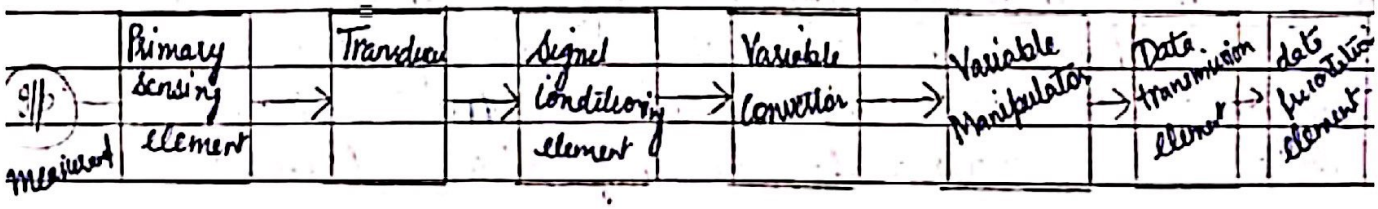
Ch 6: Basic Instruments

Imp 2 marks

The instruments which are used to measure the electrical quantities like current, voltage, power and energy etc are known as Electrical measuring Instrument.

Current → Ammeter
Voltage → Voltmeter
frequency → frequency meter
Energy → Energy meter or Watt hour meter
power → Watt meter
R, I, V → Multimeter

Block diagram of possible arrangment of function element in a generalized instrument.



1. Measurand. The I/p quantity to be measured.

2. Primary sensing Element: It make contact with physical quantity under measurement. It produces an output which depend in some way on measurand. Eg. emf output of thermocouple depends upon the temp of the I/p.

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3. Transducer It convert non electrical signal output from primary sensing element to electrical output signal.

4. Signal Conditioning: It is done to remove source error. It may be linear (addition, subtraction, differentiation, integration, amplification etc) or non linear (filtering, chopping, sampling etc).

5. Variable conversion element The electrical signal from the output of signal conditioner may not be suitable to the system / instrument to perform the desired operation. So it may be necessary to convert the above electrical o/p to some more suitable form while retaining the information content of the original signal.

Eg: when the o/p is in analog form the next stage in digital instrument may need a digital form of its signal. For this purpose analog to digital converter (ADC) required.

5. Variable manipulation element: Manipulates the signal presented to it's input preserving the nature of original signal. eg An electronic amplifier acts as a variable manipulation element.

7. Data transmission element: Used to transmit data from one place to another. eg. Signal from satellite to ground equipment element by radio.

3. Data presentation element The information regarding

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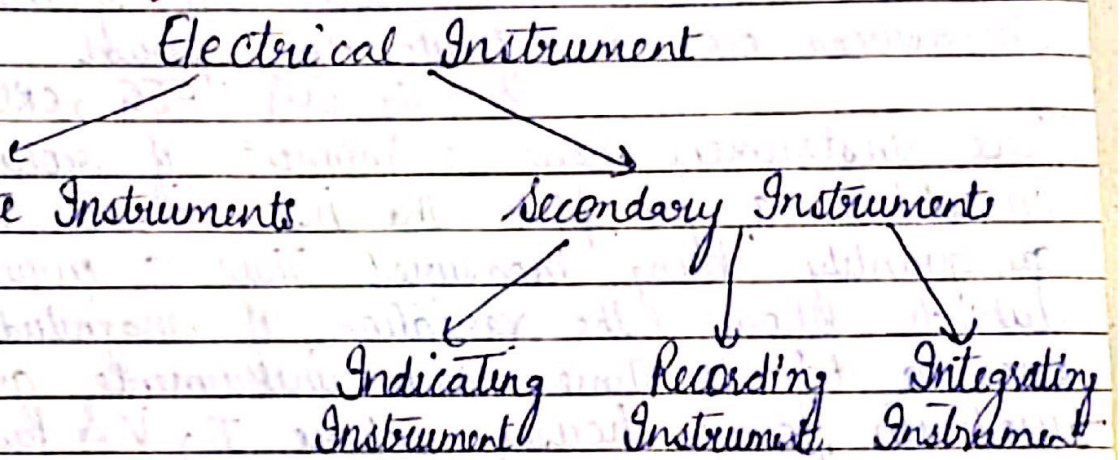
measurand is to be conveyed to system for monitering, controlling or purpose of analysis. This may be in analog or digital format. Such device are read out or displayed eg To record data recorder like magnetic tape, CDs may be used.

Classification of Instruments 2/4 marks.



1. Absolute Instruments : Give the value of quantity to be measured in terms of constants of instrument and its deflection. Such instrument do not require any comparison with any other standard instrument eg tangent galvanometer.

2. Secondary Instrument : determine the electrical quantity to be measured directly in terms of needle deflection.
These instrument are required to be calibrated by comparison with either an absolute instrument or with secondary Instrument which has already been calibrated before putting into use.

These instruments are used practically in life.

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a) Indicating Instruments. which indicate the magnitude of quantity being measured at an instant. A pointer moves across the scale to indicate the magnitude of electrical quantity to be measured.

eg Ammeter, Voltmeter, wattmeter.

b) Recording Instruments give a continuous record of the variations of the electrical quantity being measured over a definite time period.

eg ECG, EEG, CRO

These instrument have a moment of rolling paper on which a pen plots the instantaneous value of the qu quantity being measured. Thus a curve is traced which shows the variation of magnitude of measurand over a definite time. Such instruments are generally used in power houses where I, V & Power etc are maintained with in specified values. eg XY plotter

c) Integrating Instruments which add up the electrical quatity like electrical energy and measure the total electrical energy in Kwh in given period. There are sets of dials or gears in the instrum They register the total quantity of electricity or total amount of electrical energy supplied to a circuit in a given period. eg. Energy meter. (which measure total quantity of electricity for given time interval)

* According to type of current. M.I may be classified as. dc, Ac, Ac/Dc.

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DC Instrument The instrument, whose deflections are proportional to the current or voltage under measurement are used for dc measurement only. eg PMMC

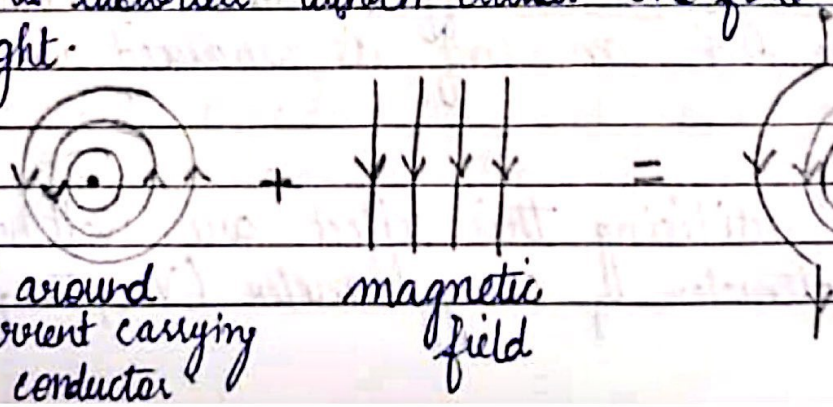
AC Instrument The instrument utilising the electromagnetic induced current for their operation are used for ac measurement only eg Induction type.

DC/AC Instrument The instruments having deflection proportional to the square of current or V under measurement can be used for dc as well as ac measurement. eg Moving iron type.

Principle of operation of electrical measuring Instrument

The principle of operating instrument depend on various effect of electric current or voltage. The effects utilized in manufacturing of electrical instruments are. 1. Magnetic effect 2. thermal effect 3. Electrostatic 4. Electromagnetic induction

1. Magnetic effect : When a conductor carries a current it produces M.field in anti clockwise direction when this conductor is placed in uniform magnetic field, the field is distorted which causes the force to act from left to right.



The reversal of either current or magnetic field will produce a force, f in opposite direction

When 2 pieces of iron are placed near the coil the 2 will be similarly magnetized. There will be force of repulsion b/w them.

The instruments utilising this effect are ammeter, voltmeter, wattmeter, integrating meter. (Vac, Vdc, Iac, Idc)

2. Thermal Effect. The current to be measured is passed through a small element. The heating effect of the current heats the element. This temp rise is converted to emf (with the help of a thermocouple attached to the instrument) & emf is measured.

The instrument utilising this effect is Voltmeter (Vac, Vdc) and current (Iac, Idc).

3. Electrostatic :- Induction effect When two plates are charged there is a force exerted b/w them. This force is used to move one of the plates.

The instruments utilising this effect is Voltmeter (Vdc, Vac)

4. Electromagnetic Induction effect When a conductor is placed in M.f an emf is induced in the conductor.

The instrument utilising this effect are Voltmeter, ammeter, wattmeter & energy meter (Vac, Iac, Pac).

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Moving Iron Instrument

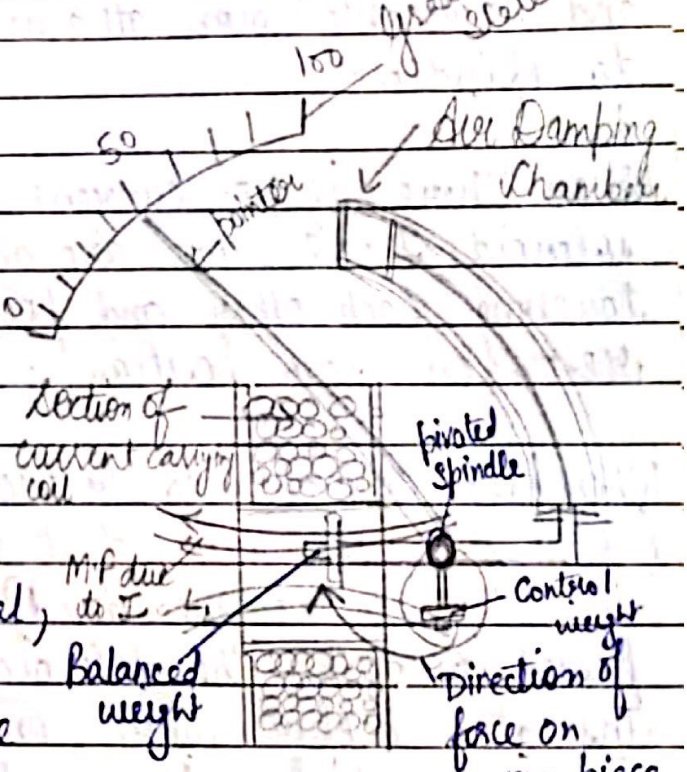
Moving Iron Instrument are widely used in laboratories at commercial frequency because they are cheaper in cost, robust in construction and can be manufactured with required accuracy. There are 2 types of such instruments

- Attraction Type
- Repulsion type

1. Attraction type Moving Iron Instrument

Attraction type M.I instrument uses a solenoid and moving oval shaped soft iron pivoted eccentrically as shown in fig.

A pointer is attached to this iron. It deflects along with the moving iron on a graduated scale. The movable iron is made of sheet metal, which is specially shaped to give approximately uniform scale as far as possible.



Attraction Type Moving Iron Inst.

When the current flows through moving iron, it is drawn into the field of solenoid. i.e from weaker m.f outside the coil into stronger m.f inside the coil regardless the direction of flow of current.

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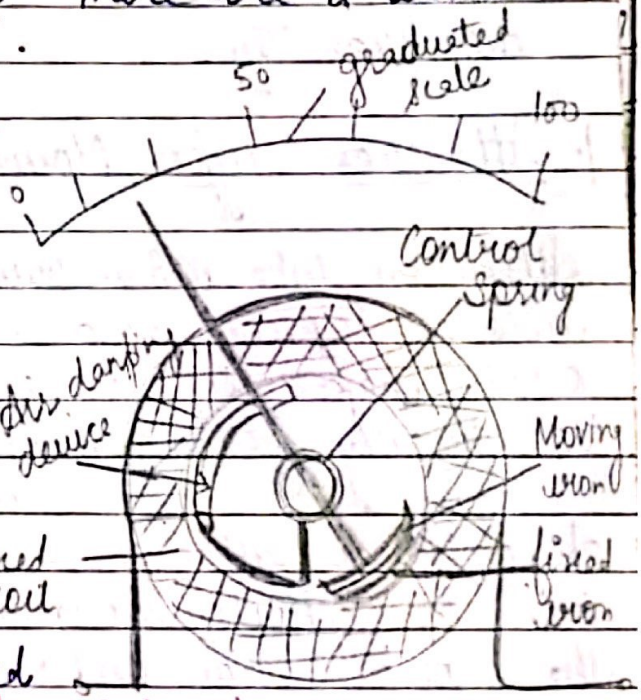
When the current to be measured (or definite fraction of the current to be measured or proportional to voltage to be measured) is passed through solenoid a m.f is set up in a solenoid which in turn magnetises the iron. Thus the iron is attracted into coil causing spindle and hence pointer to rotate.

2. Repulsion Type MI Instruments There are 2 iron. One fixed and one moveable.



Fixed iron is fixed to frame and moveable iron attached to spindle.

When there is no current in solenoid the 2 irons are almost touching each other and pointer rest on zero position.

When the current to be measured (or a definite fraction of it or prop. to voltage to be measured) is passed through the solenoid, which is wound with insulated copper wire on a cylinder non magnetic former (a few turns of thick wire for ammeter + large no. of turns of fine wire for voltmeter) a magnetic field is set up inside the solenoid & 2 irons are magnetized in the same direction which sets up a repulsive force so moving iron is repelled by fixed iron thereby resulting in motion of moving iron. Pointer comes to rest when equilibrium is attached b/w repulsion force and controlling force.

Repulsion Type MI Inst.

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

$dE = \frac{1}{2} I^2 dL$

$dw = T_d \, d\theta$

$dw = dE$

I = instrument current.

L = self inductance corresponding to a total angular deflection of θ

$\frac{dL}{d\theta}$ = rate of change of inductance with deflection.

Ranges Ammeter 20mA to 750A max without C.T
Voltmeter 0.1V to 750V max without P.T

Error in Moving Iron Instrument 1. friction 2. Temperature 3. Stray Magnetic field 4. frequency 5. hysteresis

Uses Generally used to measure alternating current.

MI as an ammeter

Since the coil is fixed, MI instrument can be designed to measure any desired value of full scale current within limits. Its limited by current carrying capacity of the coil. The ammeter is required to measure the current in a circuit ∴ its connected in series with the component carrying the current. This current flowing through the coil produces the desired deflecting torque. It should have a low resistance.

MI Voltmeter

It is always connected in parallel. Current flowing through the operating coil of meter produces deflecting torque. It should have low high resistance ∴ Res. of the order of Kilo Ω is connected in series with the coil of the instrument

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Merits and Demerits of MI Instrument circuits:

Merits: 1) Used in both ac & dc: As T∝ depends on square of I.
2) low cost (Simplicity of construction)
3) These instrument possess high operating torque
4) These instrument can withstand over load momentarily.

Demerits 1. Scales of these instrument are not uniform
2. Power consumption is higher for low voltage range.
3. The error caused due to hysteresis in the iron of operating s/s and due to stray magnetic field.

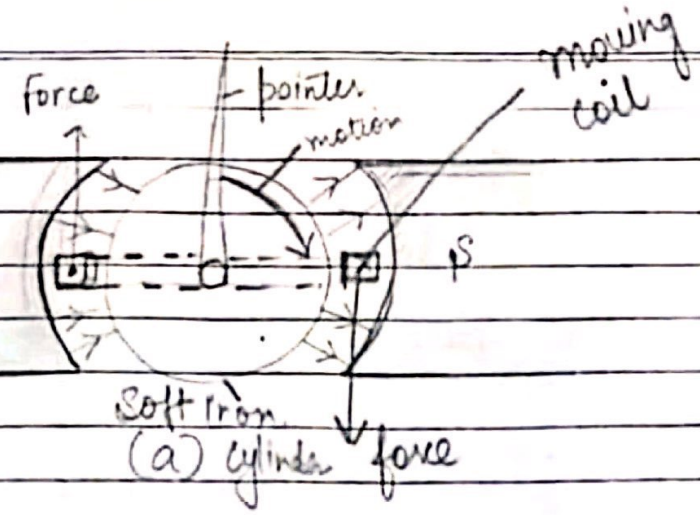
Moving Coil Instrument

Two types

- Permanent magnet Type
- Dynamometer Type

1. PMMC is most accurate and useful for dc measurements.
2. Dynamometer * can be used both on dc as well ac
   * The calibration is same for both dc as well as ac. * Useful as transfer instrument

Permanent Magnetic Moving coil Instrument



(b) and (c) fig on next page.

It consists of permanent magnetic with soft iron pole pieces. A cylindrical iron core is mounted b/w 2 poles of magnetic giving very narrow air gap in which the sides of pivoted light rectangular coil lies.

The rectangular coil is wound of many turns from fine wires on light aluminium or copper former frame and acts as a moving element.

The purpose of iron core is to make field uniform and to reduce the reluctance of the magnetic circuit as low reluctance helps to retain permanence of magnet for a longer period.

The current is led in and out of the coil by means of phosphor bronze hair spring provide at both ends. Springs provide controlling torque.

Torque Equation (PMMC)

When the current to be measured (or a definite fraction of it or proportional to voltage to be measured) is passed through the coil → a deflecting torque is produced (on account of reaction of permanent M.F

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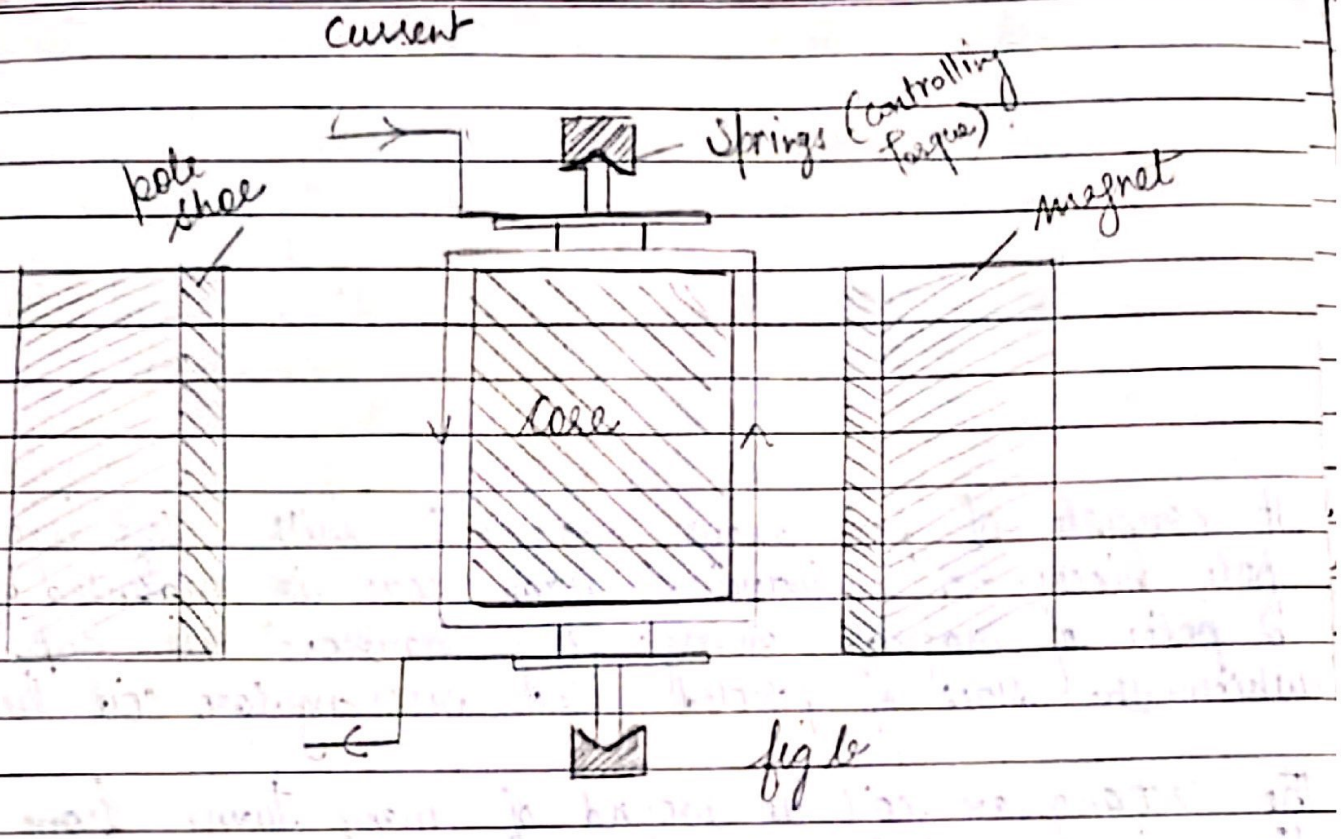
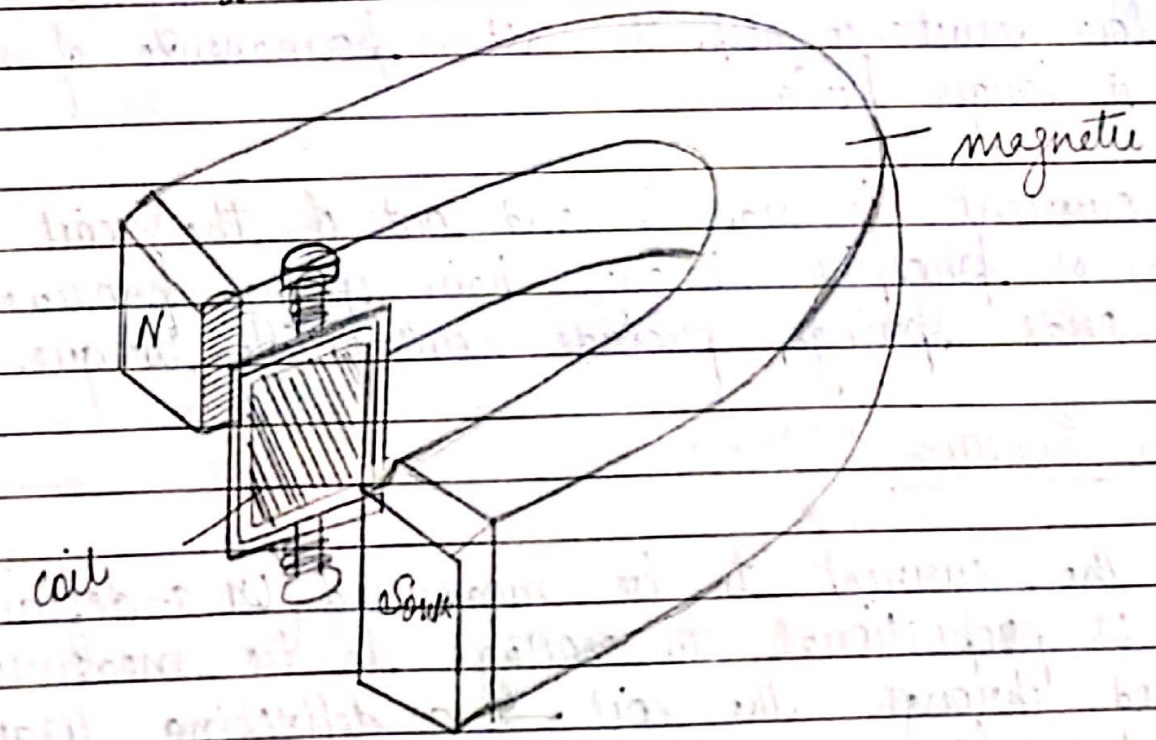


fig 1a

Moving Coil (permanent magnet type Instrument)



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with coil magnetic field)

Direction of deflecting torque determined by flemings left Hand Rule.

when current flowing through l metres is i (A) then for N number of turns and B flux density (Tesla) deflecting force f will be.

$$f = BilN \text{ newton}$$

if r is the distance b/w centre of the coil & force, f then deflecting torque,

$$T_d = f \times r$$
$$= BilNr \text{ Nm.}$$

if B = constant

$T_d \propto i$ (since such instruments are spring controlled)

∴ Controlling Torque

$T_c \propto$ deflection θ

$T_c \propto \theta$

In steady deflection position

$T_c = T_d$

$\theta \propto i$

∴ usually linearly spaced scale markings.

Ranges · 1) 0 - 5 μA & upto 20 mA with internal shunts
0 - 5000 A with external shunts

2) 0 - 100 mV without series resistance.
20 KV - 30 KV with external series resistance

Merits and Demerits of PMMC

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Merits 1. Uniform scale
2. No hysteresis losses as former is of Cu or Al.
3. High accuracy
4. Use of single instrument for measurement of current and voltages by employing shunts and multipliers of different resistance.

Demerits 1. These instruments cannot be used for ac measurements.
2. Costly as compare to MI instrument (delicate construction and necessary accurate machining is required)
3. Sometimes friction & temp causes errors

Comparison b/w moving iron & moving coil Instrument

Moving Iron	Moving coil
1. Are simple & robust in construction ∴ cheaper in cost	1. Are costlier, because of delicate construction and the necessary accurate machining & assembly of various part
2. Air friction damping is provide which is not effective	2. Eddy current damping is provided which is very effective
3. Consume more power	3. Consume less power
4. Non uniform scale	4. Uniform scale
5. less sensitive	5. More sensitive (high torque weight ratio)

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6. less accurate & reliable	6. More accurate & reliable (because they have no hysteresis losses and they are not affected by stray M.f)
7. Can be used both dc as well as ac circuit	7. Cannot be used in ac circuits.

Ammeters and Voltmeters

Ammeter which is connected in series with circuit carrying the current under measurement, must be of low resistance so the V.D across ammeter and power absorbed from the circuit are as low as possible.

Voltmeter which is connected in parallel with the circuit across which the voltage is to be measured must be of very high resistance so that current flowing through the voltmeter and power absorbed from the circuit are minimum possible.

(So instrument manufactured as a voltmeter to cannot be employed as ammeter or vice versa)

But An ammeter of low range may be used as a voltmeter by connected high resistance in series with it provided the current through the series combination is within the range of ammeter when connected across the voltage to be measured.

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Errors common to all types of Instrument

Temperature errors (mainly due to heating of working coils & other resistance coil connected internally in instrument causing by the operating current)

friction errors (The friction of pivot & jewel produces Due to frictional torque which it oppose the deflection of moving element and as a result the pointer come to rest a short distance from its correct position so there is an error occur).

observational errors (due to miss reading of the scale & error of estimation)

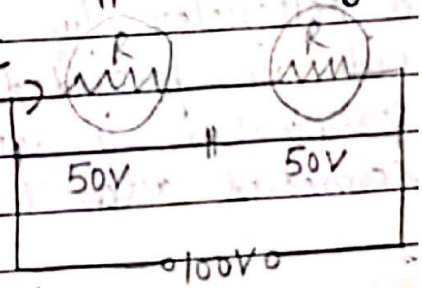
Numerical In MC Instrument, coil consist of 100 turns wound on a square former of $l = 3cm$. B in air gap $= 0.06T$. Calculate the turning moment acting on the coil when carrying current of 12 mA.

Sol $N = 100$ $l = 3cm$ $b = r = 3cm = 0.03m$.
$B = 0.06T$ $i = 12mA = 0.012A$

$$\text{So } T_d = BilNr = 0.06 \times 0.012 \times 0.03 \times 100 \times 0.03$$
$$= 6.48 \times 10^{-5} \text{ Nm dns}$$

Numerical Two voltmeter one with full scale reading of 100V & another with a full scale reading 200V are connected in series across 100V supply. The internal resistance of both meters in same. What are readings?

Sol. Let internal Resistance $= R$



When the 2 meters are connected in series 100V supply the V.D across each meter is 50V
So meter will lead 50V

$$V_1 = \frac{R}{R+R} \times V_T = \frac{R}{2R} \times 100 = 50\Omega$$

Essential torque of indicating instrument (2 marks)

1. Deflecting torque (To) It causes the moving s/s to move from zero position to the required value, when the instrument is connected in the circuit.

2. Controlling Torque Once To is applied, the pointer starts movement controlling torque opposes the deflecting torque, and the pointer comes to rest when the two opposing torque are equal. (Tc) a) Spring control
b) Gravity control

3. Damping torque When To and Tc are acting simultaneously, the point will oscillate due to inertia. To avoid the kind of oscillation, damping torque is applied.
1. Air damping 2. fluid friction damping 3. Eddy current damping

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