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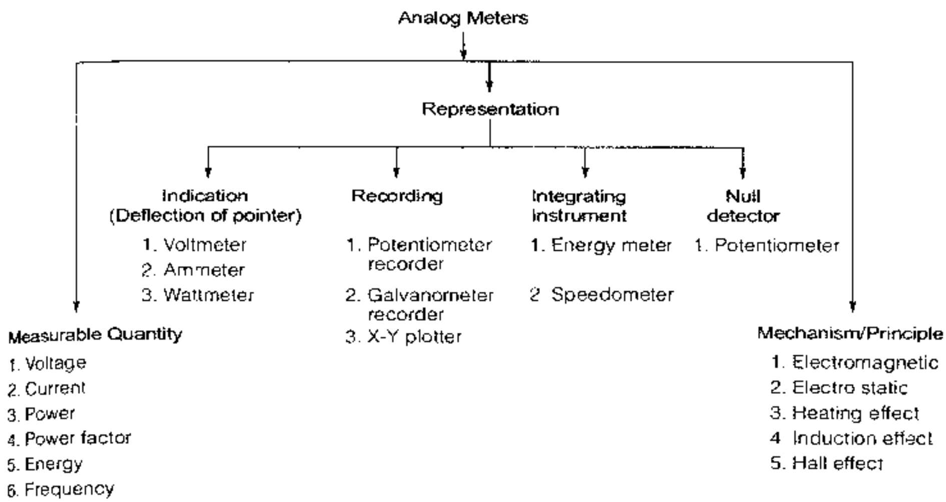
Analog Meters

Classification of Analog Meters



Torque in Analog Meter

1. Deflecting Torque (T_D)

Deflecting torque is proportional to quantity under measurement. This torque deflect the pointer away from initial or zero position.

$$\boxed{T_D \propto \text{Measurable quantity}}$$

2. Controlling Torque (T_C)

The controlling torque is opposite to deflecting torque. When, deflecting torque equals to controlling torque, pointer comes to final steady state position.

At equilibrium, $\boxed{T_C = T_D}$

Note:

- Control torque is also used to bring the pointer in zero initial position, if there is no deflecting torque.
- Except in PMMC, in all other instruments if the control spring is failed or broken then pointer moves to the maximum position of scale.
- Control torque is provided by
  (i) Spring control (ii) Gravity control

3. Damping Torque

It is used to damp out oscillation at final steady state position. The time response of the instrument depends on damping torque.

Damping torque provided by:

(i) **Air friction damping:** Used where low magnetic fields are produced

(ii) **Fluid friction damping:** Used where deflecting torque is minimum.

(iii) **Eddy current damping:** Used where permanent magnet produces the required deflecting torque.

Error in Analog Meters

1. Frictional Error

To reduce the frictional error, the torque to weight ratio of the instrument should be high.

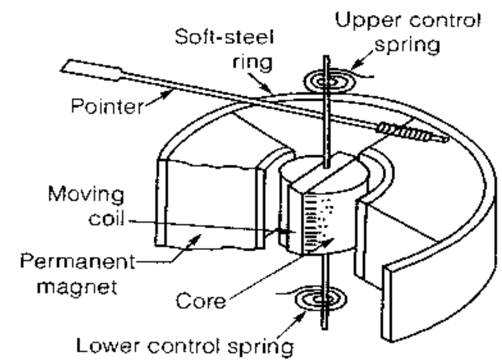
2. Temperature Error

Due to change in temperature, change in resistance of meters and shunts and series multiplier occurs. To reduce this effect, resistances are made up of manganin material.

3. Frequency Error

Due to change in frequency, error produce in instrument because change in frequency cause change in reactance. To reduce this error, a capacitance is used in case of voltmeter and for ammeter, the time constant and shunt impedances are maintained at same value.

Permanent Magnet Moving Coil (PMMC)



- Deflection torque

$$T_D = nBAI$$

$$T_D = GI$$

where, $G = nBA$

n = Number of turns

B = Flux density

A = Area of core

I = Current to be measured

- Final steady state deflection

$$\theta = \left(\frac{G}{K}\right)I$$

where, K = Spring constant

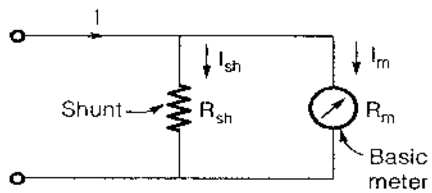
Note:

- PMMC instrument measures only DC or average values.
- Scale is linear.
- Spring is used for controlling torque.
- Damping torque provided by eddy current damping.
- It has more, torque to weight ratio so accuracy and sensitivity is higher compare to other instrument.

- In direct measurement, the PMMC measures upto a current of 50 mA or a voltage of 100 mV, without any external device.

Enhancement of Ammeters and Voltmeters

1. Ammeter Shunts



Basic ammeter circuit

$$I_{sh} R_{sh} = I_m R_m$$

$$I = \left(1 + \frac{R_m}{R_{sh}}\right) I_m$$

where, I = Current to be measured ;
$I_m = I_{fs}$ = Full scale deflection current ; A
R_m = Internal resistance of meter ; Ω
R_{sh} = Resistance of the shunt ; Ω

- Shunt resistance

$$R_{sh} = \frac{R_m}{m-1}$$

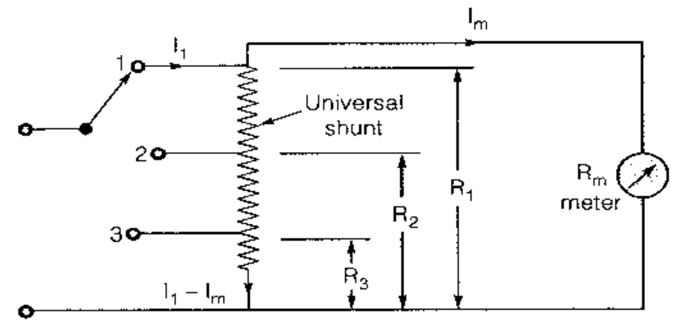
where, $m = \frac{I}{I_m} = 1 + \frac{R_m}{R_{sh}}$

m = Multiplying factor for shunt

Note:

To reduce the temperature effect, swamp resistance made up of manganin is added in series with ammeter.

2. Universal or Ayrton Shunt



(Multi-range ammeter using universal shunt)

- For switch at a position 1

$$R_1 = \frac{R_m}{(m-1)}$$

- For switch at a position 2

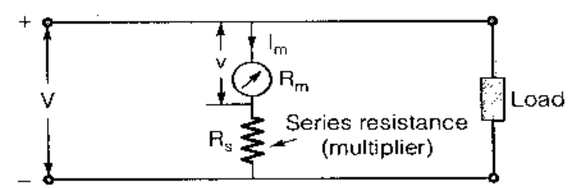
$$R_2 = \frac{(R_1 + R_m)}{m_2}$$

- For switch at a position 3

$$R_3 = \frac{(R_1 + R_m)}{m_3}$$

where, $m_1 = \frac{I_1}{I_m}$, $m_2 = \frac{I_2}{I_m}$, $m_3 = \frac{I_3}{I_m}$

3. Voltmeter Multipliers



- Multiplying factor for multiplier

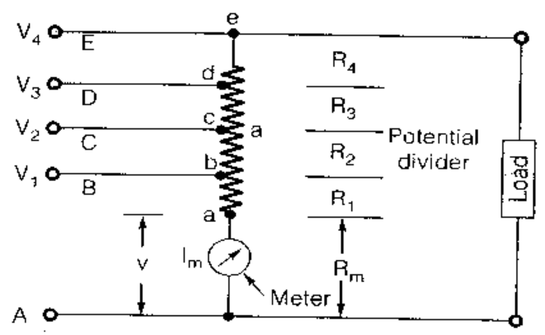
$$m = \frac{V}{v} = 1 + \frac{R_s}{R_m}$$

- Resistance of multiplier

$$R_s = (m-1)R_m$$

where, R_s = Multiplier resistance
R_m = Internal resistance of meter

4. Potential Divider Arrangement



$R_1 = (m_1 - 1)\,R_m$
$R_2 = (m_2 - m_1)\,R_m$
$R_3 = (m_3 - m_2)\,R_m$
$R_4 = (m_4 - m_3)\,R_m$

where, R_1 = Resistance between point a and b
R_2 = Resistance between point b and c
R_3 = Resistance between point c and d
R_4 = Resistance between point d and e

- Voltmeter Sensitivity (S_v)

$$S_V = \frac{1}{I_{fs}} = \frac{R_s + R_m}{V}\ \Omega/V$$

Remember:

To reduce loading effect, a voltmeter with higher value of sensitivity is preferred.

Moving Iron Instruments

- Deflecting torque

$$T_d = \frac{1}{2} I^2 \frac{dL}{d\theta}$$

- Deflection

$$\theta = \frac{1}{2}\frac{I^2}{K}\frac{dL}{d\theta}$$

- For linear scale

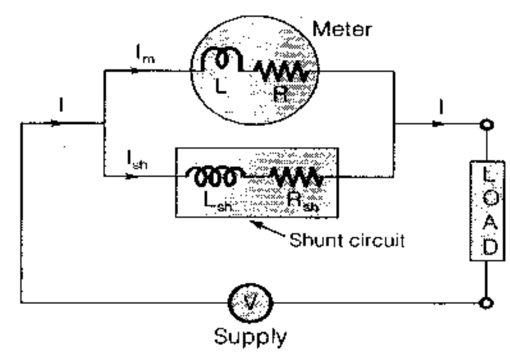
$$\theta \cdot \frac{dL}{d\theta} = \text{constant}$$

Scale is cramped at lower and higher end.

Note:

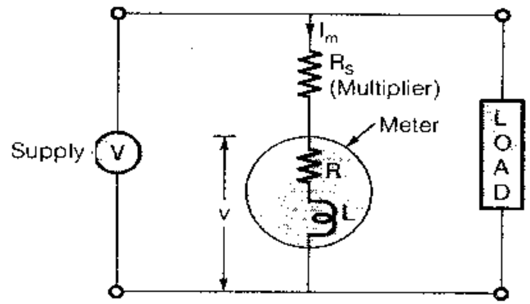
- Moving iron instrument measure both A.C. and D.C. quantities.
- In case of A.C., it measure RMS value.
- Scale is non linear.
- Controlling torque is provided by spring and air friction damping is used.
- Curve between $\frac{dL}{d\theta}$ and θ is rectangular hyperbola.

Shunts for Moving Iron Instruments



$$\frac{I_{sh}}{I_m} = \frac{R}{R_{sh}}\frac{\sqrt{1+(\omega L/R)^2}}{\sqrt{1+(\omega L_{sh}/R_{sh})^2}}$$

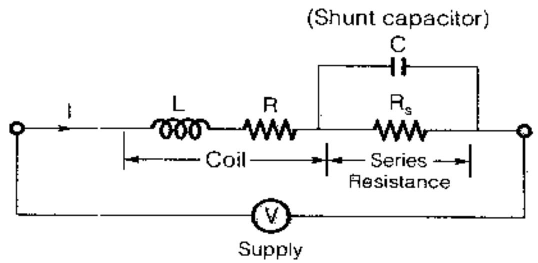
Multipliers for Moving Iron Instruments



- Voltage multiplying factor

$$m = \frac{V}{v} = \frac{\sqrt{(R+R_s)^2 + \omega^2 L^2}}{\sqrt{R^2 + \omega^2 L^2}}$$

Errors in Moving Iron Instruments



- Shunt capacitance

$$C = 0.41 \frac{L}{R_s^2}$$

- Eddy currents

When ω is small

$$I_e' = \frac{\omega^2 M L_e I}{R_e^2}$$

When ω is large

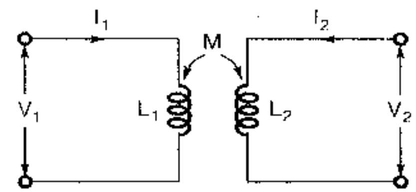
$$I_e' = \frac{MI}{L_e} = \text{constant}$$

where, R_e, L_e = resistance and inductance of eddy current path

Note:

- Moving iron instrument is not suitable for measurement of current or voltage for frequency above 125 Hz because eddy current is constant at higher frequency.
- If meter time constant is equal to shunt time constant then ammeter is made independent of input supply frequency.
- The voltmeter is made independent of input supply frequency by connecting a capacitor in parallel to the series multiplier resistance R_s.
- To reduce hysteresis error, the iron part of moving iron is made up of Nickel iron alloy.
- To reduce the external stray magnetic field, the instrument is kept inside the iron case or iron shielding is done.

Electrodynamometer



(a) If i_1 and i_2 are D.C. current i.e. $i_1 = i_2 = I$

$$T_d = I^2 \frac{dM}{d\theta}$$ (Measure average value)

(b) If i_1 and i_2 are A.C. current and no phase shift

$$i_1 = i_2 = I$$

$$T_d = I^2 \frac{dM}{d\theta}$$ (Measure RMS value)

(c) If $i_1 = I_{m_1} \sin\omega t$ and $i_2 = I_{m_2} \sin(\omega t - \phi)$

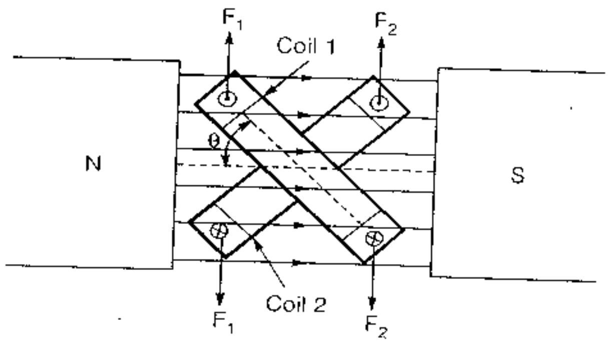
$$T_d = I_1 I_2 \cos\phi \frac{dM}{d\theta}$$ (Measure RMS value)

Where, $I_1 = \frac{I_{m_1}}{\sqrt{2}}$ and $I_2 = \frac{I_{m_2}}{\sqrt{2}}$

Note:

- Electrodynamometer instrument is a transfer instrument.
- It measures both A.C. and D.C.
- Scale is nonlinear.
- Its sensitivity is lesser than PMMC and M.I. type instruments.

Ratiometer



- Deflecting torque acting on coil 1

$$T_{d1} = N_1 B l_1 d_1 I_1 \cos\theta$$

- Deflecting torque acting on coil 2

$$T_{d2} = N_2 B l_2 d_2 I_2 \cos\theta$$

where, I_1, I_2 = current in coil 1 and 2

N_1, N_2 = number of turns in coil 1 and 2

l_1, l_2 = length of coil 1 and 2

d_1, d_2 = width of coil 1 and 2

B = flux density of magnetic field

- Deflection at equilibrium

$$\theta = k\left(\frac{I_1}{I_2}\right)$$

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