Chapter 4 / Part B

AC
Indicating instruments measurements

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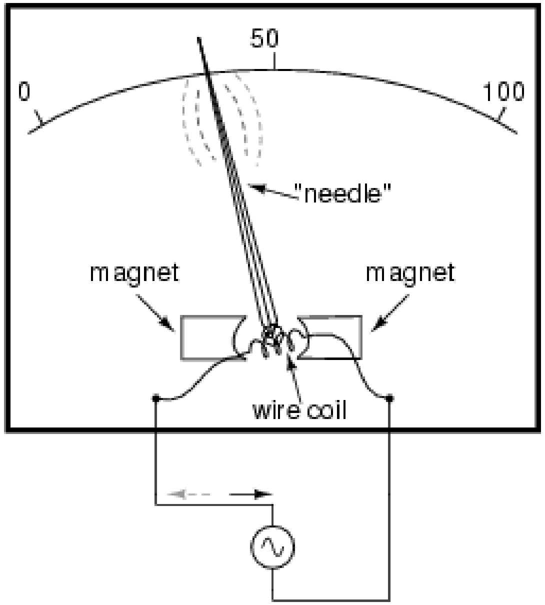
AC METERS

AC electromechanical meter movements come in two basic arrangements:

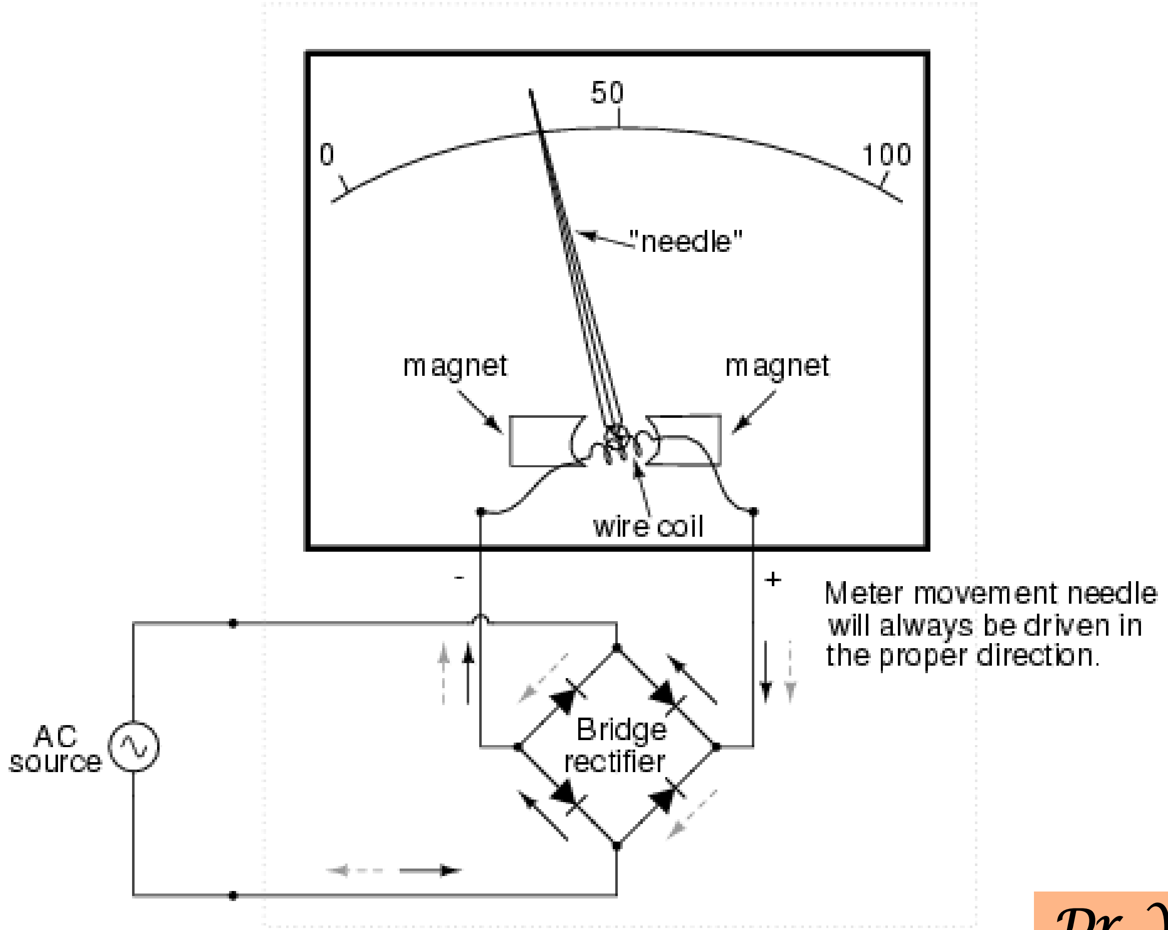
- based on DC movement designs, and
- engineered specifically for AC use (measure **RMS** value)

Permanent-magnet moving coil (PMMC) meter movements will not work correctly if it **directly connected to alternating current**

because the direction of needle movement will change with each half-cycle of the AC.

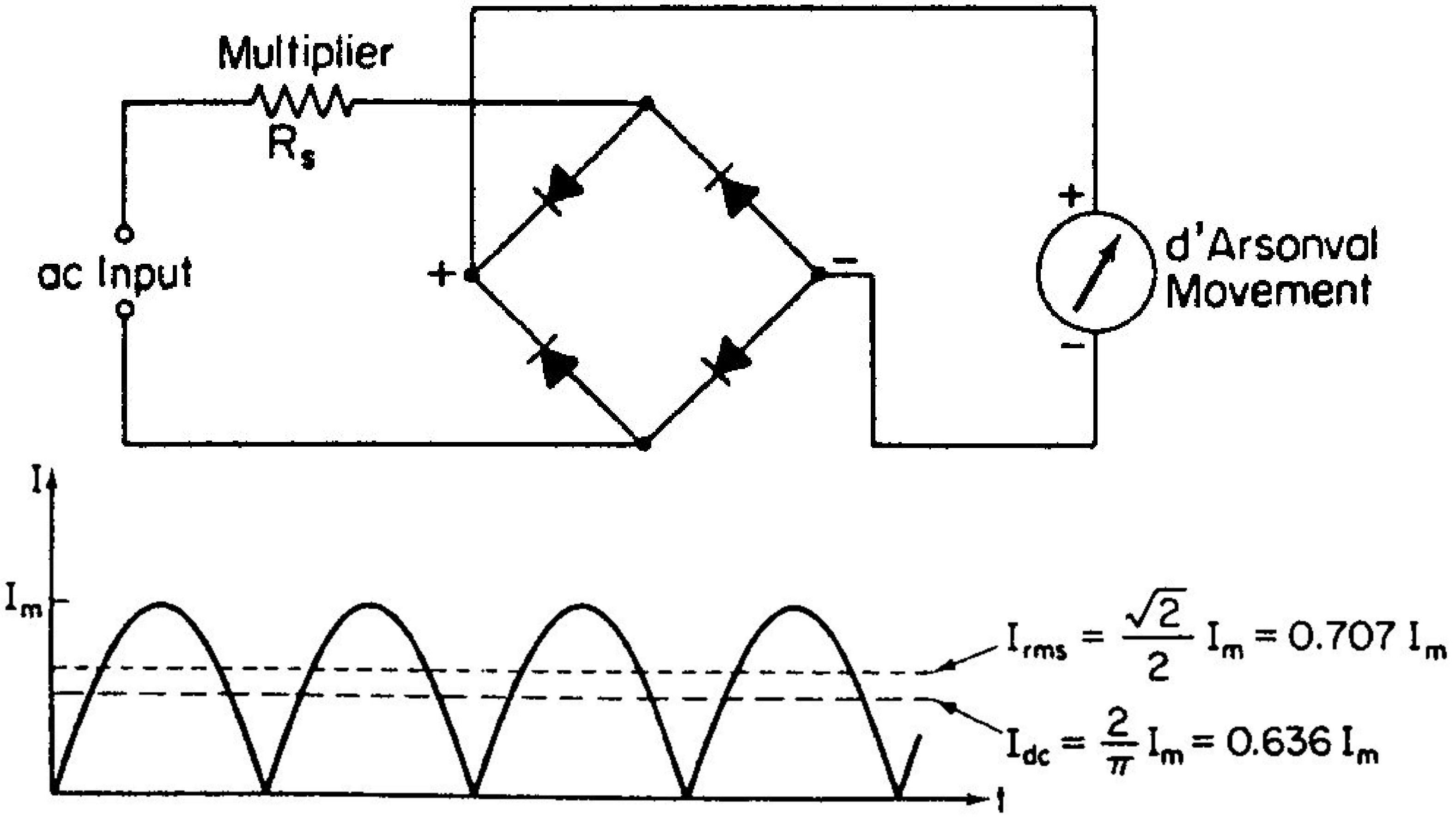


- In order to use a **DC-style meter** movement such as the D'Arsonval design, the alternating current must be ***rectified* into DC**.
- This is most easily accomplished through the use of devices called ***diodes***.



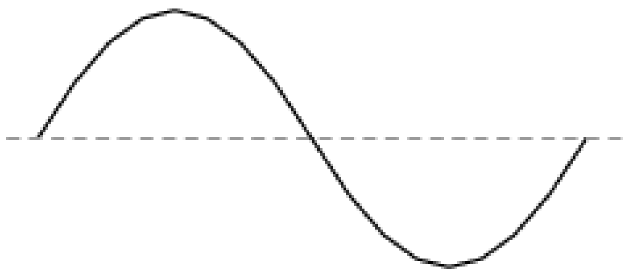
RECTIFIER-TYPE AC METERS

The meter deflection is proportional to the average current ac measurement expressed usually in r.m.s scale is used

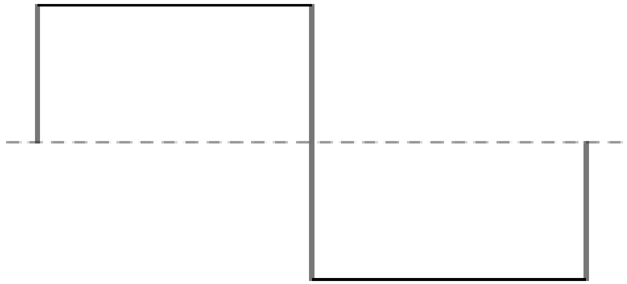


RMS AN AVERAGE VALUES (AFTER RECTIFIER)

	Half-wave Rectifier	Bridge Rectifier
Average voltage	$V_{dc} = \frac{V_m}{\pi}$	$V_{dc} = \frac{2V_m}{\pi}$
rms voltage	$V_{rms} = \frac{V_m}{2}$	$V_{rms} = \frac{V_m}{\sqrt{2}}$

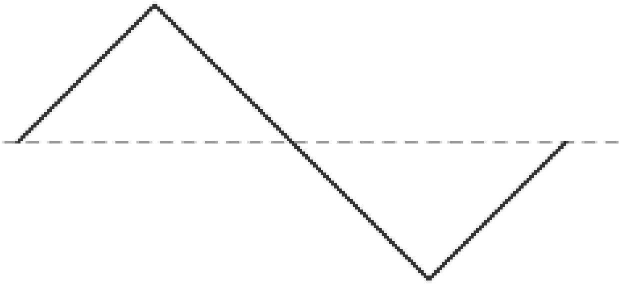


RMS = 0.707 (Peak)
AVG = 0.637 (Peak)
P-P = 2 (Peak)



RMS = Peak
AVG = Peak
P-P = 2 (Peak)

$$V_{dc} = \frac{2(\sqrt{2}V_{rms})}{\pi} \cong 0.9V_{rms}$$

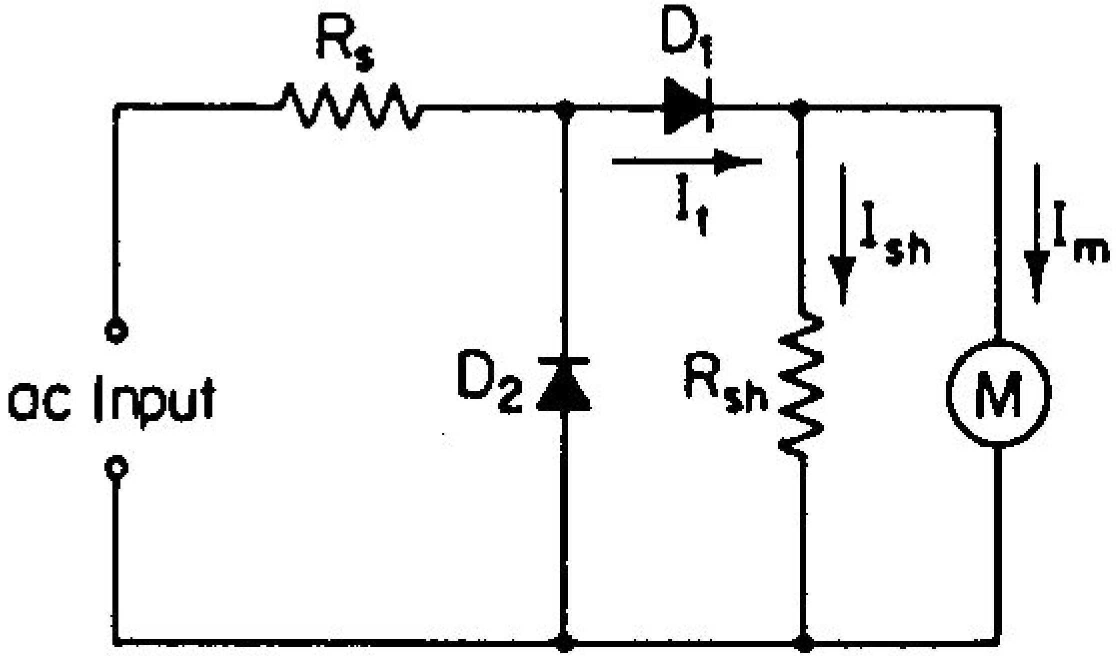


RMS = 0.577 (Peak)
AVG = 0.5 (Peak)
P-P = 2 (Peak)

VOLTMETER CIRCUIT

Rsh is placed in order **D1** to draw more current to move its operating mode into **linear** potion.

Diode **D2** is placed to protect the meter from the **reverse current** during the **–ve** half cycle.



VOLTMETER CIRCUIT (MULTIRANGE)

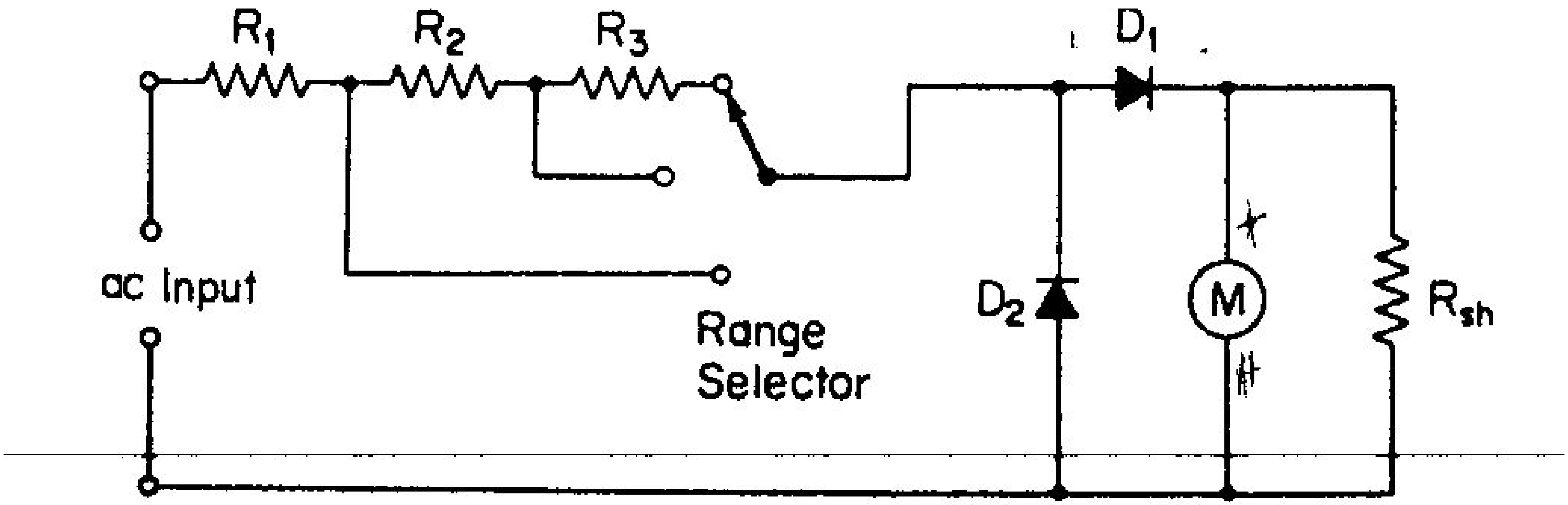


Figure 4-34 Typical ac voltmeter section of a commercial multimeter.

Example [4-10]: A meter has internal resistance of 100Ω requires 1mA DC for f.s.d. A shunt resistor with value of 100Ω is placed across the meter . The diodes forward resistance is 400Ω. For 10V ac range calculate the value of Rs and the *sensitivity* of the voltmeter.

Solution

10V ac -- rms

(a) Since R_m and R_{sh} are both 100 Ω, the total current the source must supply for full-scale deflection is I_t = 2 mA. For half-wave rectification the equivalent dc value of the rectified ac voltage will be

For FW
$E_{dc}=0.9E_{rms}$

$$E_{dc} = 0.45\,E_{rms} = 0.45 \times 10\text{ V} = 4.5\text{ V}$$

The total resistance of the instrument circuit then is

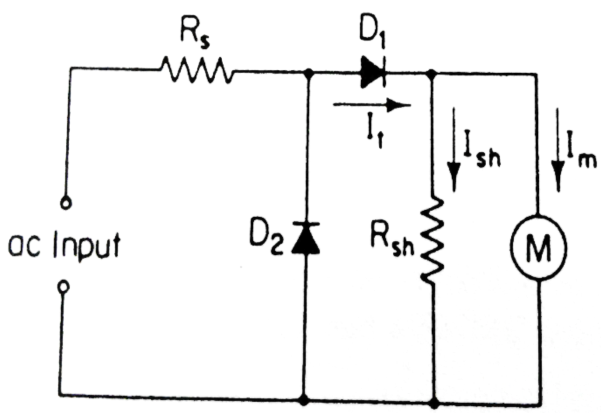
$$R_t = \frac{E_{dc}}{I_t} = \frac{4.5\text{ V}}{2\text{ mA}} = 2{,}250\ \Omega$$

This total resistance is made up of several parts. Since we are interested only in the resistance of the circuit during the half-cycle that the movement receives current, we can eliminate the infinite resistance of reverse-biased diode D_2 from the circuit. Therefore

$$R_t = R_s + R_{D_1} + \frac{R_m R_{sh}}{R_m + R_{sh}}$$

and

$$R_t = R_s + 400 + \frac{100 \times 100}{200} = R_s + 450\ \Omega$$



The value of the multiplier therefore is

$$R_s = 2{,}250 - 450 = 1{,}800\ \Omega$$

(b) The sensitivity of the voltmeter on this 10-V ac range is

$$S = \frac{2{,}250\ \Omega}{10\text{ V}} = 225\ \Omega/\text{V}$$

MULTIRANGE VOLTMETER CIRCUIT EXAMPLE

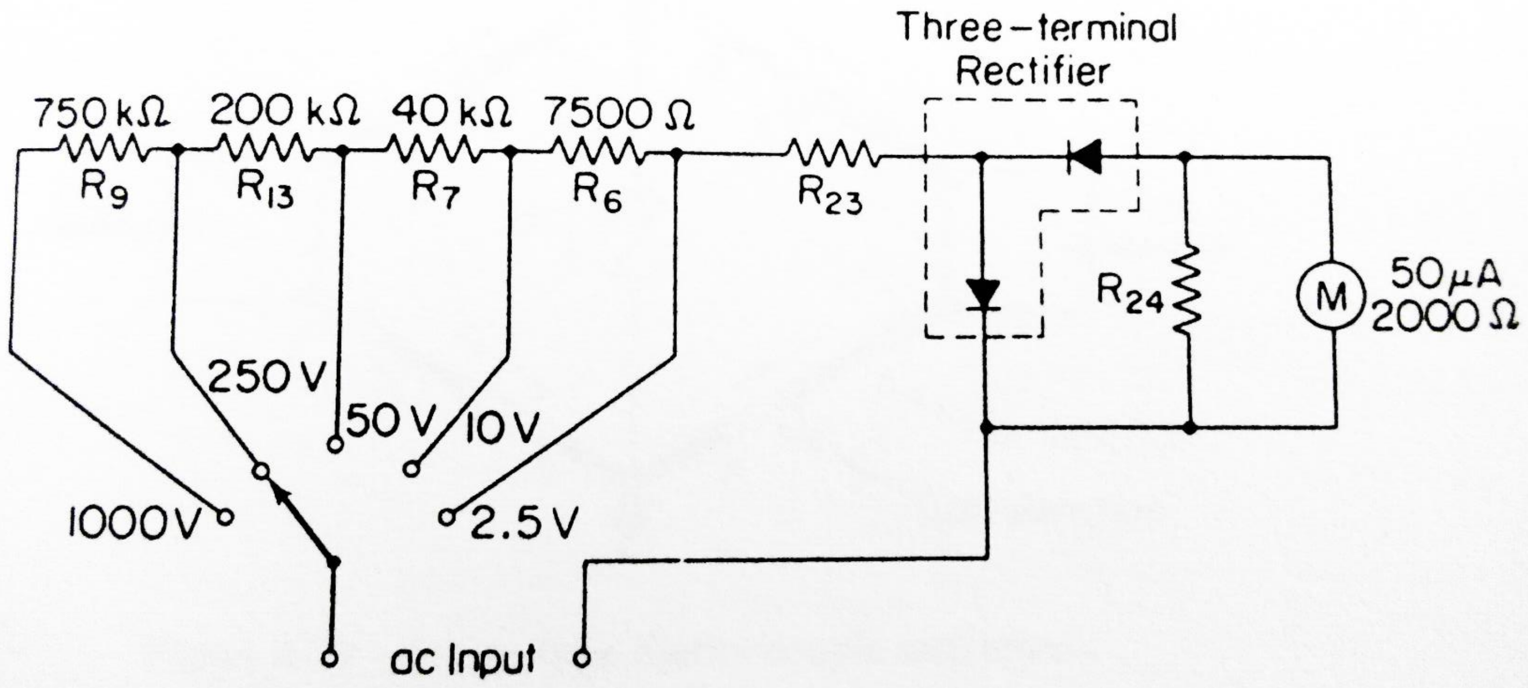
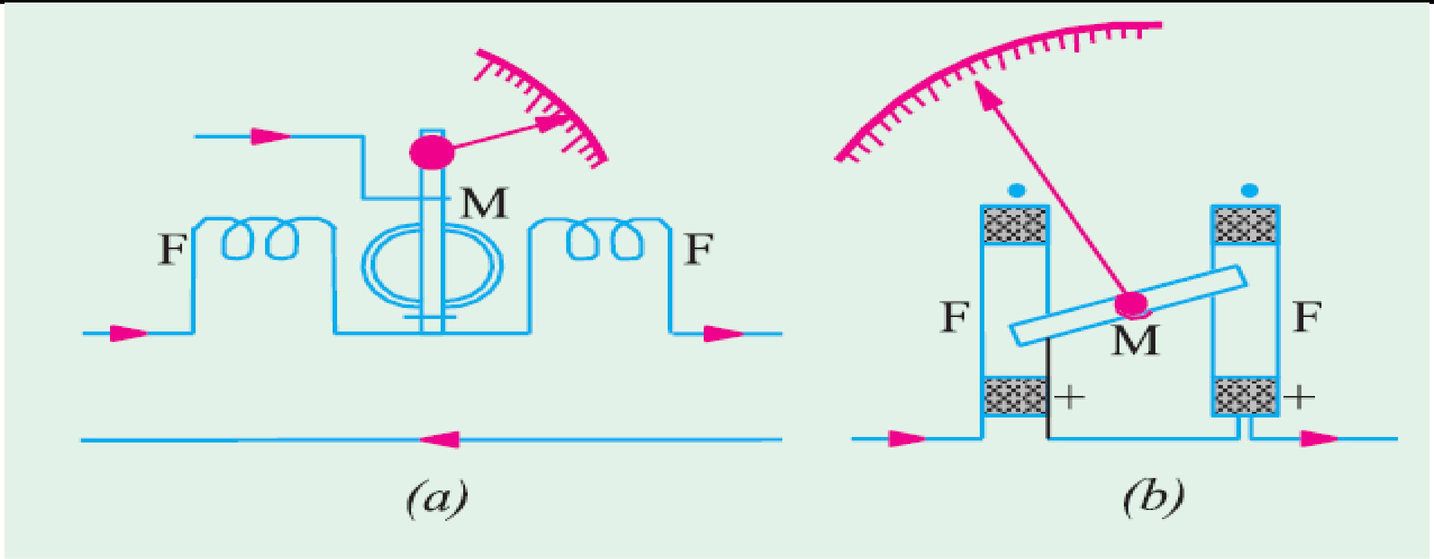


Figure 4-36 Multirange ac voltmeter circuit of the Simpson Model 260 multimeter (courtesy of the Simpson Electric Company).

Dynamometer or Electrodynamic Instrument



- **Operating magnetic field** is produced by a pair of fixed coils (field coils)
- Fixed coils are placed closed together, <u>parallel</u> to each other & <u>air-cored</u>
- Air core: to avoid ***hysteresis*** effects and to provide magnetic field for moving coil to move more **<u>uniformly</u>**
- ***Used in low freq.***

ElectroDynamometer

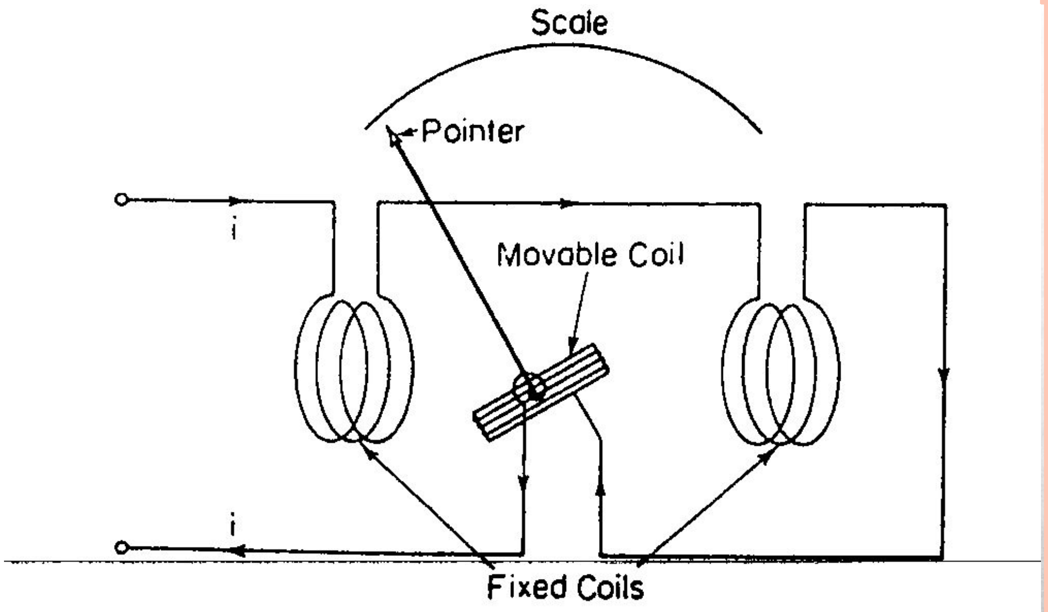
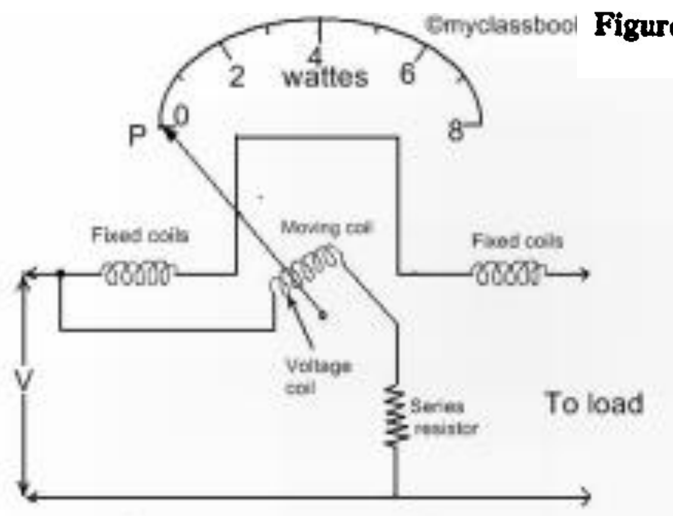


Figure 4-30 Schematic diagram of an electrodynamometer movement.



Dynamometer type Wattmeter

- ➢Generally used as ***wattmeter***

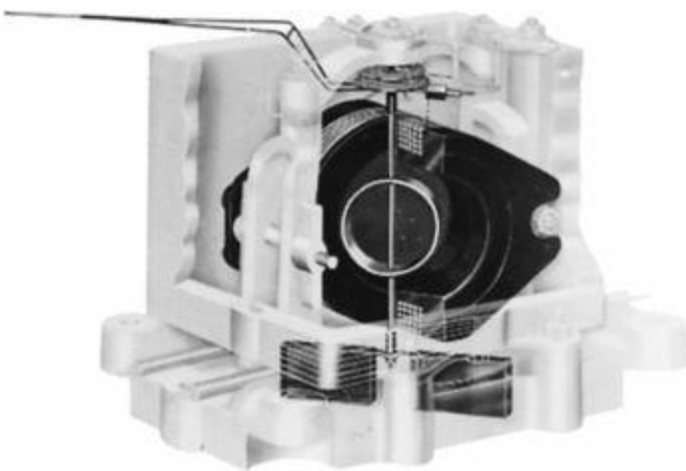
ELECTRODYNAMOMETER

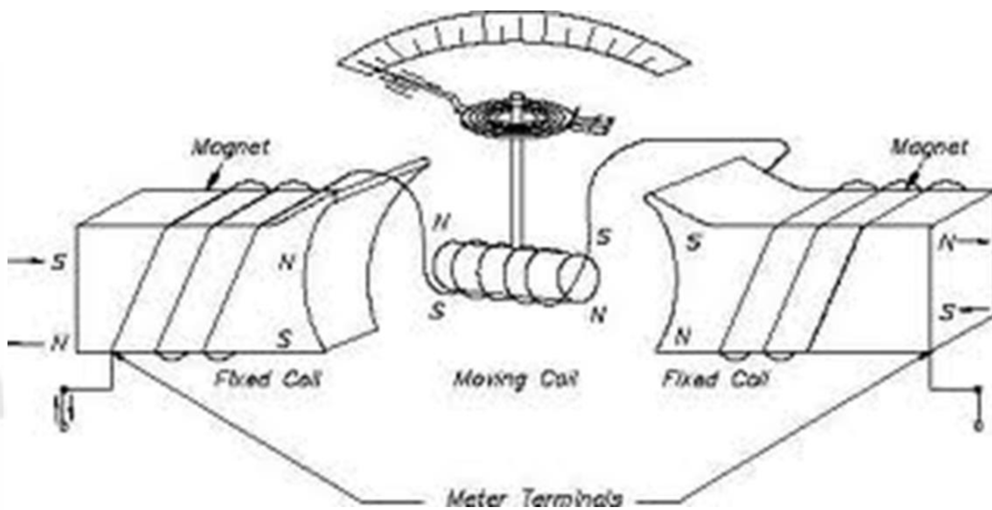
- The working principle of a basic electrodynamometer instrument is same as the PMMC instrument.
- The only difference in this case is that the permanent magnet is **replaced with two fixed coils** connected in series.
- The **moving coil** is also connected in **series** with the fixed coils.
- The **two fixed coils** are connected to electromagnets in such a manner that they form poles of **opposite polarity**.
- As the moving coil **carries** current through it and it being **placed** in the field of fixed coils, it experience a **force** due to which the **moving coil rotates**.

ELECTRODYNAMOMETER

$$I = \sqrt{\frac{1}{T}\int_0^T i^2 dt} = \sqrt{a\,\mathrm{var}\,age\ i^2}$$

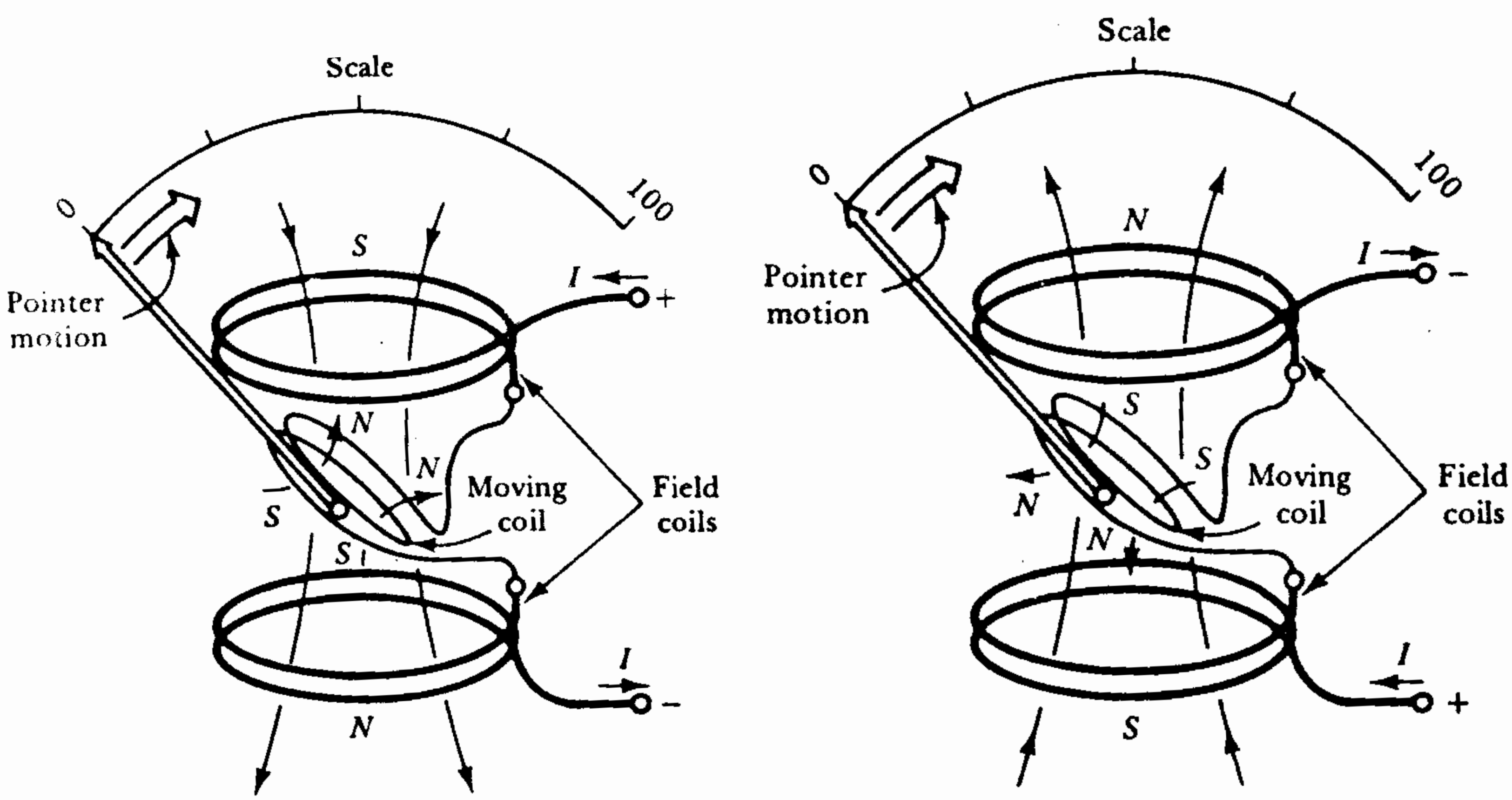
The Electrodynamometer reads the current ***I*** (the *root mean square*) which equivalent to **DC value**.





ELECTRODYNAMOMETER

Positive deflection of pointer occurs in an electrodynamic instrument regardless of current direction. The instrument can be used directly for both ac and dc measurements.

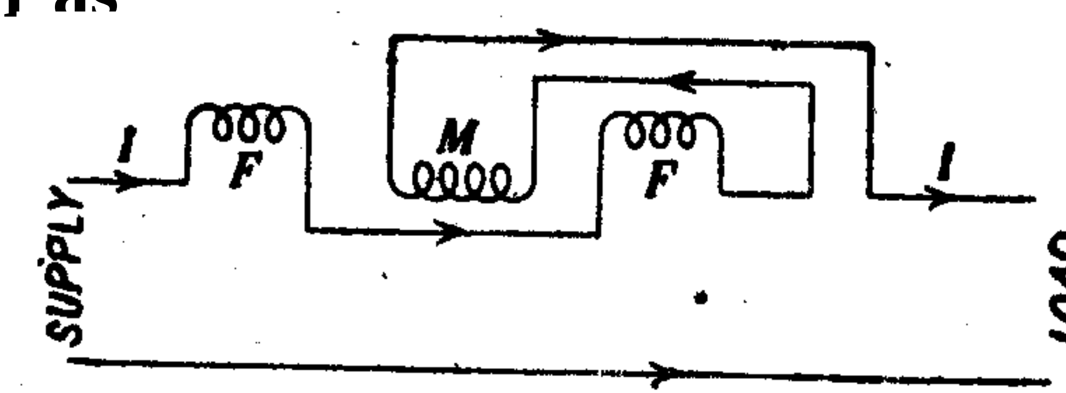


(a) Current flowing from top to bottom produces positive deflection

(b) Current flowing from bottom to top also produces positive deflection

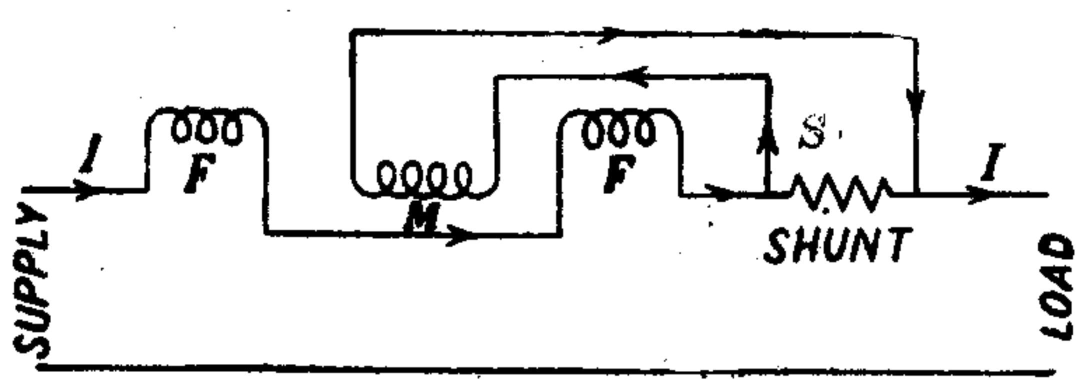
Electrodynamometer as **Ammeter**

Without shunt

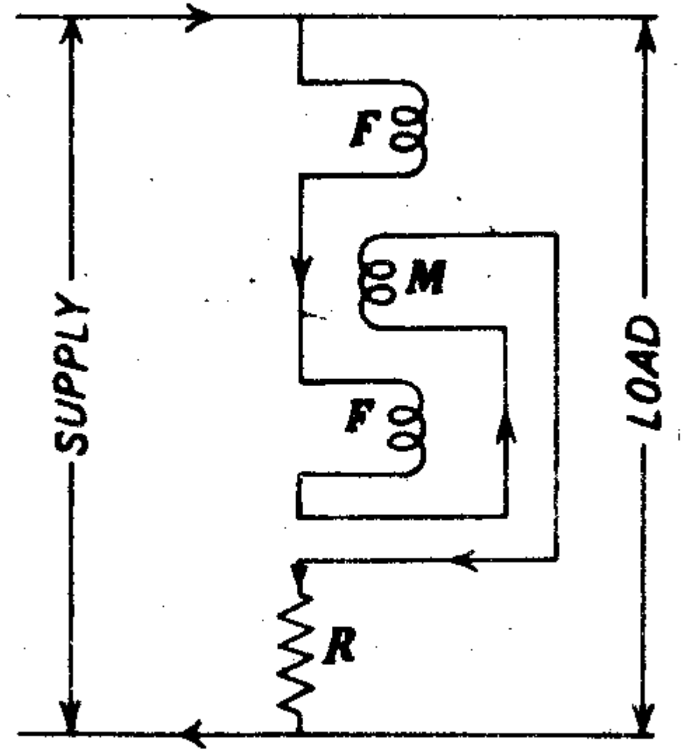


I_1 = fixed coil I , I_2 = moving coil I

With a shunt



Electrodynamometer as <u>Voltmeter</u>

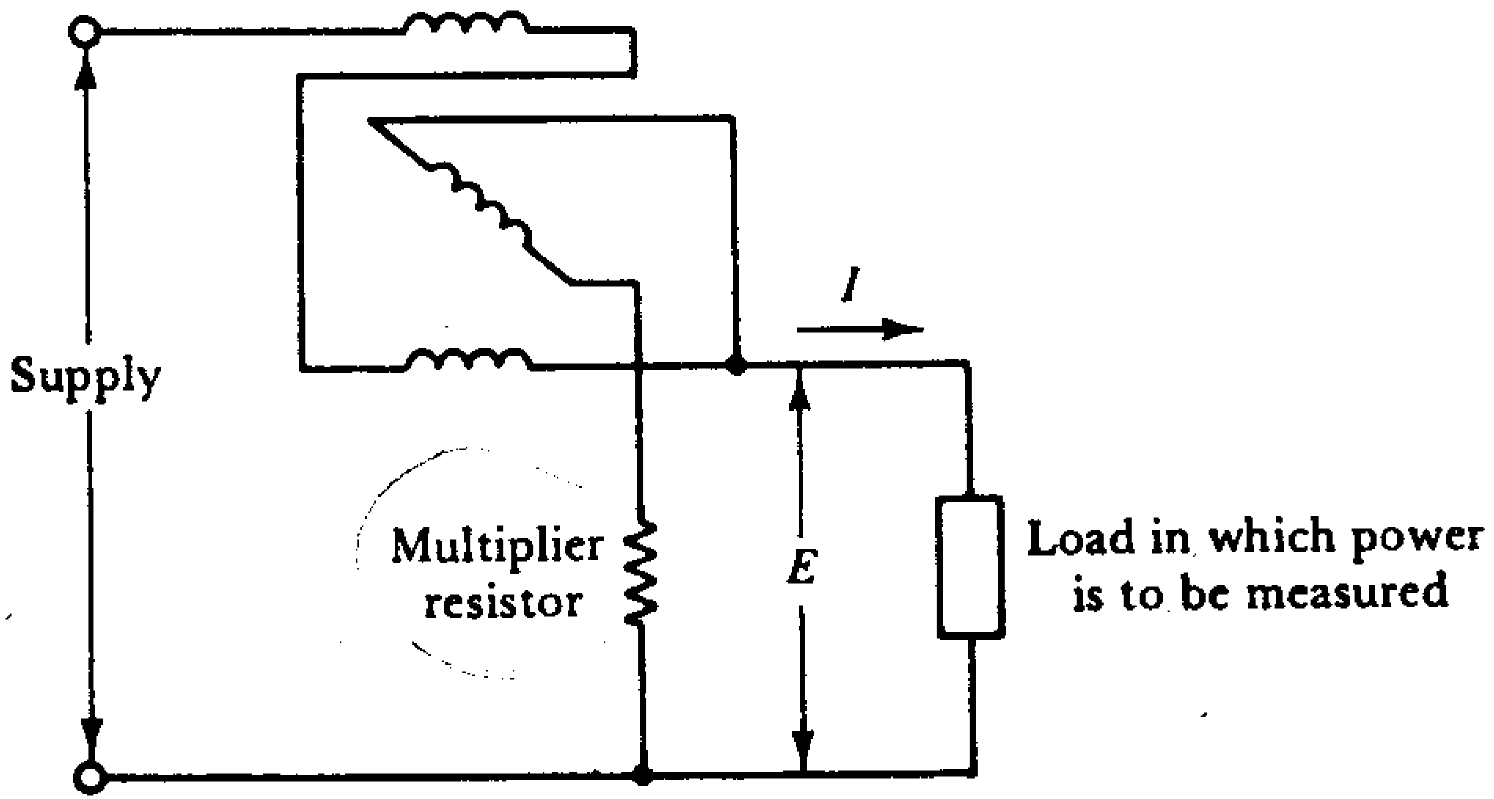


<u>Damping</u> :

- ➢ Pneumatic (air chamber or vanes)
- ➢ Eddy current damping is not efficient due to weak operating magnetic field.

ELECTRODYNAMOMETER POWER MEASUREMENTS

Wattmeter



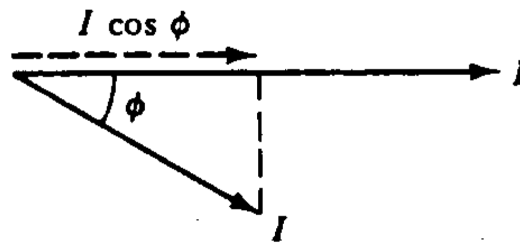
(a) Electrodynamic wattmeter circuit

The deflection of the moving coil is proportional to the product of the i_p and i_c

The average deflection over a period:

$$i_p = e / R_p$$

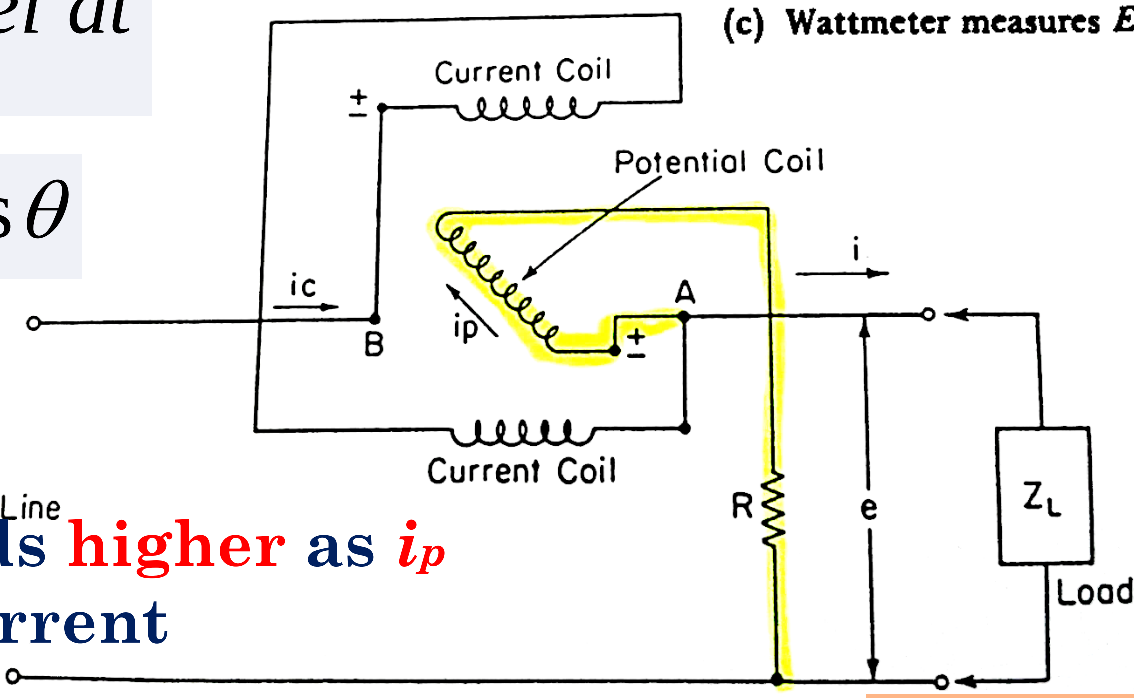
$$\theta_{av} = K \frac{1}{T}\int_0^T i_c i_p dt = K_2 \frac{1}{T}\int_0^T ei\ dt$$



(c) Wattmeter measures $EI \cos\phi$

$$P_{av} = \frac{1}{T}\int_0^T ei\ dt$$

$$\theta_{av} = K_3 EI \cos\theta$$



Wattmeter reads higher as i_p is not a load current

Wattmeters

To compensate the current *i_p* to get more accurate reading of the power.

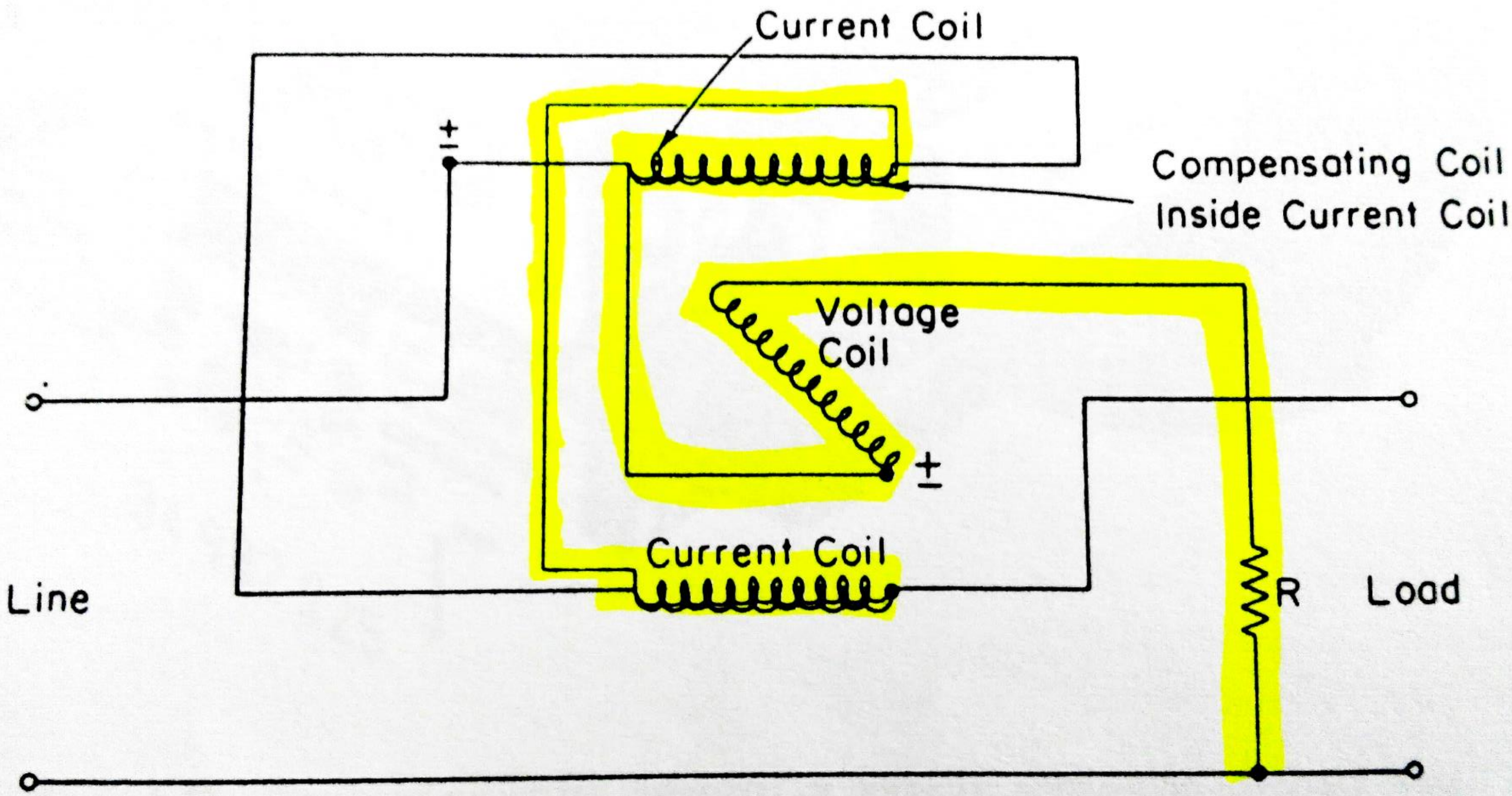


Figure 4-41 Diagram of a compensated wattmeter in which the effect of the current in the potential coil is canceled by the current in the compensating winding.

Electronic Wattmeters

Why using the Electronic Watt-Meters:

- ✓ Small power measurements.
- ✓ Power measurements at frequencies beyond the range of electro-dynamometer type instruments.
- ✓ It has a higher accuracy than the analog meters.

WATTHOUR METERS

Current coil in series with line

Voltage coil connected across the line

Eddy currants flow in the disk

Reaction of Eddy currents creates a torque (rotates)

The number of rotations is proportional to the energy consumed (KWh)

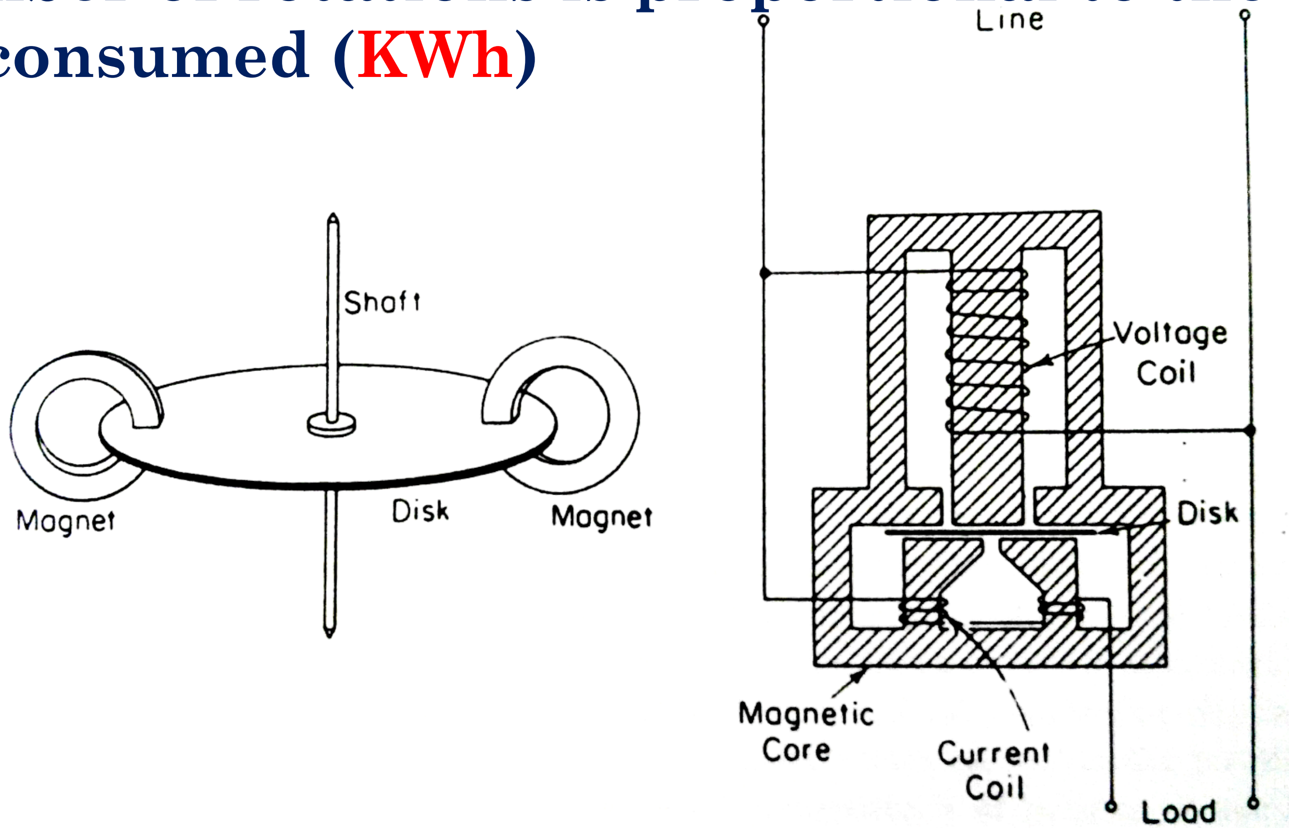
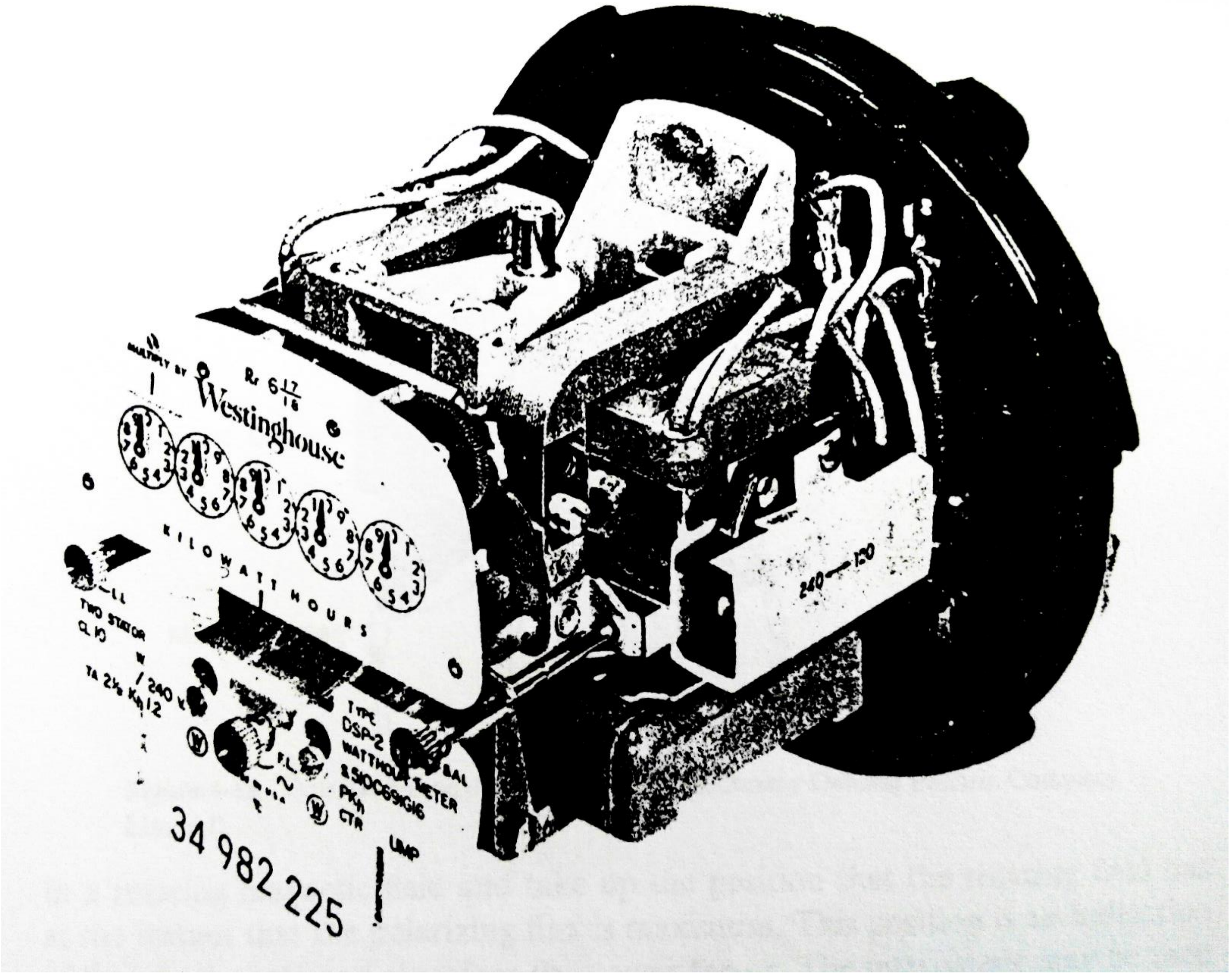
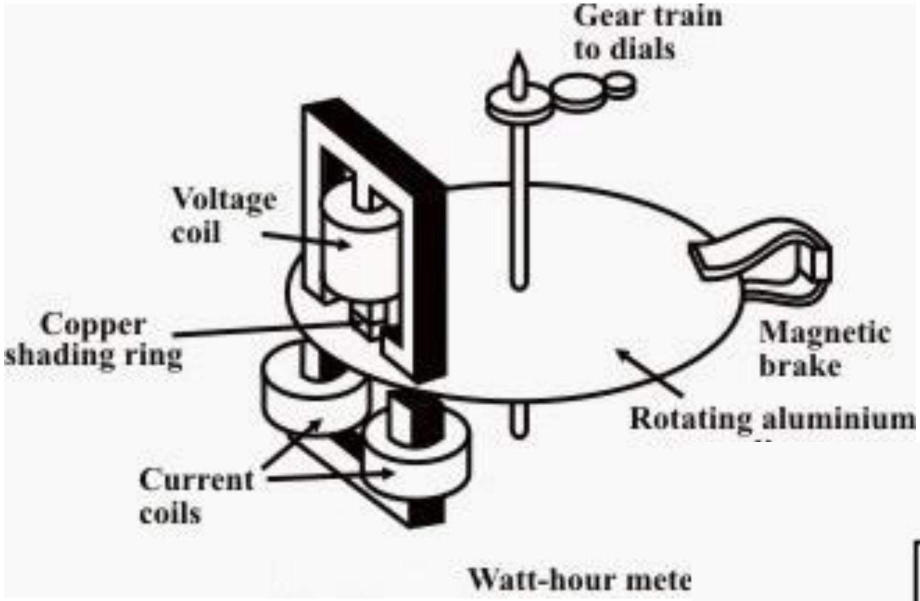


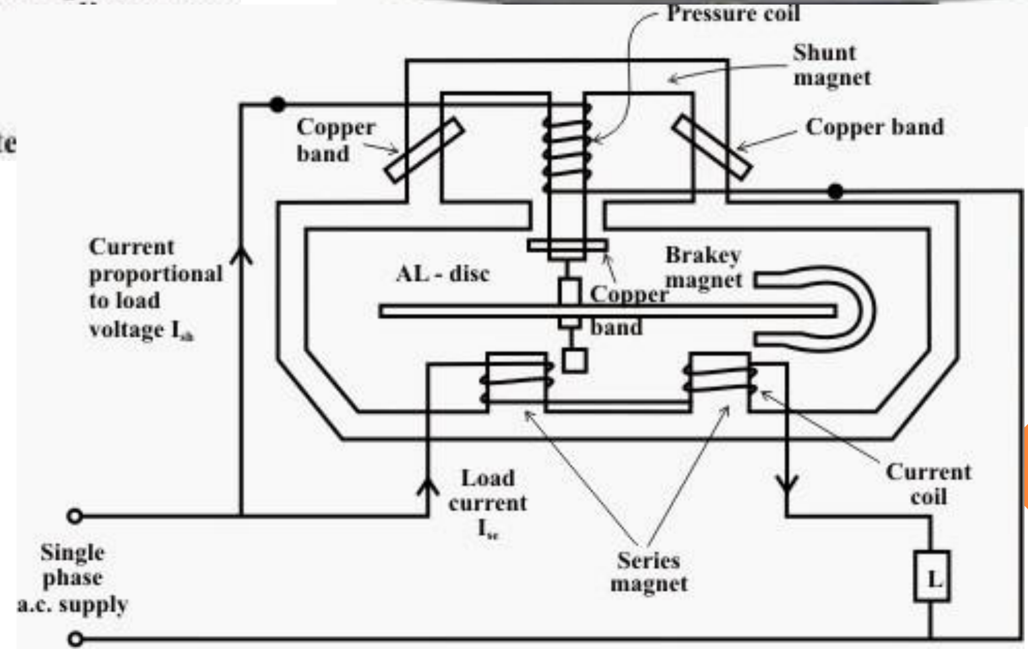
Figure 4-42 Elements of a single-phase watthour meter.

WATTHOUR METERS



Overview of Single Phase Induction Type Energy Meter





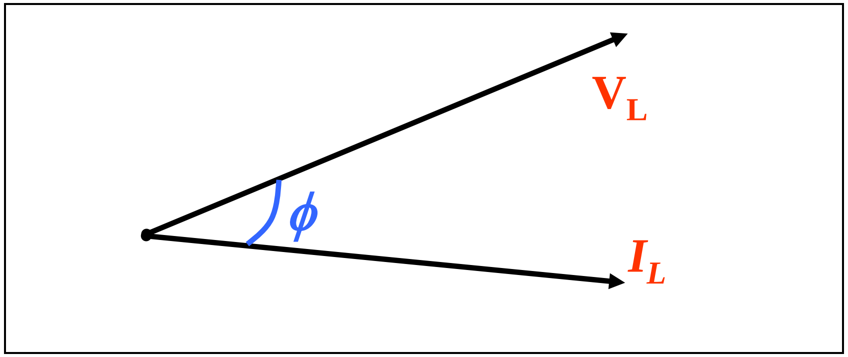
POWER - FACTOR METERS

Power Factor Meters are meant for measuring power factor of a circuit as the ratio between the effective true power & the apparent power.

$$P.F = \cos\phi = \frac{\text{True Power}}{\text{Apparent Power}} = \frac{V.I.\cos\phi}{V.I}$$

The power factor is indirectly determined by measuring the phase angle (ϕ) between current and voltage.

However, the indicators are calibrated in values of cos (ϕ)



POWER-FACTOR METERS

The torque is also proportional to the mutual inductance between each part of the crossed coil and the stationary field coil. This mutual inductance depends on the angular position of the crossed-coil elements with respect to the position of the stationary field coil. When the movable element is at balance, it can be shown that its angular displacement is a function of the phase angle between line current (field coil) and line voltage (crossed coils). The indication of the pointer, which is connected to the movable element, is calibrated directly in terms of the phase angle or power factor.

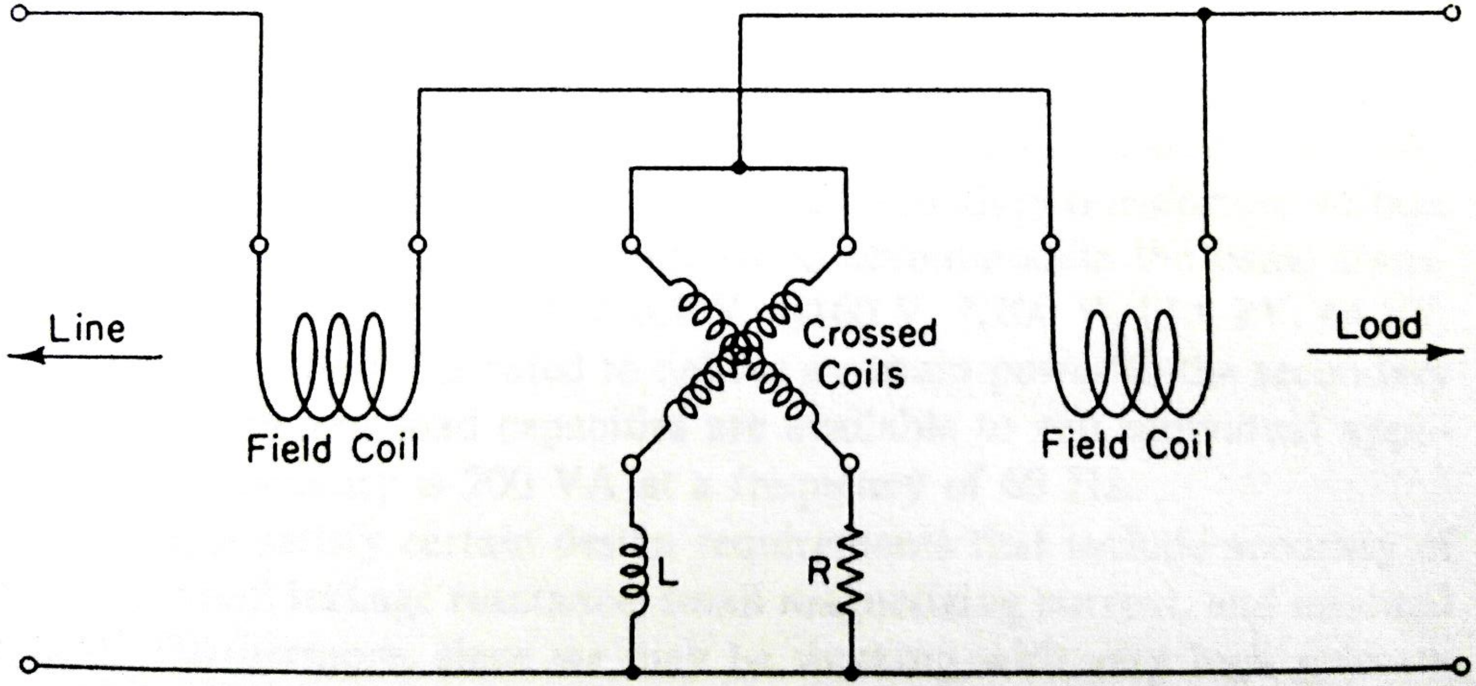
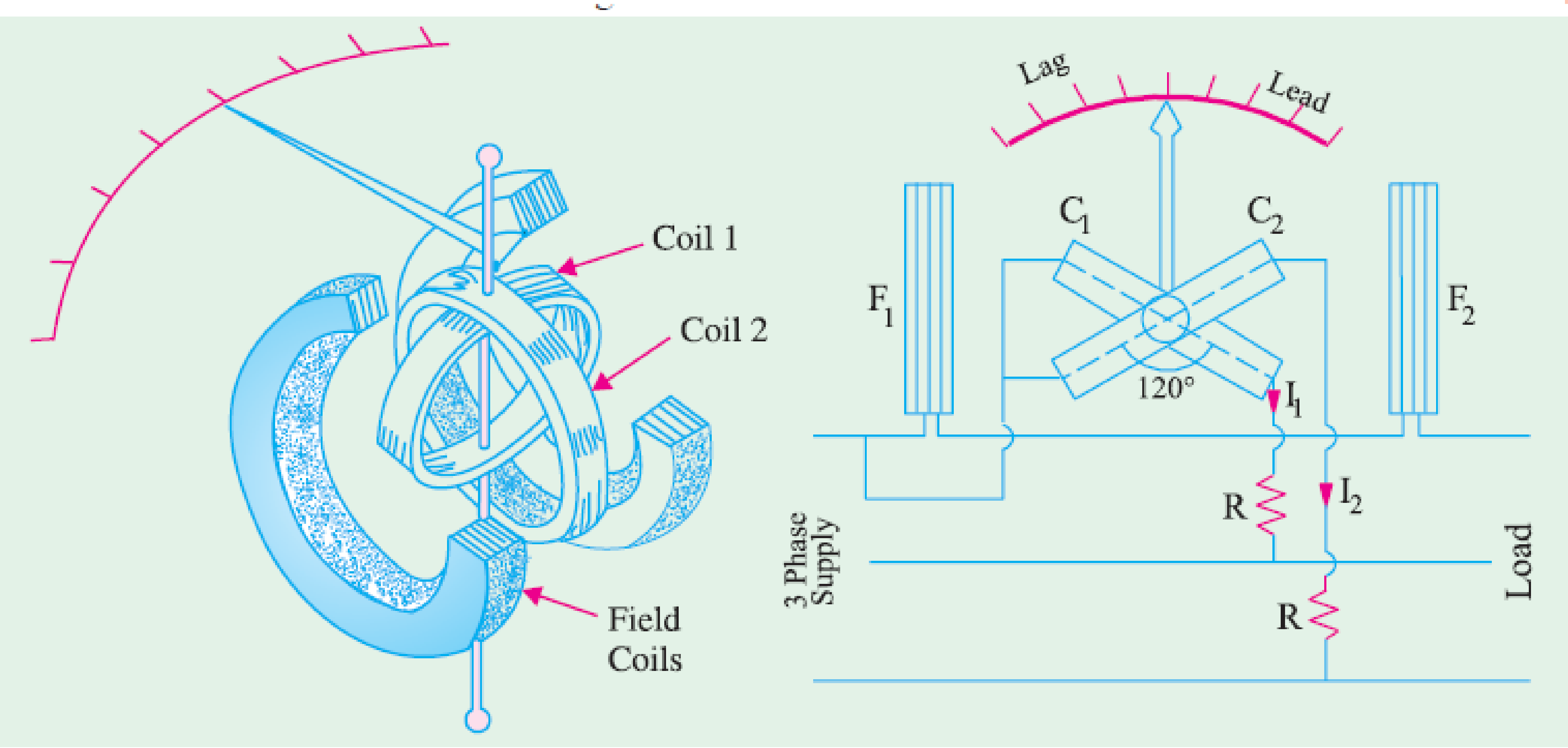


Figure 4-44 Connections for a single-phase crossed-coil power-factor meter.

POWER-FACTOR METERS



For reliable readings, the instrument has to be calibrated at the frequency of the supply on which it is to be used. At any other frequency (or when harmonics are present), the reactance of L will change so that the magnitude and phase of current through C_2 will be incorrect and that will lead to serious errors in the instrument readings.

POWER- FACTOR METER

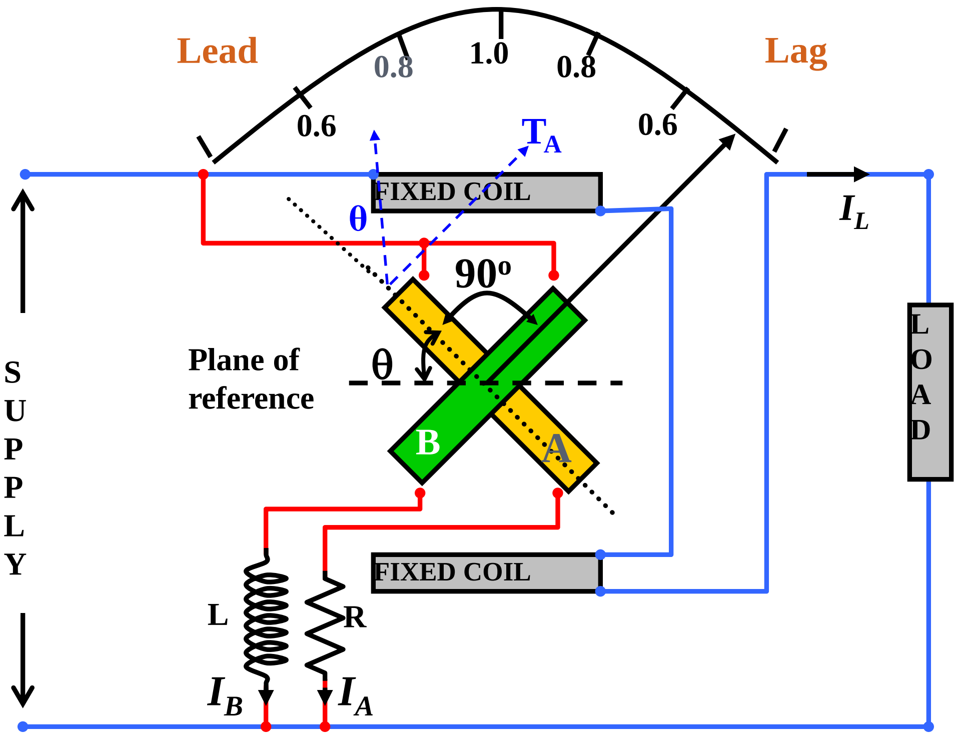
called a *cross coil power factor meter*.

It has two moving coils (A and B), mounted on the same shaft.

The currents in the two coils are equal in magnitude but displaced in time by 90. This is achieved by setting ($R = \omega L$) .

For unity power factor ($\phi=0$) , the current in coil (A) will be in phase with the I_L, while the current coil (B) will be out of phase by 90.

Thus, there will be a torque T_A acting on coil (A) alone, the other coil experiencing zero torque.



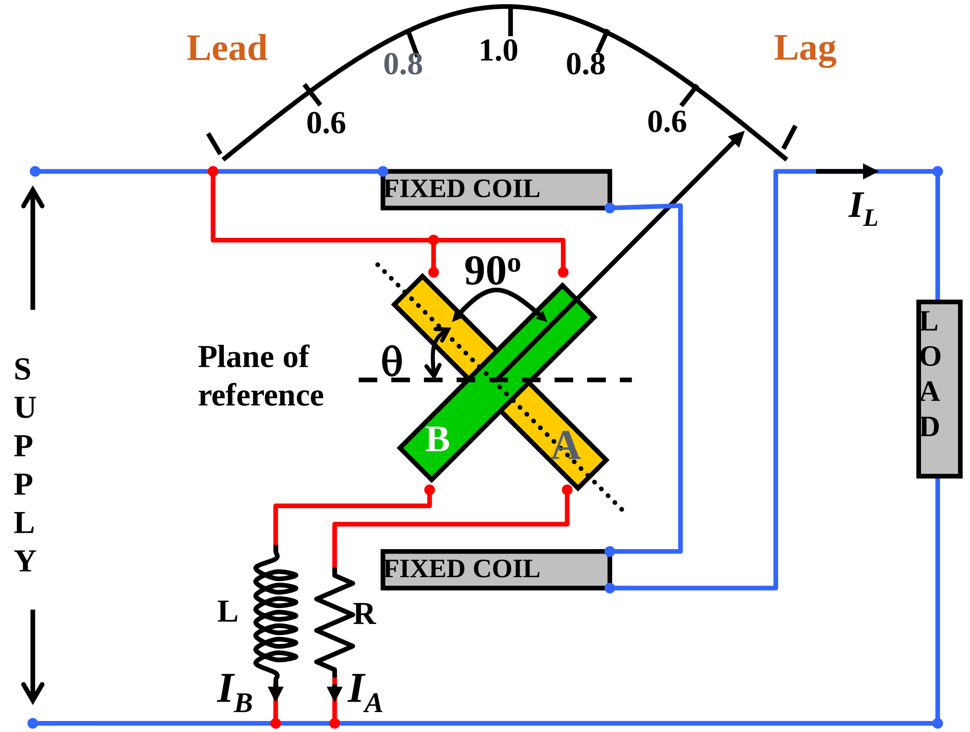
$T_A = K*V_L*I_L*\cos\phi * \sin\theta.$

$T_B = K*V_L*I_L*\cos(90^o-\phi) * \sin(90^o+\theta).$

Consequently coil (A) will rotate until it is perpendicular with the fixed coils. Under this condition, the pointer shows a reading equal to '1'

FOR A P.F. EQUAL TO ZERO ($\Phi=90$), THE CURRENT IN THE COIL (B) IN PHASE WITH THE I_L.

THUS, COIL (B) WILL NOW ROTATE UNTIL IT IS PERPENDICULAR WITH THE FIXED COILS.

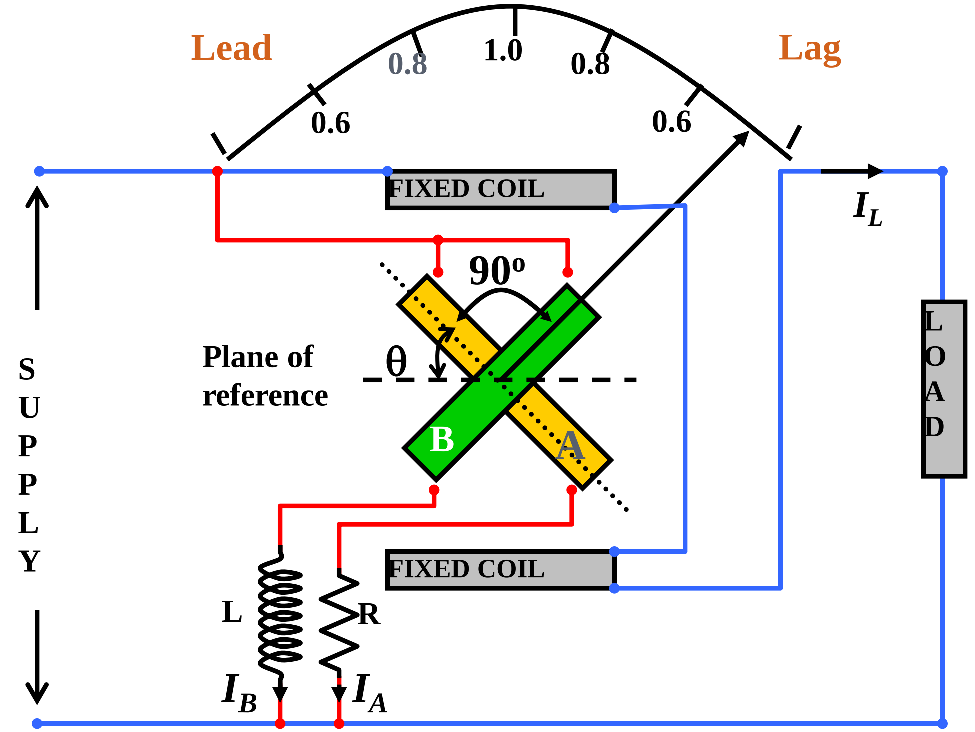


$$T_A = K*V_L*I_L*\cos\phi * \sin\theta. \quad (\text{ equal to} \Rightarrow 0)$$

$$T_B = K*V_L*I_L*\cos(90^o - \phi) * \sin(90^o+\theta).$$

$$\therefore T_B = K*V_L*I_L*\sin(\phi) * \cos(\theta).$$

FOR OTHER P.F. LYING BETWEEN 0 AND 1, THE DEFLECTION OF THE COILS WILL BE TO SOME INTERMEDIATE POSITION DEPENDING ON THE VALUE OF THE **P.F. THE DIRECTION DEPEND ON** THE NATURE OF THE POWER FACTOR : LAG OR LEAD.



$T_A = K*V_L*I_L* \cos\phi * \sin\theta.$ and $T_B = K*V_L*I_L* \cos(90^o - \phi) * \sin(90^o + \theta).$

$\therefore T_B = K*V_L*I_L* \sin(\phi) * \cos(\theta).$

in the **resting position**, the two torque forces T_A and T_B have to balance themselves.

$$K*V_L*I_L* \cos\phi * \sin\theta = K*V_L*I_L* \sin(\phi) * \cos(\theta)$$

$$\therefore \quad \phi = \theta$$

Thus, the scale is calibrated to automatically reflect the power factor.

POWER-FACTOR METERS

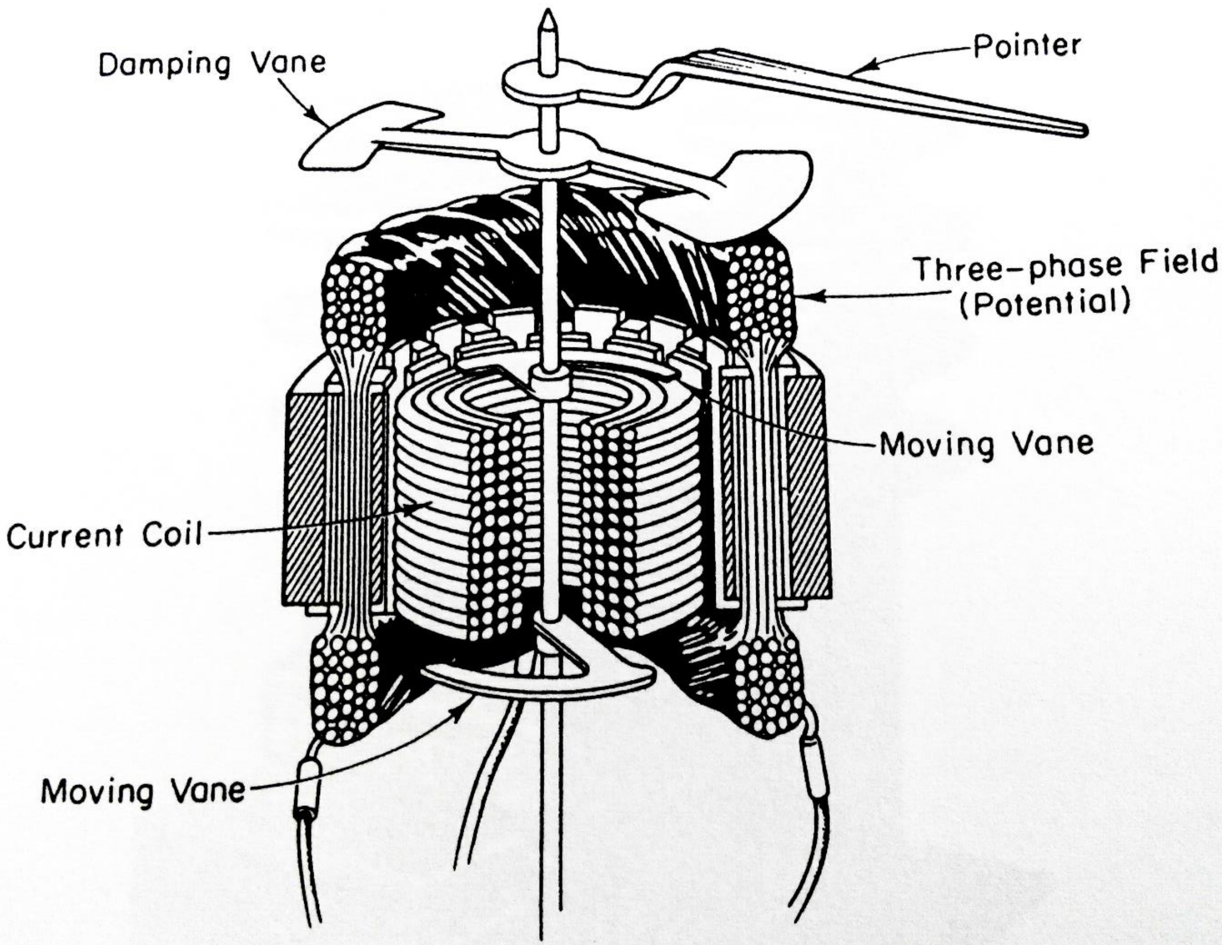


Figure 4-45 Polarized-vane power-factor meter (courtesy General Electric Company Limited).

Instrument Transformer

Function:

1. **Extend** the range ac measurement
2. **Isolate** the measuring instrument from high voltage power line.

Types

1. Current Transformer (CT)
2. Potential Transformer (PT)

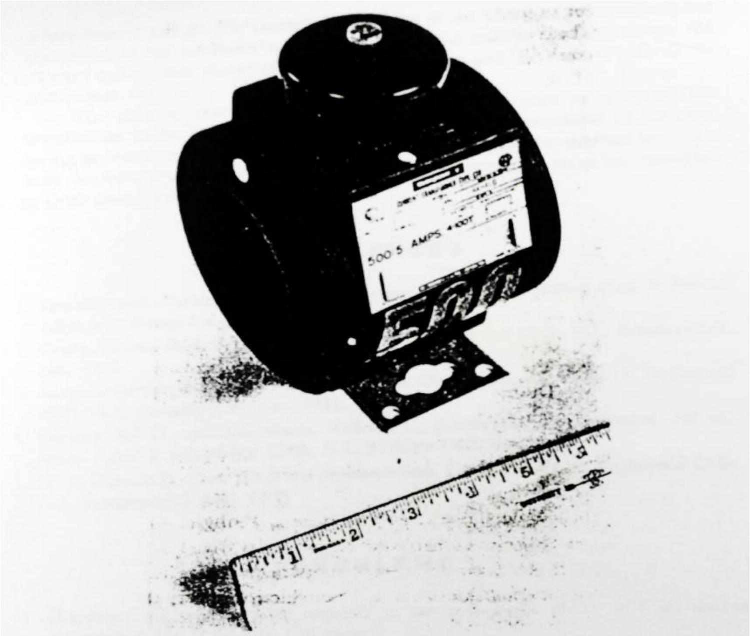


Figure 4-47 Current transformer (courtesy Westinghouse Electric Corporation).

Potential transformer

Instrument Transformer

1. Extend the range ac measurement using resistors is more suitable for DC measurement.
2. In ac measurements the circuits reactance is frequency dependent, so to get more accurate measurement over a range of freq. Transformers.
3. The range of extension depends of the transformer ratio.

The Isolation of the measuring instrument from high voltage power line is **important due to**:

- **safety hazards** and
- **insulation difficulties** of high voltage lines.

INSTRUMENT TRANSFORMER

voltmeters, and two ammeters. The potential transformers are connected across phase lines *A* and *B*, and phase lines *C* and *B*; the current transformers are in

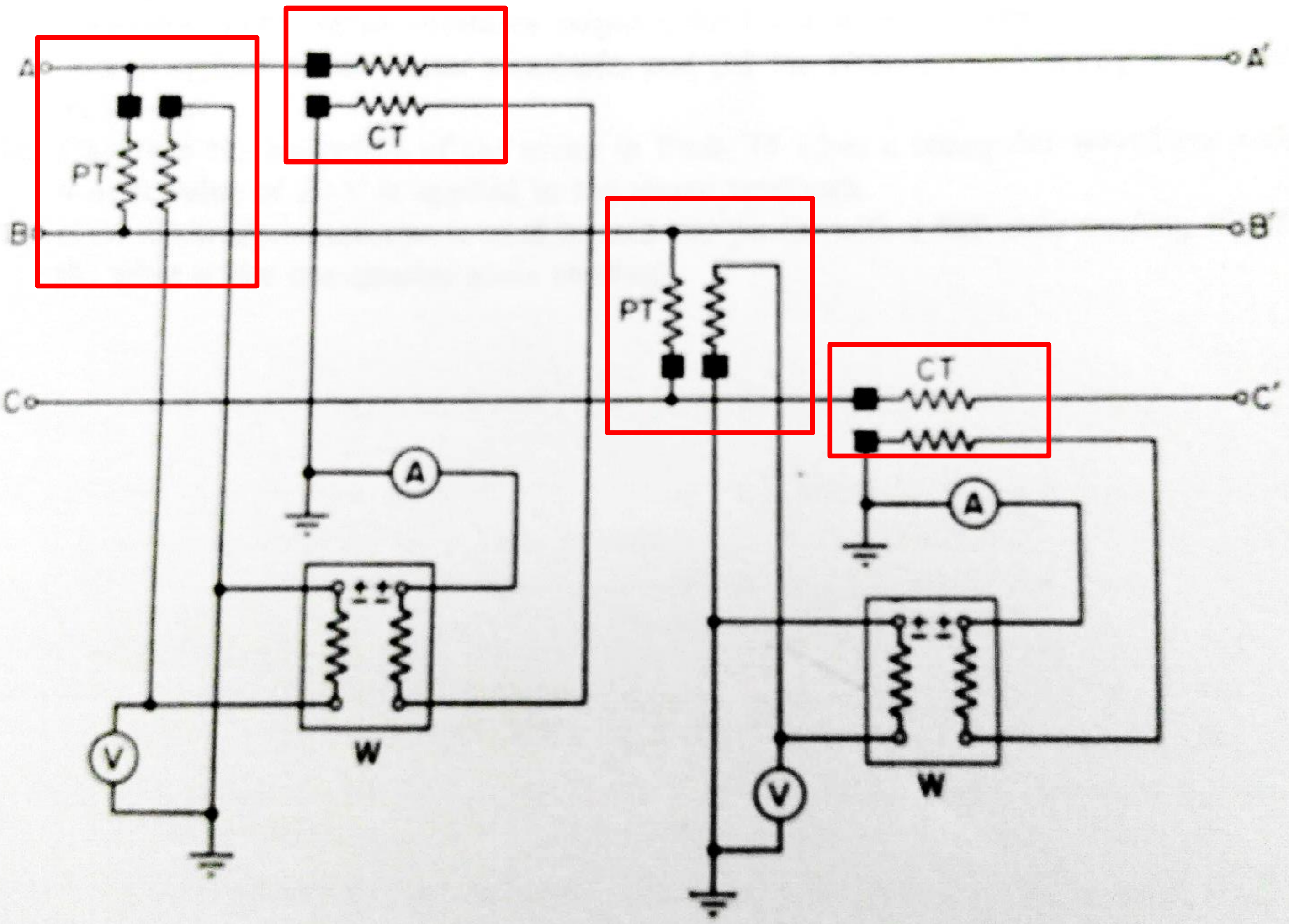


Figure 4-48 Instrument transformers in a three-phase measurement application. Polarity markings of the potential and current transformers are indicated by blac