

the necessity for making
during the test.

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Chapter - 1 MEASURING INSTRUMENTS

Measurement : — Measurement is a act of comparison between a given quantity with its predefined standard unit.

The device used for comparing the given quantity with the predefined standard unit is known as measuring instrument.

Accuracy : — → Accuracy is defined as the closeness or conformity to the accepted standard value or the true value of the quantity under measurement.

- In some cases there is difference between the true value & the value of instrument indicates & this is known as measurement error.
- The accuracy of the instrument may be specified in the following ways : —

i) point Accuracy : — Hence the accuracy of an instrument is indicated only in range of one or more points. so such accuracy doesn't give any information about the general accuracy of the instrument. It is applicable to temp. measuring instrument.

ii) Percentage of true value : — By using this we can measure the percentage of errors.

$$\text{Error} = \frac{\text{measured value} - \text{True value}}{\text{True value}} \times 100$$

It is the maximum for any point in the range of the instrument.

iii) Percentage of full scale deflection : -

Hence the errors are calculated on the bases of max^m value of the scale.

$$\text{Error} = \frac{\text{Measured value} - \text{True value}}{\text{True scale value}} \times 100$$

iv) Complete Accuracy statement : -

In other side it is not sufficient to specify accuracy at a limit no. of points & the accuracy at a larger no. of points is specified in tabulated or graphical form.

Precision : - → It is the degree of closeness to the true value for which an instrument is designed or intend to perform for.

Ex : - Let the value of resistance is 1632 Ω and is measured by multimeter 1.6 KΩ. Hence the observer can't read the true value on the scale, there is no of deviations on the observed value. The errors created the limitation of the scale is precision.
→ precision is composed of 2 characteristics.

i) Conformity (1632 Ω read as 1.6 KΩ)

ii) Significant numbers (250 v close to 250.0 than 250.1)

Error : - Static Error : - The difference betw the measured value & the true value or exact value of unknown quantity is known as static errors or absolute errors.

$$E_0 = \delta A = A_m - A_t$$

Relative or percentage error : -

The relative error is the ratio of absolute error to the true value of quantity to be measured. And it is denoted by Err.

$$\text{Erc} = \frac{\text{Absolute Error}}{\text{True value}} = \frac{\delta A}{A_{\text{true}}} = \frac{E_0}{A_{\text{true}}}$$

$$\text{Percentage Error} = \frac{E_0}{A_{\text{true}}} \times 100 = E_{\text{rc}} \times 100$$

$$\text{Again } A_{\text{true}} = A_{\text{m}} - \delta_A \\ = A_{\text{m}} - E_0 = A_{\text{m}} - E_{\text{rc}} A_{\text{true}}$$

$$\Rightarrow A_{\text{true}} + E_{\text{rc}} A_{\text{true}} = A_{\text{m}}$$

$$\Rightarrow A_{\text{true}} = \frac{A_{\text{m}}}{1 + E_{\text{rc}}}$$

Static Correction : — It is the difference bet' the true value & measured value of a quantity. It is denoted as δ_c .

$$\delta_c = A_{\text{true}} - A_{\text{m}}$$

$$\Rightarrow \boxed{\delta_c = -\delta_A}$$

Errors are classified into 3 types.

- i) Gross Error
- ii) Systematic Errors →
 - Instrumental Error
 - Environmental Error
 - Observation Error
- iii) Random Error

Resolution : — If the input is slowly increased from a arbitrary value & the output does not change at all until the increment exceeds the certain value called as resolution or discrimination of the instrument.

Sensitivity : — It is defined as the ratio of o/p signal to response of the instrument to the change of input signal or quantity under measurement. Always sensitivity needed to be high.

Tolerance : — Tolerance is related to the accuracy & defines the maximum error which is to be expected over some range of tolerance. It is the limit of error of a system.

And this errors may be due to noise in temp. or heat generate due to excess of current or friction in parts.

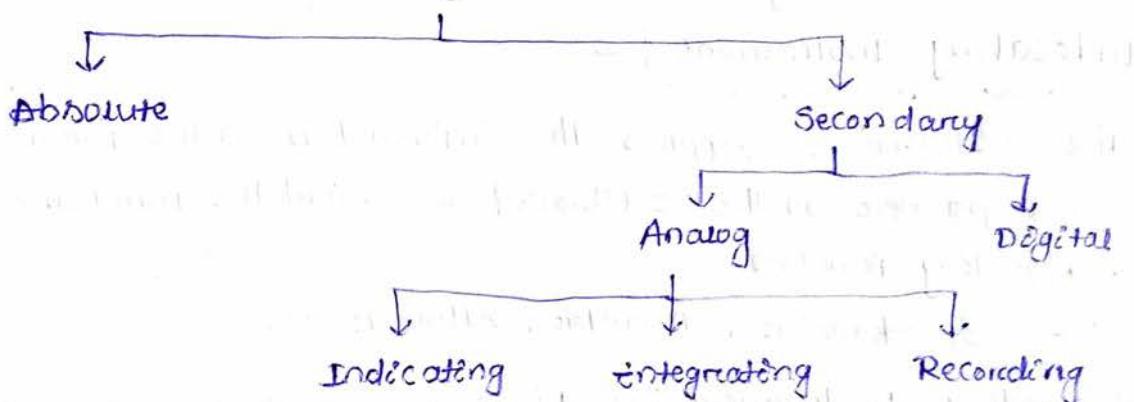
Repeatability :-

It is defined as the closeness of output reading when the same input is applied repetitively over a short period of time, with the same measurement condition, same instrument & with the same condition.

Drift :- It is slow variation in the output signal of a measuring system, which is not due to change in input quantity & it is generally due to change in operating condition of the component inside the measuring system.

Classification of Instruments :-

Measuring Instrument



Absolute Instrument :-

The instruments are used in research laboratory, standard laboratory. These instrument indicate the value of the quantity being measured by deflection of the needle & instrument constant. They doesn't require any calibration or comparison.

Ex :- Tangent Galvanometer, Absolute electrometer etc.

Secondary Instrument :-

Through this instrument the quantity can be measured by observing the o/p indicated by the instrument and it is required to calibrated by comparison with an absolute instrument.

Ex:- Ammeters, voltmeter, wattmeter etc.

Analog Instrument :-

Analog instruments are such instrument on which signal that vary in continuous fashion & the pointer moved over a calibrated scale & indicate the quantity being measured.

It provides an output which varies continuously as the quantity under measurement changes.

Digital Instrument :-

In digital instruments the signal vary in discrete steps & thus take up only finite different values in a given range are termed as digital signals.

It provides an output which varies in discrete step but can only have a finite no. of values.

Indicating Instrument :-

The instrument supplies the information in the form of deflection of a pointer on the calibrated scale. And the function is known as indicating function.

Ex:- Speedometer, Ammeter, voltmeter etc.

Recording Instrument :- It keep a continuous record of the variation of the magnitude of the unknown quantity to be observed over a definite period of time. In this instrument there is a moving system on which a pen or pencil is attached, which record the data on a graph sheet over a duration of time.

Ex:- Speed log usually provided with commercial vehicle, temperature & pressure recorder etc.

Integrating Instrument : In these types of instrument the quantity being measured by adding with successive user.

Ex:- Kilowatt hour meter, Energy meter.

Passive Instrument : - In ⁽⁶⁾ passive instrument, the movement of pointer for a particular quantity of charges is closely defined by type of instruments. To increase the measurement resolution, the pointers should be longer which is restricted.

Active Instrument : - In these instruments adjustment of magnitude of external energy input allows much greater control over measurement resolution.

Essentials of indicating Instrument : -

An indicating instrument essentially consists of a moving system. A pointer is attached to it which indicates on a graduated or calibrated scale, the value of electrical quantity being measured.

For satisfactory operation of the indicating instruments the following torques are required.

- ① Deflecting torque (Operating torque)
- ② Controlling torque (Restoring torque)
- ③ Damping torque

Deflecting Torque : - The deflecting torque is produced by utilising the various effects of electric current or voltage & cause the moving system to move from zero position. It is denoted as T_d . Ex:- magnetic effect \rightarrow Ammeter, voltmeter, wattmeter

Thermal effect : - Ammeter, voltmeter

Chemical effect — integrating meter

Electrostatic effect — voltmeter

Electromagnetic induction effect \rightarrow Ammeter, voltmeter, energy meters etc.

Controlling Torque : - If deflecting torque acting alone, the pointer would continue to move or swing over maximum deflected position irrespective of the magnitude of electrical quantity.

So controlling torque or opposing torque (T_c) is provided to oppose the deflecting torque & should increase with the deflection of the moving system. The pointer should be come to rest position when $T_d = T_c$

The controlling torque provided is 2 function.

- It increase with the deflection of the moving system so that the final position of the pointers on the scale will according to the current or voltage to be measured.
- It bring the pointer to zero position, when the deflecting torque is removed.

The controlling torque is provided in 2 ways.

- i) Spring control (By one or more springs)
- ii) Gravity control (By weight of moving parts).

Spring control:-

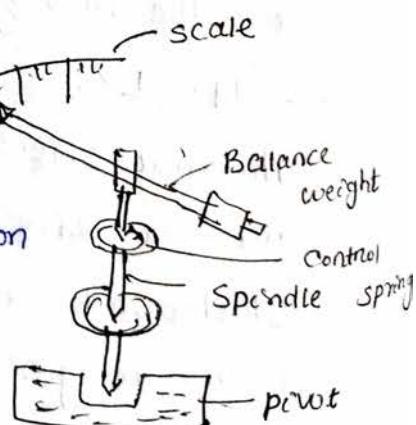
- In Spring control, a special spring made up of nonmagnetic material like phosphor bronze is attached to the moving system.
- With deflection of the pointers, the spring is twisted in opposite direction. And the twist of spring provides controlling torque.

- Since the spring torque is proportional to the angle of twist, the controlling torque is also proportional to the deflection of pointers. $T_c \propto \theta$

- The pointers will come to at rest when $T_d = T_c$.

where deflecting torque is unit, then $T_d \propto I$

where $I \rightarrow$ current flowing through the operating coil with spring control $T_c \propto \theta$



In the final deflected position $T_c = T_d$ (8)
 $\Rightarrow I \propto \theta$

Since the deflection is directly proportional to I , scale of such instrument is uniform.

Gravity control: —

- In this method a small adjustable weight w is attached to the moving system, which provides controlling torque.
- In the zero position of the pointer, the control weight hangs vertically downward & therefore provides no controlling torque.
- Under the deflection the pointer moves from zero position & control weight move in opposite direction. Due to gravity, the control weight comes to original position & provides opposing or controlling torque.
- The pointer comes to rest, when controlling torque is equal to the deflecting torque.
- The weight w can be resolved into 2 components i.e. $w \sin\theta$ & $w \cos\theta$. But only $w \sin\theta$ provides the controlling torque (T_c).

$$T_c = w l \sin\theta$$

$$\Rightarrow T_c \propto \sin\theta \quad (\text{for fixed } w \text{ & } l)$$

where, $w \rightarrow$ is the control weight

l is the distance from axis of rotation

θ is the deflection.

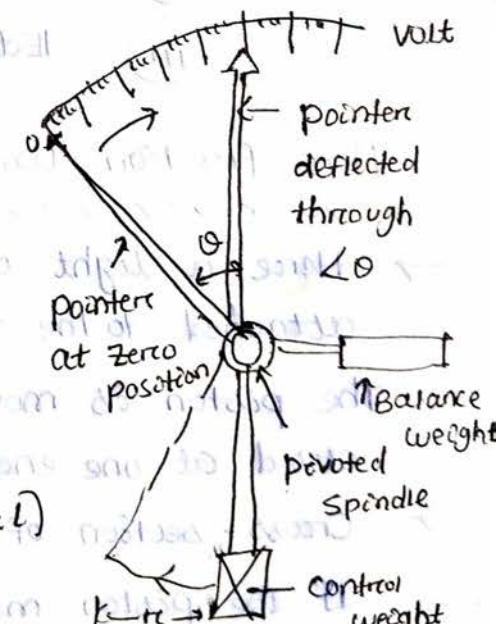
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where w is the control weight

l is the distance from axis of rotation

θ is the deflection.



Damping Torque :-

The main function of the damping torque is to absorb oscillating energy & to bring the moving system to rest as quick as possible. So that the indication may be observed.

If the moving system take some time to come to the rest, then it is said to be under damped.

If the moving system become slow, then it is said to be over damped condition.

If the moving system quickly reached to the deflected position without any oscillation. It is said to be critical damped condition.

In practice the damping value always set to the slightly lower than the critical value.

Various methods to obtain damping are

i) Air friction damping

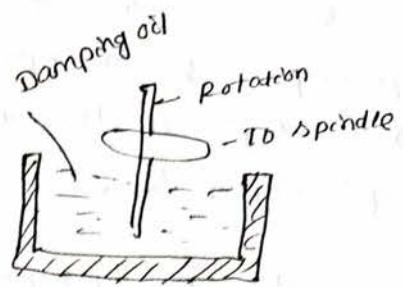
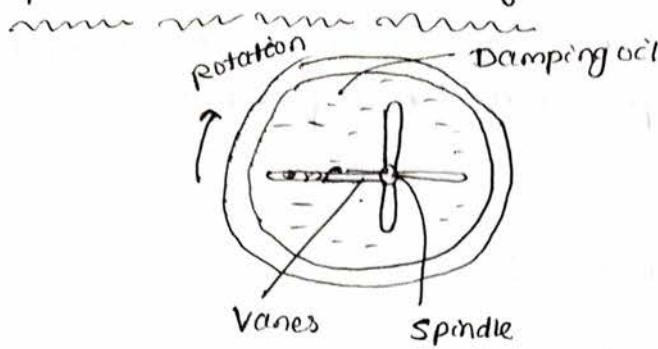
ii) Fluid friction damping

iii) Eddy current damping

Air friction Damping:-

- Here a light aluminum piston is attached to the moving system.
- The piston is moved in fixed air chamber closed at one end.
- Cross-section of the chamber may be circular or rectangular.
- If the piston moves inside the chamber, the pointer moves anti-clockwise & vice-versa.
- In the other hand when the inside pressure becomes equal to the outside atms. pressure, the spindle will be in steady state.
- This type of damping is used in the moving iron & dynamometer types instruments.

Fluid Friction damping :-



- In this damping light vanes or discs are attached to the moving system & it moves in the damping oil.
- In one method, the light vanes are attached to the spindle. The motion of the moving system always opposed by the friction of the damping on the vanes.
- So that the damping force always increase with increase of velocity of vanes.
- In the other method, the frictional drag developed during the motion of the disc, which is always oppose the motion of the moving system.

Advantage : → Oil required for damping can be used for insulation purposes.

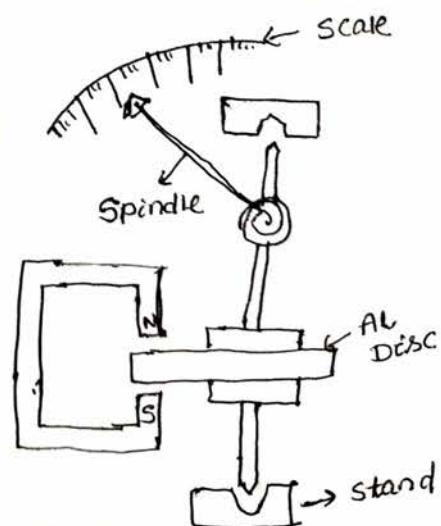
→ There is no requirement of clearance.

Dis-advantage : → Creeping of oil is required.

→ The instrument always must be used in vertical manner.

Eddy current Damping :→

- In eddy current damping an aluminium disc is attached to the spindle.
- The aluminium disc is passed through the magnetic field.
- When the pointer deflects, the aluminium disc cuts the magnetic lines of force produced by the damping magnet.
- An emf is induced on the aluminium disc due to Faraday's law & eddy current is established on the aluminium disc.



- (11)
- These eddy currents interact with the magnetic field & produce a opposing torque to oppose the movement of the aluminium disc.
 - It is a very effective & powerful damping and it can be easily adjustable.

Calibration of Instruments :-

- Calibration process is simple.
- It consists of reading the standard & test instruments simultaneously when the input quantity held constant at several values over the range of the test instrument.
- The calibration is better carried out under the stipulated environmental condition.
- While calibrating it is usual to take reading in both ascending & descending order.
- It can reveal an inherent flaw in the electrochemical instrument & other mechanical transducers involving elastic element.
- The test instrument is calibrated under several environmental condition in order to ensure that the grade of performance conforms to its standard specification.
- Calibration in laboratory may be a simple process, but statistical approach may be necessary sometimes.

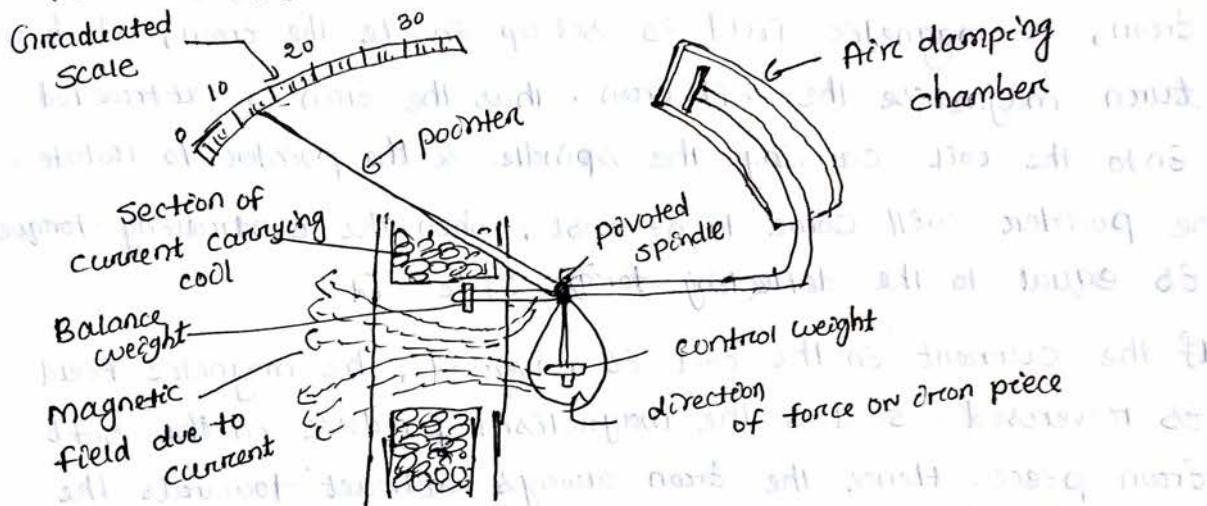
• Standard Instrument

Moving Iron type Instrument :-

This type of instrument generally works on A.C as well as D.C & used for both current & voltage measurement. Here spring & gravity control with air friction damping is provided. It is cheaper to manufacture & generally used as an indicating instrument. It is very accurate on ac as well as dc if properly designed. It is generally of 2 types.

i) Attraction type ii) Repulsion type

Attraction type Instrument :-



Construction :-

- The above fig. shows the construction of attraction type of moving iron instrument.
- It consists of a magnetic coil having no. of turns wound over a H-type bobbin. When current passes through the coil it produces the necessary magnetic field.
- An oval shape soft iron piece is placed near the magnetic field which is attached to the spindle in such a way that it can move inward & outward according to the field.

- A pointer is attached to the spindle so that it is deflected with the movement of the soft iron piece.
- The controlling torque provided either by sprung control or by gravity control.

Principle of operation: —

- The attraction type instrument operates on the principle of attraction of single piece of soft iron into a magnetic field.
- The movement of iron is always from weaker magnetic field i.e. outside of the coil onto the strong magnetic field i.e. inside the coil irrespective of the flow of current.
- When the current to be measured is passed through the soft iron, a magnetic field is set up inside the iron, which in turn magnetise the soft iron. Thus the iron is attracted onto the coil causing the spindle & the pointer to rotate.
- The pointer will come to rest, when the controlling torque is equal to the deflecting torque $\therefore T_c = T_d$
- If the current in the coil is reversed, the magnetic field is reversed. So does the magnetism produce in the soft iron piece. Hence the iron always attract towards the magnetic field & the deflecting torque is remain unchanged by changing the direction of current. So that it is used for AC as well as DC measurement.

Derivation for T_d : —

Due to force of attraction the pointers try to deflect. The force which pulling the soft iron piece towards the coil is directly proportional to

- Field Strength (H) produce by the coil
- pole strength (M) produce by the soft iron piece.

$$\therefore F \propto MH$$

(3)

$$\text{Against } H \propto I, M \propto H \propto I$$

The deflection produced depends on the force.

$$\therefore T_d \propto F$$

$$\Rightarrow T_d \propto MH \quad T_d \leftarrow \text{deflecting torque}$$

$$\Rightarrow T_d \propto I^2 \quad I \leftarrow \text{operating current}$$

If the instrument is gravity control.

$$T_c \propto \sin \theta$$

$$\Rightarrow \boxed{T_c = k \sin \theta}$$

where $T_c \rightarrow$ is the controlling torque.

$k \rightarrow$ is the gravity constant

$$\text{At Steady state } T_c = T_d$$

$$\Rightarrow k \sin \theta = I^2$$

$$\Rightarrow \theta = \sin^{-1}(I^2) \times \frac{1}{k}$$

$$\text{OR} \quad \boxed{\theta \propto \sin^{-1} I^2}$$

If it is spring control

$$T_c \propto \theta$$

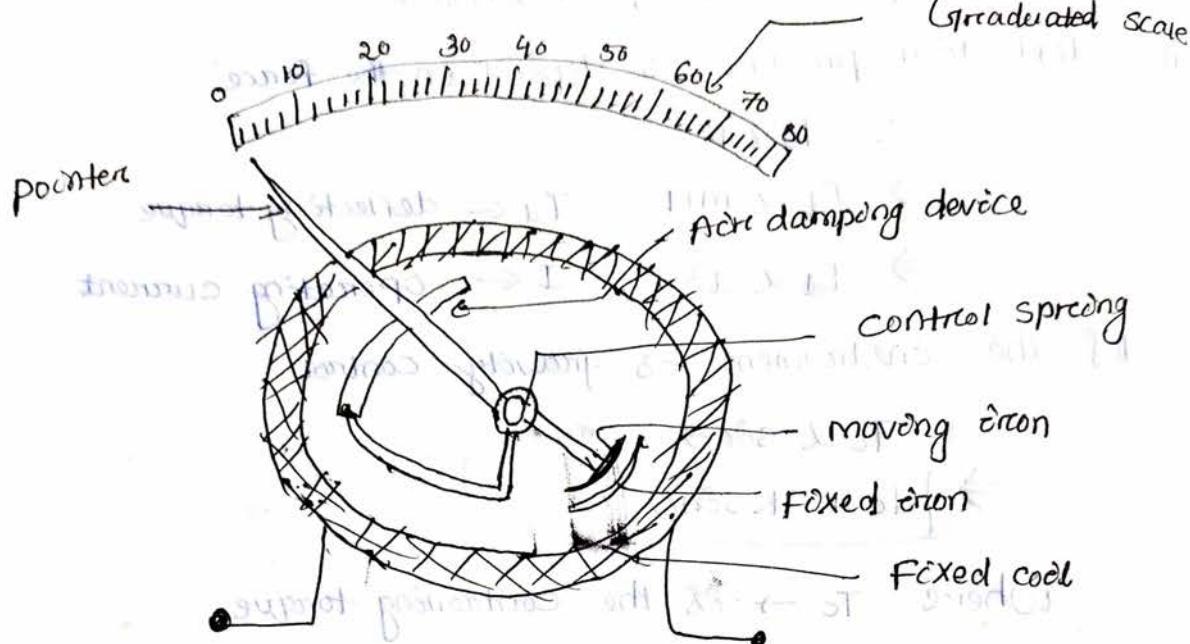
$$\Rightarrow T_c = k\theta$$

$$\text{At Steady state } T_c = T_d$$

$$\Rightarrow k\theta = I^2 \Rightarrow \theta = I^2/k$$

$$\boxed{\theta \propto I^2}$$

Repulsion type Instrument:-



Construction :- → The above fig. shows the constructional detail of repulsion type moving iron instrument.

- It consists of cylindrical hollow core which has wound with no. of turns. When current passes through the coil, a magnetic field is set up.
- Inside the cylinder two soft iron pieces known as vane is placed. One is fixed on the coil & another is movable & attached to the spindle.
- The pointer is attached to the spindle & move over a calibrated scale.
- For controlling purpose two helical spring is attached.
- Necessary damping is provided by air friction damping due to motion of the piston inside the air chamber.

Principle of Operation :-

- Repulsion instrument operates on the principle of repulsion of two adjacent piece of magnetised iron by the same magnetic field.

- (5)
- The two iron cores lie on the magnetic field produced by the coil of solenoid.
 - When there is no current in the solenoid, the moving iron & fixed iron touch each other & the pointer rest at zero position.
 - When the current to be measured is passed through the solenoid a magnetic field is set up inside the solenoid & the two iron are magnetised in same direction. Hence a repulsive force is created.
 - Due to the repulsive force the moving iron is repelled by the fixed iron. Thereby result in the motion of the pointer - which is fixed to moving iron.
 - The pointer comes to the rest, when repulsive force is equal to the controlling force.
 - If the current in the coil is reversed, the direction of deflecting torque remain unchanged because reversal of the field coil as well as both magnetized iron. So that they repel each other irrespective of the current. That's why such instruments are used both for A.C & D.C.

Derivation for T_d : —

The deflecting torque is produced in the moving system is due to force of repulsion exist between two soft iron.

$T_d \propto$ Force of repulsion

$$T_d \propto M_1 \times M_2$$

where $M_1, M_2 \leftarrow$ Pole strength

$$T_d \propto H \times H \quad (\because M_1 \& M_2 \propto H)$$

where $H \leftarrow$ Field strength

$$T_d \propto I \times I \quad (\because H \propto I)$$

$$\boxed{T_d \propto I^2}$$

Since it is sprung control, $T_c \propto \theta \Rightarrow \boxed{T_c = k\theta}$

where k is the spring constant

In steady state $T_c = T_d$
 $\rightarrow k\theta = kI^2$
 $\Rightarrow \boxed{\theta = I^2}$

Advantages :-

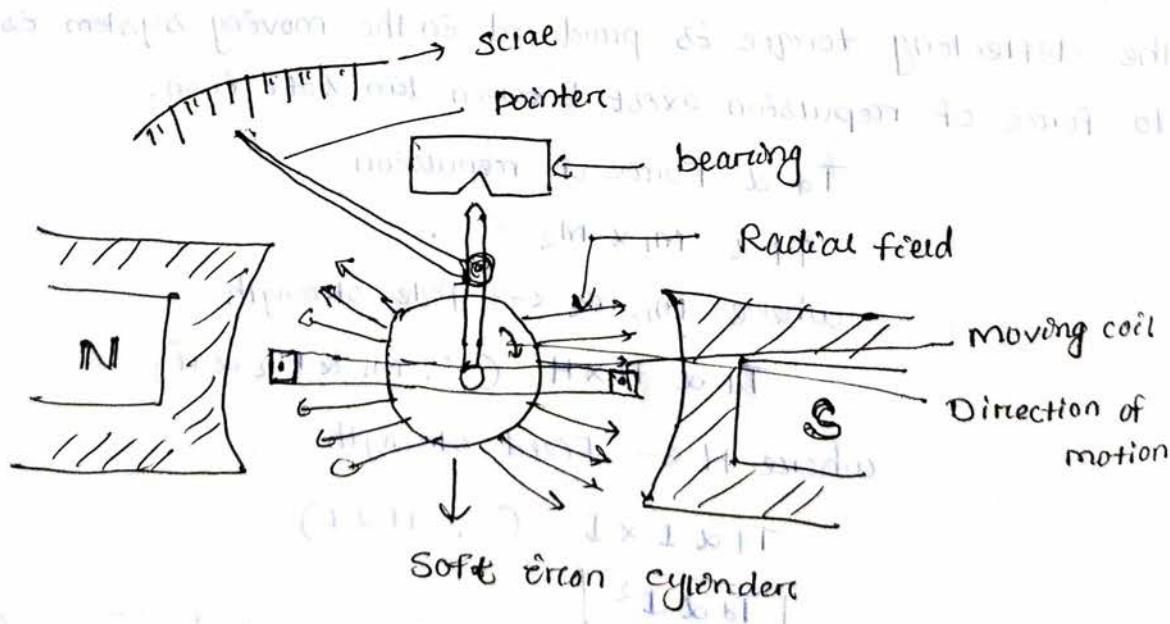
- It is used for AC as well as DC measurement.
- Its cost is low.
- The construction is robust.
- There is no ageing effect.
- Overload efficiency is high.
- Less frictional error.

Dis-advantages :-

- Scale is not uniform as $\theta \propto I^2$.
- Power consumption is high.
- These are not sensitive as compared to PMMC.

Permanent magnet moving coil (PMMC) :-

PMMC is the most accurate & useful for dc measurement.
It is used as ammeter & voltmeter.



Construction :-

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- As the name suggest the instrument consist of a permanent magnet & soft iron cylindrical moving coil of no. of turns with fine wire wound over a aluminium former.
- Spring control mechanism & eddy current damping is provided.
- Here two springs are fixed with the pointers & coiled in opposite direction.
- The control spring also conduct the operating current into & out of the moving coil.
- The coil is attached to the spindle & the spindle is pivoted on two bearings.
- A pointer is attached to the spindle & move over a calibrated scale.
- The two ends of the springs are connected to the coil.

Working principle :-

- The principle of pmmc instrument based on whenever a current carrying conductor kept in a magnetic field, a force is experienced by the coil to which the coil try to move out of the field & produce the necessary deflecting torque.
- When the instrument is connected in the circuit, the operating current flows through the coil.
- Since a current carrying coil is kept inside the magnetic field, a force is acted on it & the moving coil will move out of the field. Hence the pointer deflected over the calibrated scale. As the pointer is attached to the moving coil.
- If the current in the coil is reverse, the deflecting torque will be reversed. Since the direction of the field is constant as it is a permanent magnet. The pointer will deflect in reverse direction.

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- When the pointers deflect, the two springs become twisted by restoring some energy & it will provide necessary controlling torque on the moving system.
 - Aluminium core not only provide the support for the coil, it also help to provide necessary damping.
 - When the moving system moves, the aluminium former cuts the lines of force & e.m.f is induced. So that eddy current is produced, which creates a opposing force & this opposing force minimize the oscillation & the pointers come to at rest.

Derivation for deflecting torque :-

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Let  $l$  be the length of the coil in meter

$n$  be the no. of turns

$B$  be the flux density of magnetic field  $\text{Am}^{-2} \text{wb}/\text{m}^2$

$b$  is the width of the coil.

When  $I$  Ampere current passes through the coil, a force is experienced by the side of the each coil & which is given by :-

$$F = BIL \text{ Newton}$$

For  $n$  turns the force acts on each side of the coil.

$$F = BILN \text{ newton}$$

Now the deflecting torque is given by

$$T_d = F \times \text{perpendicular distance}$$

$$= BILN \times b = BIN(l \times b)$$

$$\boxed{T_d = BIN A \text{ N/m}^2}$$

Since, here a spring control is used

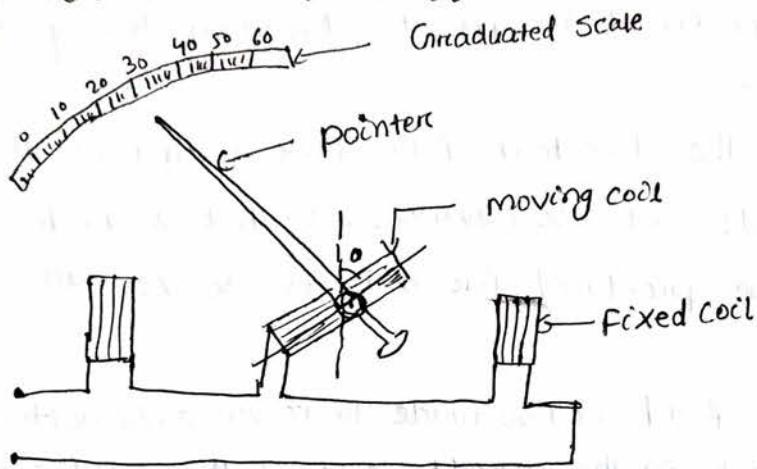
$$T_c \propto \theta \Rightarrow T_c = K\theta$$

At steady state,  $T_c = T_d$

$$\begin{aligned}\Rightarrow K\theta &= BI NA \\ \Rightarrow \theta &= \frac{BI NA}{K} \\ \Rightarrow I\theta &\propto I\end{aligned}$$

As  $B, I, N$  &  $K$  all are constant.

Dynamo-meter type Instrument :-



construction :- It consists of following parts.

- i) Field System :- The operating field is produced by the fixed coil. For low current operation the field is wound with fine wires & for high current operation, the field is wound with thick wires. To reduce eddy current losses in the conductors the coils are usually varnished.
- ii) Moving system :- The moving system or coil is wound either as a self sustaining coil or a non metallic former. It is supported by a aluminum spindle & the pointer is attached to it.
- iii) Control system :- Two hair spring are use to create controlling torque in the instrument.
- iv) Damping system :- Air friction damping is used in these instrument, it may be either piston type or vane type.
- v) Shielding :- The operating magnetic field produced by the fixed coil is somewhat weaker. So it is essential to provide magnetic shielding to this instrument.

Working principle :-

- It is based on the principle of whenever a current carrying conductor or coil keeping in between two fixed coil, which produces the field. A mechanical force act on the current carrying coil & which will try to move out of the field & produce the deflecting torque.
- It would have a torque in one direction during one half of the cycle & an equal effect in opposite direction during the other half of the cycle.
- If we reverse the direction of the flux each time the current through movable coil also reverses. So that a unidirectional torque would be produced for both +ve & -ve half cycle of the supply.
- Hence, here the field can be made to reverse, simultaneously with the current in the movable coil if the fixed coil is connected in series with the movable coil.
- It is also used as transfer instrument, i.e. it may be calibrated with a dc source & then can be used to measure ac without modification.
- It is used as ac ammeter, Voltmeter, wattmeters, etc.

Derivation for deflecting torque :-

The deflecting torque acting on the moving system depends on the force acting on the moving system.  
Let If  $\rightarrow$  be the current flowing through the fixed coil.

If  $\rightarrow$  be the current flowing through the moving coil.

Td d. Force

Again Td d. B If As B d If

Td d. If Im

Since it is a spring control  $T_c \propto \theta$

$$\Rightarrow T_c = k\theta$$

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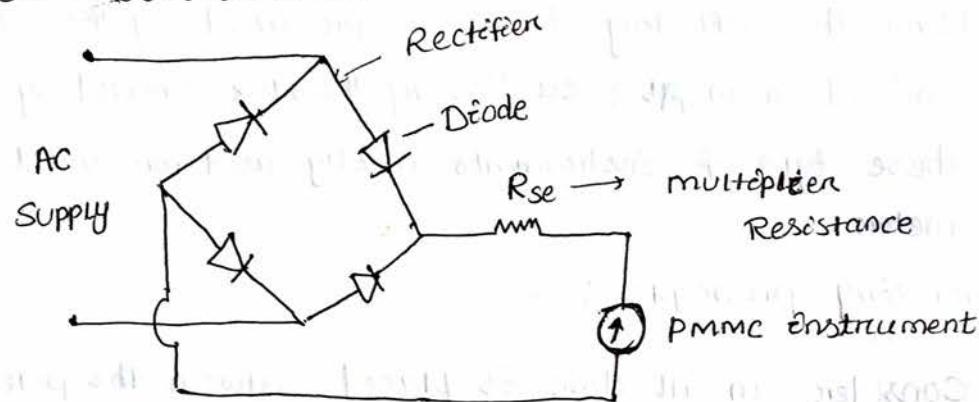
At steady state  $T_c = T_d$

$$\Rightarrow k\theta = I_f I_m$$

$$\Rightarrow \theta \propto I_f I_m$$

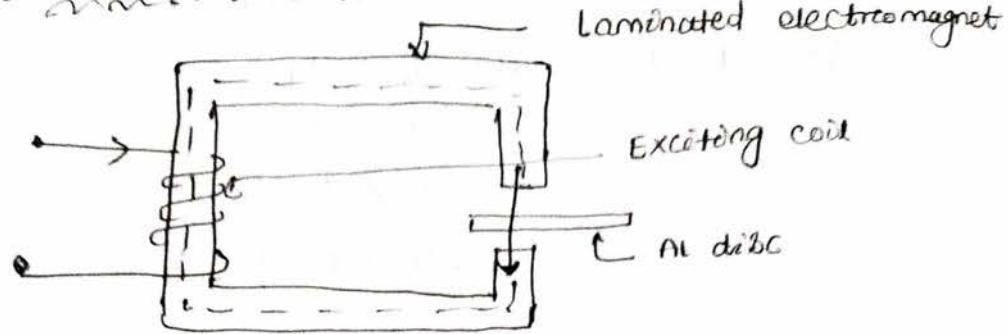
$$\Rightarrow \boxed{\theta \propto I^2}$$

### Rectifier Type Instrument :-



- This instrument is used for measurement of DC voltage & AC current by using rectifier ckt.
- Rectifier ckt is helps to convert AC to DC & then using a DC ammeter indicate the value of rectified AC.
- The indicating instrument is pmmc type.
- This method is very popular as pmmc type instruments are very accurate & sensitive in comparison to electro dynamo meter & MI instrument.
- These type of instrument consists of full wave bridge type rectifiers ckt using 4 diodes as a rectifying element. It is primarily used as Voltmeter.
- Rectifiers type instruments are particularly suitable to measurement of communication ckt & for all other light current work where the voltage are low & resistance is high. → It is essential that for these applications other than the current drawn by the voltmeter doesn't exceed say 1 mA.

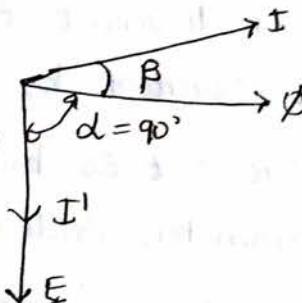
## Induction Type Instrument :-



- Such instruments are suitable for AC measurement only.
- Here the deflecting torque is produced by the eddy current induced on an Al & cu disc by the flux created by electromagnet.
- These type of instruments mostly used for wattmeters & energy meters.

### Working principle :-

- Consider an Al disc is placed between the poles of an electromagnet.
- Let the flux produced by the flow of current of  $I$  A through the coil be  $\phi$ .
- $\phi'$  is lagging behind the  $\phi$  by a small angle  $\beta$ .
- Since Al-disc act as a secondary winding of transformer, an e.m.f ( $E$ ) is induced in it.
- $E$  is lagging behind the  $\phi'$  by an angle  $d = 90^\circ$ .
- Eddy current  $I'$  induced in the disc will be in phase with  $E$ . As the Al disc is purely resistive.
- As the component of  $I'$  along flux  $\phi'$ . The torque produced is zero. So it has greater deflection.



- Advantages :- → A full scale deflection of some  $300^\circ$  can be obtain giving long & open scale.
- Damping is easier & effective.

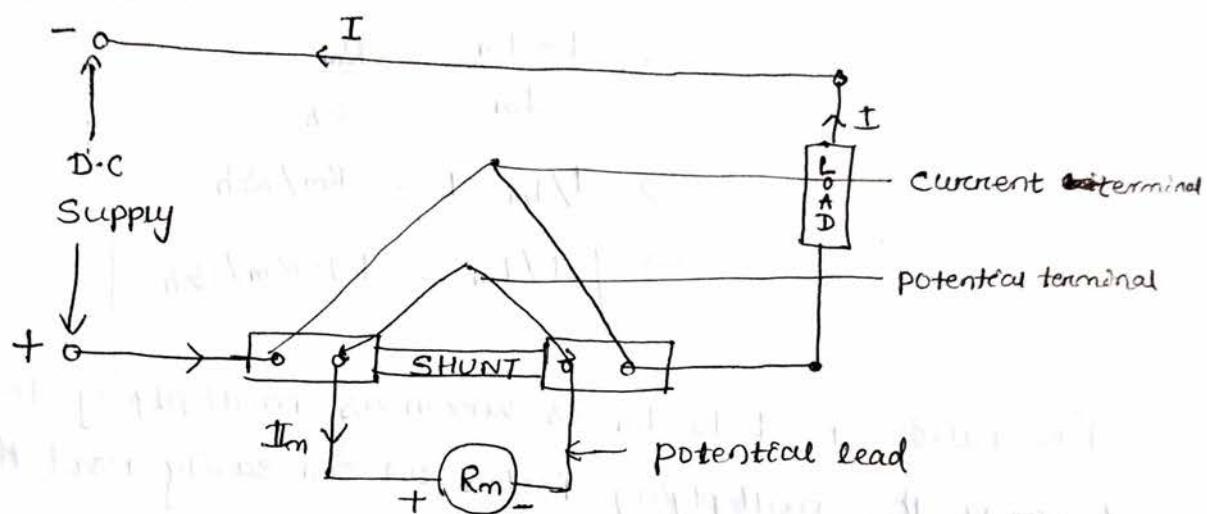
Dis-advantages :-

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- The greater deflection causes more stresses in the control springs.
- Variation in supply frequency & temp. may cause serious error unless compensating device is employed.
- These instruments are costlier & consume more power as compared to other instruments.

### Extension Range of Instruments :-

#### Ammeter Shunts :-



- An ammeter shunt is merely a low resistance that is placed in parallel with the coil ckt of the instrument.
- It is used to measure large current.
- The shunt has 4 terminals. Two for large current carrying capacity known as current terminal inserted in series with the main ckt.

Others two are known as potential terminal in which the ammeter is connected across it.

Theory :- Let  $I \rightarrow$  be the current of the ckt to be measured.

$R_{sh} \rightarrow$  is the resistance of the shunt.

$R_m \rightarrow$  is the resistance of the ammeter & potential lead.

Now from the diagram  $I = I_m + I_{sh}$

where  $I_m \rightarrow$  current through the ammeter

$I_{sh} \rightarrow$  current through the shunt

The voltage drop across the shunt is equal to the voltage drop across the ammeter.

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

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

$$\Rightarrow \frac{I_m}{I - I_m} = \frac{R_{sh}}{R_m}$$

$$\Rightarrow \frac{I - I_m}{I_m} = \frac{R_m}{R_{sh}}$$

$$\Rightarrow \frac{I}{I_m} - 1 = \frac{R_m}{R_{sh}}$$

$$\Rightarrow \boxed{\frac{I}{I_m} = 1 + \frac{R_m}{R_{sh}}}$$

The ratio of  $I$  to  $I_m$  is known as multiplying factor. By knowing the multiplying factors we can easily read the value of current over the scale.

Working principle (Induction Type) :-

when 1-φ AC supply is given to the both series & shunt magnet coil will produce magnetic fluxes  $\phi_1$  &  $\phi_2$ .

$$\phi_1 \propto I_1 \text{ & } \phi_2 \propto V$$

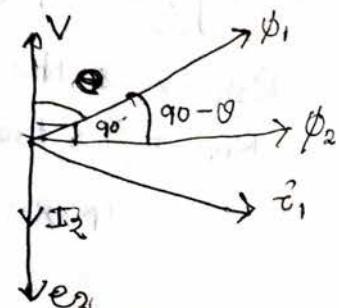
The cu. band will make  $\phi_2$  lag with an angle of  $90^\circ$  w.r.t  $V$

Now  $T \propto \phi_1 \phi_2 \sin(90^\circ - \theta)$  (Angle betw  $\phi_1$  &  $\phi_2$ )

$$T \propto \phi_1 \phi_2 \cos \theta$$

$$\Rightarrow \boxed{T \propto V I \cos \theta}$$

$V \cos \theta \propto$  power



$$\text{Electrical energy} = P \times t \\ = P \cdot dt$$

(15)

$$\therefore T \propto \int V I \cos \theta \cdot dt \propto \text{Electrical energy}$$

The controlling torque will be produced by the braking magnet which will control the speed of the disc.

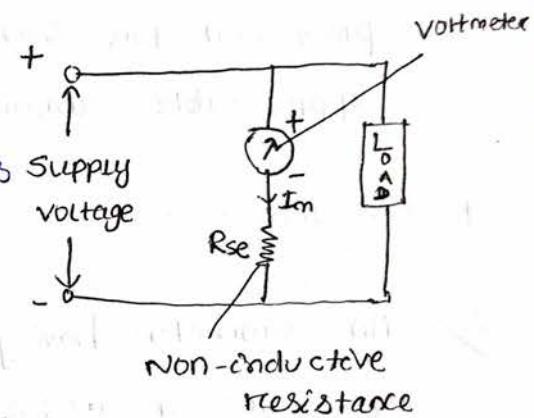
$$[T_c \propto N]$$

$$\text{under balanced condition } T_c = T$$

$$\Rightarrow \text{Electrical energy} \propto N$$

### Voltmeter Multiplier :-

- In voltmeter multiplier a high non-inductive resistance connected in series with the voltmeter.
- Voltmeter is used for the measurement of high voltage.



Let  $R_m$  be the meter Resistance

$R_{se}$  is the series resistance

$V_v$  is the voltage of the voltmeter

$V_L$  is the load voltage.

$I_m$  is the current through voltmeter

$$\text{from the figure } V_v = I_m \times R_m \quad (1)$$

$$\& V_L - V_v = I_m R_{se}$$

$$\Rightarrow R_{se} = \frac{V_L - V_v}{I_m} \quad (2)$$

$$I_m = V_v / R_m$$

put the value of  $I_m$  in eqn (2)

$$R_{se} = \frac{V_L - V_v}{V_v} \times R_m$$

$$\text{Again } \frac{V_L - V_v}{V_v} = \frac{R_{se}}{R_m}$$

$$\Rightarrow \frac{V_L}{V_V} - 1 = \frac{R_{se}}{R_m}$$

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

The ratio of  $V_L$  to  $V_V$  is known as the multiplying factor.

The requirements of voltage multiplier are :-

- Resistance should not change with time of usage.
- Temp. coefficient of resistance must be very low so that change in temp. may not affect their resistance value.
- Provision for cooling to dissipate the heat developed as an appreciable amount of power is developed in such resistance.

### Problems:-

Q.) An ammeter having a range of 0-20 A having an internal resistance of  $0.08\Omega$  is to be used to measure up to a range of 0-200 A. calculate the value of shunt resistance required. show the connection diagram?

Soln:-

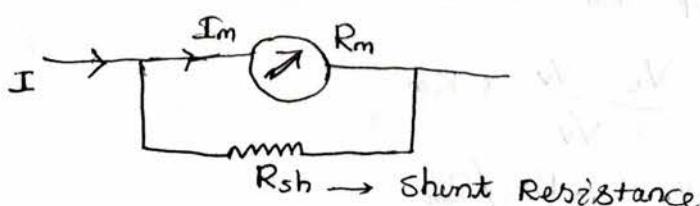
Given  $I = 200A$

$$I_m = 20A, R_m = 0.08\Omega$$

$$\begin{aligned} m &= \text{multiplying factor} = \frac{I}{I_m} \\ &= \frac{200}{20} = 10 \end{aligned}$$

$$\therefore \text{shunt resistance } R_{sh} = \frac{R_m}{m-1}$$

The connection diagram is :-



$$\begin{aligned} &= \frac{0.08}{10-1} \\ &= 0.08/9 \\ &= 8.88 \times 10^{-3}\Omega \end{aligned}$$

Q: How will you use a P.M.M.C instrument which gives full scale deflection at 50 mV p.d and 10 mA current as:- (17)

- i) Ammeter 0-10A range
- ii) Voltmeter 0-250V range.

Soln:-  $R_m = 50\text{mV}/10\text{mA} = 5$

i) As ammeter :-  $I_m = 10\text{mA} = 0.01\text{A}$

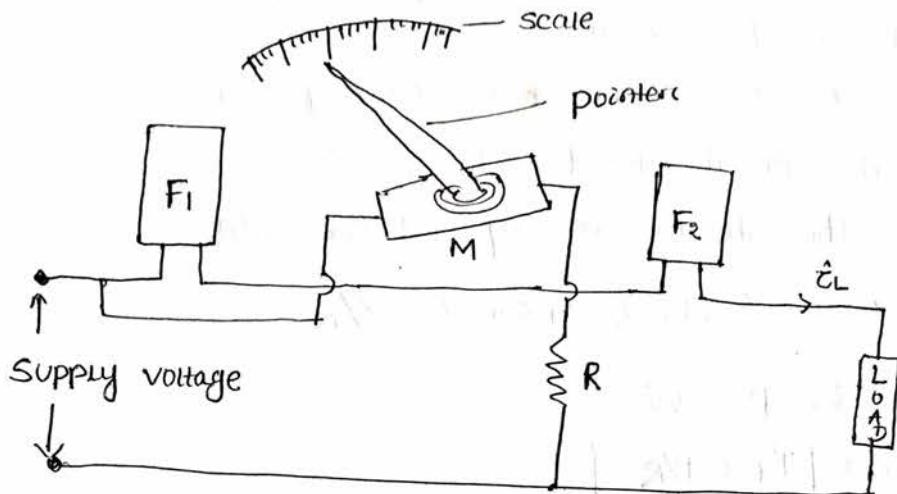
$$I_s = I - I_m = 10 - 0.01 = 9.99\text{A}$$

$$S = \frac{I_m R_m}{(I - I_m)} = \frac{0.01 \times 5}{9.99} = 0.0005\Omega$$

ii) As voltmeter :-  $V = 50\text{mV} = 0.05\text{V}$ ,  $V = 250\text{V}$

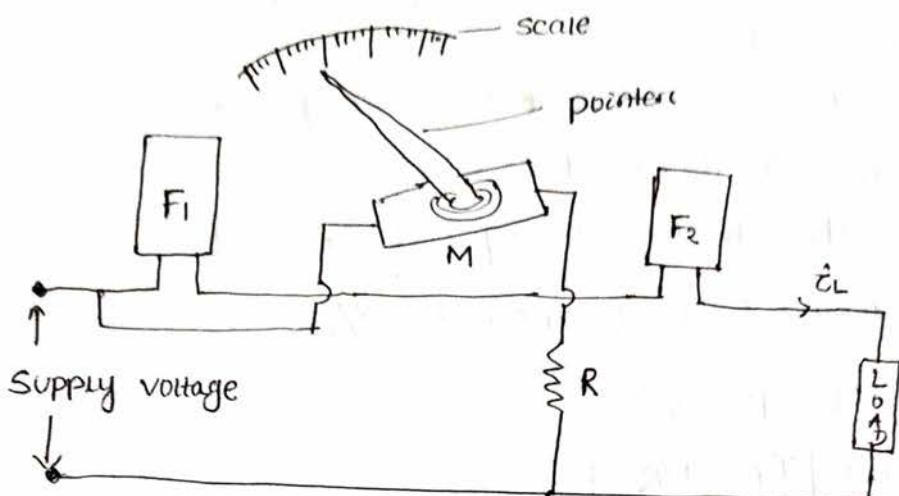
$$R = \frac{V - V}{I_m} = \frac{250 - 0.05}{0.01} \\ = 24995\Omega$$

## Electro Dynamometer Type Wattmeter :-



- It is used both for AC & DC Supply.
- When dynamometer type instrument is used as an wattmeter, the fixed coil which is divided into two equal parts in order to provide uniform field is employed as current coil & the moving coil is used as pressure coil.
- The fixed coil carries the current flowing through the circuit & the moving coil carries the current proportional to the voltage across the circuit.
- A high non-inductive resistance is connected in series with the moving coil in order to limit the current in it.
- The magnetic field of the fixed & moving coil react on one another causing the moving coil to turn around its axis.
- The movement is controlled by hair spring which also lead the current inside & outside of the moving coil.
- Damping is provided by light aluminium vanes moving in the air dash pot.
- Electro magnetic & eddy current damping can't be used as permanent magnet is required for this type of damping.
- A pointer is fixed to the moving coil spindle & move over a calibrated scale.

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Derivation for deflecting torque :-

DC ckt

In a dc ckt let  $V$  is the supply voltage  
 $i$  is the load current

$R$  is the total resistance of the moving coil

Current through the fixed coil.  $i_f = i$

current through the moving coil  $i_m = V/R$

Deflecting torque ( $T_d$ )  $\propto i_f i_m \propto i^2 V/R$

In a dc ckt,  $P = Vi$

Hence  $T_d \propto P/R$

The deflecting torque is proportional to the power.

AC circuit :-

The average value of deflecting torque is given by :-

$$(T_d)_{avg} = V_{avg} \times i_{avg}$$

$$(T_d)_{avg} \propto \frac{1}{2\pi} \int_0^{2\pi} V_{max} \sin \theta \cdot I_{max} \sin(\theta - \phi) d\theta$$

$$\propto \frac{V_{max} I_{max}}{2\pi} \int_0^{2\pi} \sin \theta \cdot \sin(\theta - \phi) d\theta$$

$$\propto \frac{V_{max} I_{max}}{2\pi} \int_0^{2\pi} \left[ \frac{\cos \phi - \cos(2\theta - \phi)}{2} \right] d\theta$$

$$\propto \frac{V_{max} I_{max}}{4\pi} \left[ \theta \cos \phi - \frac{\sin(2\theta - \phi)}{2} \right]_0^{2\pi}$$

$$\propto \frac{V_{max} I_{max}}{4\pi} \times 2\pi \cos \phi$$

$$\propto \frac{V_{max} I_{max}}{2} \times \cos \phi$$

$$\propto \frac{V_{max}}{\sqrt{2}} \times \frac{I_{max}}{\sqrt{2}} \cos \phi$$

$$\propto VI \cos \phi$$

$T_d$  & True power

Thus an electro dynamo type wattmeter, it indicates power, irrespective of the AC or DC supply.

- Advantages :- → Since deflecting torque is proportional to true power in both the cases, i.e. DC & AC and the instrument is spring controlled, the scale of the instrument is uniform.  
→ High degree of accuracy can be obtained by careful design, hence these are used as standard for calibration purposes.

Dis-advantages :-

- As there is no iron core in the coils, the field is very weak. Hence a fairly large number of ampere-turns are required for the fixed as well as the moving coil. This makes the moving system heavy, as well as the power loss in the instrument large.
- A heavy moving element makes the torque-weight ratio small resulting in large frictional errors.
- At low power factors the errors due to the conductance of pressure coil is very serious unless special features are incorporated to reduce its effect.

Errors :— i) pressure coil inductance :-

Let  $r_p$  → Resistance of the pressure coil

$L$  → inductance of the pressure coil

$R$  → Resistance in series with the pressure coil

$R_p$  → Total resistance of the pressure coil cut  
 $(r_p + R)$

$V$  → Voltage applied to the pressure coil cut

$I$  → Current in the current coil cut

$I_p$  → Current in the pressure coil cut

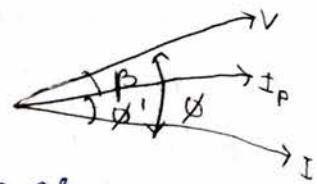
$Z_p$  → is the impedance of the pressure coil cut

$$= \sqrt{(R + r_p)^2 + (\omega L)^2}$$

### Lagging p.f :-

If the pressure coil of the wattmeter has an inductance, the current in it lag the voltage by an angle  $\beta$ .

$$\text{And } \beta = \tan^{-1} \frac{\omega L}{R_p} = \tan^{-1} \frac{\omega L}{(R_p + R)}$$



For lagging p.f, the angle betn

$I_p$  &  $I$  is less than that of  $\phi$  & is given as

$$\phi' = \phi - \beta$$

The actual wattmeter reading

$$= \left( \frac{I_p I}{K} \right) \cos \phi' \frac{dm}{d\theta}$$

$$= \left( \frac{V}{Z_p K} \right) I \cos \phi' dm/d\theta$$

$$= \left( \frac{V}{Z_p K} \right) I \cos(\phi - \beta) dm/d\theta$$

$$\text{And } Z_p = R_p / \cos \beta$$

$$\text{Now actual wattmeter reading} = \frac{VI \cos(\phi - \beta)}{K \left( \frac{R_p}{\cos \beta} \right)} \cdot \frac{dm}{d\theta}$$

$$= \frac{VI}{K R_p} \cos \beta \cos(\phi - \beta) \frac{dm}{d\theta} \quad (1)$$

In the absence of inductance  $Z_p = R_p$  &  $\beta = 0$  & the wattmeter will read true power.

$$\text{True power} = \frac{I_p I}{K} \cos \phi \frac{dm}{d\theta}$$

$$= \frac{VI \cos \phi}{K R_p} \frac{dm}{d\theta} \quad (2)$$

By dividing eqn (2) by eqn (1) we get

$$\frac{\text{True power}}{\text{Actual wattmeter reading}} = \frac{\frac{VI \cos \phi}{K R_p} \frac{dm}{d\theta}}{\frac{VI \cos(\phi - \beta)}{K R_p} \frac{dm}{d\theta} \cos \beta} = \frac{\cos \phi}{\cos \phi \cos \beta}$$

$$\text{True power} = \frac{\cos\phi}{\cos\beta \times \cos(\phi-\beta)} \times \text{Actual wattmeter reading}$$

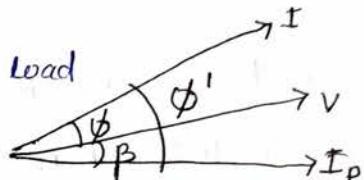
The correction factor is a factor by which the actual wattmeter reading is multiplied to get the true power.

$$\therefore \text{Correction factor} = \frac{\cos\phi}{\cos\beta \times \cos(\phi-\beta)}$$

(for lagging load)

For leading p.f. :-

The wattmeter will read low when the load power factor is leading. Hence the angle between pressure coil & current coil is increased.



$$\text{Correction factor for lagging p.f.} = \frac{\cos\phi}{\cos\beta \cdot \cos(\phi-\beta)}$$

The error in terms of instrument deflection

$$\text{Actual wattmeter reading} - \text{True power}$$

$$= \left( 1 - \frac{\cos\phi}{\cos\beta \cdot \cos(\phi-\beta)} \right) \cdot \text{Actual wattmeter reading}$$

As  $\beta$  is very small, so  $\cos\beta$  is nearly equals to 1.

$$= \left[ 1 - \frac{\cos\phi}{\cos(\phi-\beta)} \right] \times \text{Actual wattmeter reading}$$

$$\text{Error} = \left( 1 - \frac{\cos\phi}{\cos\phi \cos\beta + \sin\phi \sin\beta} \right) \times \text{Actual wattmeter reading}$$

$$= \left( 1 - \frac{\cos\phi}{\cos\phi + \sin\phi \sin\beta} \right) \times \text{Actual wattmeter reading}$$

$$= \left( \frac{\sin\phi \sin\beta}{\cos\phi + \sin\phi \sin\beta} \right) \times \text{Actual wattmeter reading}$$

Divide by  $\sin\phi$  in both the numerators & denominators

$$= \left( \frac{\sin\beta}{\cos\phi \cot\phi + \sin\beta} \right) \times \text{Actual wattmeter reading}$$

This type of error can be minimised by connecting a capacitor across the series resistance.

ii) Pressure coil capacitance :-

Due to capacitance of the pressure coil cut, the current will tend to lead the supply voltage. So errors will be introduced due to capacitance only.

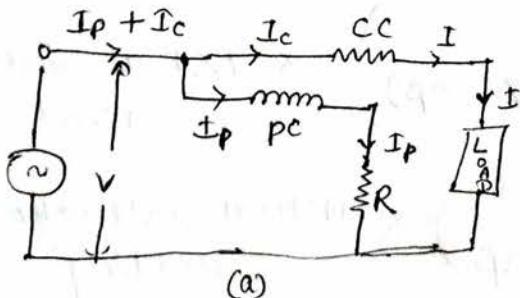
$$\text{The correction factor} = \frac{\sin \theta}{\sin \theta - \cot \theta}$$

If the capacitive reactance is equal to the conductive reactance then the errors will be completely eliminated.

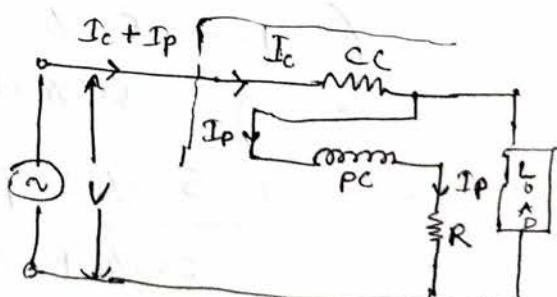
iii) Due to Eddy current :-

- The alternating magnetic field of current coil induces eddy current in the solid metal parts near by the current coil.
- These eddy current set up their own magnetic field & thus alter the magnitude & phase of the magnetic field causing deflection. Thus an error is introduced.
- To eliminate this type of error, solid metal parts are removed as far away from the current coil as possible.

iv) Power loss in pressure coil & current coil :-

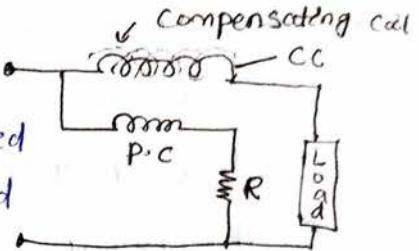


(Current with small value)



(Current of large value)

- In the 1st method, the pressure coil is connected on the supply side of the current coil.
- The potential across the pressure coil is higher than that of the current coil. Wattmeter reads small cu-loss in current coil ( $I^2 R_c$ ). So wattmeter reads  $(W + I^2 R_c)$ .
- In 2nd method the current coil carries the current equal to the load current plus potential coil current.
- So the wattmeter reads the load power plus power load  $[I_p^2 (R + r_{wp})]$  in the pressure coil.
- To overcome these errors, the wattmeter is provided with compensating coil connected in series with the potential coil but so placed that it produces a field in the opposite direction to that of current coil. Thus magnetic compensation is affected for the amount of power taken by the potential coil cut.



#### V. Errors due to friction : -

To reduce the fractional error, the weight of the moving system should be reduced & proper care should be taken in pivoting system.

#### VI. Errors due to heating : -

- Heating errors is mainly due to pressure cut, which carries a current proportional to the potential difference across the terminal & inversely proportional to the impedance.
- This type of error is very small.
- To reduce the error, the pressure coil is wound with pressure coil with as few turns as possible.
- Reduce the current value to obtaining the required torque.

#### VII. Errors due to mutual inductance effect : -

- Errors are caused due to mutual inductance bet<sup>n</sup> the current & potential coil of the instrument.

- The effect of mutual inductance is to increase the phase angle when the current coil is connected on the load side.
- It decrease the phase angle when the current coil is connected on the supply side.
- To overcome the above problem, the wattmeter is so arranged that the mutual inductance bet' the two coil is zero.

VIII. Error due to vibration in moving system : -

- Such type of error is occurred in case of AC only.
- The torque on the moving system varies cyclically with a frequency twice the value of voltage.
- So the pointer spring & some other component of moving system has a natural frequency which is in resonance with the frequency of the torque. Hence there is a considerable vibration on the moving system.
- This errors can be avoided by designing the instrument in such a way that natural frequency of the moving system is very much different from twice the frequency of the system.

ix. Error due to stray magnetic field : -

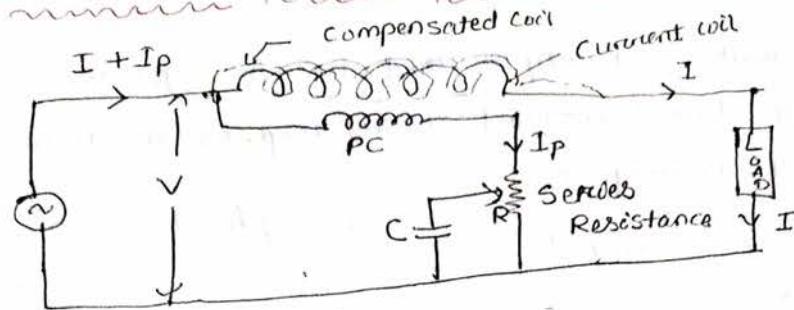
External fields may cause serious errors in ordinary non astatic dynamometers wattmeters unless shielded by means of iron case or laminated shield.

To avoid this type of errors, a covering is provided to the magnetic equipments.

The presence of cover increase the working field & the instrument intend to higher reading.

(9)

Low Powerfactor Electro dynamo meter type wattmeter :-



Ordinary electro dynamo meter type wattmeter can't measure the power in low p.f ckt. Because

- Small deflecting torque on the moving system even when current coil & pressure coil are fully excited.
- Large errors as arises due to inductance of the pressure coil at low power factors.

The dynamo meter type wattmeters can be made suitable for measurement of power in low p.f by following ways.

Pressure coil ckt : - The pressure coil ckt is made of low resistance to make the pressure coil current large resulting in large operating torque.

Compensation for pressure coil current : -

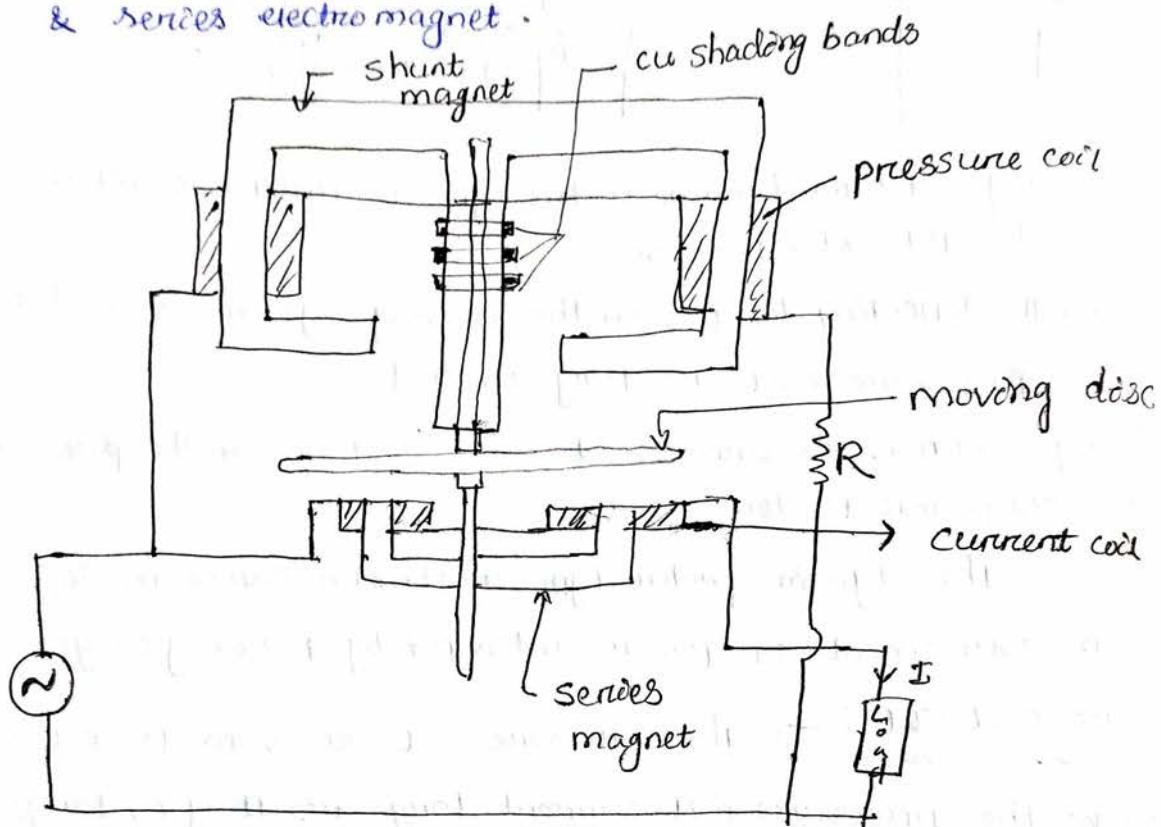
A compensating winding is connected in series with the pressure coil but placed so that it produces a field in opposite direction to that of current coil.

Compensation for inductance of pressure coil : -

- The error caused by inductance of pressure coil is  $\frac{\sin\theta}{\sin\theta + \cot\phi}$  times the actual wattmeter reading.
- At low power factor, the value of the  $\cot\phi$  is large, therefore the error is large.
- The error is reduced by connecting a capacitor across a part of the series resistance in the pressure coil ckt.

## Induction type Wattmeter:-

- This instrument can only be used for AC system.
- It consists of two laminated electro magnets known as shunt magnet & series electromagnet.



- Shunt magnet is excited by the current proportional to the voltage across the load flowing through the pressure coil.
- Series magnet is excited by the load current flowing through the current coil.
- A thin disc made up of Cu or Al is pivoted at the centre & placed in bet<sup>n</sup> the two magnet, so that it cuts the flux from both the magnet.
- The deflecting torque is produced by the interaction of eddy current induced in the disc & inducing flux.
- In order to cause the resultant flux lags by 90° with the supply voltage, copper shading is given to one limb of the shunt magnet.
- The phase displacement bet<sup>n</sup> series & shunt magnet flux can be adjusted by adjusting copper shadings.

- The instrument is provided with spiral spring for controlling torque & permanent magnet for damping torque.
- The scale of such type instrument is quite uniform.
- Two pressure coil are connected in series in such a way that both of them send flux through centre limb.
- Series magnet carries two current coil connected in series & wound so that they magnetise their respective core in same direction.

Theory :-

- The flux  $\phi_{sh}$  lags the voltage  $V$  by  $90^\circ$
- By neglecting hysteresis & saturation effect,  $\phi_{se}$  is proportional & in phase with load current  $I$ .
- EMFs  $E_{sh}$  &  $E_{se}$  induced in the disc due to  $\phi_{sh}$  &  $\phi_{se}$  respectively & lags behind their respective fluxes by  $90^\circ$ .
- The eddy currents  $I_{sh}$  &  $I_{se}$  are set up by emfs  $E_{sh}$  &  $E_{se}$  respectively & are in phase with their respective emfs.
- Now two opposite torque  $\phi_{sh}I_{se}$  &  $\phi_{se}I_{sh}$  will act on the disc.

Hence the net torque is given as :-

$$\phi_{sh}I_{se} - \phi_{se}I_{sh}$$

Angle of  $\phi_{sh}$  &  $I_{se}$  is  $\phi$ .

Angle between  $\phi_{se}$  &  $I_{sh}$  is  $(180 - \phi)$

$$\begin{aligned} \text{Avg torque (Tav)} &\propto [\phi_{sh}I_{se} \cos \phi - \phi_{se}I_{sh} \cos(180 - \phi)] \\ &\propto (\phi_{sh}I_{se} \cos \phi + \phi_{se}I_{sh} \cos \phi) \\ &\propto (\phi_{sh}I_{se} + \phi_{se}I_{sh}) \cos \phi \quad \text{(1)} \end{aligned}$$

Since  $\phi_{sh} \propto V$ ,  $\phi_{se} \propto I$ ,  $I_{se} \propto I$  &  $I_{sh} \propto V$

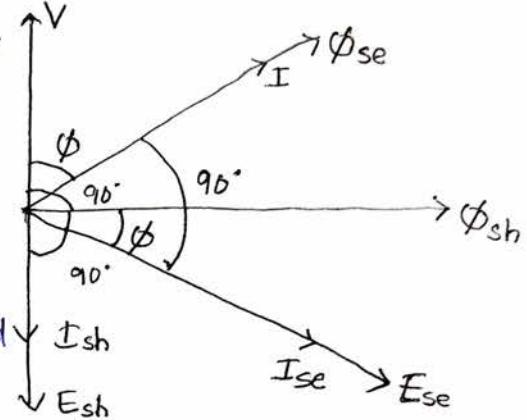
$$\phi_{sh}I_{se} \propto VI = K_1 VI$$

$$\text{And } \phi_{se}I_{sh} \propto VI = K_2 VI$$

Substituting this value in the equ<sup>n</sup>(1) we get

$$(T)_{\text{avg}} \propto (K_1 VI + K_2 VI) \cos \phi$$

$T \propto VI \cos \phi$ ,  $T \propto \text{true power}$  of the circuit.



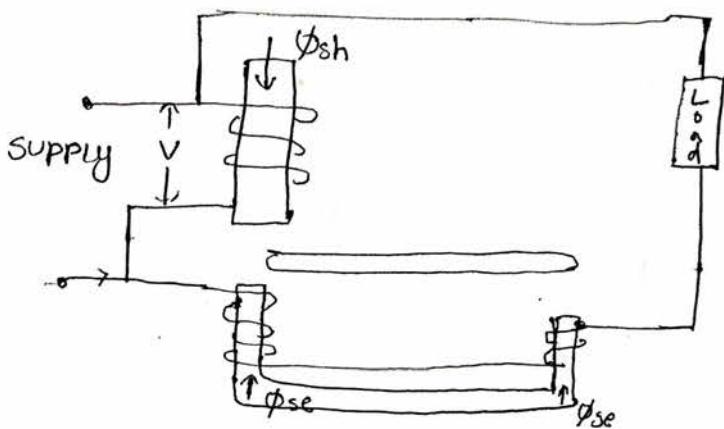
Electrical energy is measured by means of energy meter or watt-hour meter. It is an integrating instrument & power & time can be considered as energy as equal to the product of power & time.

Energy meter keeps a record of total energy consumed on the circuit for a particular period.

It is generally of 3 types

- i) Electrolytic meters
- ii) motor meters
- iii) clock meters

Single phase induction type Energy meter :-



Construction :- Induction type energy meter essentially consists of i) Driving system ii) moving system iii) Braking system iv) Registering system.

- The driving system consists of two electromagnet called as shunt magnet & series magnet.
- The core of these electromagnet is made up of silicon steel lamination.
- The shunt magnet consists of a no. of iron laminations assembled together to form a core.
- A coil having large no. of turns of fine wire is fitted on the middle limb of the shunt magnet. This coil is known as pressure coil & is connected across the supply.

- The potential coil is highly inductive as it has very large no. of turns & reluctance of the cut is very small.
- The series electromagnet consists of no. of iron laminations assembled together to form a core & is wound with few turns of gauge wire known as current coil.
- When load current flows through the current coil it is energized & set up a magnetic field cutting by the rotating disc.
- Copper shading is given on the central limb. So that phase displacement of  $90^\circ$  can be set up between supply voltage & shunt field magnetic flux. It is also known as power factor compensator.
- The moving system consists of rotating Aluminium disc.
- The shunt magnetic field is pulsating in nature & cut by the rotating disc. Hence induces eddy current.
- The reaction bet<sup>n</sup> the two magnetic field & eddy current sets up a driving torque in the disc.
- The breaking system consists of a permanent magnet called the brake magnet.
- The magnet is mounted so that the disc revolves freely in the air gap.
- By changing the position of the brake magnet or by diverting some flux, the speed of the disc may be adjusted.
- The registering system consists of train of gears.

Theory: — Similar to induction type wattmeter. The breaking torque is due to eddy current produced in the Al. disc. Since the magnitude of the eddy current proportional to the speed of the disc. So that  $T_b$  is proportional to the speed.

For steady speed of rotation  $T_d = T_b$

Hence Power  $\propto N$

Meter constant :- We know that

$N \propto$  Energy

$$\Rightarrow N = K \times \text{Energy}$$

$$\text{So meter constant } (K) = \frac{N}{\text{Energy}}$$

$$\Rightarrow K = \frac{\text{No. of revolution}}{\text{kwh}}$$

### Compensation & Adjustment :-

- i) For low lagging p.f. :- The meter will read correctly at only when the shunt magnetic flux lags behind the supply voltage by  $90^\circ$ .  
→ Due to presence of resistance component in potential coil, the shunt magnetic flux lags the supply voltage less than that  $90^\circ$ .  
→ So to make the flux ( $\phi_{sh}$ ) lag behind the voltage by  $90^\circ$ , the following steps are taken.  
ii) place a few turns of fairly thick wire around the central limb of the shunt magnet.

Due to the above arrangement increase in resistance cause decrease in current & mmf in the lag coil. So decrease in value of lag angle. Hence the  $\phi_{sh}$  made to lag behind the supply voltage at an angle  $90^\circ$ .

- iii) place a cu-shading band around the central limb of the shunt magnet.

Hence the adjustment can be made by moving the cu-shading along the axes of the central limb. An error arises due to incorrect adjustment of cu-shading. This can be eliminated by bringing the shading band nearer to the disc.

2) Force friction on light load : -

- Despite every care on the design, the frictional errors are available specially at light load.
- To ensure the meter reading for light load it is necessary to provide a small compensating torque independent load to overcome friction at the bearing & register mechanism.
- The above things can be achieved by placing a small shading loop between the central limb of shunt magnet & disc.
- The interaction between the portion of the flux which are shaded & unshaded & the current induced in the disc produces a small driving torque.
- The torque is independent of load as it depends upon the supply voltage.
- This torque can be adjusted by lateral movement of the loop.

3) Force Creeping : -

- A slight torque developed by the light load adjustment may cause to rotate the disc slowly, when potential coil are excited with no load current. This defect is known as creeping.
- This is prevented by making hole on opposite side of spindle, when one of the holes come under, one of the pole of the shunt magnet, the disc come to rest.
- The adjustment, to avoid creeping called as the preliminary light load adjustment.

4) Force over load : -

- As the disc rotates in between the series magnetic field, an emf is induced in the disc which induces eddy current.
- Due to interaction of eddy current with the field a breaking torque proportional to the square of the current is developed.

- Increase in braking torque increases the current. Hence the resistance tends to low.
  - To minimize self-braking action, the speed is kept low, so that current and flux become low. Hence induced emf responsible for braking is reduced.
- 5) For full load : —
- There is some error in registering system when the meter operate at rated voltage & current at unit power factor.
  - The adjustment can be done by varying the positioning of the magnetic shunt to control the flux passing through the disc.
  - (OR) by moving the brake magnet with respect to disc. So that the meter registers correctly during errors.
- 6) For voltage : —
- The variation in voltage will cause some errors due to non-linear magnetic characteristics of shunt magnet core & due to self-braking torque.
  - The compensation to the variation in voltage can be obtained by using saturated magnetic shunt which do not large amount of magnetic flux, when supply voltage increases.
- 7) For Temperature : —
- An increase in temp. causes increase in resistance so it results decrease in shunt magnetic flux so that there is reduction in angle between  $\phi_h$  & supply voltage.
  - Drop in torque caused by shading bands.
  - An increase in eddy current path resistance.
  - Reduction in angle of lag of the eddy current.

## Methods of Testing of Energy meters : -

(6)

There are 3 methods of testing of energy meters.

### ① Method A - Long period Dial Test : -

- In this method of testing motor meters, a rotating meter of substandard grade is employed to measure the amount of energy passing through the meter under test during given time.
- The current coils of the two meters are connected in series with each other and in series with the load circuit and the voltage coils of the two meters are connected in parallel across the supply cut.
- The two meters are started simultaneously, and after suitable time interval, stopped simultaneously.
- The duration of the test must be long enough for the register of the meter to advance by at least 10 revolutions of the pointer on its lowest reading dial.
- Percentage errors of the meter under test can be calculated from the relation,

$$\boxed{\text{percentage error} = \frac{R - r}{r} \times 100}$$

where R & r are the readings of the test & substandard meters respectively.

Advantage : - only on dial indications of the test meter, the complete elimination of errors due to starting or stopping of substandard stop-watches and the avoidance of any necessity for holding the load absolutely constant.

Dis-advantage : - The length of time required for a single accurate test and thus for the complete set of tests.

### ② Method B - short period Test using a Rotating substandard : -

- In this method of testing of motor meters, a substandard rotating meter of precision type is employed to measure the

Amount of energy passing through the meter - under test  
for a stated number of revolutions of the disc of the meter  
under test.

- The scale of standard meter's largest dial is subdivided so that the position of its pointers can be read to  $\frac{1}{100}$ th of a revolution of the meter's disc.
- An arrangement is also fitted so that the registers of the standard & test meters can be started & stopped instantaneously.
- The three lowest reading pointers can be reset to zero at will.
- After adjusting the load to the required value, the meter under test is allowed to make a certain number of revolutions and the number of revolutions made by the standard in the same time are observed.
- If the constants of both meters are the same, the error in the meter being tested can be obtained directly and if the constants of meters are different then the errors of the meter under test can be found as follows.

Let  $K_x$  be the number of revolutions per kWh for the meter under test.

$K_s$  be the number of revolutions per kWh for the standard &  $N_s$  be the number of revolutions made by the standard during the time, the meter under test takes to complete certain number of revolutions say  $N_x$ .

Now energy supplied = Energy indicated by the standard =  $\frac{N_s}{K_s}$  kWh

Energy indicated by meter under test  
=  $N_x/K_x$  kWh

% age error =  $\frac{N_x/K_x - N_s/K_s}{N_s/K_s} \times 100$

$$= \left( \frac{N_x \cdot K_s}{N_s \cdot K_w} - 1 \right) \times 100$$

(8)

Advantage :- Less time required in comparison with long period dial test, the complete elimination of errors owing to starting or stopping of substandard or stop watches, and the avoidance of any necessity for holding the load absolutely constant.

### ③ Method c - short period Test using a Standard Wattmeter:-

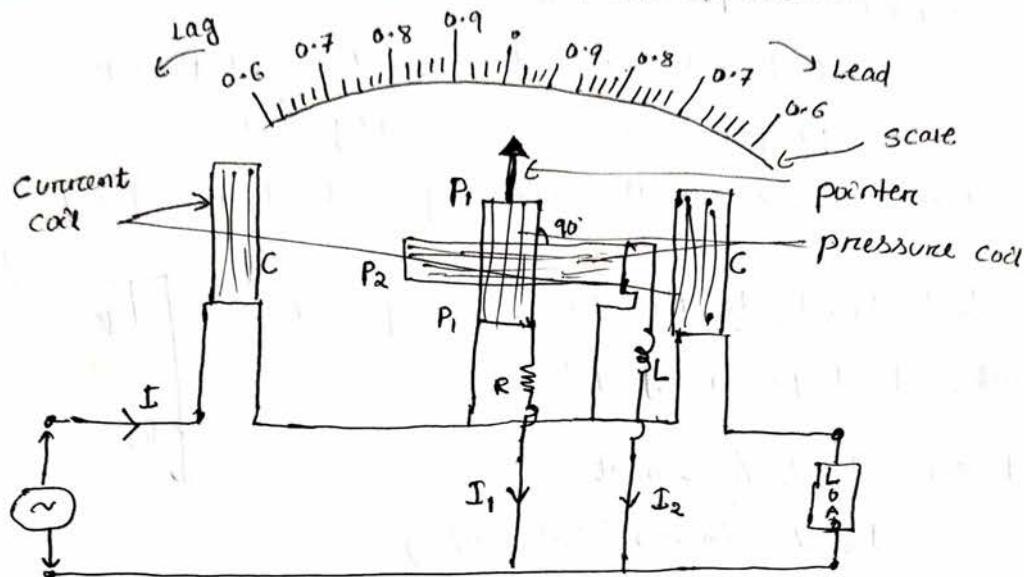
- This is the alone method which is to be used for testing direct current motor meters.
- In this method of testing of meters precision grade indicating instruments are employed as the standard of reference and are connected in the circuit with the meter under test.
- The time taken by the rotor disc of the meter under test to complete 3 revolutions, or the number of revolutions that will make the test period not less than 100 seconds is measured.
- The current & voltage are maintained constant during the test. It may be possible to make the load constant by automatic stabilizers.
- % error of the meter under test is given by -

$$\begin{aligned} \% \text{ error} &= \frac{\frac{N_x}{K_x} - \frac{K_w \cdot t}{3600}}{\frac{K_w \cdot t}{3600}} \times 100 \\ &= \left( \frac{N_x \times 3600}{K_x \times K_w \cdot t} - 1 \right) \times 100 \end{aligned}$$

where  $N_x$  is the number of revolutions made by the meter under test, during time  $t$  seconds when the load is  $K_w$  in Kilowatts, and the constant of the meter under test being  $K_x$  rev/kwh.

Chapter-5 Measurement of Speed, frequency & Power factor

Dynamo meter type 1-φ power factor meter:-



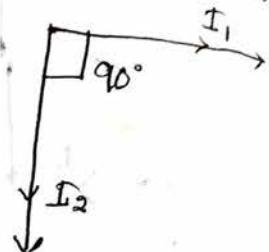
Construction :- → It consists of two fixed coil CC connected in series carrying the load current.

- Two identical coil  $P_1$  &  $P_2$  of fine conductors pivoted on the spindle & fixed at the right angle to each other forming the pressure coil & constituting the moving system.
- The pressure coil  $P_1$  is connected across the supply through the non-inductive resistance  $R$  & pressure coil  $P_2$  through the choke coil of inductance  $L$  to the supply.
- The value of non-inductive resistance  $R$  & the inductance  $L$  are so chosen that for the normal frequency, the current in the two pressure coil  $P_1$  &  $P_2$  are same.
- Due to above reason  $P_1$  &  $P_2$  produce equally strong magnetic field displaced by  $90^\circ$  in space as well as in phase.
- The pressure coil  $P_1$  &  $P_2$  move together & carry a pointer, which indicates the power factor of the circuit directly on the scale.
- For measurement of power factor on high voltage system, the pressure & current coil of the instrument may be connected to the main circuit through the CT & PT respectively.

## Working operation :-

- When the instrument is connected across the ckt to measure the power factor & phase angle.
- The two current  $I_1$  &  $I_2$  flow through the coil  $P_1$  &  $P_2$  & the currents are proportional to the supply voltage.
- These two current in the moving coil differed by an angle  $90^\circ$ .

Let  $I_1, I_2$  be the two moving coil current,  $I_2$  lags  $I_1$  by  $90^\circ$ .



Then  $I_1 \propto V_m \sin \omega t$

$$I_2 \propto V_m \sin(\omega t - \pi/2)$$

The current in the fixed coil depends upon the load & instantaneous value of this current.

$$I \propto I_m \sin(\omega t - \phi)$$

where  $\phi$  is the phase angle bet' the current & voltage of the ckt under test.

The flux produced in the fixed coil given as

$$\phi \propto I_m \sin(\omega t - \phi)$$

Now, the two torque acting on coil  $P_1$  &  $P_2$

The instantaneous value of torque on  $P_1$

$$(T)_{\text{inst} P_1} \propto V_m \sin(\omega t - \pi/2) \cdot I_m \sin(\omega t - \phi) \cdot \cos \theta$$

where  $\theta$  is the angle made by the moving coil with the fixed coil.

The Avg. torque on coil  $P_1$  &  $P_2$  is given as

$$T_{P_1} = VI \cos \phi \sin \theta$$

$$T_{P_2} = VI \sin \phi \cdot \cos \theta$$

The voltage & current <sup>cut</sup> under test at equilibrium position, the two opposing torque are equal.

$$\text{i.e. } T_{P_1} = T_{P_2}$$

$$\Rightarrow VI \cos \phi \sin \theta = VI \sin \phi \cos \theta$$

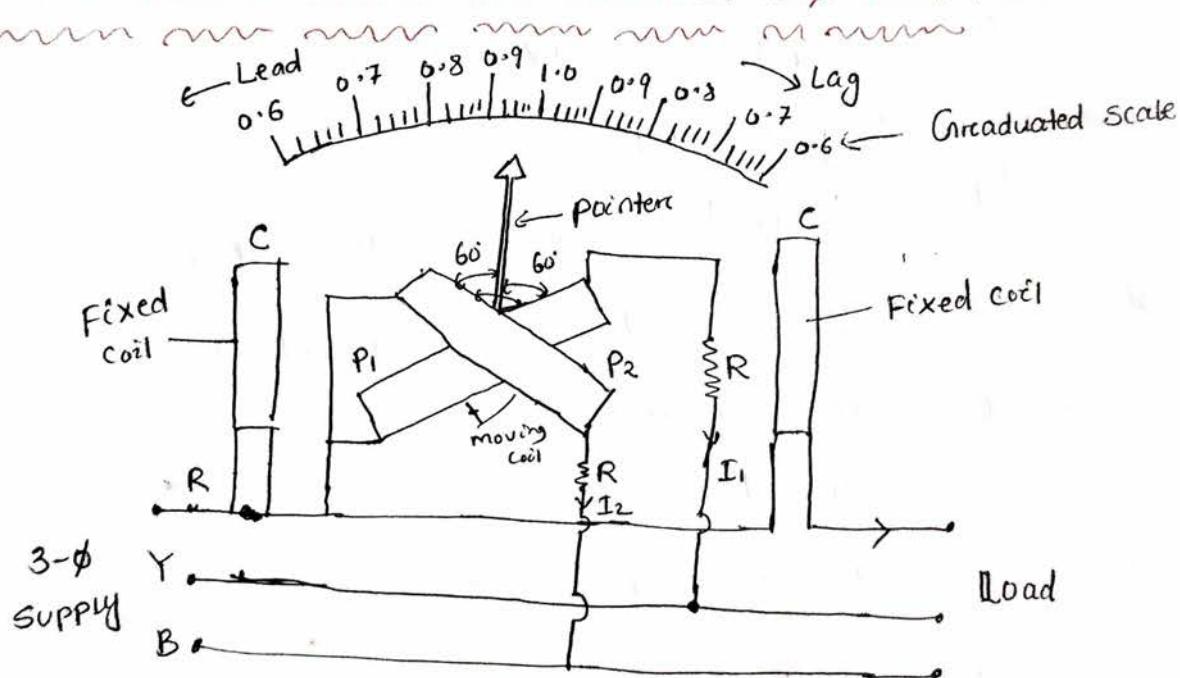
$$\Rightarrow \frac{\sin \theta}{\cos \theta} = \frac{\sin \phi}{\cos \phi}$$

$$\Rightarrow \tan \theta = \tan \phi$$

$$\Rightarrow \boxed{\theta = \phi}$$

As  $\theta$  is the angle bet<sup>n</sup> the moving coil & fixed coil &  $\phi$  is the angle bet<sup>n</sup> the current & voltage are equal, therefore the scale is calibrated in terms of power factor.

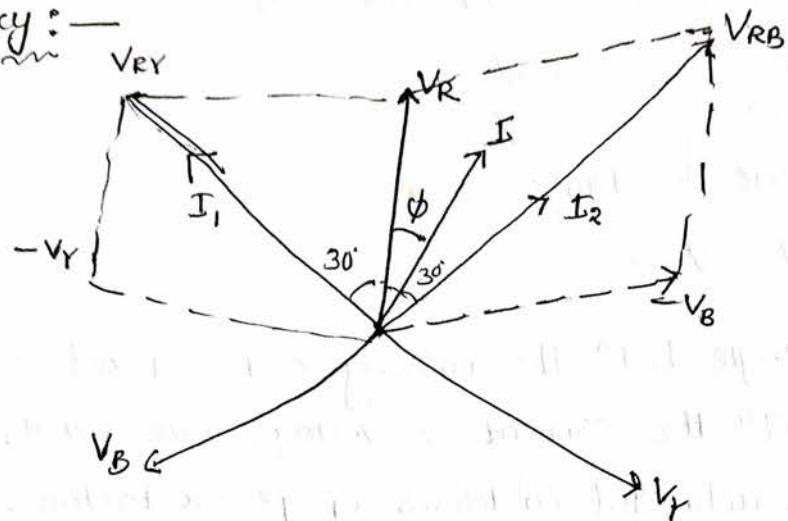
Power factor meter for balanced 3- $\phi$  load :-



- In case of 3- $\phi$  balanced load only one current coil split-up into two halves & two pressure coil are required.
- In all cases instrument transformers can be employed if required.
- The fixed or current coil of the instrument is connected in series with one of the phases.
- The two moving or pressure coils are fixed with their

planes  $120^\circ$  apart on a common spindle carrying a pointer, & are connected through resistance  $R$  across two different phases of the supply current.

Theory:-



From the phasor diagram, the torque acting on coil  $P_1$

$$T_1 = KV_{RY}I \cos(30^\circ + \phi) \sin(60^\circ + \theta)$$

Torque acting on coil  $P_2$

$$T_2 = KV_{RB}I \cos(30^\circ - \phi) \sin(120^\circ + \theta)$$

Since the torque  $T_1$  &  $T_2$  act in opposite direction

So at equilibrium state,

$$T_1 = T_2$$

$$\Rightarrow \cos(30^\circ + \phi) \sin(60^\circ + \theta) = \cos(30^\circ - \phi) \sin(120^\circ + \theta)$$

By solving the above equation we get

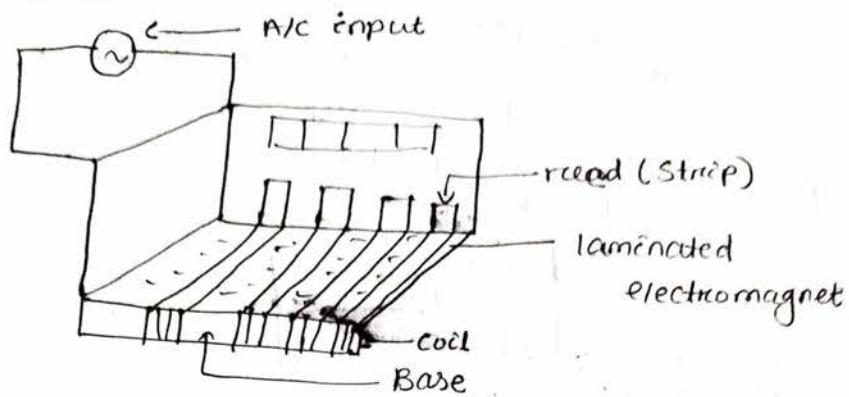
$$\boxed{\theta = \phi}$$

Advantage:- The dynamometer type instrument is more accurate than moving iron type.

Dis-advantages:- → The scale arc is limited.

→ The connecting ligaments or threads to the moving coils are required, which subject the moving system of the instrument to a minimum of restraint.

## Mechanical Resonance type frequency meter :-



Principle :- Its working based on the principle of mechanical resonance of thin strip which are arranged vertically close to the electromagnet.

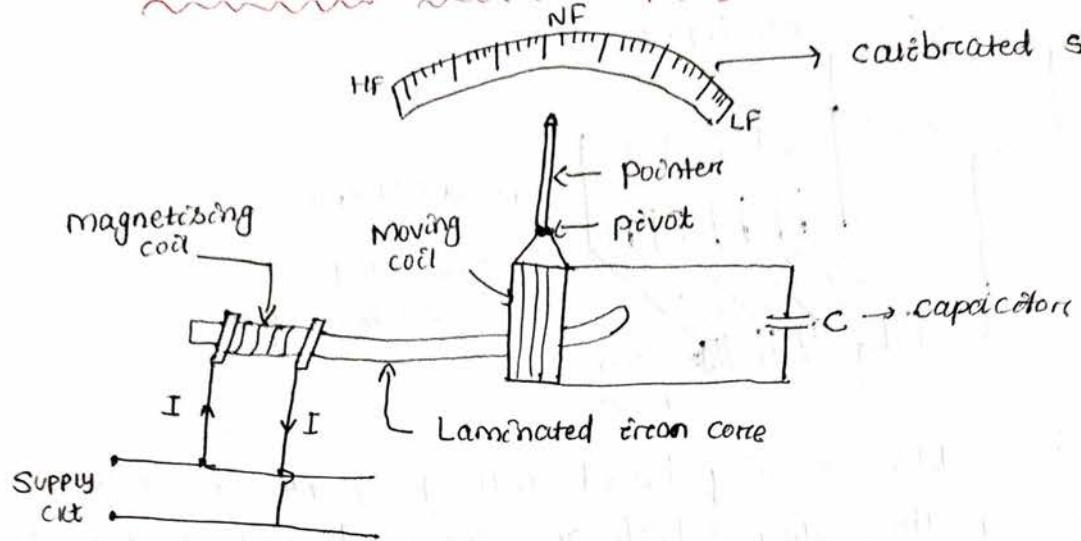
Construction :- → It is also known as vibrating reed type instrument.

- It consists of a laminated electromagnet which is wound with few no. of turns in series with some external resistance.
- Some mechanical reeds arranged vertically & mounted side by side on a common base which will carry the armature of a electromagnet.
- The upper free end of the reed are bent over at right angle & it is pointed with white for better visibility.
- The successive reeds are not exactly similar to the natural frequency of vibration & differing by half cycle.
- The reeds are arranged ascending order of natural frequency

Operation :- → When A.C voltage is applied to the coil of the electromagnet, whose frequency is to be measured, a current is passes through the coil & a mmf will set up a flux in the core.

- As the mmf is alternating in nature, hence the electromagnet exerting alternating force on each reed in every half cycle.
- All reed will tend to vibrate but ~~not~~ only that whose frequency is double.
- The supply frequency vibrate with max<sup>n</sup> amplitude due to mechanical resonance. → The supply frequency read the direct frequency, note the scale mark opposite the white painted flag which is vibrate more.

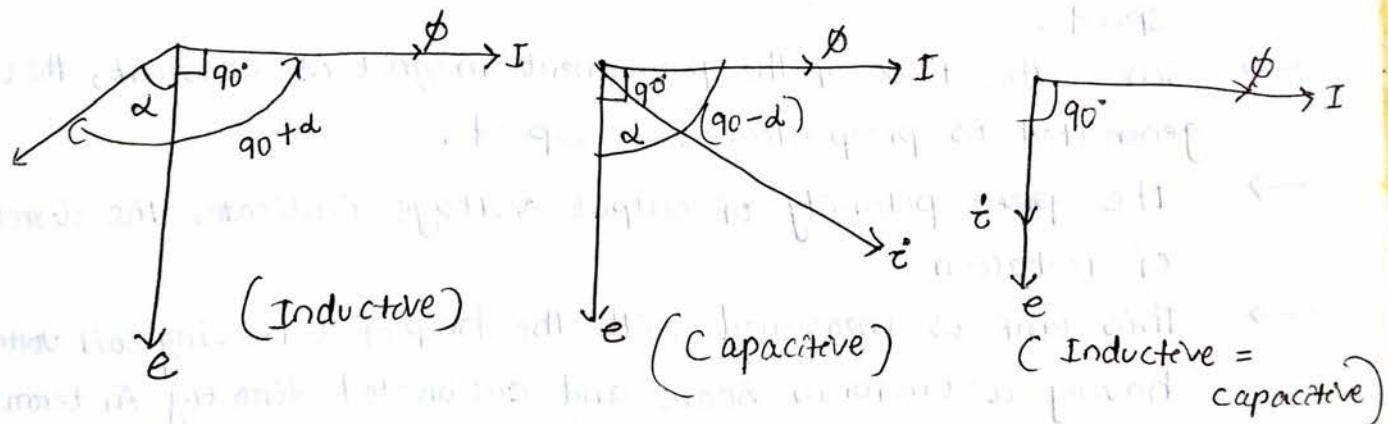
## (6) Electrical Resonance type Frequency meter:-



- It consists of a laminated iron core of varying cross-section.
- a fixed magnetizing coil mounted at one end of the iron core.
- It also consists of a moving coil with a pointer attached to it & pivoted in such a way that it can move freely over the iron core.
- The magnetizing coil is connected across the supply whose frequency is to be measured.
- When the magnetizing coil is connected across the supply cut
  - i) current  $I$  flows through it & a flux  $\phi$  is in phase with current  $I$ .
  - ii) An emf ' $e$ ' lagging the flux  $\phi$  at an angle  $90^\circ$  is induced in the moving coil.
- If the cut is largely inductive, the current in the moving coil lags the emf  $e$  & if the cut is capacitive, the current in the moving coil lead the emf  $e$ .
- When  $X_L = X_C$  in the cut of the moving coil, the current  $I$  is in phase with e.m.f.  $e$ .
- The torque on the moving system which has no controlling device proportional to  $I_i \cos(90^\circ \pm \alpha)$ .  
where  $I$  → magnetizing coil current  
 $i$  → moving coil current

(7)

- When the inductive reactance is equal to capacitive reactance, the phase angle will be zero. Hence the torque on the moving system will be zero & there is no movement of the moving system.
- When the magnetising coil connected across the supply cut, & the supply frequency is such that inductive reactance is not equal to capacitive reactance, the torque will act on the moving system.
- If the supply frequency increases, the capacitive reactance decreases, the pivoted coil will move away from the magnetising coil till its inductance become equal to the capacitive reactance & indicate increased frequency.
- If the supply frequency falls, the capacitive reactance increases, the pivoted coil will move towards the magnetising coil till its inductive reactance become equal to the capacitive reactance & indicate reduced frequency.



## Electrical Tachometers :-

The electrical tachometers are preferred over mechanical tachometers for all applications because these tachometers offer all the advantages associated with electrical transducers.

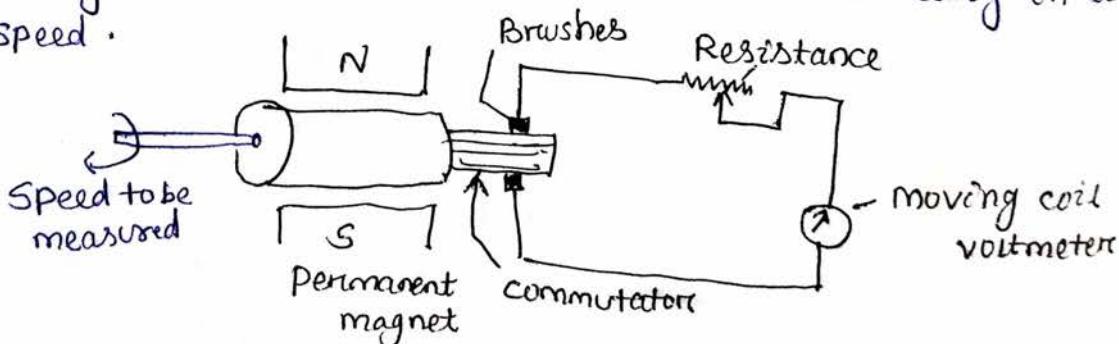
### Electromagnetic Tachometer Generators :-

There are 2 types of electromagnetic tachometer generators called tacho generators. These are:-

- i) D.C. tachometer generators & ii) A.C. tachometer generators

#### i) D.C. Tachometer Generators :-

- D.C. tachometer generator consists of a small armature which is coupled to the machine whose speed is to be measured.
- This armature revolves in the field of a permanent magnet.
- The emf generated is proportional to the product of flux & speed.
- Since the flux of the permanent magnet is constant, the voltage generated is proportional to speed.
- The ~~pole~~ polarity of output voltage indicates the direction of rotation.
- This emf is measured with the help of a moving coil voltmeter having a uniform scale and calibrated directly in terms of speed.



#### Advantages :-

- The direction of rotation is directly indicated by the polarity of the output voltage.
- The o/p voltage is typically  $10\text{mV}/\text{rpm}$  and can be measured with conventional type d.c voltmeters.

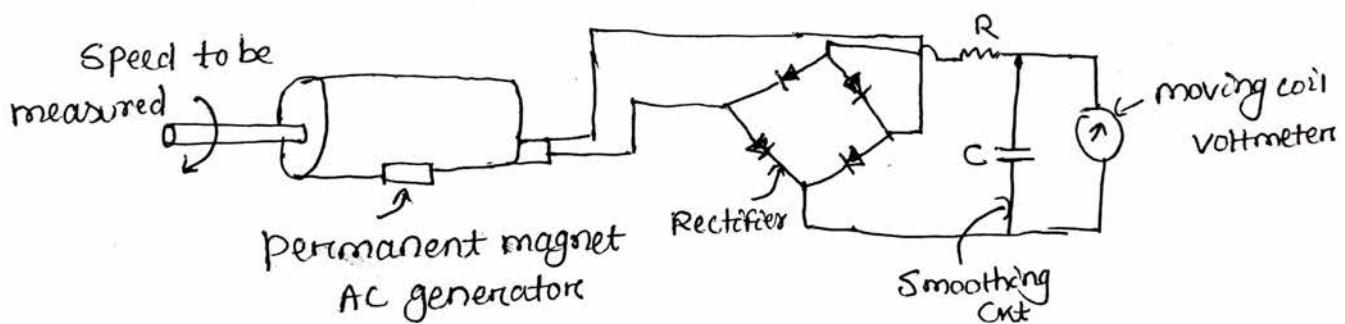
## Dis-advantages :-

(9)

Brushes on small tachometer generators often produce maintenance problems as their contact resistance may vary and produce appreciable errors.

## ② A.C Tachometer Generators :-

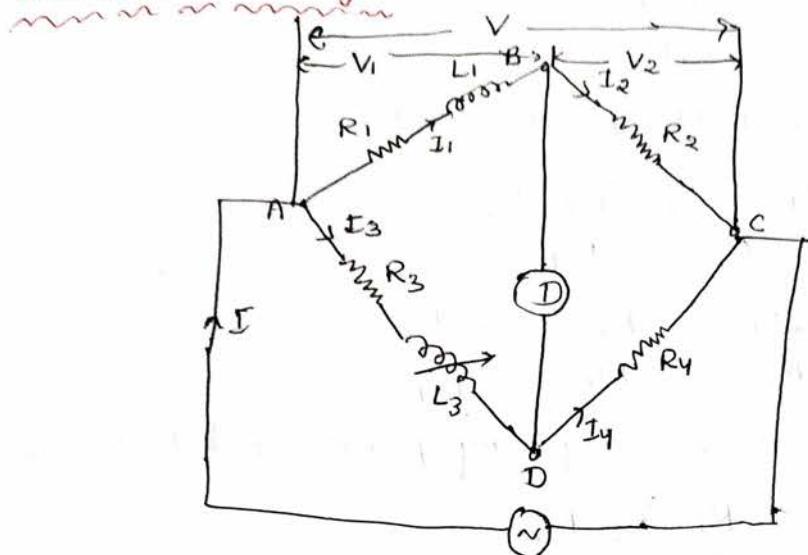
- In order to overcome some of the difficulties mentioned above, a.c tachometer generators are used.
- The tachometer generator has rotating magnet which may be either a permanent magnet or an electro magnet.
- The coil is wound on the stator & therefore the problems associated with commutator (as in d.c tachometers) are absent.
- The rotation of the magnet causes an emf to be induced in the stator coil.
- The amplitude & frequency of this emf are both proportional to the speed of rotation. Thus either amplitude or frequency of induced voltage may be used as a measure of rotational speed.



Limitation :- → The difficulty with this system is that at low speed, the frequency of o/p voltage is low and hence it is very difficult to smooth out the ripples in the output voltage wave-shape. → High speeds also present a problem.

① Chapter-6 Measurement of Resistance, Inductance & capacitance

Maxwell's Bridge:



- This method is very suitable for accurate measurement of medium inductances.
- In this method unknown inductance is determined by comparing it with a standard self inductance.
- Such a bridge circuit is shown in fig. in which  $L_1$  is an unknown self inductance of resistor  $R_1$ .
- $L_3$  is a known variable inductance of resistor  $R_3$  whose resistance is constant,  $R_2$  &  $R_4$  are pure resistances and  $D$  is a detector.
- The magnitude of  $L_3$  should be of the same order as that of  $L_1$ .
- The bridge is balanced by varying  $L_3$  and one of the resistances  $R_2$  or  $R_4$ .

When the bridge is balanced, the current flowing through detector  $D$  is zero and

$$I_1 = I_2 ; I_3 = I_4$$

P.D across arm AB = P.D across arm AD =  $V_1$

$$\therefore I_1 Z_1 = I_3 Z_3 = V_1$$

$$\text{Or } I_1 (R_1 + j\omega L_1) = I_3 (R_3 + j\omega L_3) = V_1 \quad (1)$$

(2)

and PD across arm BC = PD across arm CD =  $V_2$

$$\text{or } I_2 R_2 = I_4 R_4 = V_2$$

$$\text{or } I_2 R_2 = I_3 R_4 \quad \text{--- (2)}$$

Dividing expression (1) by expression (2) we have

$$\frac{R_1 + j\omega L_1}{R_2} = \frac{R_3 + j\omega L_3}{R_4}$$

$$\text{or } \frac{R_1}{R_2} + \frac{j\omega L_1}{R_2} = \frac{R_3}{R_4} + \frac{j\omega L_3}{R_4}$$

Equating the real & imaginary parts of both sides separately we have  $\frac{R_1}{R_2} = \frac{R_3}{R_4}$

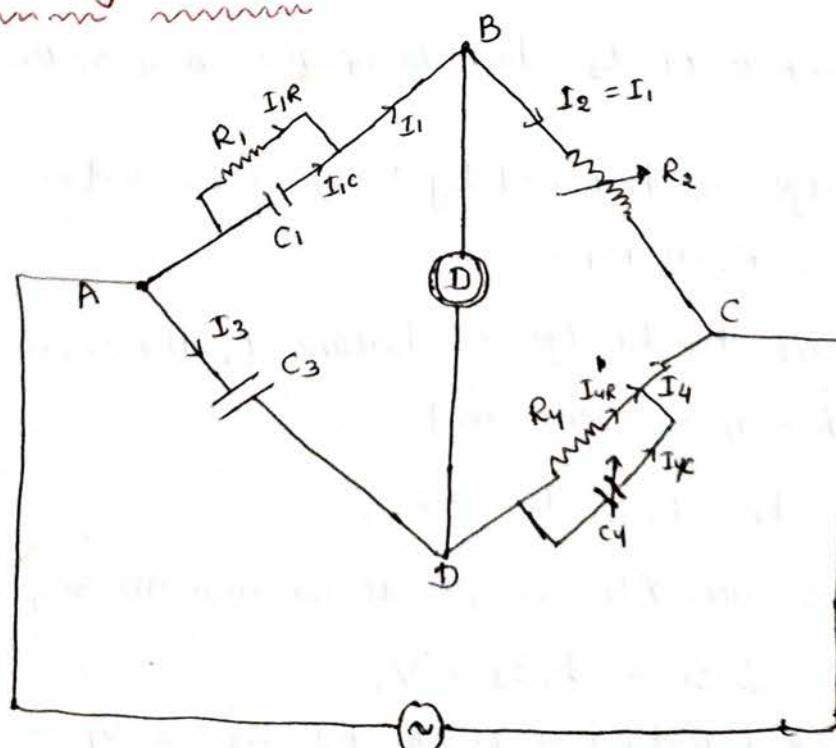
$$\text{or } R_1 = \frac{R_2}{R_4} R_3$$

$$\text{and } \frac{\omega L_1}{R_2} = \frac{\omega L_3}{R_4}$$

$$\text{or } L_1 = \boxed{\frac{R_2}{R_4} \cdot L_3}$$

Thus value of unknown self inductance  $L_1$  can be determined.

### Schering Bridge : —



- The Schering bridge is one of the most important and useful circuit available for measurement of capacitance and dielectric loss.
- It is widely used for both measurement of capacitors on low voltage & also at high voltage.
- In the above figure,

$C_1 \rightarrow$  is the unknown capacitor

$R_1 \rightarrow$  is an imaginary resistance representing its dielectric loss component

$C_3 \rightarrow$  is the standard capacitor

$C_4 \rightarrow$  is the variable capacitor

$R_2, R_4 \rightarrow$  are known non-inductive resistors  
& the resistance  $R_2$  is variable.

$$Z_1 = \frac{1}{\frac{1}{R_1} + \frac{1}{-\jmath/\omega C_1}} = \frac{R_1}{1 + j\omega C_1 R_1}$$

$$Z_2 = R_2, \quad Z_3 = -\jmath/\omega C_3$$

$$Z_4 = \frac{1}{\frac{1}{R_4} + \frac{1}{-\jmath/\omega C_4}} = \frac{R_4}{1 + j\omega C_4 R_4}$$

At balanced condition

$$Z_1 Z_4 = Z_2 Z_3$$

$$\Rightarrow \frac{R_1}{1 + j\omega C_1 R_1} \times \frac{R_4}{1 + j\omega C_4 R_4} = \frac{-jR_2}{\omega C_3}$$

$$\Rightarrow \frac{R_1 R_4}{1 + j\omega C_1 R_1} = \frac{-jR_2}{\omega C_3} (1 + j\omega C_4 R_4)$$

$$\Rightarrow \frac{R_1 R_4 (1 - j\omega C_1 R_1)}{(1 + j\omega C_1 R_1)(1 - j\omega C_1 R_1)} = \frac{-jR_2}{\omega C_3} (1 + j\omega C_4 R_4)$$

$$\Rightarrow \frac{R_1 R_4 (1 - j\omega C_1 R_1)}{1 + \omega^2 C_1^2 R_1^2} = \frac{-jR_2}{\omega C_3} + \frac{R_2 C_4 R_4}{C_3}$$

Equating real terms in the above equation

$$\frac{R_1 R_4}{1 + \omega^2 C_1^2 R_1^2} = \frac{R_2 C_4 R_4}{C_3} \Rightarrow \boxed{\frac{R_1}{1 + \omega^2 C_1^2 R_1^2} = \frac{R_2 C_4}{C_3}}$$

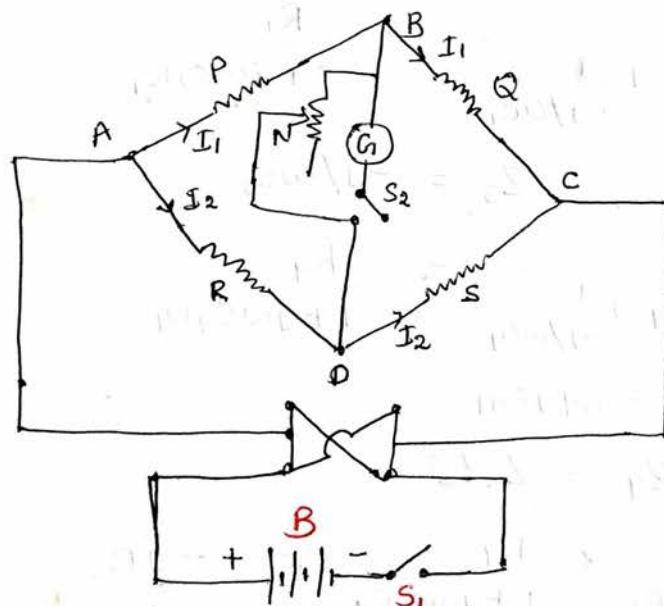
## (4) Classification of Resistance :-

Resistance is classified into 3 types.

- i) Low Resistance : - Resistance of  $1\Omega$  & under this include in this class.
- ii) Medium Resistance : - Resistance ranging from about  $1\Omega$  to about  $100\Omega$  are included in this class.
- iii) High Resistance : - Resistance of  $100\Omega$  & above included in this category.

### Wheatstone Bridge method : -

→ This is one of the most widely used method for the measurement of resistance of medium value.



- In the above circuit P, Q, & S are the known adjustable resistances.
- The unknown resistance  $R$  is connected through A & D.
- A sensitive galvanometer  $G$  shunted by  $N$  to avoid deflection of galvanometer, when the bridge is out of balance.
- Balance the bridge by closing the switch  $S_1$  &  $S_2$  and by adjusting the resistance  $P$ ,  $Q$  &  $S$ .

$$\text{At balance condition } I_1 P = I_2 R \quad \text{--- (1)}$$

$$I_1 Q = I_2 S \quad \text{--- (2)}$$

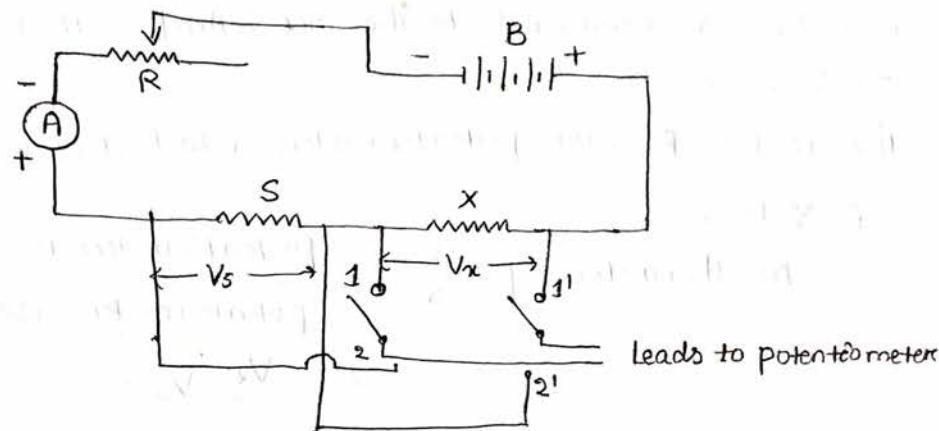
By dividing eqn(1) by eqn(2) we get

(5)

$$\frac{P}{Q} = \frac{R}{S}$$
$$\Rightarrow R = \frac{P \times S}{Q}$$

Thus from known value of P, Q & S, the unknown resistance can be calculated.

### Measurement of low Resistance by Potentio-meter method :-



- This instrument is used for the measurement of very low resistance.
- It is based on the comparison of one resistance against another resistance.
- Here the unknown resistance is X, an ammeter A, a rheostat R is used to limit the current & A standard S are connected & all are connected in series with low voltage high current supply source.
- The resistance of the standard resistor must be same order, & same current or higher current rating than the resistance under testing.
- The ammeter inserted in the ckt is to indicate whether the current flowing through the ckt is of correct magnitude or not.
- The current flowing through the ckt is adjusted so that potential difference across each of resistor of about 1V.

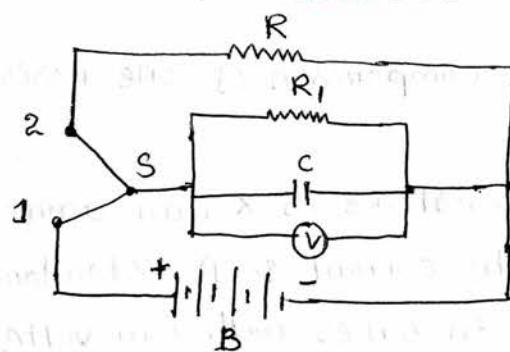
(6)

- The current leads used in the ckt must be adequate cross-section to carry the rated current without heating.
- The voltage drop across both the unknown resistance  $X$  & known resistor 'S' are measured by a dc potentiometer.
- The ratio of two potentiometer readings gives the ratio of  $X$  to  $S$ .
- The switch when placed on position 1 & 1', the unknown resistance  $X$  to potentiometer & the drop across the resistor is  $V_x$ .
- Then the switch is placed on position 2 & 2', the standard resistor is connected to the ckt. And voltage drop across it is  $V_s$ .
- The ratio of two potentiometer readings gives the ratio of  $X$  to  $S$ .

Mathematically  $\frac{X}{S} = \frac{\text{Potentiometer reading across } X}{\text{Potentiometer reading across } S}$

$$= V_x / V_s$$

### Measurement of High Resistance by loss of charge method



- In the above ckt  $C$  is the capacitor of known capacitance
- $V$  → is the electrostatic voltmeter
- $R_1$  → is the total leakage resistance of the capacitor & voltmeter
- $R$  → is the resistance to be measured

At first the capacitor is charged by means of battery to some suitable voltage by putting switch 'S' on stud 1.

Then allowed to discharge through the resistance  $R$  &  $R_1$  by throwing switch 'S' on Stud-2.

$t$  is the time taken for the potential difference to fall from  $V_1$  to  $V_2$  during discharge.

Let the equivalent resistance of  $R_1$  &  $R$  connected in parallel with  $R$ .

If at any instant, the voltage across the discharging capacitor is  $v$  volt.

The charge on the discharging capacitor is  $q$  coulombs.  
And capacity of capacitor is  $C$  farad.

Then the current  $i$  at this instant is given as

$$i = -\frac{dq}{dt} = -C \frac{dv}{dt}$$

Also  $i = \frac{\text{Potential drop across resistance } R'}{R'} = \frac{v}{R'}$

Comparing two expressions, we have

$$\frac{v}{R'} = -C \frac{dv}{dt}$$

$$\Rightarrow \frac{dv}{v} = -\frac{dt}{CR'}$$

Integrating the above equation from  $V_1$  to  $V_2$  & 0 to  $t$  we have

$$\int_{V_1}^{V_2} \frac{dv}{v} = \int_0^t -\frac{dt}{CR'}$$

$$\Rightarrow \left[ \log_e v \right]_{V_1}^{V_2} = \left[ -\frac{t}{CR'} \right]_0^t$$

$$\Rightarrow \log_e V_2/V_1 = -\frac{t}{CR'}$$

$$\Rightarrow V_2 = V_1 e^{-t/CR'}$$

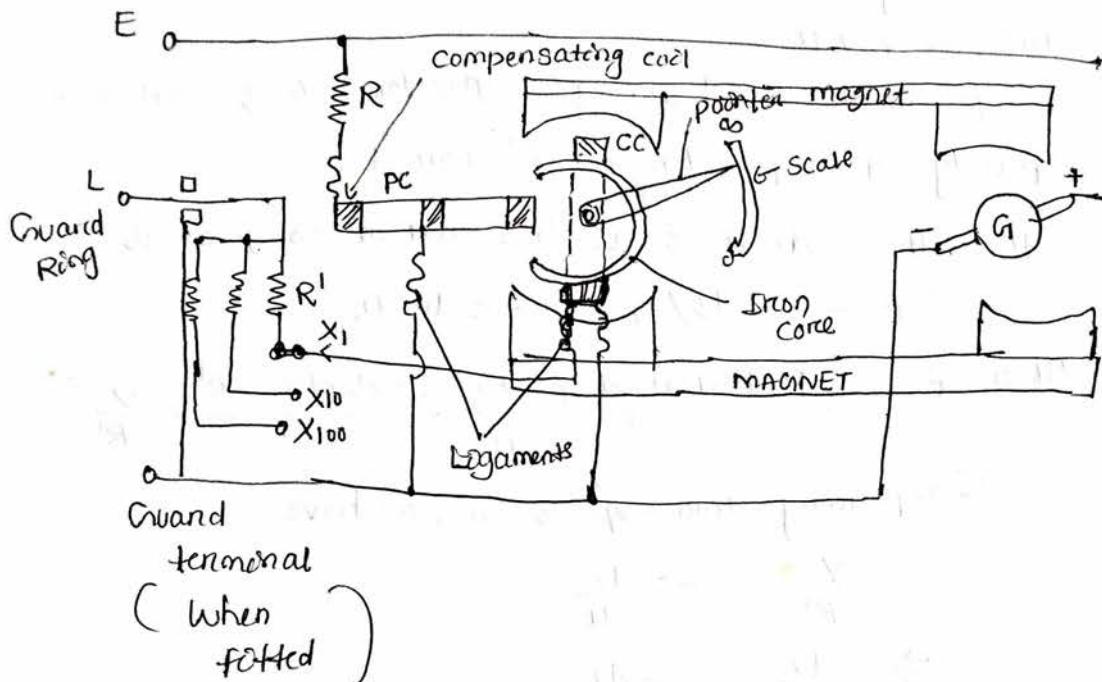
From the above equation the value of  $R'$  can be determined.

The above test is then repeated with unknown resistance  $R$  disconnected, now the capacitor is discharged through  $R_1$  only. And the value of  $R_1$  can be determined.

By knowing the value of  $R'$  &  $R_1$ , the unknown resistance  $R$  can be determined from the equation

$$\frac{1}{R} = \frac{1}{R'} + \frac{1}{R_1}$$

Measurement of insulation Resistance by megger : -



- The megger is an instrument used for the measurement of high resistance & insulation resistance.
- It consists of hand driven dc generator & a direct reading true ohm-meter.
- The moving element of ohm-meter consists of 3 coils known as current coil, pressure coil & compensating coil which are mounted on central shaft, which are free to rotate over a stationary C-shaped iron core.
- The coils are connected to the circuit by means of flexible leads that exert no restoring torque on the moving element.
- The current coils are connected in series with the resistance  $R'$  between one generator terminal & the test terminal 'L'.

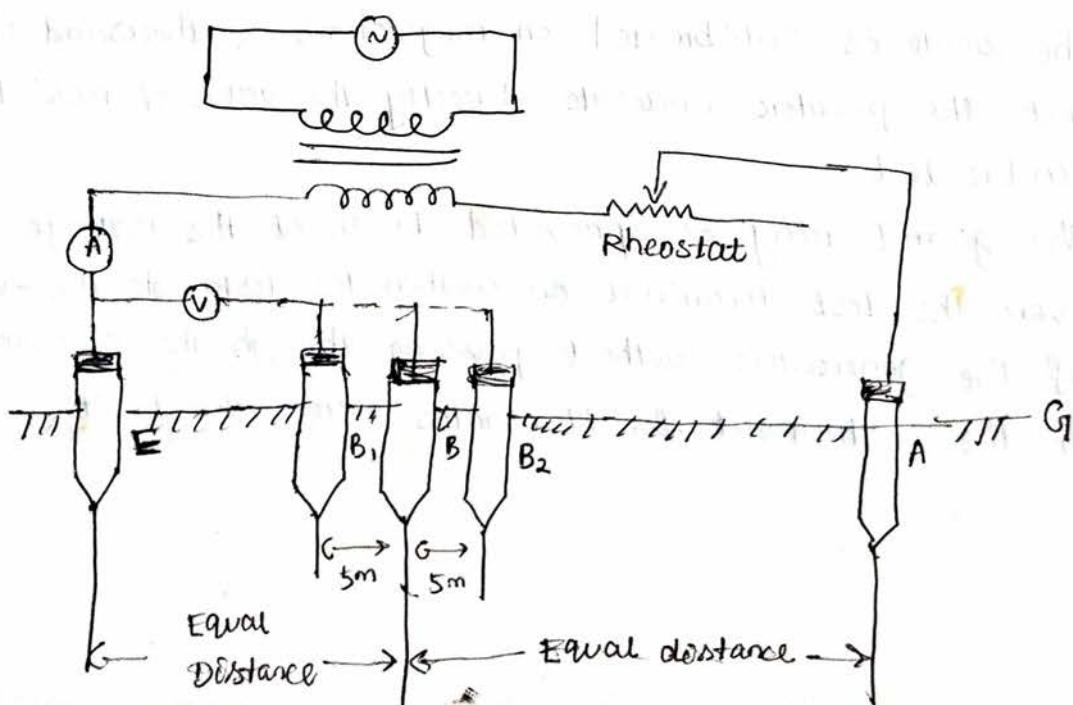
- (9)
- The series resistance  $R$  protect the current coil in case the test terminal are short circuited & also control the range of the instrument.
  - The pressure coil in series with a compensating coil & protection resistance  $R$  is connected across the generator terminals.
  - When the current from the generators flows through the pressure coil, the coil tends to set itself at right angle to the field of the permanent magnet.
  - The pressure coil thus governs the motion of the moving element, causing it to move to its extreme counter clockwise direction.
  - Current coil is wound to produce clockwise torque on the moving element.
  - The current flowing through current coil is large enough to produce enough torque to overcome counter clockwise torque of pressure coil.
  - It moves the pointer to its extreme clockwise position.
  - The point on the scale indicated by the pointer under this condition is marked zero resistance.
  - When a resistance under test is connected between the test terminal L & E, the opposing torque of the coil balance each other so that the pointer comes to rest at some intermediate point on the scale.
  - The scale is calibrated in megohms & thousand ohm so that the pointer indicate directly the value of resistance under test.
  - The guard ring is provided to shunt the leakage current over the test terminal or within the tester to the -ve terminal of the generator without passing through the current coil of the instrument & eliminates errors due to it.

## 10 Measurement of Earth Resistance : -

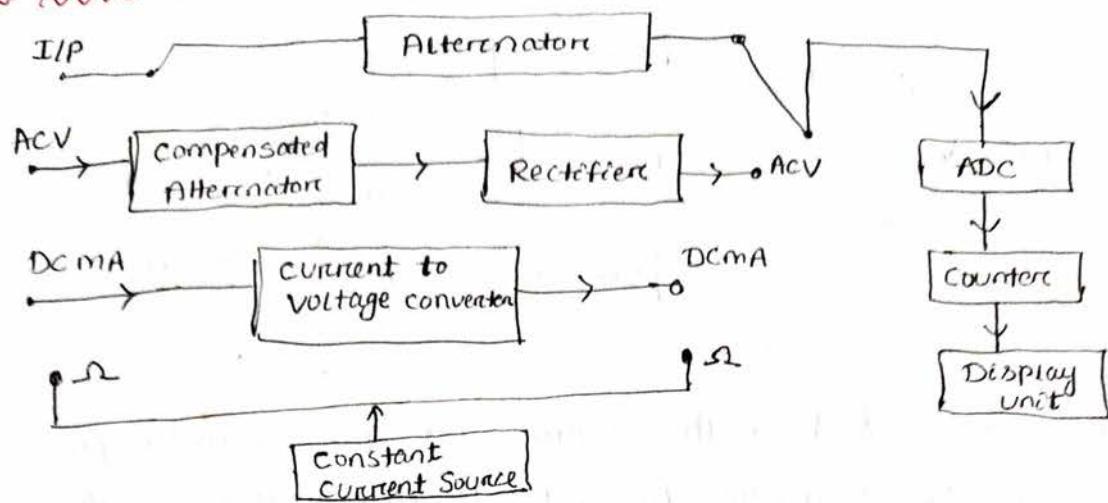
- The determination of resistance between earth plate and the surrounding ground is made by the potential fall method.
- In the fig. E is the earth electrode under test.
- A' is an auxiliary earth electrode positioned. So that two resistance areas do not overlap.
- B is a second auxiliary electrode placed half way between E & A.
- An alternating current of steady value is passed through the earth path E & A and the voltage drop between E & B is measured.

$$\text{Earth Resistance } (R_E) = \frac{\text{Voltage drop bet' E & B}}{\text{current through earth path}}$$

- The auxiliary electrode B is moved to position B<sub>1</sub> & B<sub>2</sub> respectively. If the value of resistance in all cases is same, then the mean of the 3 readings can be taken as the earth resistance.
- The auxiliary electrode A must be driven in at a point further away from E & the above test repeated until a group of 3 readings obtained are in good agreement.

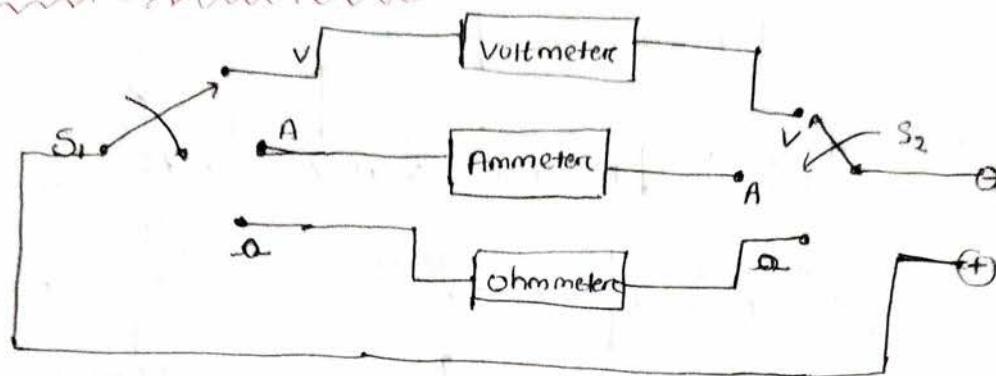


## Digital Multimeter :-



- Digital multimeter is basically a digital voltmeter & used for measurement of voltage, current & resistance.
- All quantities other than dc voltage are first converted into an equivalent dc voltage by some device.
- For measurement of Ac voltage, the input voltage is converted into dc voltage by a rectifier.
- Here a compensated alternator is employed.
- For measurement of resistance a constant current depending upon range supplied from a battery & the voltage developed across it is measured.
- The resistance value displayed in  $\Omega$ .
- For measurement of current, the unknown current is passed through digital multimeter & the voltage developed on the precision resistor is measured.
- The current value displayed in mA.
- For measurement of current a current to voltage converter is also employed.
- The current under measurement is applied to the summing junction at the input of the op-amp.

## (12) Analog Multimeter :-



- It works based on the d'Arsonval galvanometer principle.
- It consists a needle to indicate the measured value on the scale.
- A coil moves in a magnetic field when current passes through it.
- With the shunt resistance, an analog multimeter can measure even multi-ammeters or ammeter ranges of current.
- Here we are using two switches namely  $S_1$  and  $S_2$  to select the desired meter.
- We may use additional range-selector switches to choose particular range required in reading amperes, volts and ohms.
- We use a rectifier to measure an AC voltage or current with the multimeter.

Advantages:- → A sudden change in signal can detect by analog multimeter more swiftly than a digital multimeter.

- All measurements are possible by using one meter only.
- Increase or decrease in signal levels can be observed.

Dis-advantages:- → Analog multimeters are bulky in size.

- They are bulky & costly.
- The pointer movement is slow, can't be used to measure voltages with frequencies higher than 50 Hz.
- Inaccurate due to the effect of earth magnetic field.

## Sensors & Transducers

Chapter - 7 ① Pg.

- ⇒ It is defined as a device which converts energy or information from one form to another.
- ⇒ These are widely used in measurement work because all quantities that need to be measured, can not be displayed as easily as others.
- ⇒ It consists of an input device, a signal conditioning or processing device and an output device.

### Classification :-

Primary Transducers :- When the input signal is directly sensed by the transducer & physical phenomenon is converted into electrical form directly, then such a transducer is called the primary transducer.

Example :- A thermistor used for the measurement of temp. fall in this category. The thermistor senses the temp. directly and causes the change in resistance with the change in temperature.

### Secondary Transducers :-

When the input signal is sensed first by some detector or sensor and then its output being of some form other than input signal is given as input to a transducer for conversion into electrical form, then such a transducer falls in the category of secondary transducers.

Example :- In case of pressure measurement, Bourdon tube is a primary sensor which converts pressure first into displacement, and then the displacement is converted into an output voltage by an LVDT. In this case LVDT is secondary transducer.

## Active Transducers :-

- Self generating type transducers i.e. transducers which develop their output in the form of electrical voltage or current without any auxiliary source are called the active transducers.
- Tacho-generators used for measurement of angular velocity, thermo couples used for measurement of temperature, piezo electric crystal used for measurement of force fall in this category.

## Passive Transducers :-

Transducers in which electrical parameters i.e. resistance, inductance & capacitance changes with change in ~~output~~ input signals are called the passive transducers.

Example :- Resistive, capacitive & inductive.

### Resistive Transducers :-

- It is generally seen that methods which involve the measurement of change in resistance are preferred to those employing other principles.
- This is because both alternating as well as direct currents and voltages are suitable for resistance measurements.

$$R = \rho l / A$$

where  $R$  = Resistance in  $\Omega$

$l$  = length of conductor in m

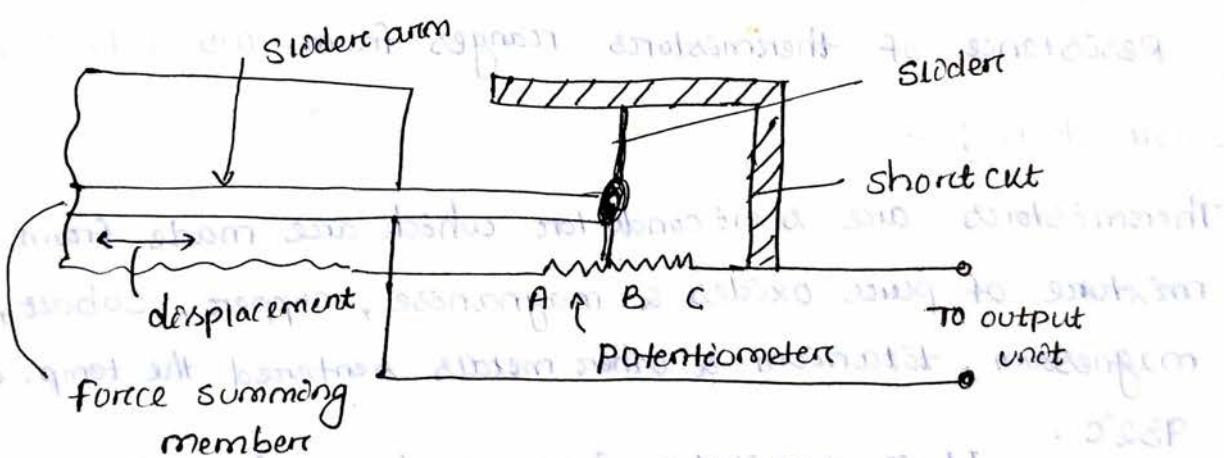
$A$  = Area of cross-section of conductor in  $m^2$

$\rho$  = Resistivity of conductor in  $\Omega-m$

Linear Potentiometers: → does not have no gradation

- It consists of a potentiometer which is short circuited by a ~~stepper~~ slider.

- (3)
- The other end of the slider is connected to a slider arm.
  - The force summing device on the slider arm causes linear displacement of the slider causing the short cut of a certain portion of the resistance in the potentiometer.
  - Let the whole resistance positions on the potentiometer be ABC.
  - Let the resistance position caused by the slider movement be BC.
  - As the movement of the slider moves further to the right, the amount of resistance increases.
  - This increase in resistance value can be noted according to the corresponding change in the linear displacement of the slider.
  - The change in resistance can be calculated with the help of a wheatstone bridge.



Advantages :- → cost-effective

- Simple design and simple working
- Can be used for measuring large displacements.
- Can produce a high electrical efficiency.

Dis-advantages :-

A huge force may be required before the slider begins to move.

## Thermistor :-

(4)

principle :- It is a thermal dependent resistor i.e. if the temperature varies, its resistance changes depending upon their resistance change.

→ They are of 2 types.

i) Positive temp. coefficient

ii) Negative temp. coefficient

In case of NTC when the temp. increases the resistance decreases and in case of PTC when temp. increases, its resistance also increases. That is why the naming of thermistor is thermally sensitive resistor.

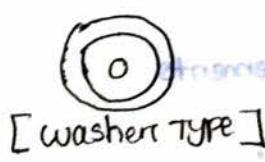
→ They are widely used to measure temp. ranging from  $-600^{\circ}\text{C}$  to  $1500^{\circ}\text{C}$ .

→ Resistance of thermistors ranges from  $0.5\Omega$  to  $0.75\text{ m}\Omega$ .

## Construction :-

Thermistors are semiconductors which are made from a specific mixture of pure oxides & manganese, copper, cobalt, iron, magnesium, titanium & other metals. Sintered the temp. above  $982^{\circ}\text{C}$ .

It is available in a number of configuration like bead type, washers type, disc type & rod type etc.



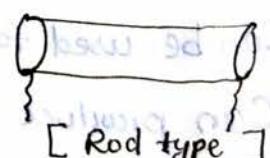
[Washer type]



[Bead type]



[Disc type]

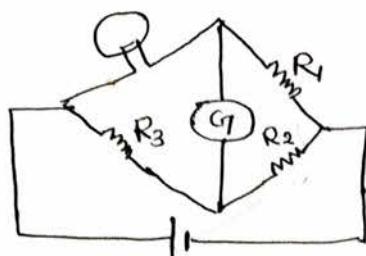


[Rod type]

Working :- Thermistors are used for measurement of temperatures. It is placed on the environment whose temp. is to be measured. If it is NTC type of thermistor as the temp. increases the resistance of thermistor decreases. The change in resistance can be measured by a ohm meter or by keeping thermistor in

(5)

the one arm of the wheat stone bridge.



For very accurate temperature measurement, a differential bridge ckt is used in which two thermistors are used in the two arms of wheat stone bridge.

Advantages : - → Small in size, fast respond.

→ Low cost → Stability of the instrument with age increase.

Dis-advantages : - → It produces a non linear characteristic.

→ It is being limited for temperature measurement.

Application : - → PTC are used in TV.

→ major application of thermistor are measurement & control temperature.

→ The other application are measurement of power and high frequency, measurement of thermal conductivity, measurement of level flow and pressure of liquids.

### Strain Gauges : -

→ It is basically a device used for measuring mechanical surface strain and is one of the most extensively used electrical transducers.

→ It can detect & convert force or small mechanical displacements into electrical signals.

### Gauge factors : -

→ It indicates the strain sensitivity of the gauge in terms of the change in resistance per unit resistance per unit strain.

→ It can be written as :-

$$G_I = \frac{\Delta R/R}{\Delta L/L}$$

$$= 1 + 24 + \frac{\Delta P/P}{\Delta L/L}$$

Change in resistance  
due to change in  
length

change in  
resistance  
due to change  
in area

change in resistance  
due to piezo-resistor  
effect

Use of strain gauge :-

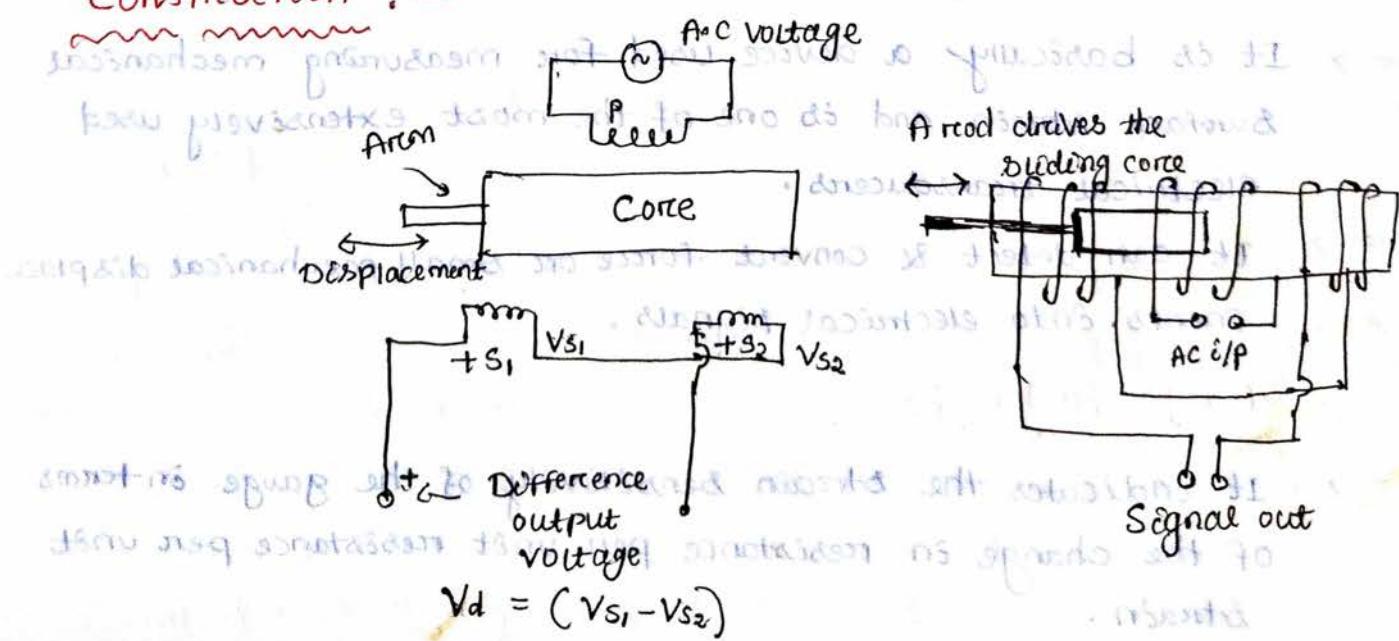
→ They are used for analysing the dynamic strain in complex structure like bridges, automobiles, roads, building, root of the building etc.

→ It is also used for the measurement of tension, torque, forces, stress, pressure etc.

### **LVDT (Linear Variable Differential Transducer) :-**

- The most commonly used inductive transducer is Linear Variable Differential Transducer (LVDT).
- It is widely used for translating linear motion & displacement into electrical signals. It is a passive transducer.

Construction :-



- It consists of two windings ① one primary winding P and  
 b) two secondary windings  $S_1$  &  $S_2$ .
- These two windings are wound on hollow cylindrical formers known as "bobbin" which is made up of either non-magnetic material or insulating material.
- The secondary windings  $S_1$  &  $S_2$  have equal number of turns and are placed on either side of the primary winding. It is connected to the AC source.
- A moveable cylindrical shape soft iron core is attached to the sensing element of the transducer.
- Core is made up of nickel iron alloy to reduce eddy current loss.
- The displacement to be measured is attached to the soft iron core.
- In order to get a differential output voltage, the two single voltage signals  $V_{S1}$  &  $V_{S2}$  from the two secondary windings  $S_1$  &  $S_2$  are connected in series in a particular fashion. Such a cut connection has been adopted to ensure that we get a difference of the two output voltages  $V_{S1}$  &  $V_{S2}$  and not a summation.
- Working:** — Any physical displacement of the core causes the voltage of one secondary winding to increase while simultaneously reducing the voltage on the other secondary winding. The difference of the two voltages appears across the output terminal of the transducer & gives a measure of the physical position of the core & hence the displacement.
- When the core is at the normal position, the flux linking with both secondary windings is equal and hence equal EMFs are induced. So the net output is
- $$V_o = V_{S1} - V_{S2} = 0$$

If the core is moved to the left of the normal position, then more flux gets linked with the winding  $S_1$  and less with the winding  $S_2$ . So  $V_{S_1} > V_{S_2}$ . Hence we get a positive voltage at the output.

Similarly if the core is moved to the right of the normal position, then more flux gets linked with the winding  $S_2$  and less with the winding  $S_1$ . So  $V_{S_1} < V_{S_2}$ . Hence we get a negative voltage at the output.

So when  $V_{S_1} > V_{S_2}$ , then

$$V_o = V_{S_1} - V_{S_2} = +ve$$

$$V_{S_1} < V_{S_2} \text{ then } V_o = V_{S_1} - V_{S_2} = -ve$$

The difference of the output voltage of the secondary windings gives the amount of displacement.

Advantages: It is widely used for the measurement of displacement ranging from few mm to few cm.

Advantages: → Its output is very high so no need of amplifying the output.

- The device consumes less power.
- It is very simple, light in weight & easy to maintain.

Dis-advantages:

These devices are very sensitive to stray magnetic field.

Another Applications:

LVDTs are suitable for use in applications where the displacements are too large for strain gauges to handle.

For example, LVDTs can be employed for measurement of displacements that range from a fraction of a mm to a few cm. If LVDT is to be employed for measurement of mechanical displacement greater than 25mm, an appropriate mechanical gearing must be used.

## Capacitive Transducer : — (1)

The principle of operation of capacitive transducers is based upon the familiar equation for capacitance of a parallel plate capacitor.

$$\text{Capacitance } C = \epsilon A/d$$

$$= \epsilon_r \epsilon_0 A/d \quad (1)$$

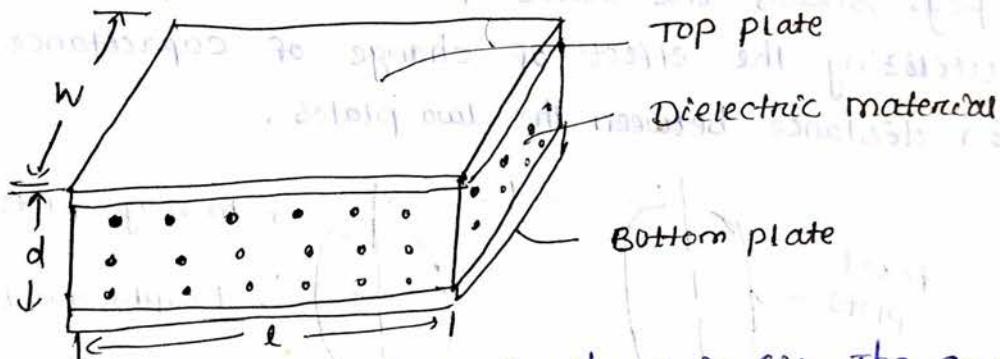
where  $A$  = overlapping area of plates in  $\text{m}^2$

$d$  = distance between two plates in metre.

$\epsilon = \epsilon_r \epsilon_0$  = permittivity of medium  $\text{F/m}$ .

$\epsilon_r$  = Relative permittivity

$\epsilon_0$  = permittivity of free space  $= 8.85 \times 10^{-12} \text{ F/m}$ .



A parallel plate capacitor is shown in fig. The capacitive transducers work on the principle of change of capacitance which may caused by :-

- i) change in overlapping area
  - ii) change in distance  $d$  between the plates
  - iii) change in dielectric constant
- These changes are caused by physical variable like displacement, force & pressure in most of the cases.
- The change in capacitance may be caused by change in dielectric constant as is the case in measurement of liquid or gas levels.
- The capacitance may be measured with bridge cuts.
- The output impedance of a capacitive transducer is

$$X_C = 1/2\pi f C$$

where  $C = \text{capacitance}$  and  $f = \text{frequency on excitation in Hz}$

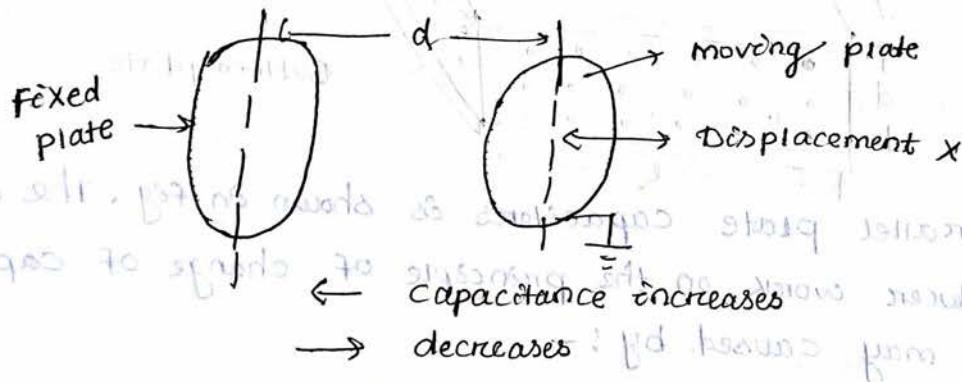
→ The capacitive transducers are commonly used for measurement of linear displacement.

These transducers use the following effects :-

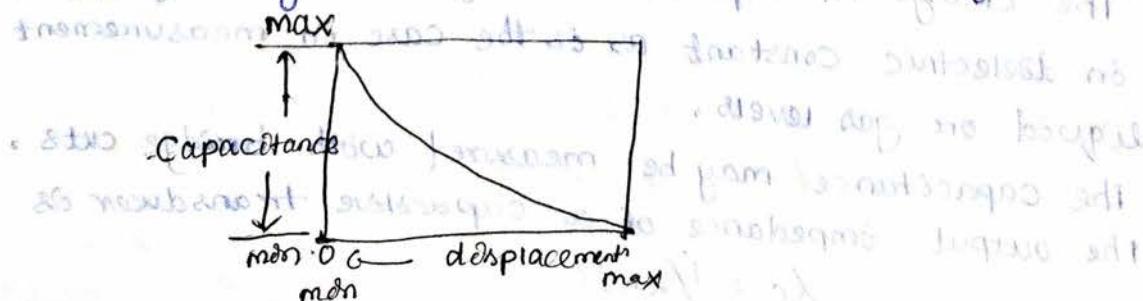
- i) change in capacitance due to change in overlapping area of plates.
- ii) change in capacitance due to change in distance between two plates.

Transducers using change in distance between plates :-

→ Fig. shows the basic form of a capacitive transducer utilizing the effect of change of capacitance with change in distance between the two plates.



- one is a fixed plate & the displacement to be measured is applied to the other plate which is movable.
- Since the capacitance  $C$  varies inversely as the distance  $d$  between the plates, the response of this transducer is not linear (as shown in fig (b)). Thus this transducer is useful only for measurement of extremely small displacement.



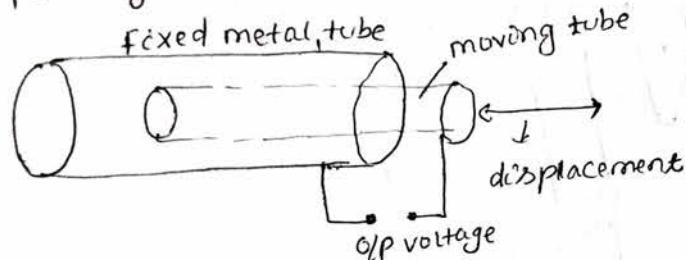
$$\boxed{\text{Sensitivity } S = \frac{\partial C}{\partial x} = -\frac{\epsilon A}{x^2}}$$

11

→ The relationship between variation of capacitance  $C$  with variation of distance bet<sup>n</sup> plates,  $x$  is hyperbolic and is only approximately linear over a small range of displacement.

Transducer using change in area of plate :-

For cylindrical tube :-



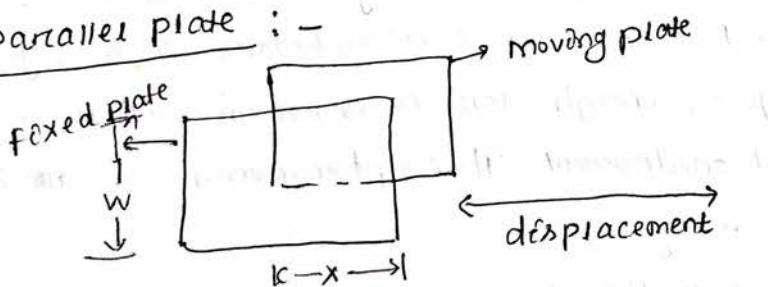
- In this diagram the moving tube is inside the fixed tube.
- The movement on the moving tube causes a change in the overlapping area ( $A$ ) due to which the capacitance changes and hence there is a change in the output voltage.

$$C = \epsilon_0 \epsilon_r A / D$$

$$C \propto A$$

and  $C \propto 1/D$

For parallel plate :-



- In this diagram the capacitance changes due to the changes in the overlapping area ( $A$ ).
- The overlapping area changes due to the displacement in the moving plate.

Currently the overlapping area ( $A$ ) is  $w \times x$ .

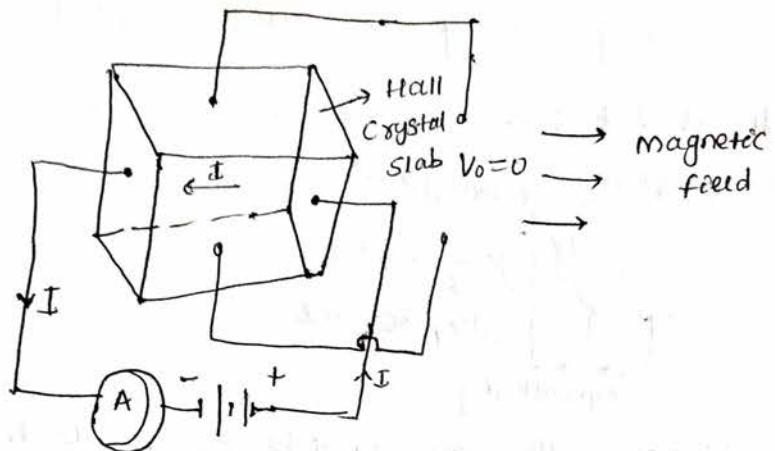
Thus the capacitance is given by :-

$$C = \frac{\epsilon_0 \epsilon_r (w \times x)}{D}$$

(12)

Hence, when there is a change in  $W$  or  $a$ , then there is a change in the capacitance due to the change in the overlapping area ( $A$ ).

Hall Effect Transducers: →



- When a conductor is kept perpendicular to the magnetic field and a direct current is passed through it, it results in an electric field perpendicular to the directions of both the magnetic field & current with a magnitude proportional to the product of the magnetic field strength & current.
- The voltage so developed is very small and it is difficult to detect it. But in some semiconductors such as germanium, this voltage is enough for measurement with a sensitive moving coil instrument. This phenomenon is called the Hall effect.
- When the magnetic field is applied so that it is perpendicular to the slab of Hall crystal, the electrons are acted on by a force because of magnetic field.
- This force acts in a vertical direction, and the electrons are forced toward the top of the slab.
- This results in an excess of electrons near the top of the slab and a deficiency of electrons near the bottom. Thus a potential difference is created bet'n the top & bottom of the slab.

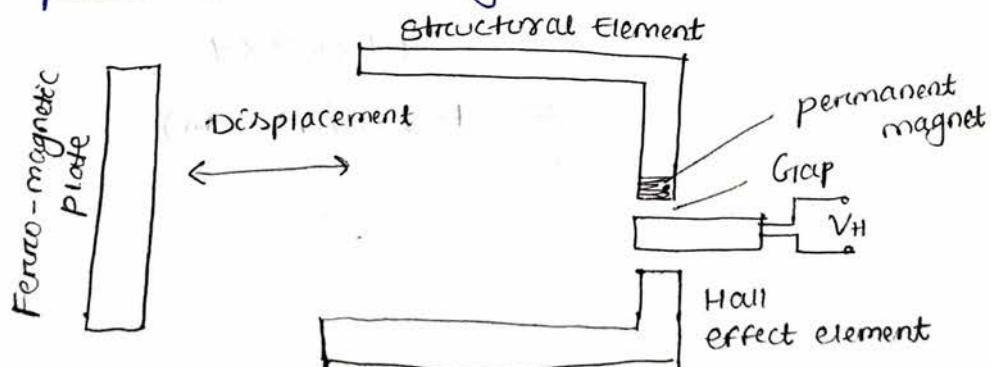
→ The magnitude of this voltage is proportional to the product of strength of the magnetic field & current flowing through the slab and is given by :-  $V_H = \frac{K_H I B}{t}$  VOLTS

where  $I$  is the current flowing through the slab in amperes.

$B$  is the flux density of the magnetic field applied in  $\text{wb/m}^2$ .  
 $t$  is the thickness of slab in metre.

&  $K_H$  is the Hall effect coefficient and is inversely proportional to the carrier density in the solid.

- Hall-effect transducers can be built to be sensitive enough to detect very small magnetic fields.
- Hall effect element can be used for measurement of current by the magnetic field produced due to flow of current.
- Hall effect element may be used for measuring a linear displacement or location of a structural element in cases where it is possible to change the magnetic field strength by variation in the geometry of a magnetic structure.
- For e.g:- the hall effect element is located in the gap, adjacent to the permanent magnet and the field strength produced in the gap, due to the permanent magnet is changed by changing the position of the ferromagnetic plate.



- The voltage output of the Hall effect element is proportional to the field strength of the gap which is a function of the position of ferro magnetic plate with respect to the structure.

Advantage :-

→ They are non-contact devices with small size and high resolution.

Drawbacks :- High sensitivity to temperature changes and variation of Hall coefficient from plate to plate, thereby requiring individual calibration in each case.

Problem :-

An Hall effect element used for measuring a magnetic field strength gives an output voltage of  $10.5 \text{ mV}$ . The element is made of silicon and is  $2.5 \text{ mm}$  thick and carries a current of  $4 \text{ A}$ . The Hall coefficient is  $4.1 \times 10^{-6} \text{ Vm/A-wb/m}^2$ .

Ans :-

$$\text{Hall effect element thickness } t = 2.5 \text{ mm} \\ = 2.5 \times 10^{-3} \text{ m}$$

$$\text{output voltage } V_H = 10.5 \text{ mV}$$

$$= 10.5 \times 10^{-3} \text{ V}$$

$$\text{current } I = 4 \text{ A}$$

$$\text{Hall coefficient } K_H = 4.1 \times 10^{-6} \text{ Vm/A-wb/m}^2$$

$$\therefore V_H = \frac{K_H I B}{t}$$

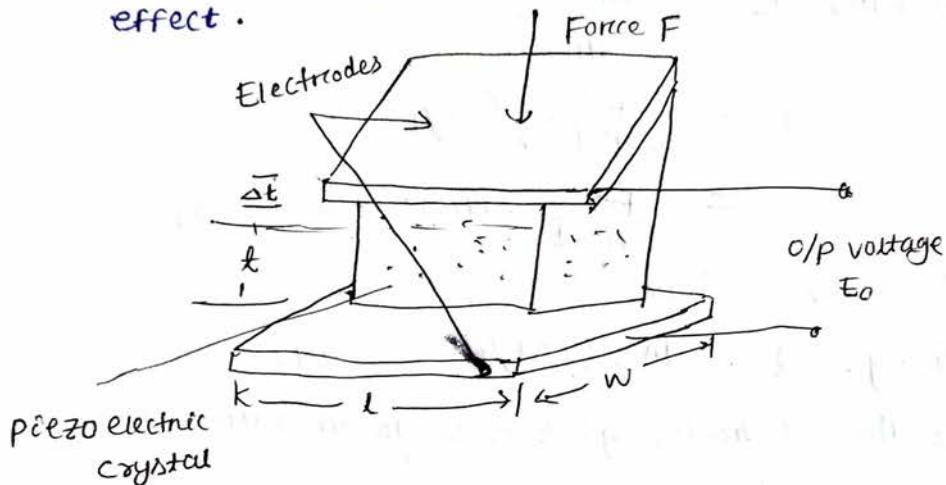
$$\text{magnetic field strength } B = \frac{V_H \times t}{K_H I}$$

$$= \frac{10.5 \times 10^{-3} \times 2.5 \times 10^{-3}}{4.1 \times 10^{-6} \times 4}$$

$$= 1.6 \text{ wb/m}^2 \text{ (Ans)}$$

## Piezo-electric Transducers : - (15)

- A piezo-electric material is one in which an electric potential across certain surfaces of a crystal of the dimensions of the crystal are changed by the application of a mechanical force. This potential is produced by the displacement of charges. The effect is reversible, if a varying potential is applied to the proper axes of the crystal, it will change the dimensions of the crystal thereby deforming it. This effect is known as piezo-electric effect.



- The materials that exhibit a significant and useful piezo-electric effect are divided into 2 categories.
- Natural group & ii) Synthetic group
- Quartz & Rochelle salt belong to natural group while materials like Lithium Sulphate, ethylene diamine tartarate belong to the synthetic group.
- A piezo-electric element used for converting mechanical motion to electric signals may be thought as charge generators and a capacitor.
- Mechanical deformation generates a charge and this charge appears as a voltage across the electrodes.
- The voltage is  $E = Q/C$
- The magnitude & polarity of the induced surface charges are proportional to the magnitude & direction of the applied force F. charge  $Q = d \times F$  coulomb — (1)

(16)  
where  $d$  = charge sensitivity of the crystal

$$F = \text{applied force N}$$

→ The force  $F$  causes a change in thickness of the crystal.

$$F = \frac{AE}{t} \Delta t \text{ newton} \quad (2)$$

where  $A$  = area of crystal in  $\text{m}^2$ .

$t$  = thickness of crystal in m.

$$\text{Young's modulus } E = \frac{\text{Stress}}{\text{Strain}}$$

$$= \left(\frac{F}{A}\right) \cdot 1/\Delta t/t$$

$$= \frac{Ft}{A\Delta t} \text{ N/m}^2 \quad (3)$$

From eqns (1) & (2) we have

$$\text{charge } Q = dAE (\Delta t/t) \quad (4)$$

The charge at the electrodes gives rise to an output voltage  $E_0$ .

$$E_0 = Q/C_p \quad (5)$$

where  $C_p$  = capacitance bet<sup>n</sup> electrodes

$$C_p = \epsilon_r \epsilon_0 A/t \quad (6)$$

From eqns (1), (4), (6)

$$E_0 = Q/C_p = \frac{dF}{\epsilon_r \epsilon_0 A/t}$$

$$= \frac{dt}{\epsilon_r \epsilon_0} \cdot F/A \quad (7)$$

But  $F/A = P$  = pressure or stress in  $\text{N/m}^2$

$$\therefore E_0 = d/\epsilon_r \epsilon_0 \cdot tP = gtp \quad (8)$$

$$\text{where } g = \frac{d}{\epsilon_r \epsilon_0} \quad (9)$$

$g$  → voltage sensitivity of the crystal

$$g = E_0/tP = \frac{E_0/t}{P}$$

but  $E = \text{Electric field strength in V/m}$ .

### Applications :-

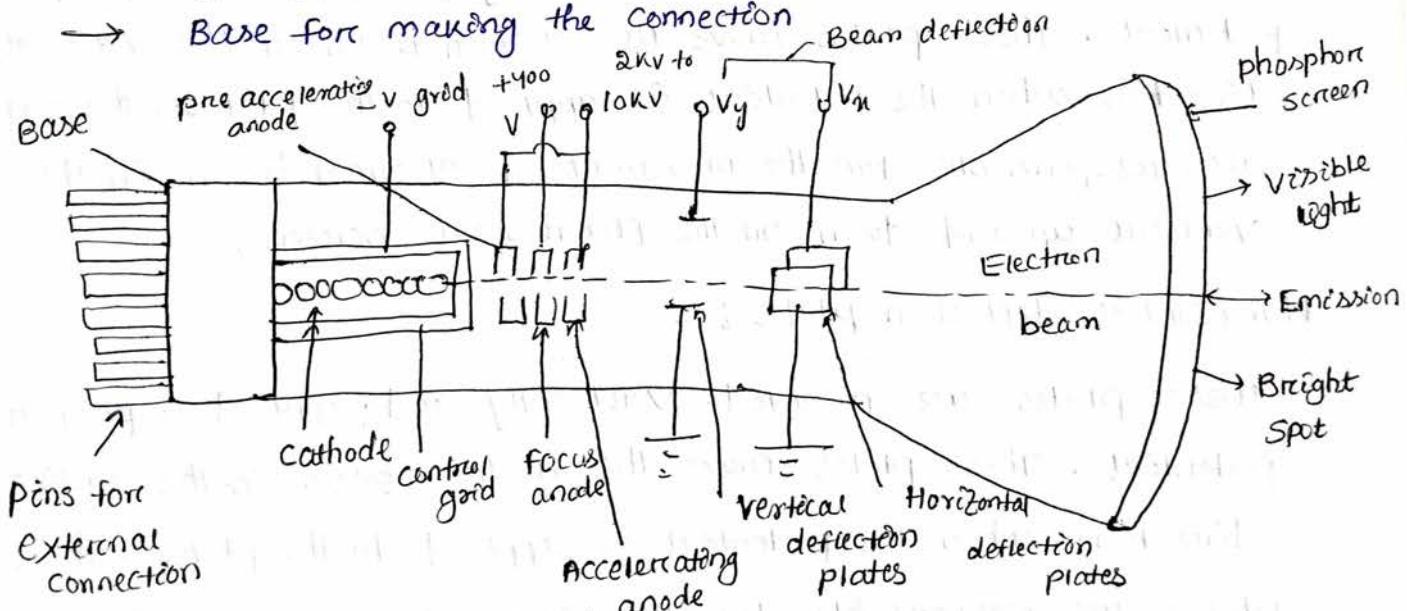
- As piezo-electric materials cannot measure static values, these are primarily used for measuring surface roughness, in accelerometers and as a vibration pick up.
- In strain gauges to measure force, stress, vibrations etc.
- They are used in ultrasonic imaging in medical applications.

### Chapter - 8

## Oscilloscope

### Cathode Ray Tube (CRT) :-

- A cathode Ray tube is the main part of Cathode Ray Oscilloscope (CRO) with additional circuitry to operate the circuit.
- It's main parts are : - → Electron gun assembly
- Deflection plate assembly
- Fluorescent Screen
- Glass envelope
- Base for making the connection



Cathode Ray tube is a vacuum tube and convert an electrical signal into visual one. It makes available plenty of electrons. The electrons are accelerated to high velocity and are focussed on a fluorescent screen. Electron beam produces a spot of light whenever it strikes. The electron beam is deflected on its journey

(17) But  $E_0/t$  = Electric field strength in V/m.

## Applications :-

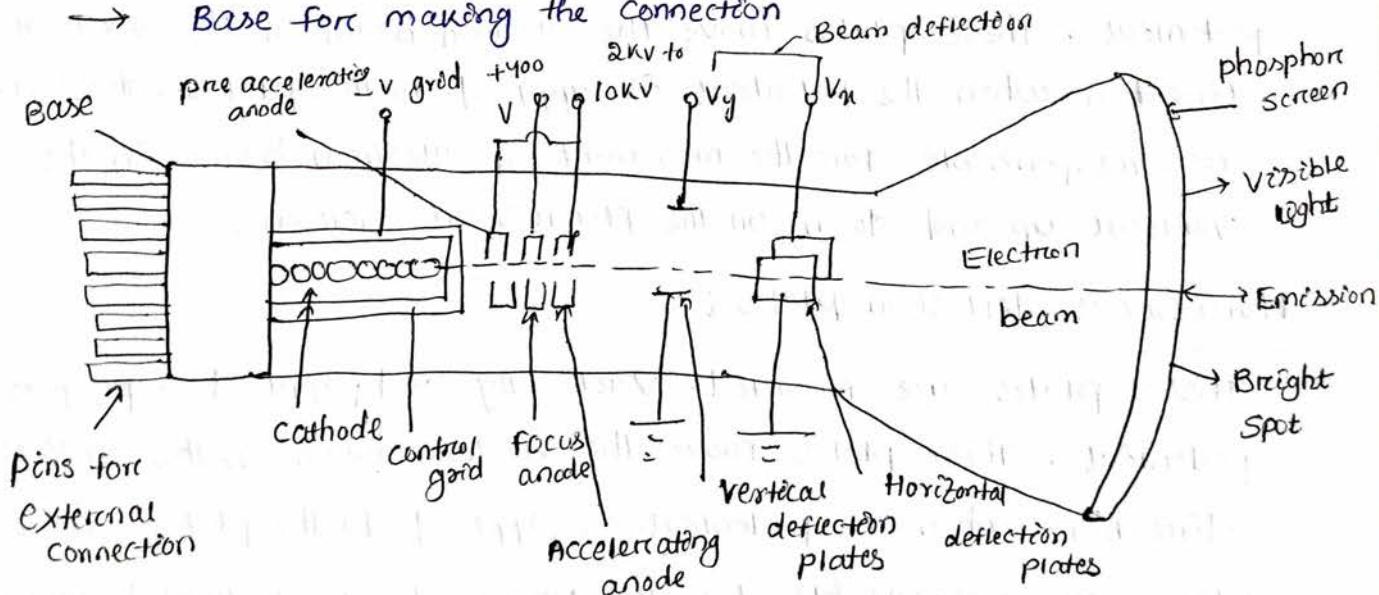
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(2) in response to the electrical signal under study. Hence the electrical signal is displayed.

### Electron gun assembly :-

The arrangement of electron which produces a focussed beam of electrons is called the electron gun. It consists of :-

- An indirectly heated cathode
- A control grid surrounding the cathode
- A focusing anode
- An accelerating anode

### Deflection plate assembly :-

It is accomplished by two set of deflecting plates placed within the tube beyond accelerating anode.

- i) one set of vertical deflection plates
- ii) other set of horizontal deflection plates

### Vertical deflection plates :-

These plates are mounted horizontally and applied a proper potential. These plates move the electron beam in the vertical direction when the potential is applied to the plates. These plates are responsible for the movement of electron beam in the vertical up and down on the fluorescent screen.

### Horizontal deflection plates :-

These plates are mounted vertically and applied a proper potential. These plates move the electron beam in the vertical direction when the potential is applied to the plates. These plates are responsible for the movement of electron beams in the horizontal left & right on the fluorescent screen.

### Fluorescent Screen :-

The end wall or inside face of tube coated with some fluorescent material called:- phosphore, Zinc oxide, Zinc orthosilicate.

(3)

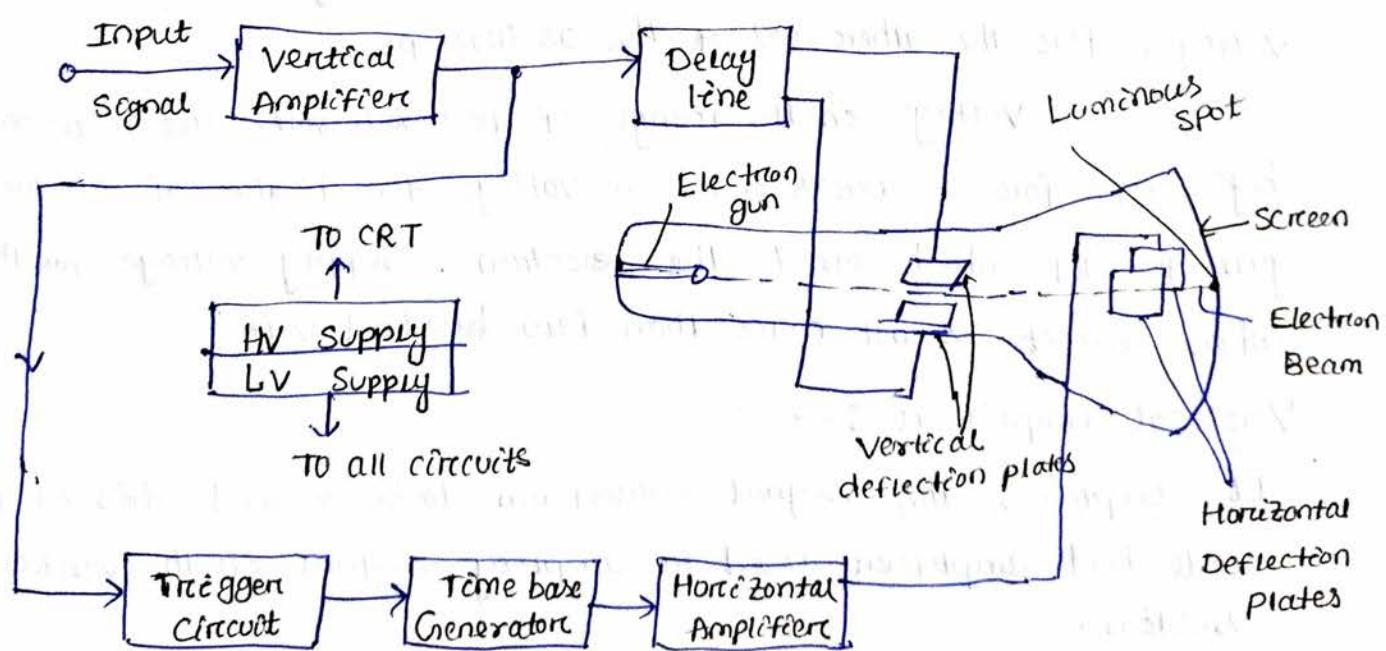
when high velocity of electron beam strikes the screen a spot of light is produced at the point of impact. It absorbs the kinetic energy of the electron & convert into light. colour of the light emitted depends on the fluorescent material used.

Glass Envelope : — It is highly evacuated glass housing in which vacuum is maintained inside. Inner wall of the CRT between neck & the screen are usually coated with conducting material called " aquadag".

Block diagram of general purpose CRO :-

It consists of the following components.

- Cathode Ray tube
- power supply block
- Vertical Amplifier
- Horizontal Amplifier
- Time base generator
- Trigger circuit



(4)

CRO is the most useful and the most versatile laboratory instrument for studying wave shapes of alternating current, voltage, power, frequency which have amplitude & waveform.

### Cathode Ray Tube :-

It is the heart of the oscilloscope. It generates sharply focused electron beam & accelerate the beam to a high velocity and deflect the beam to create image. It contains the phosphorescent screen where the electron beam became visible. While travelling from the electron gun to screen, the electron beam passes between

- Set of :-
- ① Vertical deflection plate
  - ② Horizontal deflection plate

Voltage applied to the vertical deflection plate to move the beam on the vertical plane & the CRT spot moves up & down.

Voltage applied to the horizontal deflection plate moves the beam on the horizontal plane.

### Power Supply Block :-

It provides the voltage required by the CRT to generate and accelerate the electron beam as well as to supply the required operating voltages for the other circuit of the oscilloscope.

Voltage in the range of few kilo volts are required by CRT for acceleration. Low voltage for heater of electron gun of CRT which emit the electron. Supply voltage for the other circuit is not more than few hundred volt.

### Vertical Amplifier :-

It amplifies the signal waveform to be viewed. This is a wide band amplifier used to amplify signal in the vertical section.

### Horizontal Amplifier :- It is fed with saw-tooth voltage.

It amplifies saw-tooth voltage before it is applied to horizontal deflection plates.

## Time base generator :-

(5)

It develops saw-tooth voltage waveform required to deflect the beam in horizontal section.

Trigger circuit :- It is used to convert the incoming signal into trigger pulses so that input frequency can be synchronized.

## CRO Measurement :-

Various parameters which can be measured by CRO are

- |               |                      |
|---------------|----------------------|
| ① Voltage     | ⑤ Phase angle        |
| ② Current     | ⑥ Amplitude          |
| ③ Time period | ⑦ Peak to peak value |
| ④ Frequency   |                      |

### Voltage measurement :-

Voltage to be measured is applied to the V deflection plates through vertical amplifier.

The 'X' deflection plate is excited by time base generator.

$$\rightarrow \text{peak to peak value } V_{p-p} = \frac{\text{volt}}{\text{division}} \times \text{no. of division}$$

$$\rightarrow \text{Amplitude } V_m = \frac{V_{p-p}}{2}$$

$$\rightarrow \text{R.M.S value } V_{rms} = \frac{2V_{p-p}}{\sqrt{2}} = \frac{V_p}{\sqrt{2}} + \frac{V_p}{\sqrt{2}}$$

Voltage / division = deflection sensitivity

$$\text{Deflection factor} = \frac{1}{\text{Deflection sensitivity}}$$

### Current measurement :-

A CRO has a very high input impedance and cannot be used for direct measurement. However the current can be measured in terms of voltage drop across a standard resistance

$$I = \frac{V}{R}$$

(6)

Time period measurement :-

For the measurement of time period  $T$  of the waveform, it is displayed on the screen such that one complete cycle is visible on the screen.

After noting the time/division selected on front panel the time period of the wave form can be obtained as

$$\text{Time period } T = \text{time/division} \times \text{no. of division occupied by one cycle}$$

$$\boxed{\text{Frequency} = f = \frac{1}{T}}$$

Frequency measurement by Leibniz method pattern :-

The unknown frequency can be accurately determined with the help of CRO.

Step-1 :- Known frequency is applied to horizontal input (2000 Hz) unknown frequency to vertical input.

The number of loops cut by the horizontal line gives frequency on the vertical plates  $f_V$ .

The numbers of loops cut by vertical lines gives the frequency on the horizontal plates  $f_H$ .

$$\frac{f_V}{f_H} = \frac{\text{No. of loops cut by horizontal line}}{\text{No. of loops cut by vertical line}}$$

$$f_V/2000 = 1/2 \Rightarrow f_V = 2000 \times 1/2$$

$$\text{Unknown frequency} = 1000 \text{ Hz}$$

It is a method to determine the unknown frequency by comparing it with known frequency.

Example-1 :-

$$\frac{f_V}{f_H} = \frac{1}{1}, f_H = 1000, f_V = f_H = 1000 \text{ Hz}$$

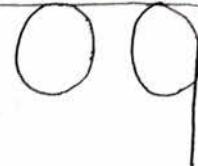
No. of loops cut by horizontal & vertical line = 1

Example-2 :- No. of loops cut by horizontal

line = 2

$$f_V/f_H = 2/1$$

$$\Rightarrow f_V/1000 = 2/1 \Rightarrow f_V = 2000 \text{ Hz}$$



Example-3 :- No. of cut by horizontal

line = 6

vertical = 1

$$f_V/f_H = 6/1, f_V/1000 = 6/1$$

$$f_V = 6 \times 1000 = 6000 \text{ Hz}$$



Phase and frequency measurement :-

mm mm mm mm mm mm

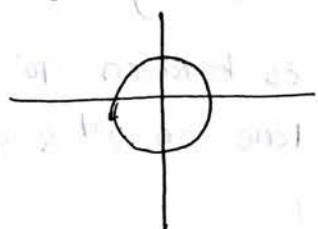
An oscilloscope can be used to find the phase angle between two sinusoidal quantities of the same frequency.

i) one of the signals is applied to Y plates time base generator is switched out and second signal is fed to X plates.

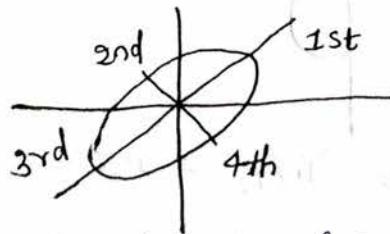
$\Rightarrow$  If the two signals are in phase the display would be a straight line at  $45^\circ$  to the horizontal.



$\Rightarrow$  If the phase angle is  $90^\circ$ , the display would be a circle.

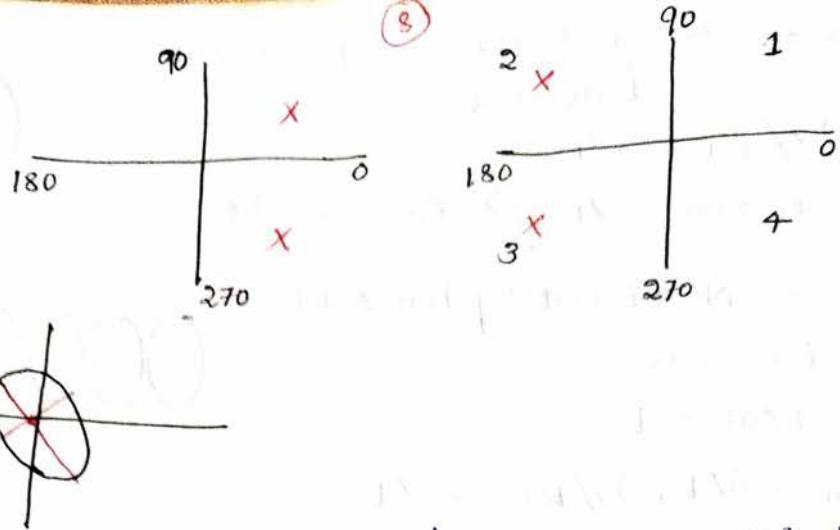


$\Rightarrow$  For any other phase difference the display would be an ellipse.



If the phase angle between  $(0-90^\circ) = (270^\circ - 360^\circ)$

The ellipse has its major axes on the 1st & 3rd quadrants.



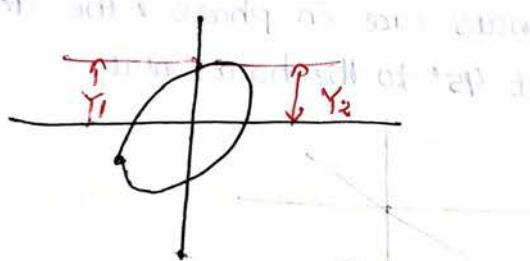
If the phase difference is between  $90^\circ$  &  $180^\circ$ , the ellipse has its major axis in the 2<sup>nd</sup> & 4<sup>th</sup> quadrant.

value of phase angle  $\phi$  is given by :-

$$\sin \phi = Y_1 / Y_2 \text{ are intercepts}$$

→ when the phase angle is between  $0$  to  $90^\circ$

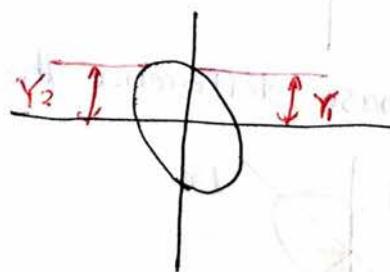
&  $270^\circ$  &  $360^\circ$  major axes lies in 1<sup>st</sup> quadrant = 3<sup>rd</sup> quadrant



$$\sin \phi = Y_1 / Y_2 = Y_2 = 0.5$$

$$\phi = \sin^{-1}(0.5) = 30^\circ \text{ or } +5^\circ$$

→ when phase angle is between  $90^\circ$  to  $180^\circ$  &  $180^\circ$  to  $270^\circ$  major axes would lie in 2<sup>nd</sup> & 4<sup>th</sup> quadrant.



$$\sin \phi = Y_1 / Y_2 = 0.5$$

$$(\text{Code-}105) \Rightarrow (\phi = 150^\circ \text{ or } 210^\circ)$$