Fig. **B**

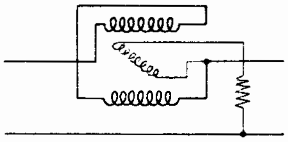


Fig. **C**

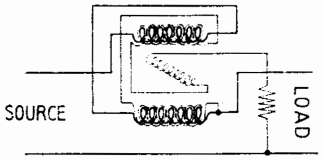


Fig. **D**

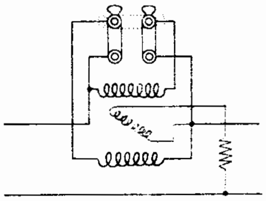


Fig. **E**

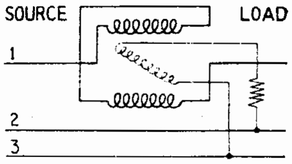


Fig. **F**

Fig. 10.—Physical arrangement of coils in single element electrodynamometer.

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

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

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

Fig. F —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.

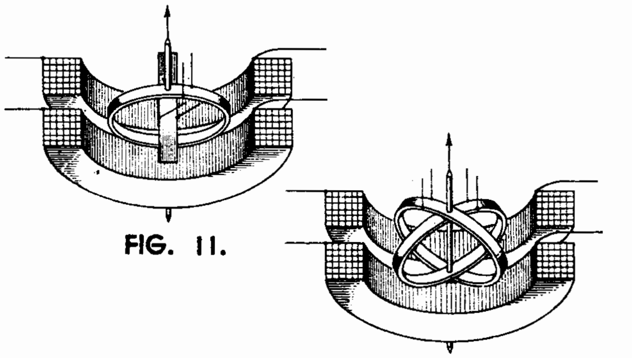


FIG. 11.

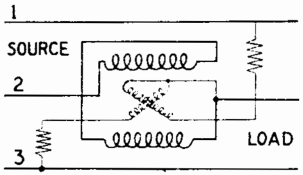


Fig. **A**

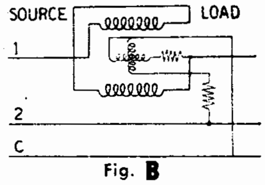


Fig. **B**

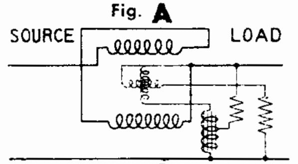


Fig. **C**

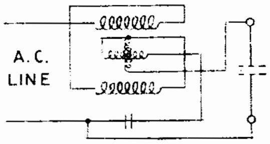


Fig. **D**

FIG. 11. —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.

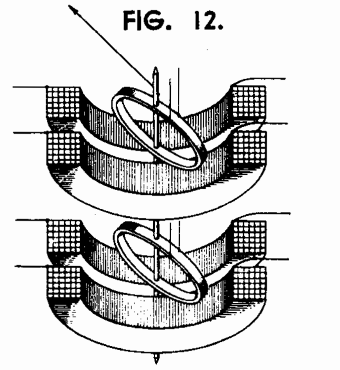
Fig. A—With crossed coils connected to opposite legs of a three phase system and with filaments rather than springs on the moving element, the moving system takes up a position dependent on the phase angle or power factor of the circuit. This is the conventional three phase power factor meter.

Fig. B —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. C —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. D —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. 12.



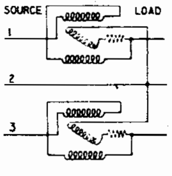


Fig. **A**

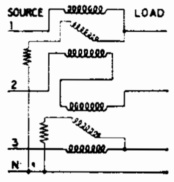


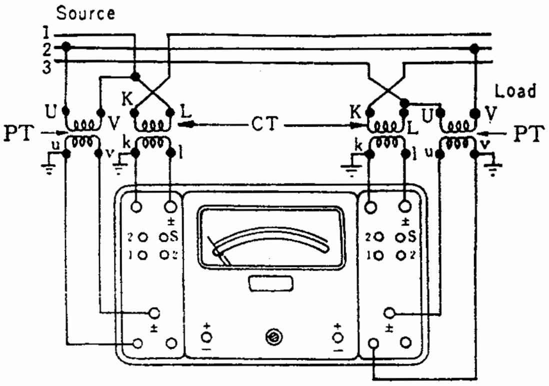
Fig. **B**

Fig. 12.—Physical arrangement of coils in two element electrodynamometer mechanism used largely in polyphase circuits.

Fig. A —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. B —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.

ure capacity is shown in Figure 11D. The ratio of the currents through the test capacitor (shown dotted) and a standard capacitor determines the position of the movement.



Connecting a dynamometer 3-phase wattmeter (Hallmark Type DPW-3) with potential transformers (PT) and current transformers (CT) for extending the basic range. (Courtesy Hallmark Standards Inc.)

DOUBLE-ELEMENT DYNAMOMETER

Double-element electrodynamometers are used for polyphase wattmeters and varmeters (Figure 12).

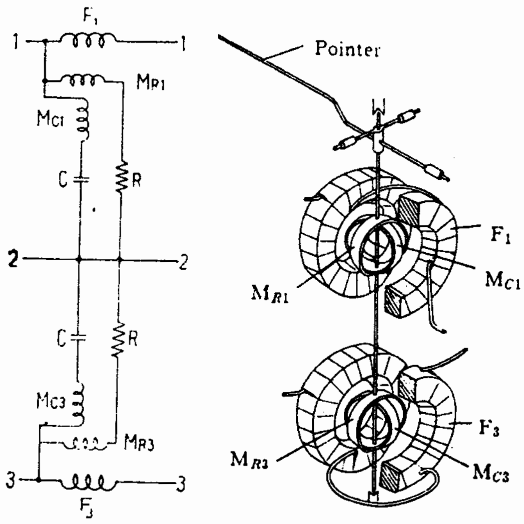
A shows a polyphase wattmeter. True power can be measured by one less wattmeter element than the number of wires of the system, provided one wire can be made common to all element potential circuits (Blondel's Theorem). In the circuit, line 2 is made common to both potential circuits; the upper field coils are in line 1, the lower in line 3. This connection (common potential-circuit connection) is suitable for single-phase 3-wire, 2-phase 3-wire, and 3-phase 3-wire circuits. A 2-phase 4-wire circuit requires that the potential circuits have separate connections.

Figure 12B shows a wattmeter for a 3-phase 4-wire system.

DOUBLE-ELEMENT CROSSED-COIL

The double-element crossed-coil mechanism is used as a vector power-factor meter for 3-phase 3-wire systems. This instrument combines the features of a 2-element polyphase wattmeter and a polyphase varmeter.

A variation of an electrodynamometer can measure frequency as shown in Figure 13. Crossed coils are connected to the line through inductive and capacitive elements. The relative strength of the two fields is a function of frequency; a freely rotatable iron vane (unrestrained by a spring) seeks the direction of the resultant field, which is proportional to the frequency of the applied signal.



Double-element crossed-coil movement (Hallmark Type DPPU) used as power-factor meter, a 3-phase wattmeter and 3-phase varmeter on common shaft. Field coils F_1 and F_3 are energized by circuit current; moving coils M_{R1} and M_{R3} by circuit voltage (by use of series resistors). Therefore, torque produced by M_{R1} and M_{R3} is proportional to effective power (watts). M_{C1} and M_{C3} are in series with capacitors so that torque produced by them is proportional to reactive volt-amps (vars). As the torques oppose each other, resulting torque is proportional to the ratio of the effective power (watts) to reactive power (vars). Since equivalent power factor (θ) is defined by

$$\cos\theta = \text{watts}/\sqrt{\text{watts}^2 + \text{vars}^2}$$

instrument can be graduated in equivalent power factor cos θ.

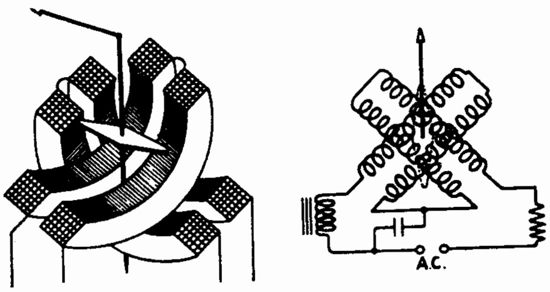


FIGURE 13. Dynamometer can measure frequency by connecting crossed coils to line through inductive and capacitive elements, which are inherently frequency sensitive.

ELECTROSTATIC MECHANISM

The electrostatic mechanism (Figure 14) resembles a variable capacitor. Of all the mechanisms used for electrical indications it is the only one that measures voltage directly, rather than by the effect of current.

The torque resulting from the attraction between fixed and movable plates is a function of the voltage between the plates, the plate area and, inversely, the distance between plates. For greater sensitivity, this distance must be reduced, clearances permitting, or the plate area (and thus the weight) must be increased.

Although not an "electrical movement," the gold-leaf electroscope (Figure 15) operates on the same principle; like charges on the ends of the lead causes a separation of the ends.

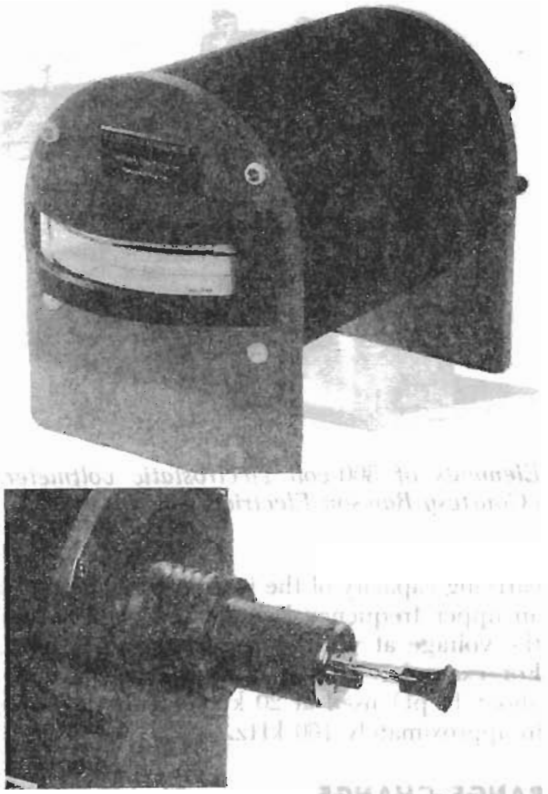
The electrostatic voltmeter measures RMS voltage, whether the voltage is DC, sinusoidal AC, or pulse type. The pulse type of voltage wave usually has an RMS value which is small compared to the peak value (the ratio of peak to RMS may be as much as one thousand to one).

Two phenomena place an upper limit on the use of the electrostatic voltmeter. The first is the effect of loading on the circuit being measured. The voltmeter is a capacitor whose capacitance lies between the limits of 225 pf (for the 120-volt instruments) to about 10 pf (for the 100 kv). In the radio-frequency range, this reactance must be considered.

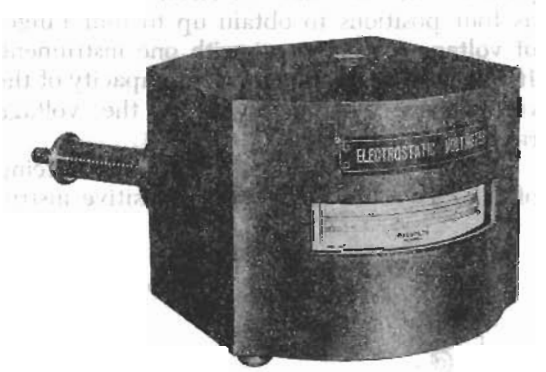
The second limitation is that the instrument and its leads behave like a resonant or partially-resonant transmission line, and a voltage distribution along the line results which is not constant. Thus the instrument may indicate a voltage which is not the same as that to which the leads are connected.

Since the electrostatic voltmeter as a circuit element is a high-quality capacitor, the power taken by the instrument is negligible. Of course, in exchange for this high power sensitivity, the electrostatic voltmeter requires that the necessary charge be supplied from the circuit under measurement, whether the measurement is alternating current or direct current. On direct current, only the initial charging circuit is required, whereas on alternating current, a capacitive alternating current flows, as in any capacitor. The capacitive current is negligibly small at power or audio frequencies, and electrostatic voltmeters are used even at radio frequencies.

Electrostatic instruments have an inherent limitation in frequency based on the current-



Model KVE electrostatic voltmeter has range to 100 kv, AC/DC. Accuracy is 1% full scale. Rear view (bottom) shows range changer by moving electrode position (Courtesy Hallmark Standards Inc.)



Model ESH 30-kv electrostatic voltmeter, discussed in text. (Courtesy The Singer Co., Metrics Div.)

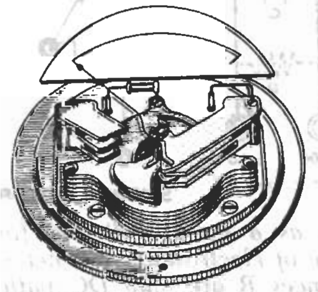


FIGURE 14. *Electrostatic mechanism.*

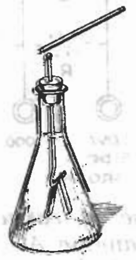
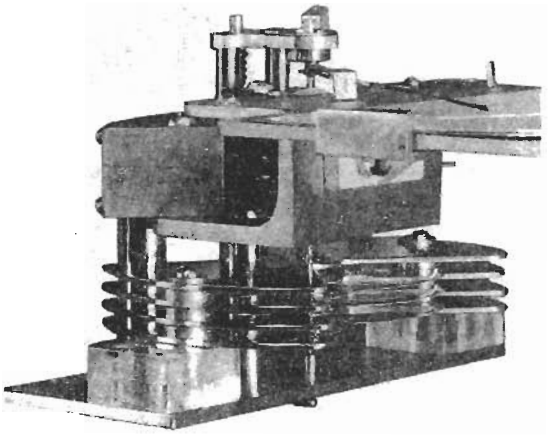


FIGURE 15. *Gold-leaf electroscope.*



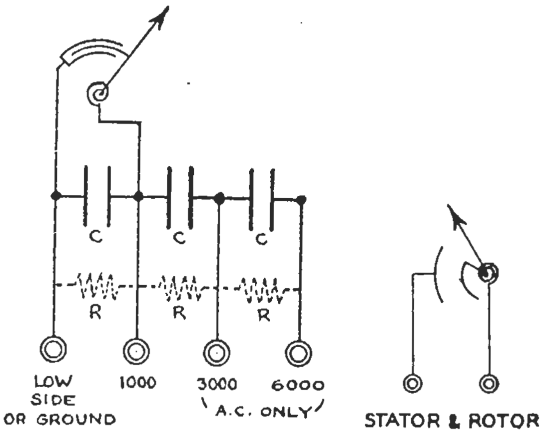
Elements of 300-volt electrostatic voltmeter. (Courtesy Rawson Electrical Instrument Co.)

carrying capacity of the instrument. This gives an upper frequency limit, which depends on the voltage at which the instrument is used. For example: A 30-kv instrument (capacity about 10 pf) used at 20 kv could be used up to approximately 160 kHz.

RANGE CHANGE

The sensitivity of an electrostatic voltmeter can be changed by varying the electrode spacing. Some high-voltage electrostatic voltmeters position the stationary electrode in as many as four positions to obtain up to four ranges of voltage measurement with one instrument. It also has the advantage of the capacity of the voltmeter becoming lower as the voltage ranges are increased.

As it is not convenient to vary the spacing of the electrodes in the more sensitive instruments, capacity-type voltage multipliers can be used. Capacitors form a voltage divider for AC which provides accurately fixed multiplying factors.



Use of capacitors as a voltage divider for changing AC range of electrostatic voltmeter. As leakage resistances R are only DC path, capacitor divider is not satisfactory for DC range change. (Courtesy The Singer Co.)

Because of the uncertainty of the leakage resistance of the voltage-divider capacitors, multi-range instruments should be used for DC readings only on the lowest range.

USES

At commercial power frequencies, the electrostatic voltmeter provides a very high impedance instrument for many measurements. For instance, the 30-kilovolt instrument shown will have an impedance of about 266 megohms at 60 Hz, due to its capacitance. It would draw a current of only 120 microamperes at 30 kv.

The electrostatic voltmeter as a DC voltmeter has no equal in high input resistance at high voltage. For instance, a 10,000-volt instrument will have a leakage resistance of at least 3×10^{15} ohms. After the initial charging current, such an instrument will draw a current of only 1/30,000th of a microampere, a negligible current. This low current is of value for applications such as Geiger counters, condenser microphones, ionization chambers, etc.

The electrostatic voltmeter is especially well-suited to measuring DC voltages in the 30-volt to 100-kilovolt range where limited power is available for operation of an instrument, as in investigation of electrostatic fields in the printing, textile and paper industries.

As an electrostatic instrument reads the RMS value of the impressed voltage, it is useful as an AC-DC transfer standard, particularly in the high voltage ranges where its low power consumption makes it an attractive transfer device.

A *peak voltmeter* can be realized by using a diode to charge the capacitance of the voltmeter. Now, instead of requiring the electrostatic voltmeter to have a long time constant, we must provide a discharge path for the voltmeter in order to permit the instrument to settle to a new reading in reasonable time in the event that the peak voltage being measured changes to a low value. As the peak voltmeter stores positive peaks, the rectifier is subjected to the inverse peak voltage of the wave during the negative swing of the voltage. Typical characteristics (Model ESH):

Maximum Inverse Peak Voltage	30,000 volts
Charging Time Constant	5 microseconds
Discharging Time Constant	5 seconds
Frequency Range	60 Hz to 1 MHz

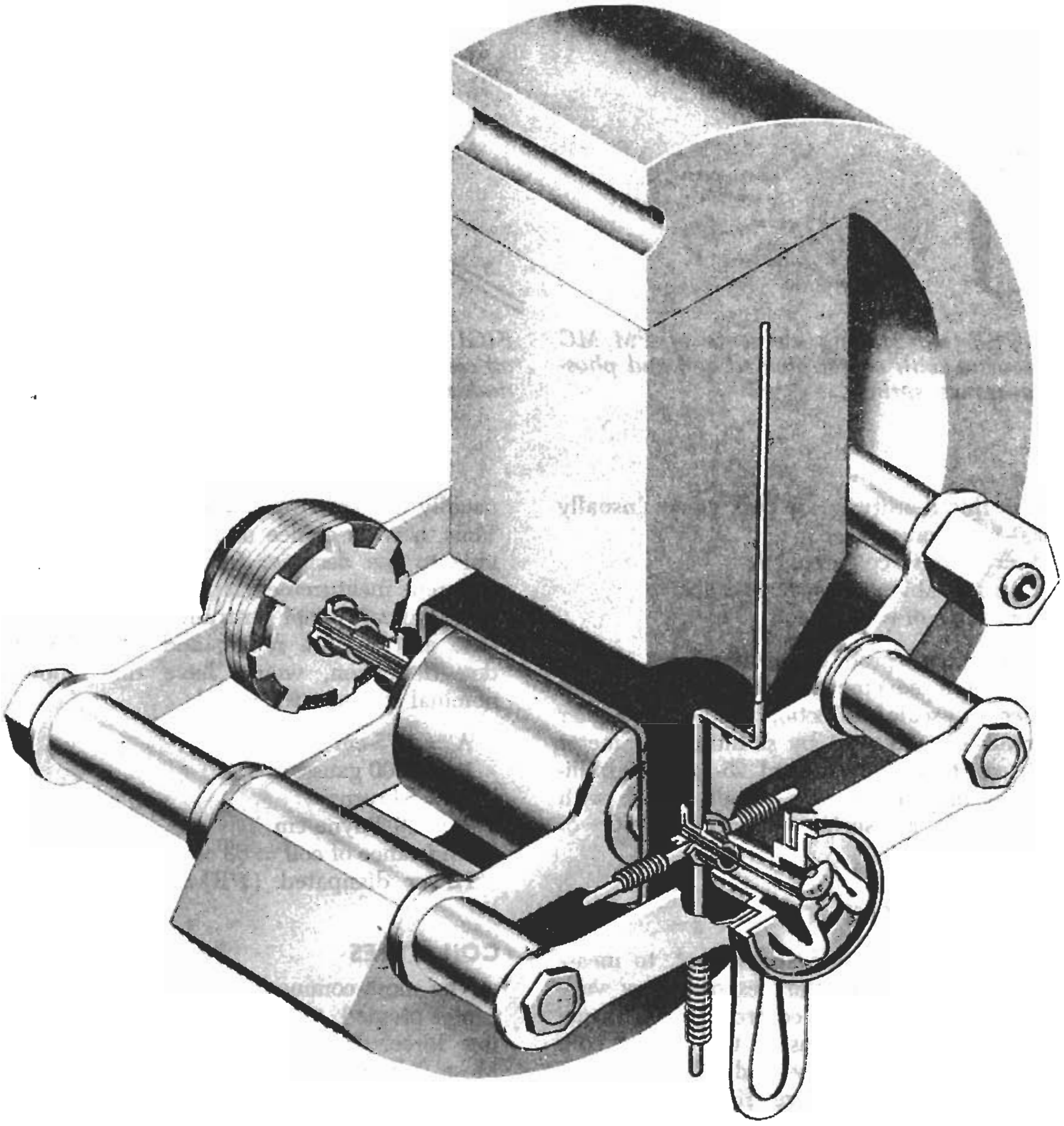
THE PERMANENT-MAGNET MOVING-COIL (PM/MC) MECHANISM

The most common electrical indicating instrument is the permanent-magnet moving-coil movement (Figure 16), which is simply a movable coil located in the field of a permanent magnet. Direct current in the coil reacts with the fixed magnetic field, producing a torque that rotates the coil. When the field is uniform, and when the rotation of the coil is opposed by a linear spring, the coil motion is linear with current. The pointer indicates the current in the coil. The path of current is through the springs and the coil.

The reaction of permanent-magnet flux with the current establishes the torque. The induced electromagnetic torque is balanced by the mechanical torque provided by control springs attached to the movable coil. This permits angular position of the movable coil to be indicated by a pointer against a fixed scalar reference. The equation for the torque is:

$$T = BAIN/10$$

where T = torque, dyne-cm



Cutaway of PM/MC taut-band mechanism. (*Courtesy API Instruments Co.*)

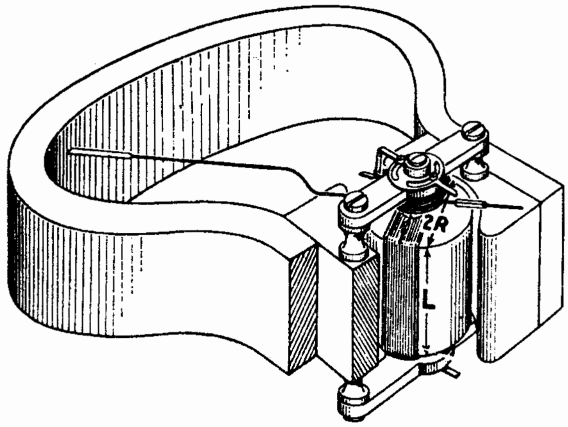


FIGURE 16. *PM/MC movement with external magnet.*

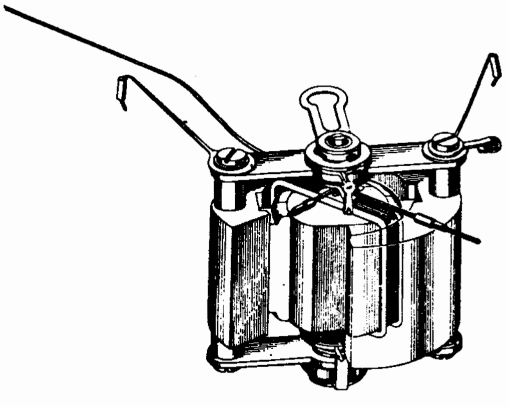


FIGURE 17. *PM/MC movement with core magnet.*

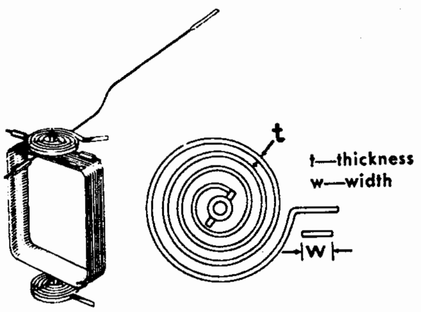


FIGURE 18. *Moving elements of PM/MC movement with center-pivoted coil and phosphor-bronze springs.*

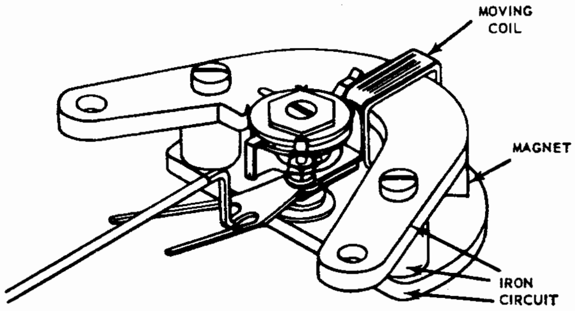


FIGURE 19. *Coil can be pivoted on end or off-center to give longer deflection or to reduce meter thickness.*

B = flux density in air gap, gauss (usually 2,000-8,000 gauss)
A = effective coil area, cm^2
I = movable coil current, amp
N = turns of wire on coil

A common production model is the 1-milliampere movement—that is, 1 milliampere causes full-scale deflection. Although higher currents can be read by shunting the meter with resistors, more-rugged 25- and 50-milliampere movements are usually used with shunts for measuring direct currents of amperes.

CURRENT SENSITIVITY

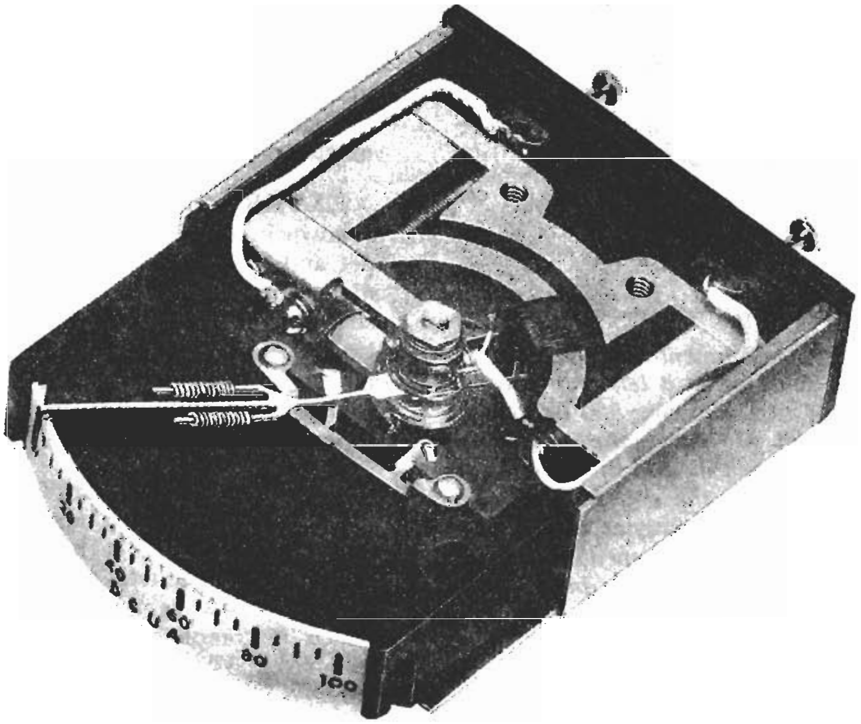
The torque equation shows that, to measure a given current, the designer may vary only the value of the control spring torque and the number of turns on the moving coil, since both flux density and effective area of the movable coil are fixed parameters for a given instrument mechanism. The practical coil area generally ranges from approximately 0.5 to 2.5 cm^2; flux density usually ranges from 2000 to 8000 gauss. Thus, a wide choice of mechanisms is available to the designer for meeting the many different measurement applications.

A typical panel instrument, with a 3½″ case and a 1-ma range, and scale for 100-deg deflection, would have the following nominal characteristics:

A = 1.75 cm^2
B = 2000 gauss
N = 84 turns
T = 29.2 dyne-cm
Resistance of coil = 88 ohms
Power dissipated (I^2R) = 88 microwatts

COIL TYPES

The most common moving-coil type is the center-pivoted type with spring for restoring force. Figure 18 shows typical parts. Most voltmeter coils have metal frames for damping—a short circuited turn in a magnetic field; most ammeter coils are frameless—the coil turns are shorted by the shunt. Pointers, springs, and pivots are assembled



Self-shielding magnetic system with single off-center pivot located out of the magnetic field, and single air gap to provide high performance in a meter with a slim, flat profile. (Courtesy International Instruments)

to the coil by means of pivot bases. The moving system is statically balanced for all positions by three balance weights.

Two phosphor-bronze springs, normally equal in strength, provide the calibrated force opposing the moving-coil torque. Constancy of performance is essential to sustained accuracy. Permanent set is avoided by establishing a length to thickness ratio of over 1500. Torque of spring material is given by:

$$\text{Torque} = \frac{\text{constant} \times \text{width} \times (\text{thickness})^3}{\text{length}}$$

It follows that spring thickness must be accurately controlled in manufacture if the finished spring is to have the required torque.

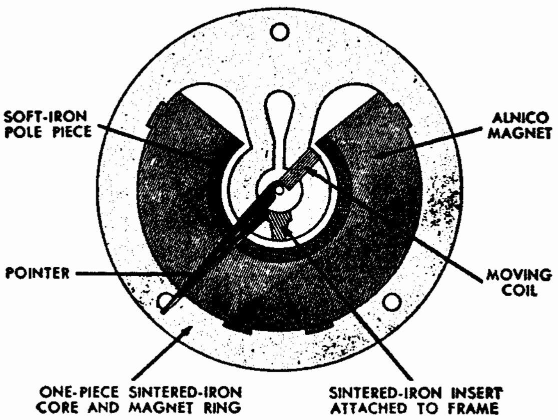
The end-pivoted permanent-magnet moving-coil mechanism is a variation of the more common center-pivoted type. In this arrangement, the coil rotates in a single air gap, allowing a full-scale deflection of as high as 270 degrees. The concept is not new; meters of this type have been made as far back as 1900, but with low magnetic flux and poor performance.

The off-center coil type is extensively used in edgewise panel and aircraft meters. The deflection is usually limited to 60° or less, with the magnetic flux concentrated over the smaller angle. One used in a 0.5″-thick edgewise meter is shown in Figure 19. A flat Alnico magnet is attached to one of two soft-iron plates separated by iron bosses to complete the magnetic circuit. The coil rotates over the upper plate and magnet with the lower side of the coil in the active air gap.

MAGNET FACTORS

Since 1888 there have been no changes in the basic theory or design of the PM/MC movement, but numerous changes in materials and technique have increased sensitivities by 125,000 fold. Few devices in any field can show this improvement: 10 milliamperes full-scale (12500 microwatts) in 1888, 0.005 milliampere (0.1 microwatt) in 1933, each on a scale of 5.2″.

The magnetic circuit for an instrument is designed to produce sufficient magnetic



The long-scale instrument differs from the conventional type in that it has only one pole face instead of two, allowing 250 degrees rotation of the coil. Moreover, the moving coil is pivoted on one side instead of in the center and only one side of the coil is effective in producing torque. The magnet of the long-scale instrument is sector-shaped, and is cast integrally with a soft steel pole face for uniform distribution of flux in the air gap. (Courtesy General Electric)

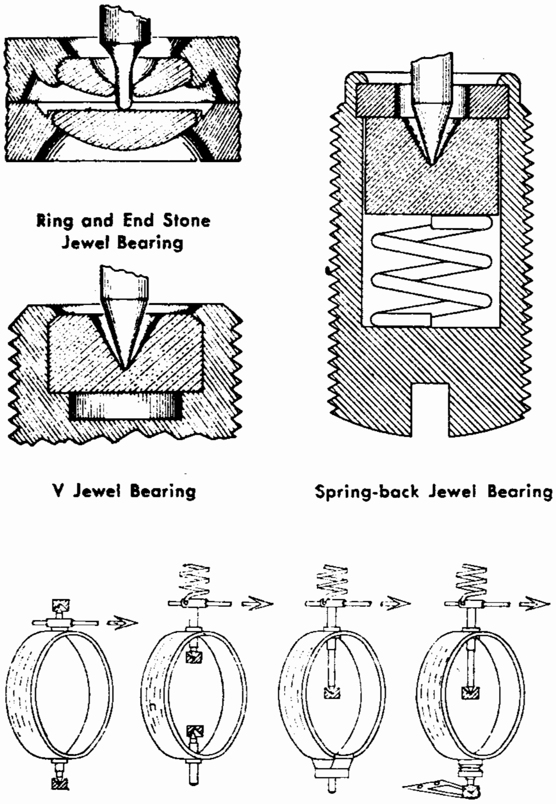


FIGURE 20. Jewel bearings include ring and end-stone, V-jewel, and springback V jewel. Evolution of clampable double-pivot arrangement is shown at bottom (feature of Rawson Electrical Instrument movements).

flux in the air gap to develop the desired moving-coil torque. This is achieved by selection of proper magnet materials and determining the size and shape of the magnet and the air gap. A flux density in the air gap of more than 5,000 gauss is common today.

Magnets are designed either in external-magnet or core-magnet types.

EXTERNAL MAGNET—This design (shown in Figure 16), uses the largest magnet and is used where maximum flux in the air gap is required in order to provide an instrument of lowest possible power consumption. Common practice is to grind one side of an Alnico-V block of magnetic material and solder or cement it to soft iron pole pieces to form a "U" shaped magnetic structure.

CORE MAGNET—In recent years, with the advent of Alnico and other improved magnetic materials, it has become feasible to design a magnetic system in which the magnet serves as a core (see Figure 17) which is completely surrounded by a soft-iron yoke. These mechanisms have the advantage of being relatively resistant to external magnetic fields, eliminating the magnetic shunting effects in a panel, or the need for magnetic shielding in the form of iron cases.

BEARINGS

Jeweled bearings for fine mechanisms, particularly clocks and watches, were invented by Nicholas 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 in Figure 20.

For instrument bearings, the ring jewel produces too much friction. Thus the V jewel (Figure 20) is almost universally used. The pivot may have a radius at its tip from 0.0005″ to as high as 0.002″, depending on the weight of the mechanism and the vibration it will encounter. The radius of the pit in the jewel is somewhat greater so that contact is in the form of a circle, a fraction of a thousandth across. The V-jewel design shown in Figure 20 has the least friction of any practical type of instrument bearing.

Although the moving element is designed to be of lowest possible weight, the minute contact area between pivot and jewel results in large stresses, for which the bearing must be designed. For example, a moving element weighing 300 milligrams and resting on an area of a circle of 0.0002″ diameter produces a stress of about 10 *tons* per sq inch (20,000 pounds per sq inch).

If the load is further increased, the contact area will not rise in equal measure, so that the stress will increase. Stresses set up by relatively moderate accelerations (jarring or dropping an instrument) may cause pivot damage (friction) except in instruments specially protected and ruggedized.

CLAMPABLE PIVOT

In pivot systems shown at bottom left in Figure 20, one pivot carries the entire weight, the other acts as a guide. Both add friction. A single pivot at the center of gravity of the system permits use of a lighter spring for greater sensitivity (since there is no friction from a second pivot) and permits use of a mechanical clamp which will lift the pivot out of the jewel and hold the movement tightly against the iron core, which will protect pivots and jewels from damage when a meter is being carried around. The other systems cannot be provided with this type of safeguard. A short-circuiting switch across the moving coil may prevent the pointer from swinging but it does not protect the pivots from damage due to vibration and mechanical shock.

The pivoting system shown at bottom right in Figure 20 (a feature of Rawson Electrical Instruments movements) has the advantages of the single-pivot system (reduced friction) with the added stability of two pivots. Further, as both pivots point in the same direction, the clamping feature can still be provided. The bottom jewel is mounted on a light spring which will not by itself support the weight of the movement. The weight of the movement, therefore, is shared almost equally by the two pivots, and both of them are in contact with the jewels at only the extreme points, providing low friction and accurate definition of the axis of rotation.

TAUT-BAND SUSPENSIONS

The suspension-type mechanism has been known for years but, until recently, the device was used only for laboratory equipment where high sensitivities were required and available torques were extremely low, so that it was necessary to eliminate even the low friction of pivots and jewels. Such devices had to be used in the upright position since the sag in the low-torque ligaments caused the moving system to come in con-

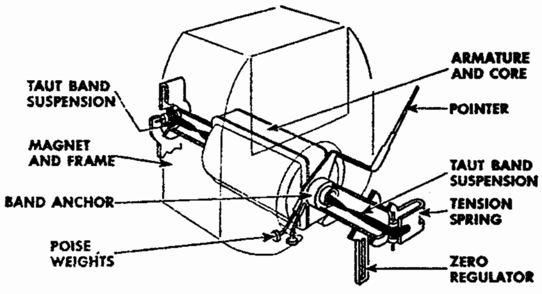
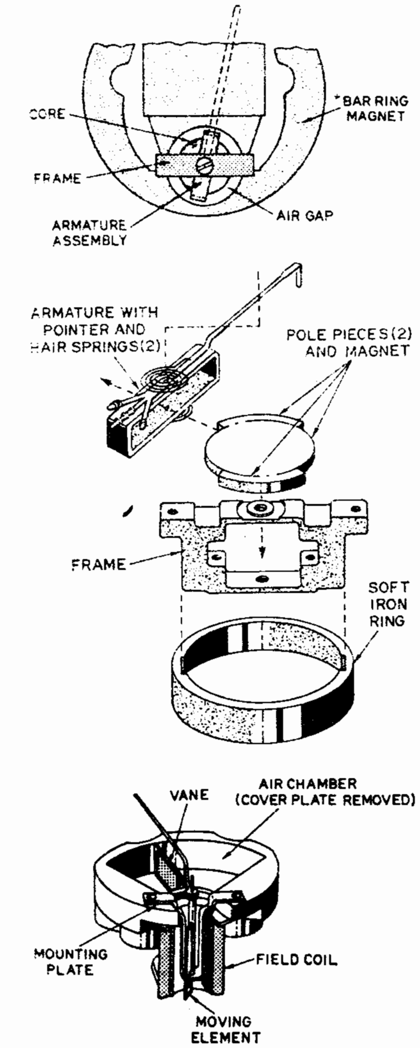


FIGURE 21. Taut-band suspension is friction free (courtesy Hickok Electrical Instrument Co.)

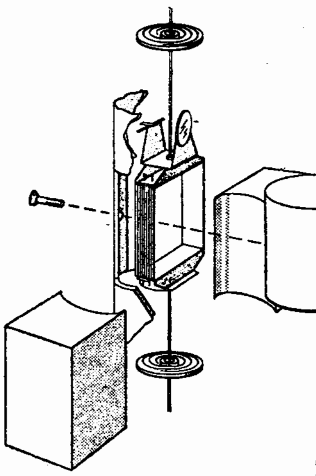


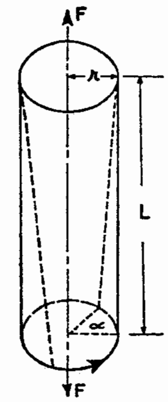
Triplett offers five movement types—(1) "Bar Ring"^{R} D'Arsonval with pivot and jewel (top), (2) "Bar Ring" D'Arsonval with taut-band suspension, (3) flat-core D'Arsonval (center), (4) AC moving-iron vane (bottom), (5) AC and DC dynamometer.

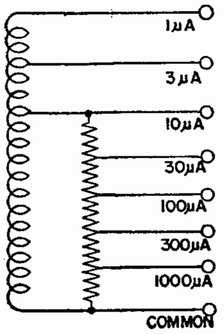
tact with stationary members of the mechanism in any other position.

Today, however, the taut-band instrument (Figure 21) enables one to obtain the advantage of the friction-free ribbon suspension, eliminating sag by placing the ribbons under tension so that the instrument can be used in any position. Generally speaking, taut-band-suspension instruments can be made with higher sensitivities than those using pivots and jewels, and can be used in virtually every application presently served by pivoted instruments.

However, the pivot and jewel movement retains some advantages. Although taut-band meters do not have the friction of the pivot and jewel, and can be made with better sensitivity and better accuracy, taut-band meters do not have as good damping qualities nor as many variations available as pivot and jewel meters. They are also subject to vibration and thus cannot be used as VU meters, and are not as rugged for many portable applications as pivot-jewel meters. Note also that pivot and jewel meters are more easily repairable than taut-band meters.







Bifilar suspension provides high sensitivity and ability to tap coil or use differential coils. (Courtesy Greibach Instruments)

BIFILAR SUSPENSION

Suspending the coil from two *pairs* of suspension wires, as shown at left, provides another type of friction-free suspension with advantages of (1) high sensitivity (0.2-µa full scale), (2) ability to use differential coils with two windings insulated from each other, (3) ability to tap coil to provide 3 ranges of current without a shunt. The two suspension wires on each end of the coil are subject to tension force F. A force S (= F/2) stretches each wire of the suspension. When deflected from parallel alignment, each of the 22 wires has a force component ($S \sin \alpha$) in the plane perpendicular to its axis of rotation. The restoring torque produced by all four force components is $T = (2S\, r^2/L) \sin \alpha$ where α is the angle of rotation of the coil, r is ½ the distance between the suspension wires (also the radius of a circle on which the ends of the suspension wires travel). For small deflections (up to 40°), the sine curve is fairly linear. The sinusoidal response can be exploited to advantage in some applications.

The four suspension wires of the bifilar suspension serve as four available electrical conducting leads to the moving coil. This permits the use of differential coils with two windings completely insulated from each other. Also, the moving coil can also be tapped in two places to provide 3 ranges of current sensitivity without resorting to a universal shunt.

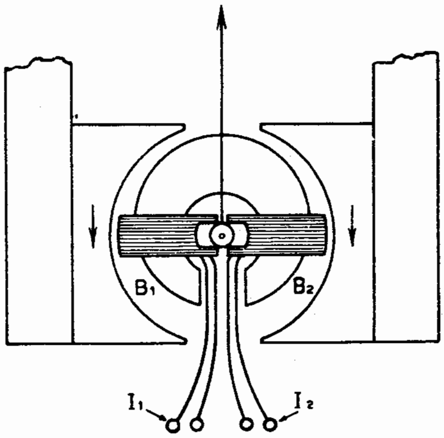
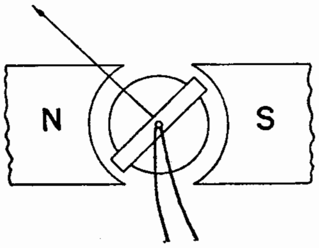


FIGURE 22. PM/MC movement with two coils on common axis measures ratio of two currents.



PM/MC mechanism without restoring-torque elements (springs) can be used as fluxmeter (with coil) or integrator (with resistor)

Since the number of turns is inversely proportional to the full scale current corresponding to the tap, the millivolt drop across each coil section remains essentially the same for all 3 ranges.

Standard bifilary meters withstand overload surges to 1000 times full-scale current; built-in protective circuit can extend the momentary overload capacity to 10,000 times.

Meters with full-scale sensitivity of 1 μa, with only 1,500 ohms internal resistance can be built. The bifilar suspension may also be operated in the horizontal plane. The high current-sensitivity makes possible voltmeters with resistance to 5 megohm/v (0.2-μa movement).

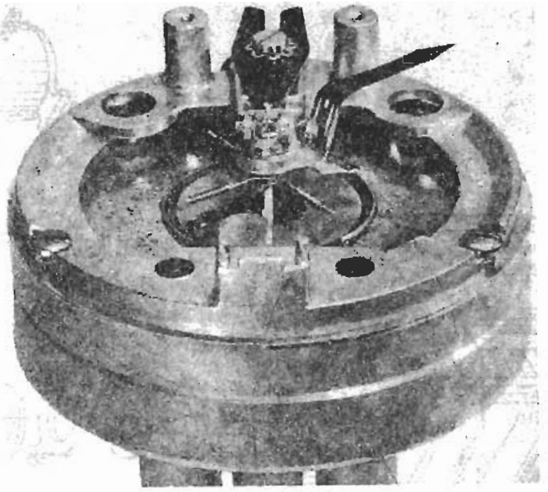
RATIO INDICATOR

Figure 22 shows a mechanism in which two independent coils, rigidly mounted on opposite sides of a common axis, move in an air gap formed by a core mounted eccentrically between the cylindrical pole faces of a permanent magnet. No control springs are attached to the moving system, the current being fed to the coils by fine filaments. The ampere-turns (or flux) developed by each coil will react with the flux in its part of the air gap, causing the pointer to move until the product of ampere-turns times gap flux will be equal on each side at balance, the indicator reads the ratio of the currents.

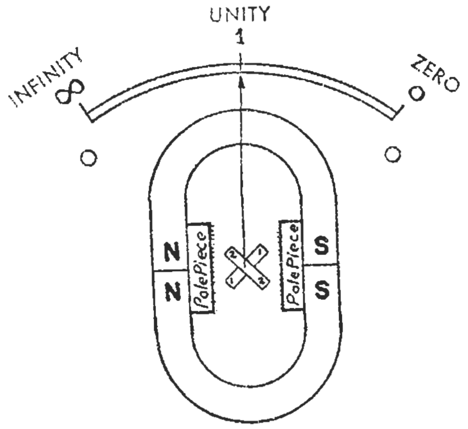
FLUXMETER/INTEGRATOR

The fluxmeter (Figure) is the same basic permanent-magnet moving-coil instrument but without springs. The current is brought in to the moving coil by fine, gold ligaments that introduce negligible torque, and the pointer will stay at any position on the scale. If the movement is connected to a coil, a current will be induced in the coil wherever it cuts a line of magnetic flux. This movement, therefore, measures external *changes* in flux—the instrument measures the difference between the flux linkages where it was and the position to which it was taken. To actually measure flux, you must either start or end at a point of zero flux.

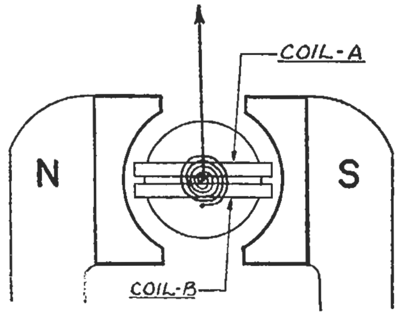
If we substitute a resistor in place of the search coil and run a current through this resistor, the fluxmeter pointer tends to move continuously until it hits the pin at the end of the scale. The current is now indicated by the rate at which the pointer moves, and the actual distance traveled becomes proportional to the integral of that current with time; it reads in terms of milliampere-seconds.



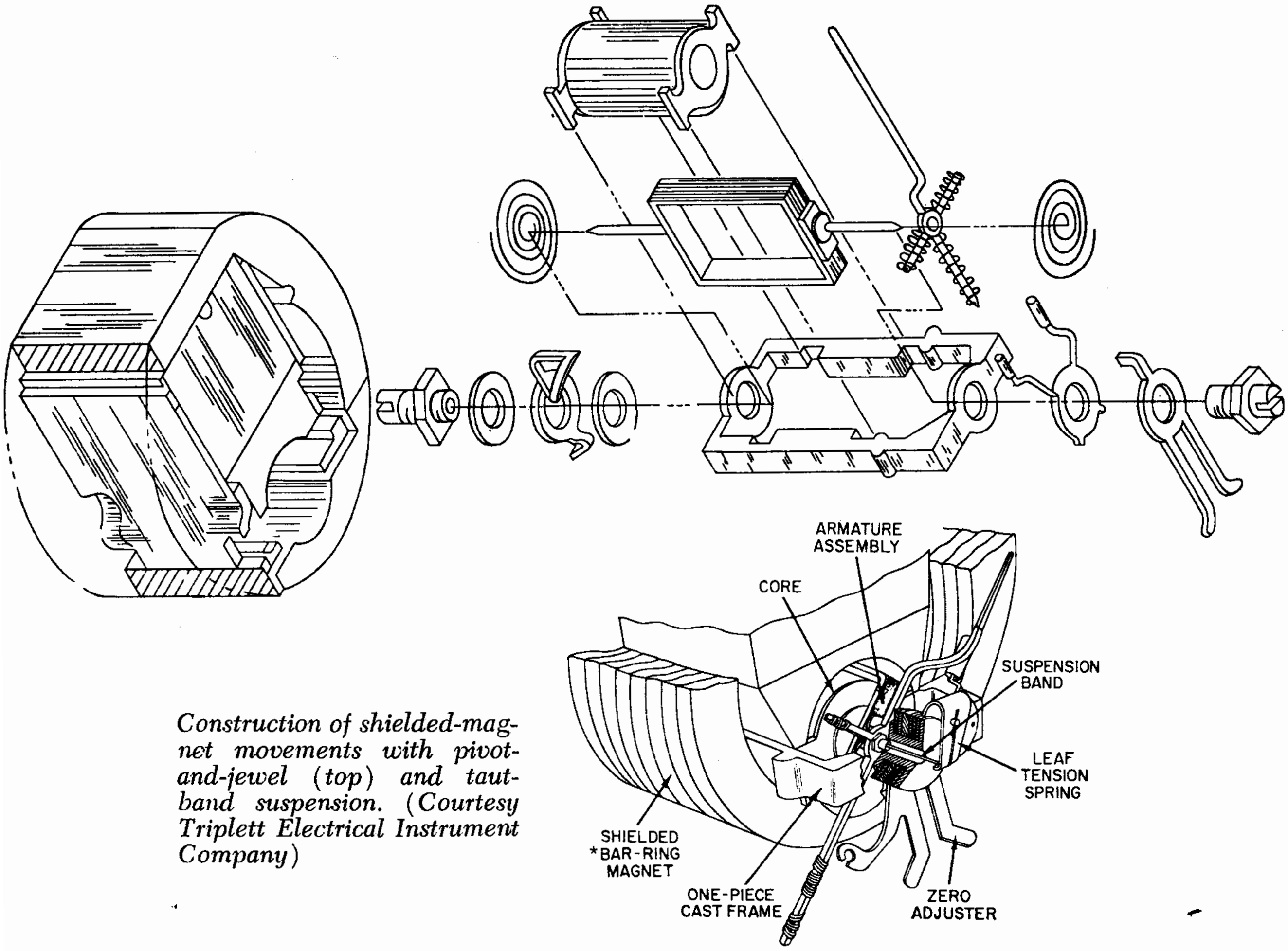
Circular-scale 250° PM/MC taut-band movement. (Courtesy Westinghouse Electric).



Ratio meter comprises two crossed coils (no spring). Indication is ratio of currents I_1/I_2. If one coil is connected to a series resistor, its torque is proportional to voltage (E); other coil will produce torque proportional to current (I). *Hence reading is E/I, or resistance (R) of circuit, measured while current is flowing in resistor being measured!*



Use of two coils permits measuring currents A+B or A—B. The difference can be measured to high accuracy by using a standardized current in one coil.



Construction of shielded-magnet movements with pivot-and-jewel (top) and taut-band suspension. (Courtesy Triplett Electrical Instrument Company)

There are two limitations to accurate integration with the fluxmeter. The integration time cannot be longer than 15 or 20 seconds because the ligaments used do have a slight torque, and the instrument tends to drift. The time cannot be so short that the signal is bypassed through the distributed capacitance of the moving coil. Hence integration is satisfactory for phenomena whose duration is from 10 or 15 microseconds to 10 or 15 seconds.

One use of this type of measurement is in photographic work involving shutters. A single reading of a fluxmeter supplied from a photocell circuit provides a measure of total light flux passed, regardless of the rate of opening or closing.

POWER REQUIRED TO OPERATE

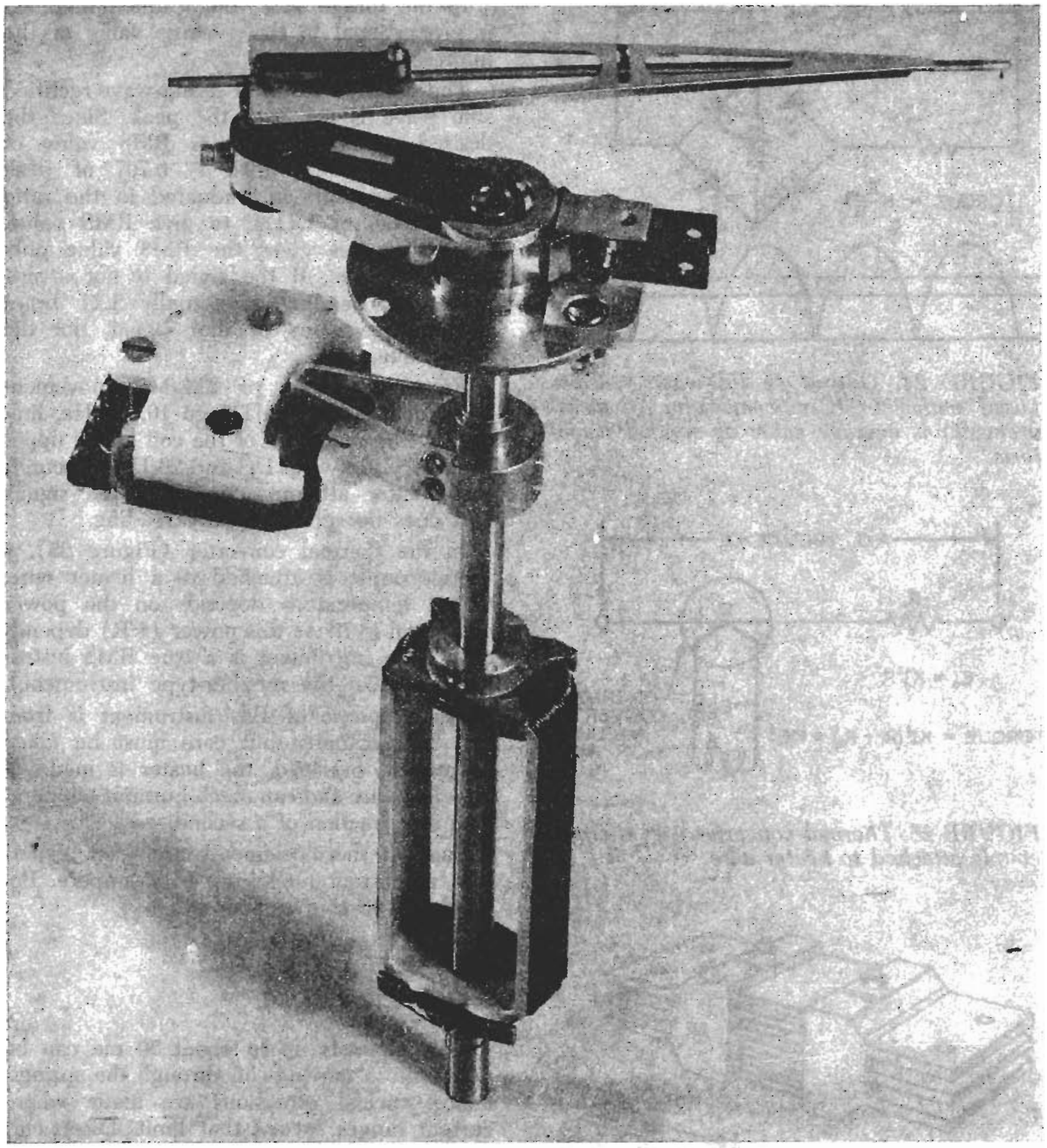
The actual power taken by the coil of the permanent-magnet moving-coil instrument can vary from approximately 0.1 μw to approximately 400 μw. This depends on the model and type of instrument as well as range. Practical ranges of self-contained (i.e., no shunt) movements is from 5 μa to 50 a. Ranges to thousands of amperes can be provided by external shunts. Voltmeters (obtained by adding resistance in series with the moving coil) require several times the power taken by the moving coil due to the additional power taken in the series resistance. Higher-range instruments require still greater power than the moving coil, and this factor may have to be considered when making measurements. Practical ranges vary from 1 mv to 750 v self-contained. Ranges to several thousand volts can be supplied by means of external resistance dividers.

USE AS VOLTMETER

To use the PM/MC as a voltmeter, a series resistor is used. When a 5-μa movement is used, the total circuit resistance must be such that 5 microamperes flow when the full-scale voltage is applied. For example, for 10-volt range, the resistance is

$R = E/I = 10/5 \times 10^{-6} = 2$ megohms.

Note that 200,000 ohms are required for each



Recorder mechanism using PM/MC movement, mechanical linkage to translate curvilinear motion of pen tip into rectilinear motion, and electrical pickoff (Metrisite) for detecting coil position, for servomechanism use. (Courtesy Brush Instruments Div., Clevite)

volt of range. Such an instrument is called a "200,000 ohm/volt" voltmeter.

Of course, the resistance of the meter movement should be considered (subtracted from the total). A typical 5-μa movement has a coil resistance of 15,000 ohms. Thus an additional series resistance of 185,000 is needed for a 1-volt range.

In practice, a 180,000 ohm plus a 10K ohm adjustable trimming resistor would be used and adjusted so that variations in resistance of meter movement can be accommodated.

Note that a 1-ma movement results in a 1000 ohm/volt voltmeter; a 50-μa movement results in a 20,000 ohm/volt voltmeter.

PM/MC FOR AC

The sensitivity and economy of the PM/MC movement make it the most commonly used type. Since it responds to DC only, it is used with a rectifier or thermal element for measurement of AC (Figure 24).

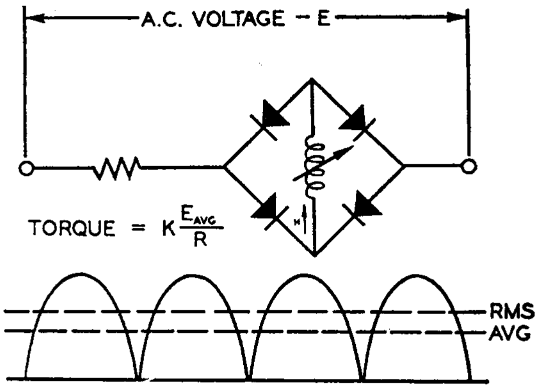


FIGURE 24. Output of full-wave rectifier (used with PM/MC movement for AC measurement) is average value of applied waveform.

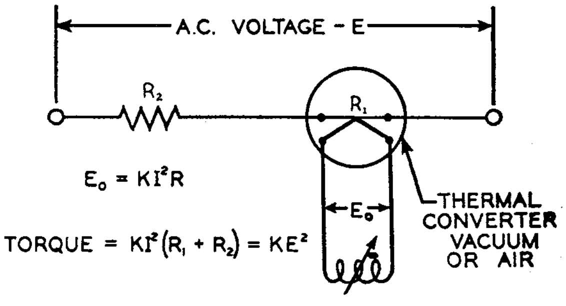


FIGURE 25. Thermal converter uses thermocouple attached to heater wire.

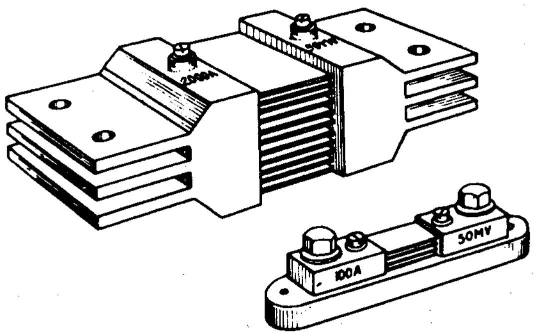
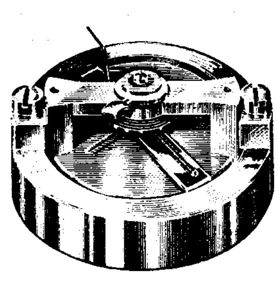


FIGURE 26. Typical shunts.



Flat-core PM/MC movement of Phaostron.

In the former case, the torque (reading) is proportional to the average value of the impressed voltage.

The average value of a full-wave-rectified sine wave is 0.636 of the peak. Since the desired reading usually is RMS value of the sine wave (which is 0.707 of peak value), the scale is graduated in the ratio 0.707/0.636, or 1.11/1, to give RMS value. Note that this gives the RMS value only for sine waves. If the signal is not a sine wave, the reading is actually 1.11 times the average value of that signal, not the RMS value.

Frequency range of PM/MC movement with rectifier is from DC to 10,000 Hz, limited by the reactance of the coil at the upper frequency. Between DC and 20 Hz, of course, the pointer attempts to follow the signal, and does not give a steady reading.

In the thermal converter (Figure 25), a thermocouple is attached to a heater wire, whose temperature depends on the power dissipated in it. As this power (I^2R) depends on I^2, the instrument is a true RMS instrument (unlike the rectifier-type instrument).

The response of this instrument is from DC to megahertz—but care must be taken to prevent overload, the heater is made of very fine wire and can reach burnout temperature in a fraction of a second.

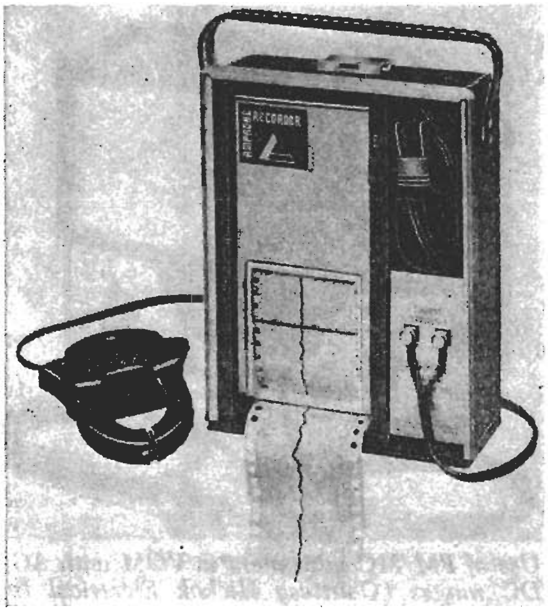
Vacuum thermoelements are used, generally, in current ranges up to 1 ampere. Beyond this, air couples are used.

SHUNTS

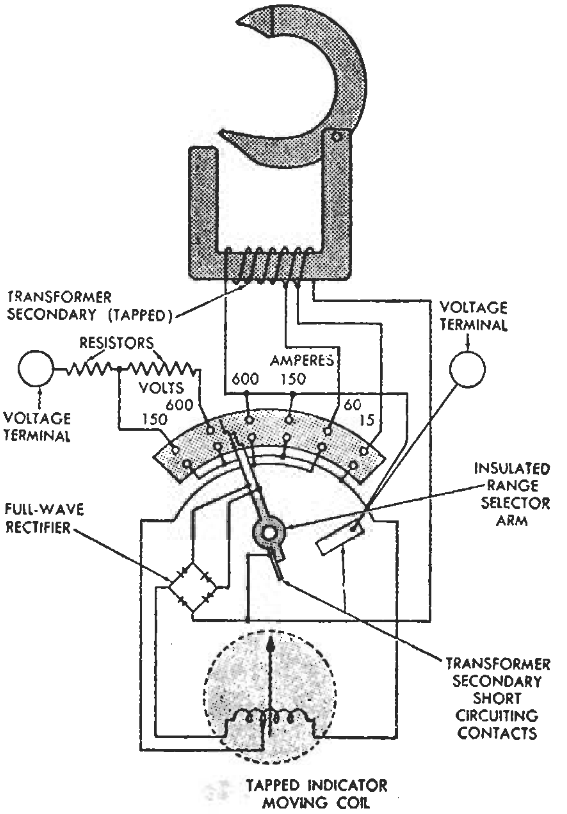
Only currents up to about 50 ma can be taken into a moving-coil through the springs; hence, special provisions are made where current ranges exceed that limit. Direct-current instruments of ranges in excess of 50 ma require the use of a parallel resistance circuit formed by one or several shunts. Where these ranges are moderate, the shunts are usually self-contained. On higher ranges the shunts become physically large and convert more than a few watts into heat, so that they are used as accessories external to the instrument (1 kilowatt for 50 millivolts, 20,000 amperes).

The shunt (British for railroad siding) is a current bypass. Small or large, it consists of one or several maganin conductors terminating in copper blocks (Figure 26).

The copper blocks are provided with current terminals separate from the terminals for connection to the instrument, to avoid



Clamp-on ammeter is single-turn-primary current transformer. Amprobe instrument is shown above; GE instrument is shown schematically at right.



errors due to the parasitic resistance of the wire-to-shunt connections.

The manganin sections are soldered into the copper blocks. Shunt construction is such that heat is carried off at a rate sufficient to keep the operating temperature below the softening point of the solder. Adequate conductors tightly fastened, clean contact surfaces and free air circulation are important.

Ammeters for use with external shunts are provided with special leads for shunt connection. Shunts are usually made to produce a standard potential drop (such as 50 mv) at rated current, and the associated DC mechanism is then built to give full scale deflection on a slightly smaller potential to allow for lead resistance. As the leads form part of the mechanism circuit, their resistance must not be altered.

Usually the current through the mechanism is a negligible portion of the total, and the potential drop across the shunt terminals is nearly the same with or without the mechanism in the circuit. In instruments of moderate precision and fairly high current-range this difference can be neglected, and shunts and instruments made interchangeable. In instruments of high precision, and in instruments of low current-range, the shunt adjustment must take into account the instrument current; such combinations are usually not interchangeable.

Because of the relatively high current consumption of AC instruments, shunts are never used with them for obtaining either multiple ranges or extending the base range. The division of current between mechanism and shunt would become unfavorable, and would invite inaccuracies due to the difficulty of obtaining good pressure contacts, as well as the fact that the current division would be a function not merely of the relative resistances of the parallel circuits but also of their relative impedances.

Moreover, AC mechanisms are not suitable for low millivolt ranges, so that shunts would have to have large potential drops and would generate excessive heat. The ranges of AC ammeters are, therfore, extended with the aid of current transformers.

INSTRUMENT TRANSFORMERS

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

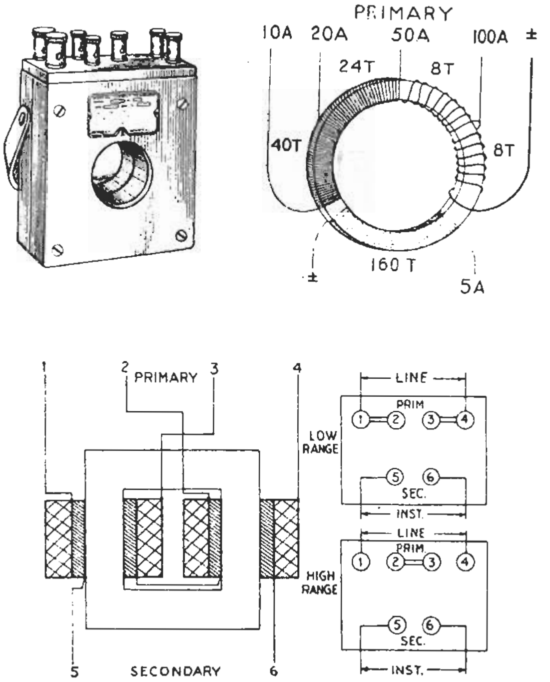
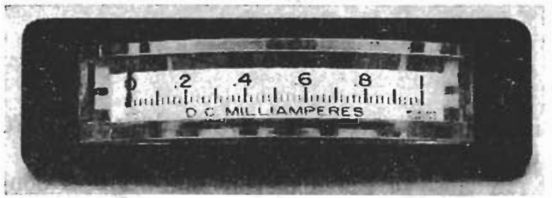
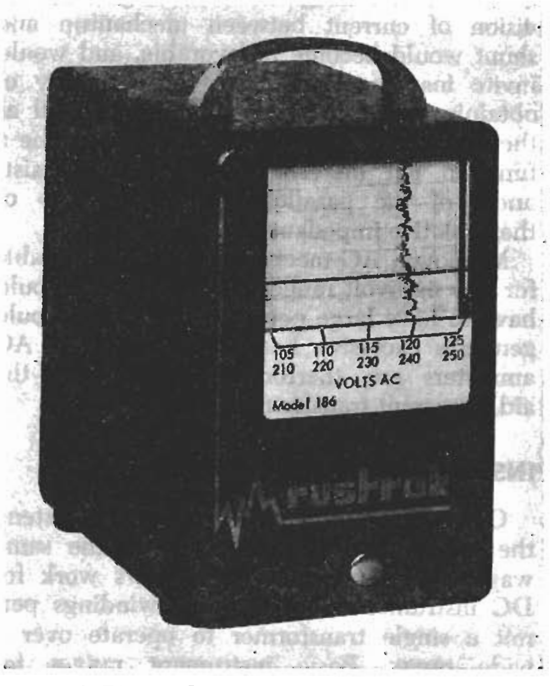


FIGURE 27. Typical potential transformer connections.



Shallow-meter design of Hoyt Electrical Instrument Works.



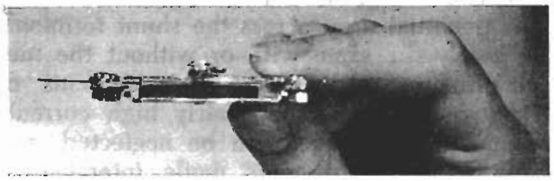
Use of PM/MC movement in economic recorder (Courtesy Rustrak Instrument Co.)

Use of PM/MC movement in VOM with AC/DC ranges (Courtesy Hickok Electrical Instrument Co.)

ranges for the transformers, and are used for computing ratios for the over-all range of the meter and transformer combined. In practice the range of the voltmeter may be 150 volts. For relatively high current ranges, the primary often consists of one or more turns passing thru the center hole. In the case of one turn, the ratio would be 800:5; two turns 400:5 etc. Standard operating procedure and safety for the current transformer requires that the secondary winding *always* be shorted or connected to the ammeter. Otherwise dangerous potentials may occur on the secondary of the transformer.

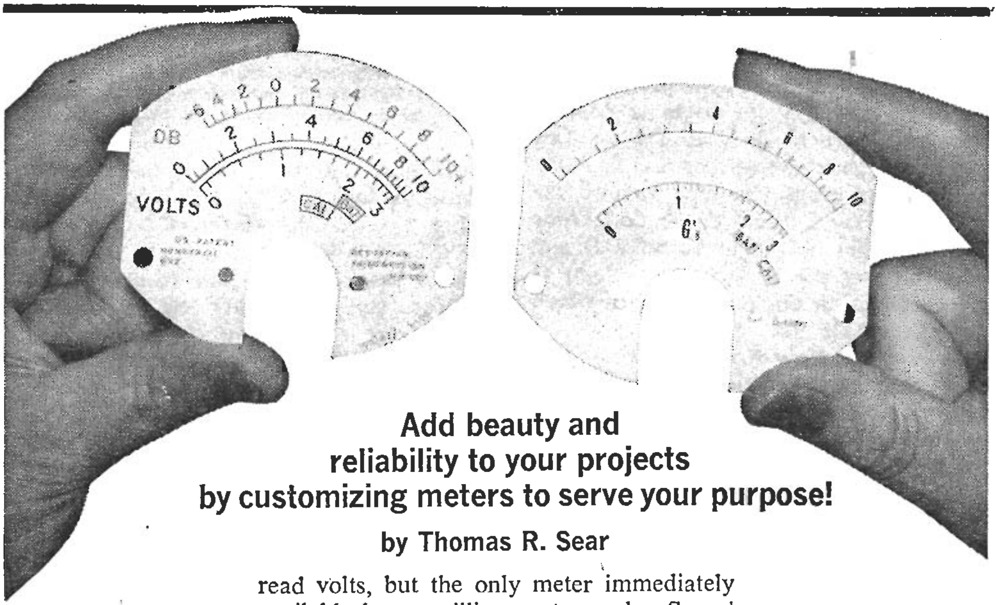
Instrument transformers, in addition to permitting measurement of large currents and voltages, perform the important function of insulating the instrument from the line.

Figure 27 shows a type of potential transformer arranged with means for connecting the two primary coils in a ratio of 2 to 1. A single secondary winding is used.



Parker Panel meters are only ½-inch thick, made possible by an etched-circuit coil in field of an annular-shaped magnet.

METER SCALES you can count on



Add beauty and reliability to your projects by customizing meters to serve your purpose!

by Thomas R. Sear

Either because nothing suitable was available, or, because of economic limitations, have you ever had to use a meter that had a scale not calibrated in the proper units for the particular application? For example, your power supply output is 65 volts, but your meter indicates 100 volts full-scale. To gain resolution you "juggle" the multiplier so that 65 volts is now the full-scale indication, but then you have to convert the reading on the meter scale by a factor which you are always forgetting. Or, the meter should read volts, but the only meter immediately available has a milli-ammeter scale. Sound familiar?

How You Do It. If so, here is a method that will enable you to customize your meters to utilize maximum scale deflection, and yet you will always know just what units you're reading. In addition, you will have a meter scale that doesn't look home-made and makes you look like a real professional.

All you need is a ruler, a compass, some dry transfer numerals, and a protractor.

If you draw the required scale several times larger than the actual size of the existing meter scale and then photographically reduce this drawing to the original size, the slight inaccuracies that inadvertently creep into your drawing will be minimized by the reduction in size. The resulting scale will look professional and will enhance the overall appearance of the project as well as making it easier to use the equipment.

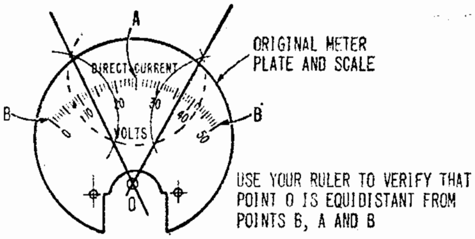
Preliminary Steps. First remove the meter movement and scale from the meter case and very carefully remove the meter scale from the meter movement. You must determine the length of the original meter scale arc in degrees before making a new scale. To do this tape the original meter scale to the center line in the lower half of a piece of paper at least 8½ x 11 in. Then place the compass point near the center of the scale (point A in Fig. 1) and draw two curved, dotted lines. Now place the compass point at each end of the scale (points B, Fig. 1) and draw the solid curved lines that are shown. Make certain that the pencil lead is kept sharp, and that the compass point is placed exactly where specified. Do not draw the lines too heavy so that they may be easily erased in the event you may require the original scale for a future application. Draw the two straight lines between point O and the crossing of the curved lines. Point O is the center of the circle, a portion of which is the meter scale arc.

Drawing the New Arc. Next, draw two lines from point O exactly through the ends of the meter scale, extending them so that they are 3 to 4 times the length of the radius of the scale, as shown in Fig. 2. Using a protractor accurately measure the angular distance between the two straight lines, and record it for later use. Using point O as a center draw an arc using a radius about 3 times the length of the original radius (OA in Fig. 3). An enlargement of 2 to 3 times produces an effective new scale size. Dry transfer letters are available in many sizes, therefore you can readily select a suitable ratio of arc enlargement to lettering size. The enlargement factor is determined by dividing the radius of the enlarged arc by the radius of the original arc.

What You Will Need

Drafting Equipment: Compass, ruler, protractor, pencils, pens, india ink (select professional quality tools and supplies) from your local art supplier. Some items are available from electronics mail order houses such as Allied Radio and Lafayette Electronics.

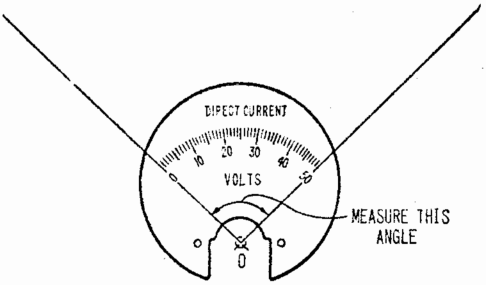
Dry Transfer Letters: Sometimes called "Press-Type," or "wax lettering." Datak offers several letter, words and numeral kits in combination or singly. Datak products are available at Allied Radio and Lafayette Electronics. Art supply stores may carry Datak as well as other products equally as good.



ORIGINAL METER PLATE AND SCALE

USE YOUR RULER TO VERIFY THAT POINT O IS EQUIDISTANT FROM POINTS B, A AND B

Fig. 1. To determine length of original scale you must know where center of original scale arc is located. Reason is that you use it as your starting point when you draw your new scale.



MEASURE THIS ANGLE

Fig. 2. Carefully measure angle of arc by placing protractor between radii and centered at O. Record reading for use later when calculating new scale.

You now remove the original scale from the paper and work directly with the newly drawn lines.

Enlarge the Scale. Draw an outline of the original scale that is enlarged by the same ratio as the radius of the arc. Make certain that cutouts are enlarged, and mounting holes are spaced in the same increased proportion as the increase in arc radius (see Fig. 4). It is advisable, also, to draw the new scale arc and its divisions proportionately thicker so that when the enlarged scale drawing is reduced photographically to the original scale size, they will not be lost in the reduction.

Dividing the Scale. Dividing the scale requires a little thought. If the new scale is an even multiple of the original scale the graduations on the original scale will be right where you want them, and you can just extend them as shown in Fig. 5. (Note: it may be easier to extend these markings before removing the original scale.) It's more likely though, that you will be changing the markings radically. For example, you may be using a 10-volt full-scale meter for a 17-volt full-scale reading. In this case you first rough out a meter scale, deciding just how you want it to be divided to match the read-out that you need (e.g. whether to have graduations every ½ volt, or every 10 volts).

Once you know how you are going to divide your scale, count how many divisions will be required on the scale. In Fig. 6 there are 20 divisions on the scale. Then divide the arc length in degrees (measured earlier), by the number of new scale divisions. For example, if the arc length of the scale in Fig. 6 was measured as 103 degrees we divide 103 by 20. The answer is 5.15 degrees per division. This tells us that the divisions on our meter will be drawn every 5.15 degrees.

To ensure that your scale graduations are uniform in length, draw four dotted lines lightly as shown in Fig. 6 (these will be erased later). For best contrast the lines of the scale should be drawn with ink; however, any dark pencil will do if you make the lines uniform in thickness. As far as the weight of the lines is concerned, they can be made as dark as you wish during the reproduction process.

Marking the Scale. Carefully apply the correct dry-transfer lettering and numbering to the scale drawing. Clean up the drawing with an eraser, and spray it with a coat of clear plastic to ensure that it remains clean and that the lettering is not accidentally scraped off in handling.

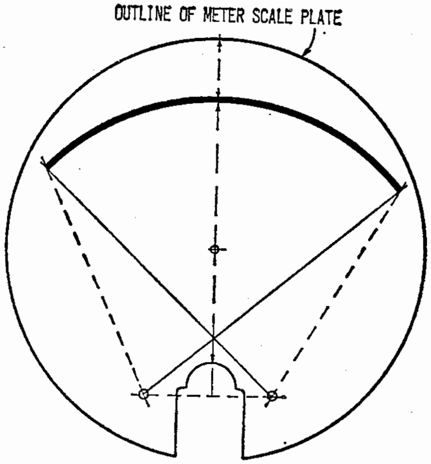


Fig. 4. Draw new meter face outline, increasing old meter face diameter by scale enlargement factor. Enlarge original cut-outs and space between old mounting holes, using same enlargement factor.

Photographing the Scale. Once the scale is drawn, accurately measure the distance between the meter scale mounting holes as shown in Fig. 7. Mark this dimension on your drawing for use in the reduction process. When the scale is being photographically reduced, the photographer will actually measure this dimension on the print with an accurate ruler.

If you have photographic equipment, proceed as follows; if not, give your drawing and these instructions to a photo lab and

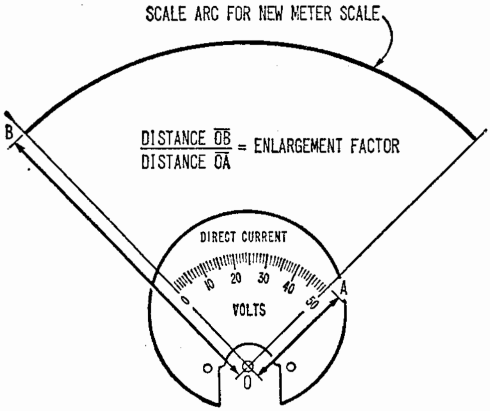


Fig. 3. To enlarge scale, extend radii OA 3-4 times to OB. Select size of transfer letters to complement scale expansion, and draw new scale arc from point O as center. Bold lines ordinarily reduce best.

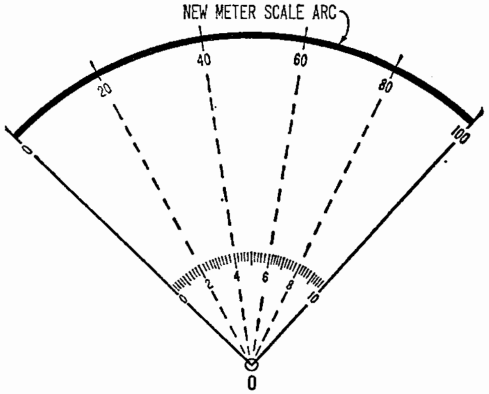


Fig. 5. When new scale divisions are even multiples of original ones, extend them to new scale arc. Use ruler, carefully centering it on point O and each division marker on old scale.

they will do the remaining work for you.

Take a closeup picture of the completed drawing so as to obtain a full-sized good quality negative. Next, make contact prints of the drawing on double-weight eggshell paper. It is during this phase of the work that the dimension determined in Fig. 7 is so important. While the film is in the enlarger or projector, and prior to making the print, measure the mounting hole spacing of the projected image and verify that it is correct. It is a good idea to make more than one copy at this time just in case your first mounting effort is not successful.

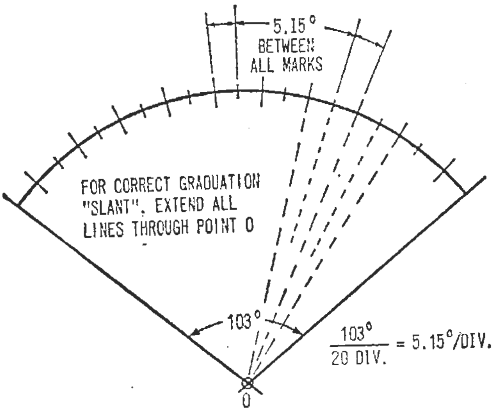


Fig. 6. When new scale divisions are not even multiples of original scale, divide arc length measured earlier (refer to Fig. 2) by number of new scale divisions desired. Extend all graduations through point O to assure correct slant of markers.

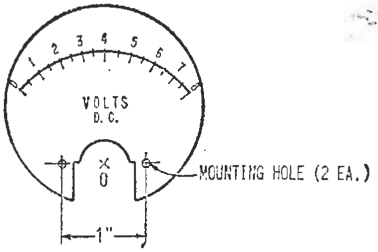


Fig. 7. When photographically printing new scale, final print must be exactly same size as original scale. To be sure, before actually exposing the sensitized paper, project negative onto easel and measure distance between mounting holes. They must exactly match original holes.

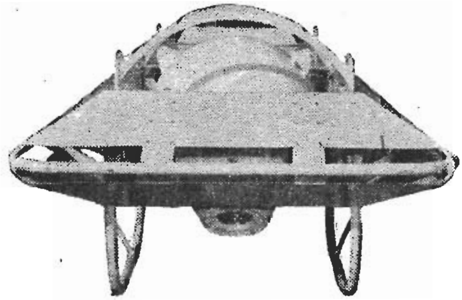
Finally. Trim the new scale to slightly larger than necessary by cutting out the scale 1/16th in. larger than the outline. Mount the new scale on the back of the old meter scale plate using a good quality cement. Alignment is very important, so line up the mounting holes and use backlighting to ensure that the scale outlines match.

Trim the excess paper off, using either a very sharp razor blade or, preferably, a very fine jeweler's file. Always work away from the viewing side of the scale.

Mount the new customized scale on the meter movement and replace the meter case.

Applications. While this article has described the process as applied to the changing of one linear scale to another linear scale, it is possible to make scales for watts, decibels, etc. The only limiting factor is your own ingenuity. The process was developed while converting a meter that was graduated in decibels and volts to one that would read out in Gs (gravity) as shown in the lead picture. ■

Two for the Fish Flicks



Two, 250-watt tungsten-halogen lamps on this underwater sea sled will help put fish on film. Developed by Sylvania, lamps will illuminate deep to probe fishes' fickle ways.

MAKING THE MOST OF METER MOVEMENTS

You can adapt almost any available, basic unit to almost any use with little trouble.

By *JACK H. FARTHING*
Director, Electronics Research Laboratories

HOW MANY times do we fail to install a meter where we need one simply because none of the units on hand seems to lend itself to direct application? It may be an arrangement where we would want to monitor some particular voltage or current constantly. It could be an improvement in an existing instrument. Perhaps it is an interesting project that has been put off because the particular meter cannot be found in the junk box.

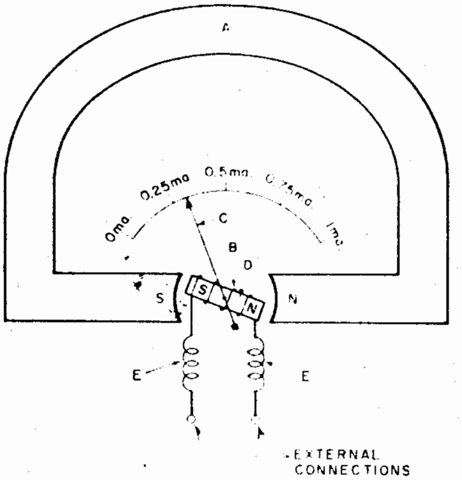


Fig. 1. The working elements, in simplified form, of a basic, moving-coil meter.

In the midst of a field as fast-moving as electronics, we become so involved with the latest complexities that we sometimes forget simple principles. Yet the few of these that apply to meter movements allow us to adapt almost any movement for any measuring purpose. To understand how, it will help if we first review fundamental operation.

The basic meter used in the majority of electronic circuits is of the moving-coil type. Construction, as shown in Fig. 1, generally consists of a permanent magnet (*A*) and a movable coil (*B*) of fine wire that actually rotates about a pivot. Attached to the coil is a pointer (*C*). A core of soft iron (*D*) is inside the coil, and a set of spiral springs (*E*) is used to return the coil and pointer to a reference or zero point.

In most cases, there are two springs, insulated from their mountings, with each connected to one end of the moving coil. Thus the springs also serve to provide a path for current through the coil. When current is applied, an electromagnetic field is developed about the coil. The polarity and intensity of the field depends on the direction of the current and its strength.

Suppose that a current of such polarity is introduced that the left end of the coil becomes a south magnetic pole. It will be repelled by the south pole of the permanent magnet but attracted by its north pole. At the same time, the right end of the coil becomes a north pole attracted to the south pole of the permanent magnet. The direction of rotation, clockwise in this case, is a function of the way in which the lines of force in the two fields are aligned with respect to each other. In practical movements, the coil is wound in such a way, not shown in the simplified illustration, that rotation is in the desired direction.

When the coil turns, it does so against the tension of the springs. If the field developed by the coil is weak compared to spring tension, the degree of rotation will be small. If current is increased, the field will be stronger and there will be correspondingly more rotation.

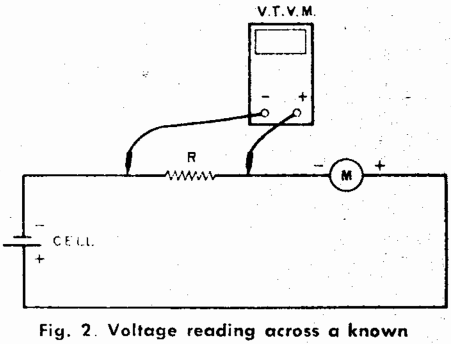
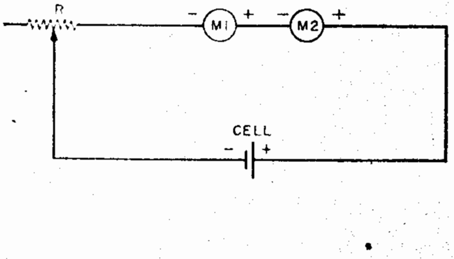


Fig. 2. Voltage reading across a known series resistor and quick calculation can be used to determine full-scale current.

Fig. 3. In another method for finding full-scale current, this value is read on another, known meter put in series.



The moving-coil meter usually has a linear-scale response. This means that, if .5 milliampere causes the pointer to deflect one inch away from the zero position, 1 ma. will cause two inches of deflection.

If you wish to adapt a basic meter to a particular purpose, you must determine two things about it: the current required for full-scale deflection and the resistance of the coil in the movement. The first characteristic is often found printed on the face of the scale in the lower left or right corner. It might, for example, read FS=100 μa., which would mean that full-scale deflection takes place when 100 microamperes flow through the meter. If no markings are found, the rating may be determined by one of the methods to be described. As a precaution against error, it may be advisable to use more than one method, checking the results against each other.

Series-Resistor Method

First remove the case from the meter (carefully!) and also remove any shunts (parallel-resistance coils), series resistors, capacitors, or other added components not essential to the basic meter movement. In this form, the instrument is most flexible, since shunts or series resistors can always be added externally to suit the particular application. In most cases, auxiliary components are bolted to the back of the case in the center of the magnet.

Some shunts will be in the form of a large wire connected directly across the meter terminals. If this is the case, the wire can be snipped with a pair of cutters and left in the meter.

Several fixed resistors are selected from whatever is on hand. Values should range from 500 ohms to 2 megohms. Tolerance should be at least 5 per-cent, with closer tolerances used if they are available. This range should cover practically all meters. Some fresh flashlight cells are also needed as a current source.

Start with the highest-value resistor (*R*) and a single cell placed in series with the meter, as shown in Fig. 2. If the meter terminals are marked as to polarity, be sure to connect accordingly. If there are no markings, tap the lead to one of the terminals momentarily and watch the pointer. If the latter is deflected off scale in the wrong direction, to the left, reverse connections to the battery or the meter. If the pointer goes off scale to the right, disconnect the battery at once and increase the value of the resistor (double it, at least); then work down until a resistor is found that will cause the pointer to rest somewhere within the center third of the scale. If the pointer is not exactly over one of the calibration markings, try to find a resistor, close in value to the one last used, that will produce a reading exactly on some mark of the scale. This will simply make calculation easier.

Note the mark and determine its fraction of full scale. In other words, if there are 100 divisions on the scale and the pointer is resting on the twentieth, the fraction would be $^{20}/_{100}$, or $1/5$ of full-scale reading. Leave the meter connected and use a v.t.v.m., as shown in Fig. 2, to measure the voltage drop across the resistor. Since this drop will be small in most cases, take care to zero the v.t.v.m. properly and use the lowest available voltage scale that will give a substantial reading to insure accurate measurement.

Since the current is the same in all parts of a series circuit, we can determine meter current if we know its value through the resistor. This can be derived from Ohm's Law ($I=E/R$), using the voltage reading for E and the known value of resistor R. If the v.t.v.m. reading was .75 volt and the resistor value is 750 ohms, then .75/750 = .001 ampere or 1 ma. This amount of current has deflected the meter pointer through $1/5$ of full scale. Since deflection in a moving-coil meter is linear, full-scale deflection would require 5 times as much current, or 5 ma. For those who want a handy formula, $I_f = D_f I_m / D_m$, where I_f is the current required for full-scale deflection, D_f is the number of calibration markings in the full scale, I_m is the current through the meter during the test, and D_m is the number of scale marks to which the pointer deflects during the test.

Second-Meter Method

Another technique, which is simpler, requires an additional current meter that is known to be correct. This can be nothing more than a multi-range v.o.m. The unknown instrument (M_1), the known meter, and a variable resistor (R) of high value are placed in series across a battery, as shown in Fig. 3, with R set for maximum circuit resistance. The resistor is then adjusted to produce usable deflection on both meters. The percentage of deflection on unknown meter M_1 is noted, as is the actual current reading on known meter M_2.

For example, suppose that M_2, with a full-scale reading of 20 ma., shows half-scale deflection, or 10 ma. This is the current flowing through both meters. If M_1 reads 20 divisions out of a total of 100 its full-scale reading would be 50 ma. The mathematical expression for this relationship is exactly the same as the one given in the first method described.

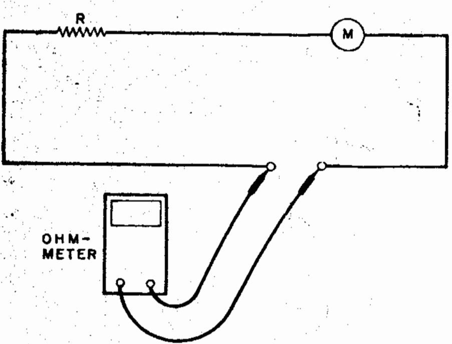


Fig. 4. An ohmmeter can be used to determine internal (coil) resistance with accuracy and no risk of movement damage.

Another method, when available information makes it possible, relies on a simple calculation alone, without measurement. On some meters, you will find an ohms-per-volt rating marked somewhere on the face. It may read something like "2000 ohms/volt" or "10,000 ohms/volt." If the scale is marked in volts, you can determine easily what total resistance is required in the meter circuit to produce full-scale reading.

Suppose that, on a 2000 ohms/volt unit, the maximum scale reading is 50 volts. Multiplying these figures reveals that 100,000 ohms is present on this scale. (This product is not necessarily the resistance of the coil in the meter movement itself; it simply establishes total resistance needed on this scale, which can be made up partly of added, fixed resistors. Nevertheless, it establishes a meaningful relationship that depends on the meter's characteristics.)

If 50 volts are needed to deflect full scale across 100,000 ohms, we can determine the current needed to produce this reading through the meter, with or without series resistors, from Ohm's Law: if $I = E/R$, then 50/100,000 = .0005 ampere, or 500 microamperes.

Checking Coil Resistance

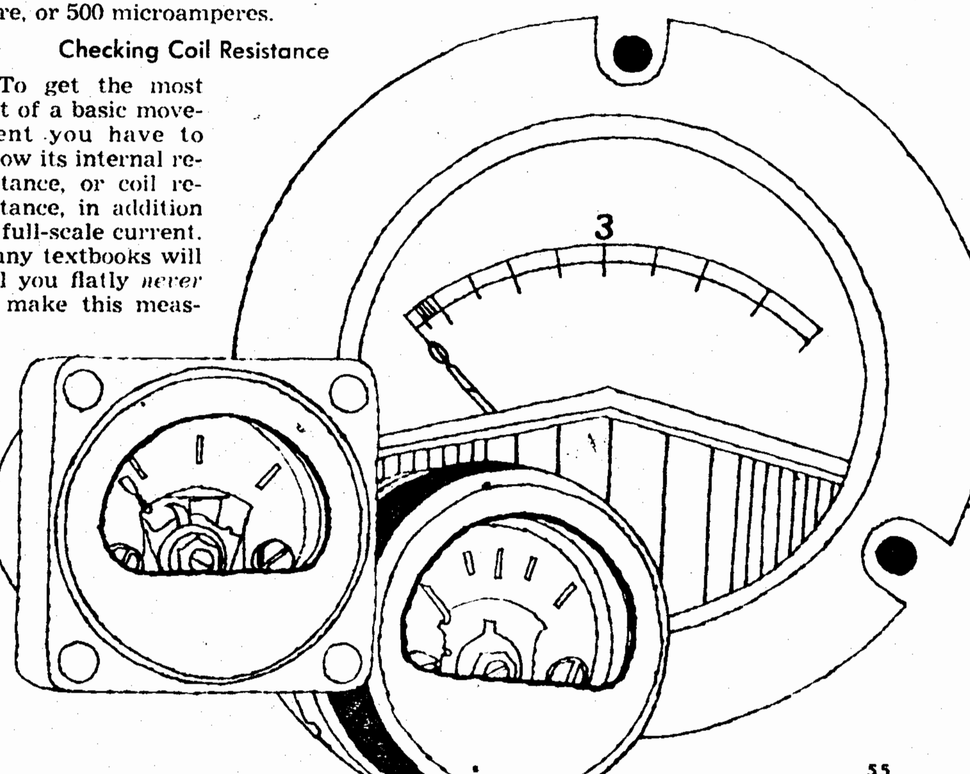
To get the most out of a basic movement you have to know its internal resistance, or coil resistance, in addition to full-scale current. Many textbooks will tell you flatly *never* to make this measurement with an ohmmeter. There are two good reasons for this warning. In the first place, the ohmmeter battery might send enough current through the coil to cause damage. Even if it doesn't, normal ohmmeter inaccuracy may falsify the reading sufficiently so that the latter is inadequate for use. In spite of the textbook injunction, you can realize both safety and acceptable accuracy with an ohmmeter—by observing a simple procedure.

As in an earlier method, all that is needed is an assortment of resistor values and they do not have to be precise. Start with the highest value in series with the movement and the ohmmeter, as shown in Fig. 4. The resistor must be large enough to prevent meter overload. About 1 megohm should do. Reduce R until the pointer deflects toward the center of full scale. If the pointer shows a tendency to move to the left, reverse leads.

With some deflection obtained as noted on the unknown meter (the exact reading does not have to be noted), observe the ohmmeter reading. Let us say that the latter is 3200 ohms. You also notice that the marked value of the resistor is 3000 ohms. Do *not* assume that the resistance of the meter movement alone is 200 ohms. Inaccuracy in the ohmmeter and tolerance variation in the resistor can combine to throw you off quite a bit.

Instead, connect the ohmmeter across the resistor alone. Suppose you read 3100 ohms. The difference, 100 ohms, is meter resistance. Ohmmeter error does not make much difference here, as it is likely to be the same on both readings, which will be made on the same range and the same portion of the scale. To be more certain, take readings using one or more other resistors different in value from the first but not too far from it. If

(*Continued on page 69*)



Making the Most of Meters

(Continued from page 55)

you do this three times, obtain slightly different answers in each case, and then average them out, you should be very close to the actual value.

Voltmeter & Ammeter Applications

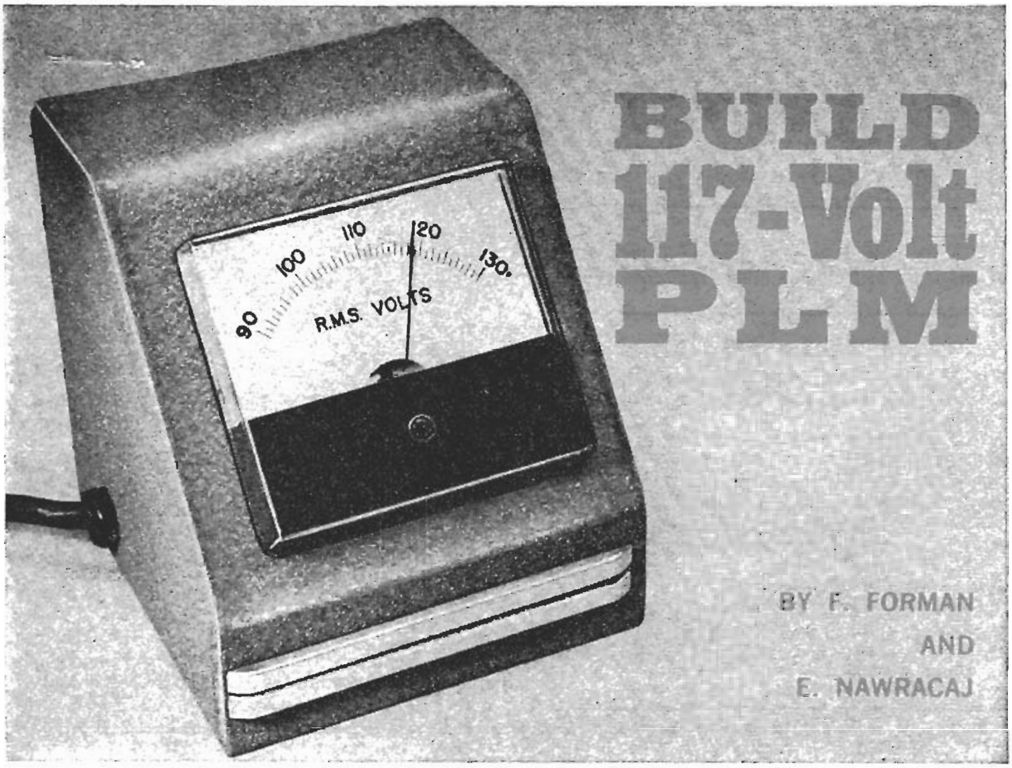
With full-scale current and internal resistance known, adapting a basic movement to a particular application is no great problem. Procedures will be reviewed briefly. For voltmeter application, you will generally need a series dropping (multiplier) resistor. Assume a movement that requires 1 ma. for full-scale deflection and whose resistance is 100 ohms. For a certain project, you want it to read 0-200 volts. Once more Ohm's Law comes into play, this time to determine the total resistance needed across 200 volts to produce full-scale current: $R_t = E_f/I_f$, where R_t is the total resistance (movement plus multiplier) needed, E_f is the maximum voltage to be read at full scale, and I_f is full-scale current. 200 divided by .001 gives an answer of 200,000 ohms.

If the meter resistance is a large part of this total value, or if you want exceptional precision, you can subtract the former quantity from the latter to obtain the value for the multiplier. In most cases, as in this one, the answer to the formula can be used directly as the multiplier value. Here the error would be only $^1/_{20}$ of 1 per-cent.

Let us say that, with the same basic movement used in the preceding example, you want a meter that will indicate 100 ma. full scale. You need a shunt across the terminals that will allow 99 ma. to flow around the movement while 1 ma. passes through the latter. Value of the shunt may be computed as follows: $R_s = I_f R_m / I_s$. R_s is the value of the shunt, I_f the current for full-scale deflection of the movement, R_m the internal resistance of the movement, and I_s the current to be absorbed by the shunt resistor. For the movement under discussion, the appropriate shunt would be 1.01 ohms.

In some applications, this parallel resistor may have to take quite a bit of current. It is a good idea to calculate the maximum power that will be dropped across it, and to choose one whose power rating is double that value.

With full-scale values determined for your application, you only have to calibrate the rest of the meter scale to suit the requirement. You may be able to make your markings directly on the old scale. If you want a new scale, you can trace it from the old one, making sure that the zero and maximum-deflection points are accurately placed. You can check with a protractor. Then, still using the protractor, you can mark off the new scale accurately in the desired number of divisions. Values can be lettered in by hand or the scale can be put in a typewriter before it is inserted in the meter. ▲



BUILD 117-Volt PLM

BY F. FORMAN AND E. NAWRACAJ

Power **L**ine **M**onitor uses expanded scale for a.c. house voltage read-out

WHEN YOUR a.c. line power is used to supply critically balanced test equipment, some erroneous results can be blamed on variations in the line voltage. While most of us rely on the power company to keep the voltage at a nominal 117 volts, it should be monitored because variations of −15 volts and +10 volts are not uncommon.

To check the voltage, it is always possible to use a standard VOM, but trying to read 117 volts on a cramped multi-scale meter is often difficult. A solution is to build a 117-volt PLM, the expanded scale voltmeter that indicates only between 90 and 130 volts, eliminating interpolation between the fine divisions on a VOM meter scale. All you need to make this device is a 0-1 milliammeter and a few spare parts.

The schematic for the voltmeter is shown in Fig. 1. Basically, it consists of a half-wave rectifier with filter (*D1* and *C1*) and a bridge circuit with the milliammeter in the middle of the bridge. One leg of the bridge is a zener diode, *D2,* which maintains a constant voltage drop of 33 volts. Potentiometer *R4* in a second leg is adjusted so that with a 90-volt line input, the drop across *R4* is just 33 volts to match the drop across the zener diode. In this case there is no flow through the meter.

When the line voltage goes up, the drop across *R4* increases while the drop across *D2* stays constant. Thus, current flows through the meter and it indicates a voltage higher than 90 volts. Potentiometer *R5* is adjusted to limit the maximum (130-volt) reading on the meter. Diode

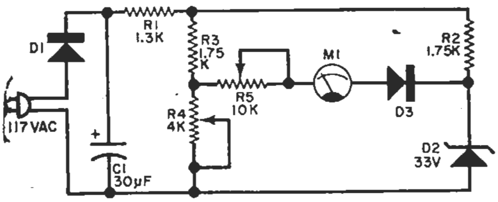
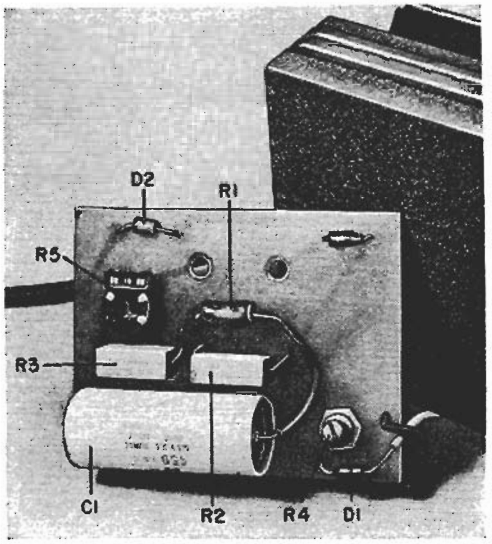


Fig. 1. The circuit is a voltage-sensitive bridge with one leg a zener diode stable reference source.

PARTS LIST

C1—30-µF, 200-volt electrolytic capacitor
D1, D3—Silicon rectifier diode, 1-ampere, 200-volts PIV
D2—Zener diode, 33-volts, 1-watt
M1—0-1 mA meter
R1—1300-ohm, 5-watt resistor
R2, R3—1750-ohm, 5-watt resistor
R4—4000-ohm, 5-watt potentiometer
R5—10,000-ohm, ¼-watt potentiometer (printed circuit type)
Misc.—Meter housing, line cord, new meter scale (see text), miscellaneous hardware.

The printed board is available etched and drilled for $2.00 from Edward Nawracaj, 3914 West 47th St., Chicago, Illinois



Every component is mounted on PC board and then the board is attached to the meter by the meter lugs.

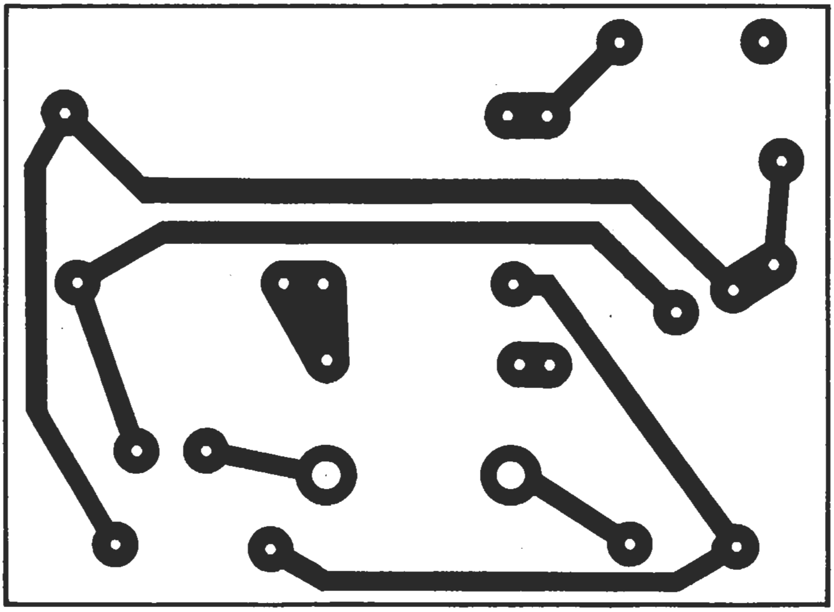


Fig. 2. Full-size drawing of the PC board designed by the authors. Component arrangement can be seen in the photo above and in Fig. 3. The diameter of the large holes should be adjusted to suit the milliammeter lugs used in your project. Some meter lugs are this diameter, but others are somewhat larger.

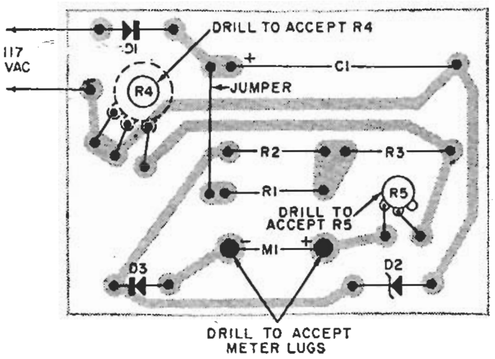
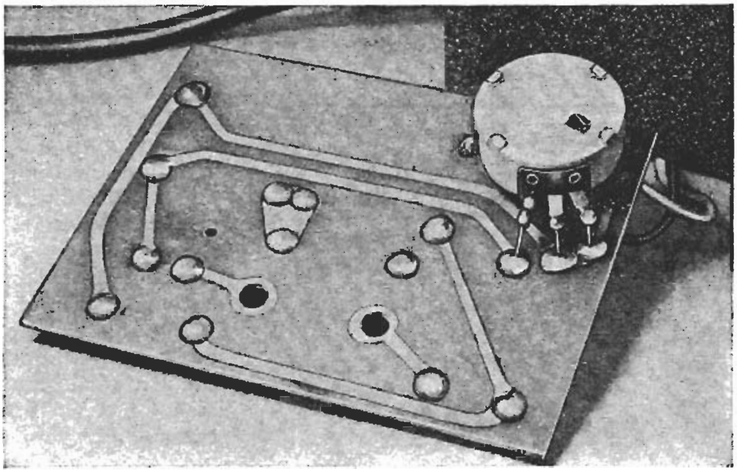


Fig. 3. Component installation on the PC board. A wire jumper connects R1 and the positive side of capacitor C1. This jumper is visible in the photo on the facing page. Alter the diameter of the holes for the meter lugs and potentiometers to fit snug.

Method of mounting potentiometer R4 is seen in this photo. Two shaft nuts enable the potentiometer to stand away from the foil side of the board. Short lengths of bare wire connect the potentiometer lugs to PC board copper foil.



D3 prevents a reverse flow through the meter.

Construction. The complete 117-v PLM circuit is assembled on a printed circuit board, shown full size in Fig. 2. After the board has been fabricated and drilled, mount the components as shown in Fig. 3. The next step is to alter the meter face.

Gently remove the meter scale and either repaint it or make up a new one. Divide the scale into four equal segments marked 90 (old zero on the meter), 100, 110 (center), 120, and 130 (full scale). If desired, the major segments can be marked off into 10 equally spaced minor segments to indicate one volt increments. Mark the 117-volt reading in red.

After the meter is reassembled and the circuit has been calibrated, the printed circuit board can be mounted and supported by the meter lugs.

Calibration. Make a temporary connection between the meter lugs and the appropriate terminals on the PC board. To calibrate the device, you will need a Variac and an accurate a.c. voltmeter covering the range between 90 and 130 volts.

Set the Variac to exactly 100 volts and gradually adjust potentiometer *R4* until the meter indicates 100 volts. Increase the Variac input to 130 volts and adjust *R5* until the meter reads 130. Repeat the process until the meter reads exactly the same as the Variac over the entire range between 90 and 130 volts.

After calibration, cement the potentiometer shafts in place to prevent them from being accidentally disturbed. Remove the Variac source from the input and remove the temporary wiring on *M1*. Secure the PC board to the meter lugs using the nuts provided with the meter.

–30–

measuring meter resistance

By PHILIP KASZERMAN

IT IS OFTEN HANDY TO KNOW THE RESISTance of a meter movement. The resistance of milliammeters ranges from fractions of an ohm to around 100 ohms and the resistance of many microammeters is in the thousands of ohms. These values are often high enough to affect circuit performance so the technician should know the resistance of the meters he uses. Some people get away with using an ohmmeter but it is hardly recommended. The ohmmeter may burn out the meter or damage it.

Figs. 1 and 2 illustrate a technique which will give the meter resistance with an accuracy better than 1%. If followed exactly, there is no danger of burning out the meter. The series potentiometer in Fig. 1 is chosen according to the meter being measured. Its value must be high enough to reduce current in the circuit below the rating of the meter. For instance, if you wish to measure the resistance of a 0 to 1 microammeter, the resistance should be greater than $R = \frac{1.5\text{ v}}{1 \times 10^{-6}\text{ amp}} = 1.5$ megohms. For a 0 to 1 milliammeter it should be greater than 1,500 ohms.

After choosing the potentiometer, *set it to its maximum value.* Then hook up the circuit of Fig. 1. Vary the potentiometer slowly and carefully until the meter reads full scale. Then place a second potentiometer across the meter as in Fig. 2. You will have to guess at the value of this parallel potentiometer. As a first try, use a 500-ohm unit for milliammeters and a 5,000-ohm unit for microammeters. Vary it until the meter reads exactly half scale. Since the battery and the series potentiometer will act approximately as a constant-current source, half the current is now passing through the meter and the other half through the potentiometer. Remove the parallel potentiometer and measure its resistance. The result will be the resistance of the meter.

For more accurate results, use the circuit of Fig. 3. It is essentially the same as Fig. 2 except that another meter has been added in series with the battery. The rating of this meter should be equal to the meter being tested or slightly higher. The procedure is now the same as before with one difference: While varying the parallel potentiometer, maintain current in the series meter at its initial value by slightly changing the series potentiometer. In this way, you make the battery act as a constant-current source. The accuracy of this method of calculating the resistance of the meter is only limited by the accuracy with which the meter itself indicates half scale. END

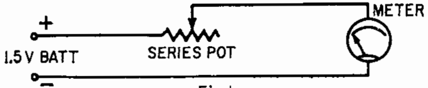


Fig.1

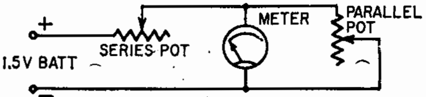


Fig.2

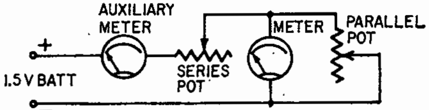


Fig.3