1 MEASURING INTRUMENTS

Measurement :- The process of determining the size, length, quantity, or amount of something using standard units.

→ It involves comparing an unknown quantity with a known standard.

→ It is essential in science, engineering, construction and everyday life for ensuring accuracy, consistency and understanding in various application.

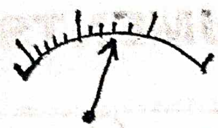
→ Here, we will measure the electrical quantity like current and voltage.

→ Two types of measuring instruments :- 1. Analog type (in our syllabus)
2. Digital type. (not in our syllabus)

Classifications of Analog measuring Instruments :-

	Absolute Instruments	Secondary Instruments
1.	→ The energy required for measurement is taken directly from the physical quantity to be measured. eg. Tangent Galvanometer (↳ not in syllabus)	→ The energy required for Measurement is taken from external supply. eg. Voltmeter, Ammeter.
2.	**Direct Instrument** → The instrument measures the value directly. eg. Voltmeter, Ammeter.	**In-direct Instrument** → The instrument measures the value indirectly by using comparison process. eg. AC bridges.

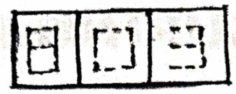
3. Indicating instruments



→ indicates the magnitude of an electrical quantity at the time when it is being measured, given by a pointer.

e.g. PMMC, M.I, E.S.V.M, Electro-dynamometer

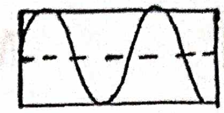
Integrating instruments



→ it measures the total amount of either quantity of electricity or electrical energy supplied over a period of time.

e.g. Energy meter.

Recording Instrument



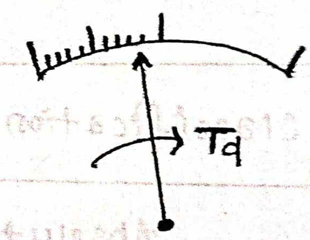
→ It continues record the variations of the magnitude of an electrical quantity to be observed over a definite period of time.

e.g. CRO, ECG, graphic recorder.

Types of ~~torques~~ and forces used :-

1. Deflecting force (F_d) ⟶ Deflecting Torque (T_d)

The deflecting system converts the electric current into mechanical force called deflecting force. The force or the torque deflects the moving pointer from its zero position. (denoted by T_d)



→ principles involved in deflecting force.

(i) Magnetic effect ⟶ PMMC, M.I, electrodynamometer.
(ii) Electrostatic effect ⟶ E.S.V.M.
(iii) Electromagnetic effect ⟶ Energy meter.
(iv) Heating effect ⟶ Thermal instruments
(v) Hall effect ⟶ pointing vector galvanometer. (not in syllabus)

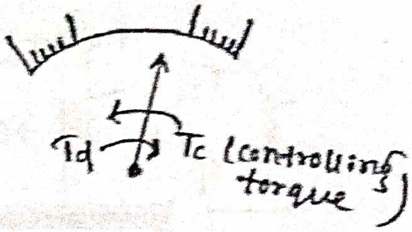
{NOTE: Discussed briefly - further sections}

2. Controlling force (F_c) ⟶ Controlling Torque (T_c)

The control system produce a force equal and opposite to the deflecting force inorder to make the deflection pointer at a definite magnitude.

→ If control system is absent, then the pointer will swing beyond its final steady position for given magnitude and deflection will become indefinite.

→ It brings the pointer to zero when deflecting force is removed.



→ Controlling system is carried out by two process :- (i) Gravity control
(ii) Spring control

Gravity control	Spring control
→ Small weight provides T_c	→ spring exerts T_c.
→ Varies	→ fixed
→ not temperature dependent	→ temperature dependent
→ Non-uniform scale.	→ uniform scale
→ $T_c \propto \sin\theta$	→ $T_c \propto \theta$
→ only vertical position.	→ at any position.
→ simple, cheap.	→ Simple, rigid, costly
→ rarely used.	→ popularly used

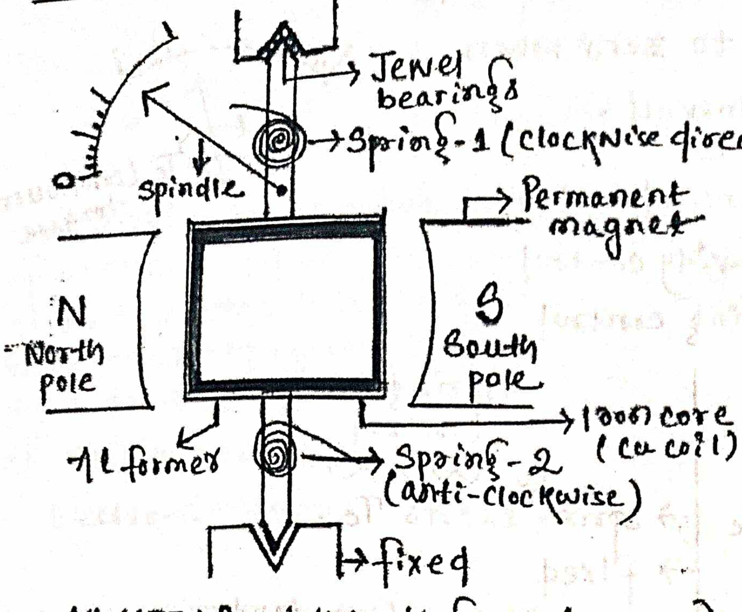
3. Damping force (F_D) ⟶ Damping Torque (T_D)

At the time when $T_c = T_d$ to make the pointer at rest, the pointer oscillates due to its inertia, about the equilibrium position. So, inorder to bring the pointer at rest totally within short time, damping system is arranged.

→ Damping system is carried out by :- (i) Air friction damping
(ii) Eddy current damping
(iii) fluid friction damping

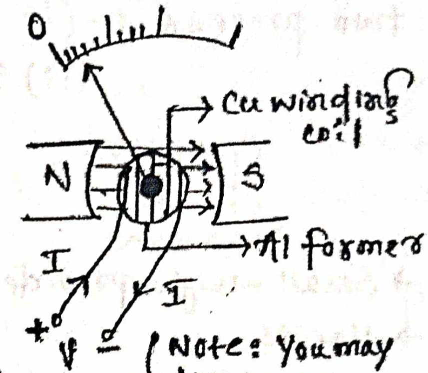
Air friction	fluid friction	Eddy current damping
→ simple cheap. → It uses either Al-piston or vane, which is attached / mounted on moving system & moves in an air chamber at one end. eg. M.I	→ use in instruments which are suspended rather than pivoted. → used in electrostatic instruments. eg. ESVM.	→ It is the most efficient method of damping. eg. PMMC.

Permanent Magnet Moving Coil (PMMC)



(#NOTE : Draw this diagram in exam)

(TOP-VIEW)



(dc supply to moving coil)

(Note: You may draw in exam, for better understanding purpose only)

Construction :-

(i) Moving coil →
- → rectangular or circular in shape.
- → Coil is suspended so that it is free to turn about in vertical axis.
- → carries current proportional to the quantity to be measured.
- → wounded over Al former.
- → made of up cupper winding.

(ii) Iron Core :- → It is spherical if coil is circular & cylindrical if coil is rectangular.

→ Iron core serve :- (I) It intensifies the magnetic field.
(II) It makes the field radial & uniform.
(III) A soft iron core is used to complete the flux passing.

(iii) Suspension :- → Jewel bearings are used to reduce frictional error.

(iv) Damping :- → eddy current damping is used.
→ damping torque is produced by movement of Al former in the magnetic field of permanent magnet.

(v) Controlling Torque :- → Controlling torque is provided by the phosphor bronz hair springs.
→ Both spring 1 & 2 are wounded in opposite direction so that one experiences tension then at the same time other should experience compression.

Principle of operation of PMMC :-

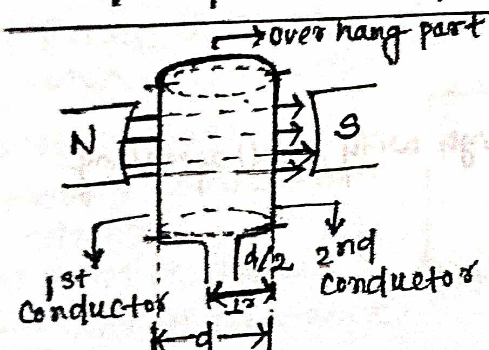
(i) When the dc supply is given to the moving coil, DC current flows through it.

(ii) When the current carrying coil is kept in the magnetic field, it experiences a force. This force produce a torque and the Al former rotates. (deflecting torque produced).

(iii) As, the spindle is attached with the moving coil so the spindle also rotates and the pointer of spindle will indicates the measured value in the calibrated scale.

NOTE :- When the polarity is reversed (AC supply provided at moving coil instead of DC), a torque is produced in the opposite direction. The mechanical stopper does not allow the deflection. Therefore, PMMC can only measure dC value not AC.

Torque developed by PMMC :-



1 turn of Cu winding = 2 conductor

1 coil has N turns.

1 coil = N turns

So, 1 coil = 2N conductor

(1 coil has 2N conductors).

(1st & 2nd conductor cuts the magnetic field at 90°

$\theta = 90^\circ$

So, force experienced by the current carrying conductor (Lorentz force)

$$F_d = BIL\sin\theta$$

$$\boxed{F_d = BIL} \quad (\sin 90^\circ = 1,\ \theta = 90^\circ)$$

→ experienced by 1 conductor.

$$\boxed{F_d = 2NBIL}$$ → experienced by coil.

T_d (torque) = F_d (force) × ⊥r distance (perpendicular distance)

$$T_d = \cancel{2}NBIL \times \frac{d}{\cancel{2}} \Rightarrow T_d = NBI(L\times d) \quad (A = L\times d \text{ area})$$

$$\Rightarrow \boxed{T_d = BINA} \text{ N·m (Torque eq}^n)$$

$T_d \propto I$ (deflection is directly proportional to flowing current).

As spring control is used $T_c = K\theta$ ($K \rightarrow$ spring constant, $\theta \rightarrow$ angle of deflection).

At final steady state;

$$T_d = T_c$$

$$\Rightarrow BINA = K\theta$$

$$\Rightarrow \boxed{\theta = \frac{BINA}{K}}$$

$$\Rightarrow \theta = \left(\frac{G}{K}\right) I \quad \text{where } G = NBA$$

Disadvantage of PMMC :-

→ Uniform scale reading only.
→ only for dc measurement
→ cost is high due to construction
→ Error can be produced due to Permanent magnet & spring.
→ friction & temperature error present.

Advantage of PMMC :-

→ Uniform scale.
→ with a powerful magnet, torque is high with small operating current.
→ Damping is effective.
→ power consumption is less.
→ Range can be extended.
→ High accuracy, high sensitivity.

Sensitivity = $\frac{\text{change in output}}{\text{change in input}}$

$$S = \frac{\Delta\, o/p}{\Delta\, i/p}$$

We know at steady state $\underset{(i/p)}{BINA} = \underset{(o/p)}{K\theta}$

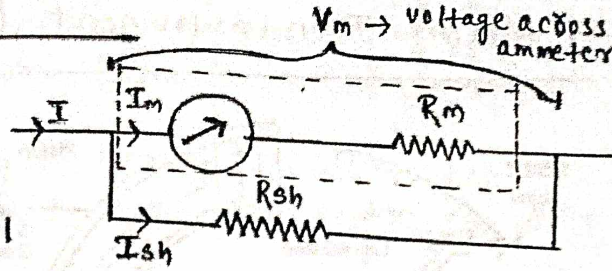
deflection (o/p)

$$\Rightarrow \boxed{\frac{\theta}{I} = \frac{BNA}{K}} = \text{sensitivity}.$$

Current (I/P)

Extension Range of PMMC :-

1° **PMMC Ammeter** $\rightarrow$



$R_m \rightarrow$ internal resistance of coil

$R_{sh} \rightarrow$ Shunt resistance

$I_m \rightarrow$ meter current

$I_{sh} \rightarrow$ Shunt current

$I \rightarrow$ total current

m = multiplying factor $= \dfrac{I}{I_m}$

$$I = I_m + I_{sh} \text{ (KCL)}$$

$$V_m = V_{sh}$$

$$\Rightarrow I_m R_m = I_{sh} \cdot R_{sh}$$

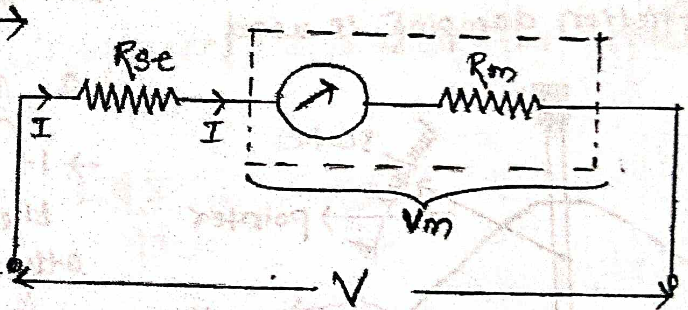
$$\Rightarrow R_{sh} = \frac{I_m}{I_{sh}} \cdot R_m$$

$$\Rightarrow R_{sh} = \left(\frac{I_m}{I - I_m}\right) R_m = \frac{\cancel{I_m}\, R_m}{\cancel{I_m}\left(\frac{I}{I_m} - 1\right)} = \frac{R_m}{m-1} \quad \left(m = \frac{I}{I_m}\right)$$

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

$\rightarrow$ So to increase the range of Ammeter 'm' times, the shunt resistance required is $\left(\frac{1}{m-1}\right)$ times the internal ammeter resistance.

2° **PMMC Voltmeter** $\rightarrow$



$V \rightarrow$ total voltage

$V_m \rightarrow$ voltage across ~~ammeter~~ voltmeter

$R_{se} \rightarrow$ series resistance

$R_M \rightarrow$ internal resistance.

m = multiplying factor

$$m = \frac{V}{V_m}$$

$$V = I(R_{se} + R_m)$$

$$V_m = I_m R_m$$

$$\Rightarrow \frac{V}{V_m} = \frac{\cancel{I}(R_{se} + R_m)}{\cancel{I_m} R_m} \quad (I = I_m)$$

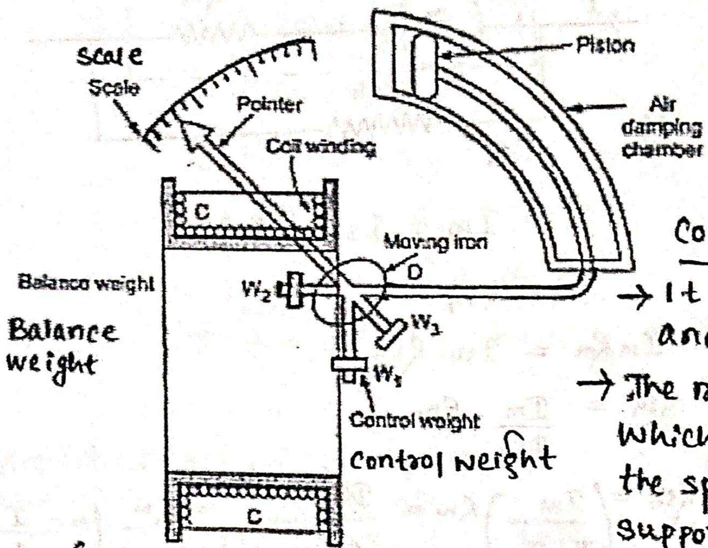
$$\Rightarrow m = \frac{R_{se}}{R_m} + 1$$

$$\Rightarrow \boxed{R_{se} = R_m(m-1)}$$

$\rightarrow$ So, to increase the range of voltmeter 'm' times, the series resistance required is $(m-1)$ times the internal resistance.

Moving Iron Instrument (M·I)

→ M·I Attraction type
→ M·I repulsion type.



(∵ Attraction TYPE M·I)

1. MI Attraction type

Construction :-

→ It consists of a fixed coil 'C' and moving iron piece 'D'.

→ The moving iron is a flat disc which is eccentrically mounted on the spindle. The spindle is supported between the jewel bearings.

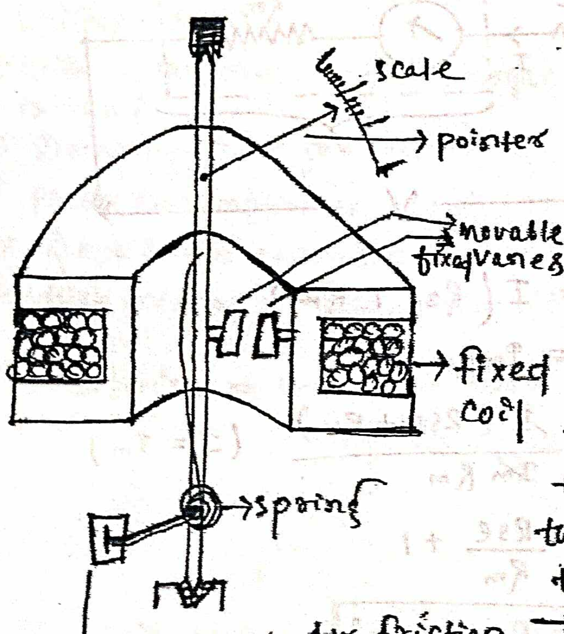
→ The spindle carries a pointer which moves over the scale.

→ The number of turns of the fixed coil are dependent on the range of instrument.

→ Gravity control is used for controlling torque.

→ Air friction damping is used.

2. Repulsion Type M·I



(∵ Repulsion Type M·I)

→ It has two vanes inside the coil, one is fixed & other is movable.

→ When the current flows in the coil, both the vanes are magnetised with like polarities induced on the same side.

→ Due to repulsion type polarities, there is force of repulsion between two vanes, causing the movement of the moving vane.

→ Spring control & air friction damping is used.

→ The needle of the instrument is attached to this movable vane.

→ Even though the current through the coil is alternating, there is always repulsion between like poles of fixed & movable vane. Hence deflection of pointer is always on same direction.

→ The deflection is effectively proportional to the actual current and hence this scale is calibrated directly to read amperes and volts.

Working principle of MI Attraction type :–

→ The current to be measured is passed through the fixed coil. It produces a magnetic field. A soft iron piece is brought near the magnet, gets attracted by the field. The force of attraction depends on the current flowing through the coil.

• Torque equation for M.I Instruments :–

→ Let there be a small current in coil carrying current of dI. There will be a deflection of $d\theta$ due to that dI current.

→ There will be a mechanical energy also used for deflection of needle ⇒ $T_d \times d\theta$

(E) Emf $= \frac{d}{dt}(LI) = L\frac{dI}{dt} + I\frac{dL}{dt}$

$\Rightarrow E\,dt = L\,dI + I\,dL$

multiplying 'I' both side ;

$\Rightarrow EI\,dt = LI\,dI + I^2 dL$ (Energy supplied)

Initial energy $= \frac{1}{2}LI^2$

Final energy $= \frac{1}{2}(L+dL)(I+dI)^2$

ΔE = change in stored energy = final energy − initial energy.

$= \frac{1}{2}(L+dL)(I+dI)^2 - \frac{1}{2}LI^2$

$= \frac{1}{2}(L+dL)[I^2 + \cancel{(dI)^2}^{\approx 0} + 2I\,dI] - \frac{1}{2}LI^2$ (expand it)

$= LI\,dI + \frac{1}{2}I^2 dL$

Energy supplied = change in energy of coil + Mechanical energy used for deflection.

$$L I \cancel{dI} + I^2 dL = \cancel{d} L I \cancel{dI} + \frac{1}{2} I^2 dL + (T_d \times d\theta)$$

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

$$\Rightarrow \boxed{T_d = \frac{1}{2} I^2 \frac{dL}{d\theta}} \quad T_d \propto I^2$$

At equilibrium steady state ;

$$T_d = T_c$$

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

$$\Rightarrow \boxed{\theta = \frac{1}{2} \frac{I^2}{K} \cdot \frac{dL}{d\theta}} \Rightarrow \theta \propto I^2$$

1. Advantage of M.I →

→ used for both AC & D.C

→ Can handle overload condition.

→ Cover wide range.

→ range can be extended.

2. Disadvantage of M.I →

→ non uniform scale.

→ eddy current damping is not used. So, it is less accurate, less sensitive compared to PMMC.

→ Affected by stray magnetic field, error causes due to hysteresis, frequency changes.

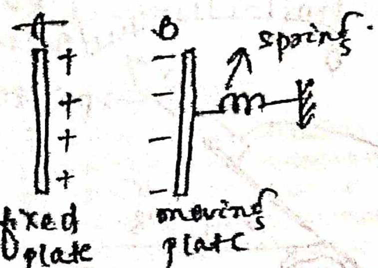
Electrostatic Instruments :-

→ basically electrostatic instruments are all voltmeters.
→ measures high voltage on both AC & DC.

Principle of operation :-

→ It is based on the principle that there exists a force between the two plates with opposite charges.

→ This force can be obtained using the principle that the mechanical workdone is equal to stored energy if there is a relative motion of plates.



$$E = \frac{1}{2} C V^2$$

E → energy, C → capacitance, V → voltage.

$$i = \frac{dq}{dt} = \frac{d}{dt}(CV)$$

$$\Rightarrow i\cancel{dt} = C\frac{dV}{dt} + V\frac{dC}{dt} \quad \text{(Multiply V)}$$

$$\Rightarrow Vi\cancel{dt} = CV\frac{dV}{dt} + V^2\frac{dC}{dt}$$

Energy supplied $\Rightarrow \boxed{V^2 dt = CVdV + V^2 dC}$ —①

As due to change in applied voltage by 'dV', capacitance increases by dC.

New stored energy $= E' - E$

$$= \frac{1}{2}(C+dC)(V+dV)^2 - \frac{1}{2}CV^2$$

$$= CVdV + \frac{1}{2}V^2 dC \quad \left(\text{by expanding the above one}\right) \text{—②}$$

so, by equating ① & ② + F.dx ;

$$CVdV + V^2 dC = \frac{1}{2}V^2 dC + CVdV + \underbrace{F.dx}_{\text{force mechanical}}$$

$$\Rightarrow \boxed{F = \frac{1}{2}V^2\frac{dC}{dx}} \rightarrow \text{for linear displacement}$$

for angular displacement

$$\boxed{T_d = \frac{1}{2}V^2\frac{dC}{d\theta}}$$

At steady state,

$$T_d = T_c$$

$$\Rightarrow \frac{1}{2}V^2\frac{dC}{d\theta} = K\theta \Rightarrow \boxed{\theta = \frac{1}{2}\frac{V^2}{K}\frac{dC}{d\theta}}$$

Types of electrostatic voltmeter :-

1. Qudrant type voltmeter → used to measure upto 10 KV to 20 KV.

2. Attracted disc type → above 20 KV.

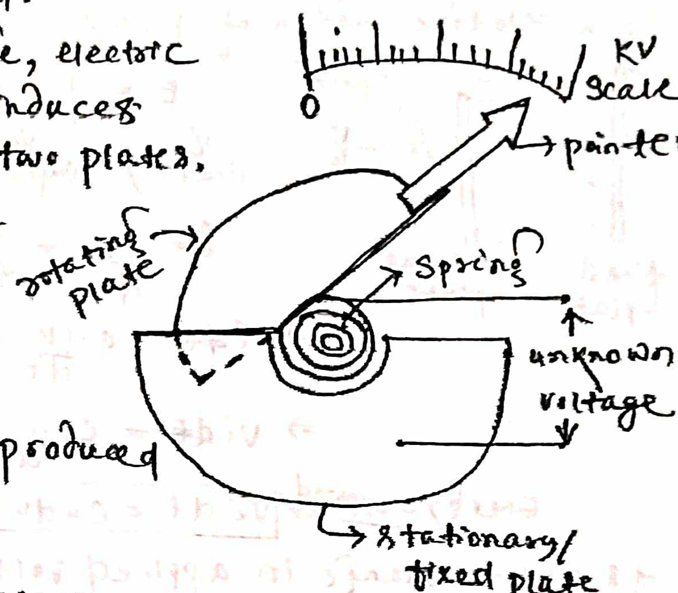
Attracted disc type :-

→ Two disc shaped plates present, one plate can move freely while other is fixed.

→ Due to supply voltage, electric field developed which induces force of attraction b/w two plates.

→ Due to which moveable plate start moving, as a result pointer points the result in scale.

→ Controlling torque is produced by spring.



Adv :- → give correct measurement in both Ac & Dc.

→ useful in high volt measurement

→ no iron part used so free from error due to eddy current & hysteresis.

→ Power loss is very small.

→ no frequency error.

→ no straymagnetic error.

Dis adv. :- → large in size, bulky

→ expensive.

→ Scale is not uniform.

→ not suitable for Low measurement.

PYQ'S ASKED IN MID & END SEMESTER ...

MODULE I

2 MARKERS

1) A moving coil milli-ammeter having a resistance of 10ohm gives full deflection when a current of 5mA is passes through it, Explain how the instrument can be used for measured of current upto 1 A and a voltage upto 5V .
2) The resistance of a moving voltmeter is 11 k ohm, the moving coil has 100 turns & is 40mm long & 30mm wide. The flux density in the air gap 0.05 Wb/m^2 . Determine the deflection produced by 220V if the spring controls gives a deflection of 1 degree for a torque of $20x10^{-7}$ Nm.
3) A (0-25) amp ammeter has a guaranteed accuracy of 1% of full reading. The current measured by this instrument is 10 A . Determine the limiting error in%?

4MARKERS

1) Explain the construction and operation of repulsion type moving iron instrument. Also mention the advantages and disadvantages of this instrument.
2) Explain the construction and operation of PMMC instrument. Also mention the advantages and disadvantages of this instrument.
3) ~~Explain different types of errors ? Explain how to eliminate error in instrument.~~
4) Explain the construction and operation of attraction type moving iron instrument. Also mention the advantages and disadvantages of this instrument.

NUMERICALS (teacher special)

1) A moving-coil voltmeter has a resistance of 200 W, and the full-scale deflection is reached when a potential difference of 100 mV is applied across the terminals. The moving coil has effective dimensions of 30 mm × 25 mm and is wound with 100 turns. The flux density in the gap is 0.2 Wb/m2. Determine the control constant of the spring if the final deflection is 100° and a suitable diameter of copper wire for the coil winding if 20% of the total instrument resistance is due to the coil winding. The resistivity of copper is 1.7 × 10-8 Ωm.
2) ~~A moving-coil instrument has the following data: number of turns = 100, width of coil = 20~~ mm, depth of coil = 30 mm, flux density in the gap = 0.1 Wb/m2. Calculate the deflecting torque when carrying a current of 10 mA. Also, calculate the deflection if the control spring constant is 2 × 10^{-6} N-m/degree.
3) A PMMC instrument has a coil of dimensions 15 mm × 12 mm. The flux density in the air gap is 1.8 × 10^{-3} wb/m^2, and the spring constant is 0.14 × 10-6 N-m/rad. Determine the number of turns required to produce an angular deflection of 90° when a current of 5 mA is flowing through the coil.
4) Distinguish between gross error, systematic error, and random error with examples. What are the methods for their elimination/reduction?
5) A moving coil instrument has a resistance of 5 Ω and gives a full-scale deflection of 10 mv. Show how the instrument may be used to measure (a) voltage up to 50 v, and (b) current up to 10 A.
6) The inductance of a moving-iron ammeter with a full-scale deflection of 90° at 1.5 A is given by L = (200 +400 - 402-θ^2) μH where θ is the deflection in radian from the zero position. Estimate the angular deflection of the pointer for a current of 1 A.

*For hints & solutions refer to the notes or for detail solution contact your mentor. (your mentor will be assigned you soon)