Unit - I

Measurement :- It is the process of comparision, where an unknown quantity is expressed interms of standard quantity.

Instrument - The device which does the comparison is known as instrument.

e.g → A length of paper which is unknown can be measured by a scale which is standard quantity.

Accuracy - It is the closeness with which an instrument reading approaches the true value of the quantity being measured. (It is guarranty about precision)

Thus accuracy of a measurement means conformity to truth.

Inaccuracy or limits of errors. or percentage of error.

Accuracy ∝ ~~Error~~ — * If any instrument will be precise then it does not needed it will be accurate

Precision (परिशुद्धता) - It is a measure of the reproducibility of measurement i.e given a fixed value of a quantity, Precision is a measure of the degree of agreement within a group of measurement. (It does not guarranty about accuracy.)

Precise → clearly or sharply defined. (Produced repeatedly one value) (or represent single value)

* Conformity & Number of significant figures.

Note : It is used in measurements to describe the consistency or the reproducibility of results.

* It does not needed to be accurate.

(* If instrument are accurate then the it will be precise)

Resolution or Discrimination :-

If the i/p is slowly increased from some arbitary (non zero) input value, it will again be found that output does not change at all until a certain increment is exceeded. This increment is called resolution or discrimination of the instrument.

* The smallest measurable input change while the threshold defines the smallest measurable input.

or It is defined as the smallest or least change in input, which can be detected by the measuring instrument.

Note :- The instrument which are used for such measurements are called measuring instrument.

Sensitivity :- It is defined as the ratio of magnitude of output signal to magnitude of input signal.
or// The ratio between change output to change in input.

$$\text{Sensitivity} = \frac{\Delta\, O/P}{\Delta\, I/P}$$

Tolerance :- It can be defined as the allowable or permittable limit by which a measurement can vary.
Eg → If any instrument has tolerance ± 0.002 & true value is 10V then 10.1 is not acceptable.
The value between (10−0.002) to (10+0.002) are acceptable.

Error (δ) :- It is defined as the difference between measured value & the true value of a quantity.
or
* It is the deviation of measured value from true value.

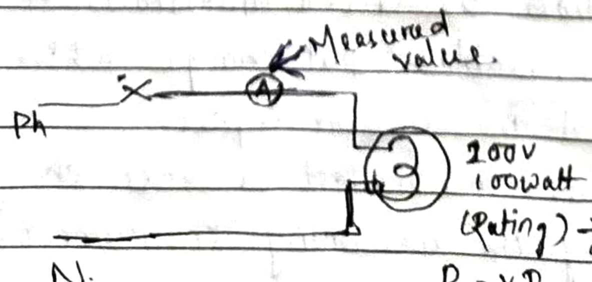
$\delta = A_m - A_T$

Error = M.V − T.V

Error = O/P − I/P

$A_m > A_T$ δ +ve
$A_m < A_T$ δ = −ve

The purpose of measurement is to be present measured value to numerical value.
Eg → 10A (Numerical value then unit)
Any value calculated from rated value is known as True value
e.g. Motor (system i/p) (M.I) Tachometer (i/p) → System o/p
N_T = 3000RPM N_m = 2990 RPM Measured value.



(Rating) → True value.
P = VI
100 = 200I → I = 100/200 = 0.5

Measured value − Any value calculated from measuring instrument
True value → " " " " rated value.

Date : / /

Classification of Measuring instrument :-

(1) Absolute Instrument :- Which gives the value of the quantity to be measured in terms of the constants of the instrument & their detection only. No previous calibration or comparison is necessary in their case.

Note : Indicate the presence of an electric quantity.

E.g → Tangent Galvanometer

(2) Secondary Instrument :- In which the values of the electrical quantity to be measured can be determined from the deflection of the instruments, only when they have been precalibrated by comparison with an absolute instrument.

E.g → Ammeters, voltmeter, wattmeter etc.

(a) Indicating Instrument - Which indicate the instantaneous value of the electrical quantity being measured at the time at which it is being measured. Their indications are given by pointer moving over calibrated dials.

E.g → Ammeters, voltmeter, Ammeter.

(b) Recording Instrument :- These instruments gives a continuous record of the given electrical quantity which is being measured over a specific period.

The readings are recorded by drawing the graph.

E.g → XY plotter, CRO

(c) Integrating Instrument - These instruments measure the total quantity of electricity delivered over period of time.

E.g → A household energy meter.

Deflecting, controlling & damping arrangement in Indicating type Instrument :-

→ In indicating type instrument a pointer is present which moves over a calibrated scale.

→ In these type of instrument generally 3 types torques are developed.

Deflecting controlling and Damping arrangements in indicating type instrument :-

→ In indicating type instrument a pointer is present which moves over a calibrated scale.

→ In this type of instrument generally 3 types torques are developed.

(1) Deflecting torque :-

This torque is used to move the pointer over the scale.

→ It is denoted by T_d.

(2) Controlling torque :-

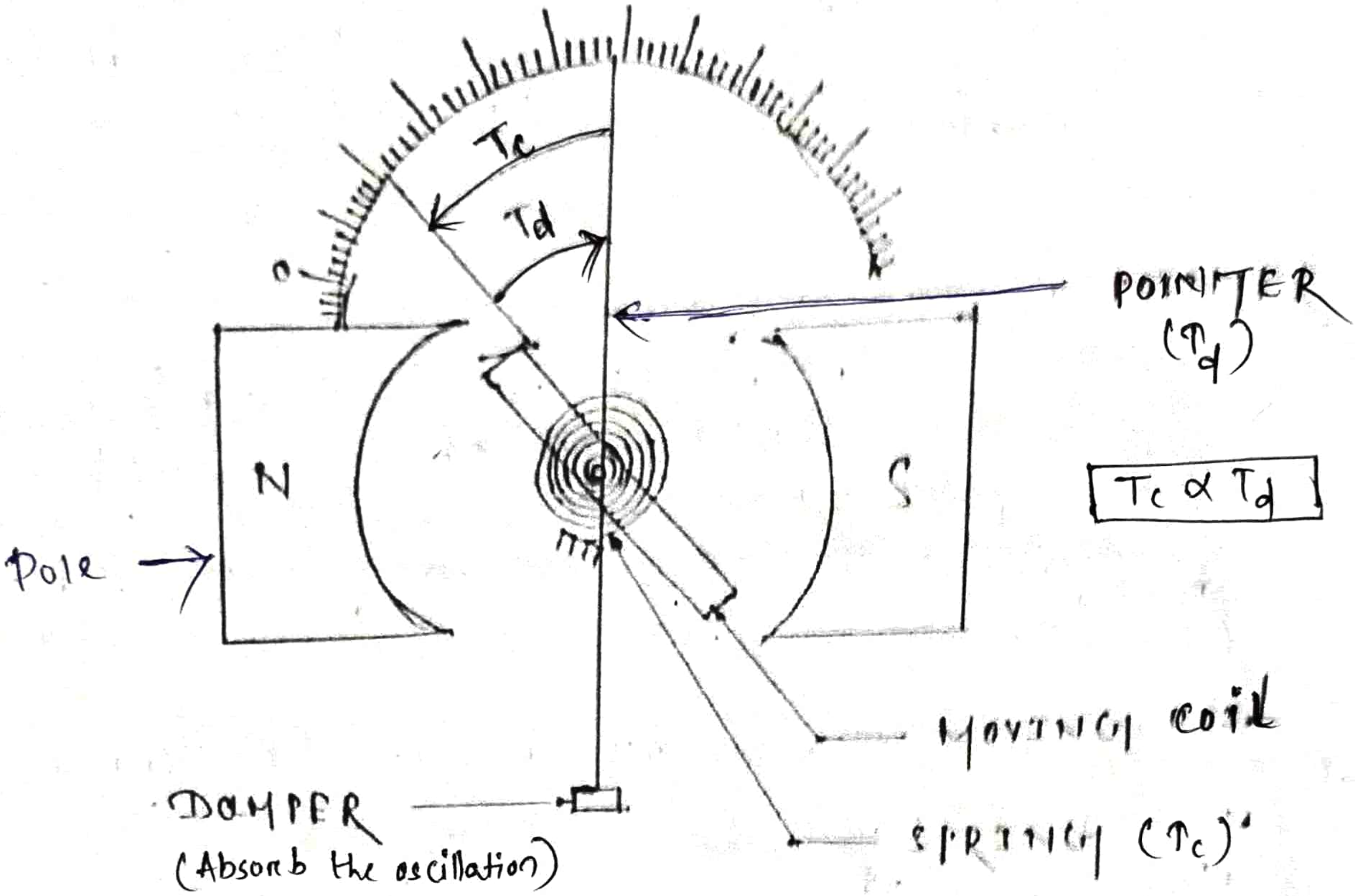
Controlling torque is used to neutralise or cancel the deflecting torque.

→ It is denoted by T_c.

→ $T_c \propto$ ~~θ~~ is proportional to the deflection done by the pointer.

Damping torque:-

This torque is used to absorb the oscillation of the pointer.



(Fig: PMMC type indicating instrument)

The above figure shows an indicating type instrument arrangement.

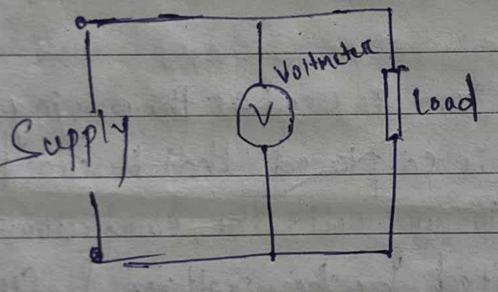
In this arrangement a moving coil is present in between the 2 poles of permanent magnet.

When current (I) flows through the moving coil then a magnetic field is developed around the coil, which interacts with the magnetic field of permanent magnet.

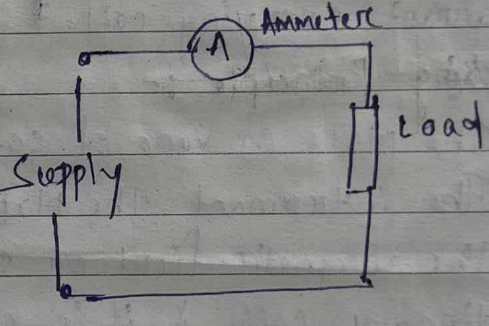
Unit - II

Ammeter → Ammeter is the instrument which is used to measure current. It is always connected in series in the circuit whose current is to be measured.
→ In an ammeter the deflecting torque is produced by the current which is to be measured.

Voltmeter :- Voltmeter is the instrument which is used to measure the voltage. It is always connected in parallel with the circuit whose voltage is to be measured.
→ In voltmeter the deflecting torque is produced by the current which is propotional to the voltage to be measured.



(voltmeter)



(Ammeter)

Error in Instrument (Ammeter & Voltmeter)
Generally 2 types of errors are common in ammeter & voltmeter which are due to friction & temperature.

friction → weight must be small → $\frac{T}{W}$ = large.
Temperature → Swamping Resistance (low Temp) → Series with the coil (galvanometer)

MI → DC or AC (V, I) → spring → Air friction damping
PMMC → DC (V, I) → " → Eddy current
Dynamometer → DC or AC (V, I, P) → Spring → Air friction damping
Rectifier → DC or AC (V, I) → " → Eddy current
Induction → AC → (V, I, P, E) → " → "

Moving Iron type Instrument (MI) :-

The instrument in which the moving iron is used for measuring the flow of current or voltage is known as the moving iron instrument.

Electromagnet is used in this instrument.

It operates on the principle of magnetic attraction. It is used as voltmeter, ammeter.

→ There are less no of turns of coil in Ammeter
Large " " " in voltmeter.

In this type of instrument a moving iron piece rotates within a current carrying coil.

Construction :-

The plate or vane of soft iron is used as the moving element of the instrument. The plate is so placed that it can freely moves in the magnetic field or stationary coil. The conductor makes the stationary coil & it is excited by the voltage & current whose magnitude is used to be measured.

The moving coil instrument uses the stationary coil as an electromagnet. (Temporary magnet)

* Magnetic field produced by an electric current.

Working Principle :-

A plate or vane of soft iron is used to make moving element of the system.

The iron plate is situated in such a way that it can move in a magnetic field produced by the coil.

The coil is excited by the current or voltage to be measured. When the coil excited it becomes an electromagnet & iron vane moves in such a way that it also moves the pointer over the graduated scale associated through it.

* MI instruments are 2 types :-
(1) Attraction Type
(2) Repulsion Type.

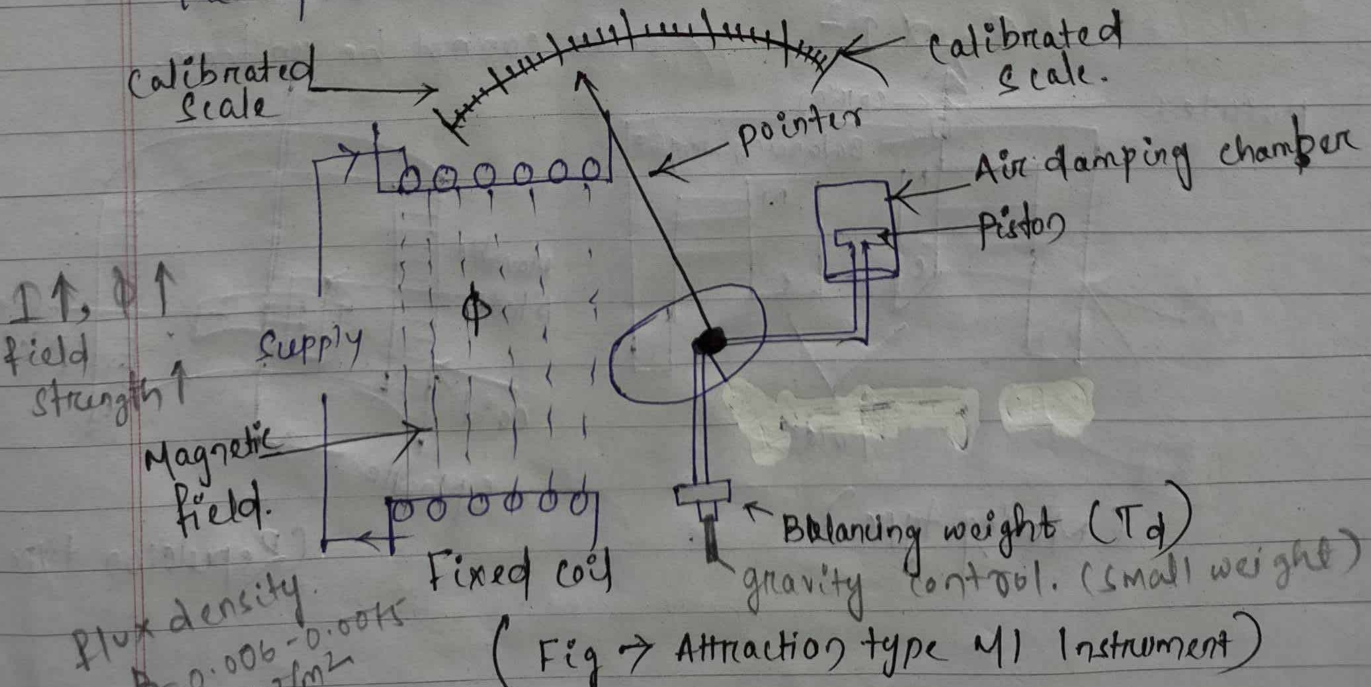
Attraction type — The instrument in which the iron plate attracts from the field such type of instrument is known as the attraction type instrument.

Construction

A moving iron instrument consists of a stationary hollow cylindrical coil. An oval shaped soft iron piece is mounted eccentrically to the spindle to which a pointer is attached. The controlling torque is provided by gravity control method while damping torque is provided by air friction.

Working principle

When the instrument is connected in the circuit, the operating current flow through the stationary circuit. A magnetic field is set up & the soft iron piece is magnetized which is attracted towards the center of the coil. Thus the pointer attached to the spindle is deflected over the calibrated scale.



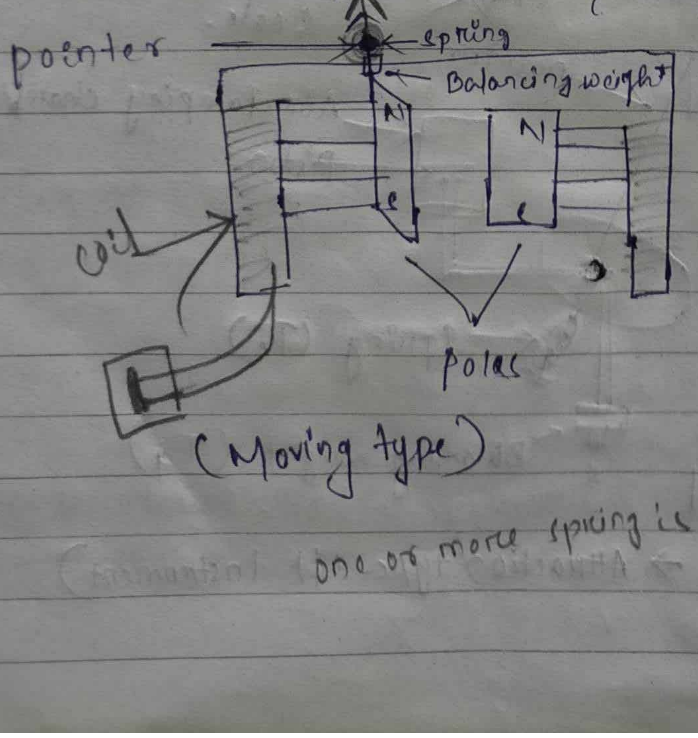
(Fig → Attraction type MI Instrument)

Repulcion type → In these instrument 2 iron vanes or plates are present inside the coil wave one is fixed & another one is movable.
when current flows through the coil then it's get magnetised & ~~a force of repulcion~~ same polarity are induced in it which results in a force of repulsion between them.
There are 2 types of repulcion type MI instrument.
(i) Radial vane type
(ii) Coaxial vane type.

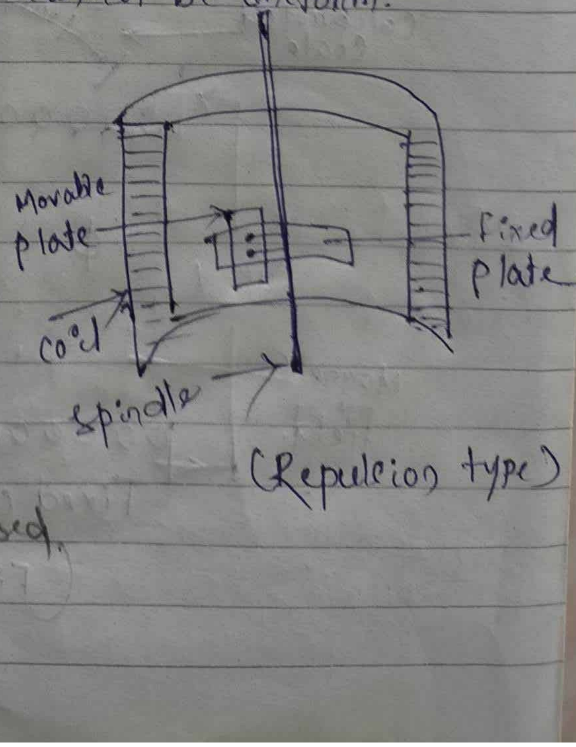
Radial Type :- It concist of two iron strip (vanes) are placed radially in which one is fixed & the other is movable. In this type of instrument ($T_D \propto$ current in the coil), thus making the scale uniform & reading can be obtained directly.

Coaxial Type - In this, the fixed & moving vane are present as a section coaxial cylinder. In which one vane is fixed to the coil frame that remains stationary & the othe is movable which rotates at the central axis inside the stationary vane.

$T_D \propto I^2$ → scale cannot be uniform.



(Moving type)



(Repulcion type)

one or more spring is used.

Reluctance → oppose the magnetic flux line.
flux always follow lower reluctance path

Permanent Magnet Moving coil (PMMC) :-
The instruments which use the permanet magnet for creating the stationary magnetic field between which the coil moves is known as permanet magnet moving coil.
→ Used for DC circuit only.
→ Used as a voltmeter or Ammeter.

Construction – (i) Moving coil → The coil is the current carrying part of the instruments which is freely moved between the stationary field of the permanent magnet. The coil is deflecte due to the magnitude of voltage & current.
(ii) Magnet System → PMMC instrument using the permanent magnet for creating stationary magnetic fields.
(iii) Control → In PMMC instrument the controlling torque is because of the spring.
(iv) Damping – It is used for keeping the movement of the coil in steady state position or rest position.
(v) Pointer – The pointer point/indicates the deflection of the coil & the magnitude of their deviation is shown on the scale.

~~Torque Eqn~~ :
Working Principle :- when the supply is given to the ckt then the current pass through the moving coil.
Due to flowing of current, a magnetic field is developed around the coil.
Due to interaction of magnetic field & coil a deflecting torque is produced.

$$T_d = NBld\,I$$

where, N = No of turns, B = flux density, l = length
d = diameter, I = Current.

Consider
$N, B, d, l =$ constant (G)

So,

$T_d = GI$

$T_d \propto$ Current flowing through it

When the pointer get deflected the springs which are connected to the pointer are stretched and controlling torque is developed in the springs.

we know $T_c \propto \theta$, $T_c = K\theta$

$$T_c = T_d$$

$K\theta = GI$

$$I = \frac{K\theta}{G}$$ $$I \propto \theta$$

Damping arrangement is made in the coil to absorb the oscillation.

Advantages -

(1) Scale of PMMC instrument is correctly divided
(2) Power consumption is very less
(3) High Accuracy
(4) ~~very convi~~ Use shelf shielding magnet for aerospace application.

Dis advantages :-

→ only used for DC.
→ cost effective

Error :- The error occurs because of ~~high~~ coil resistance on the shunt resistance. This happen because coil made up of copper wire (Cu has high shunt resistance & shunt wire - low resistance) To over come this error, the swamping resistance is placed in series with the moving coil.
Swamping resistance reduce the effect of temp on the moving coil.

Electrodynamometer Type Instrument (~~EMMC~~)
or/ Electro Magnet Moving Coil (EMMC)
or/ Dynamometer type Instrument

The instrument whose working depends on the reaction between the magnetic field of moving & fixed coil is known as the Electro dynamometer instrument.

→ Used for measuring both AC & DC circuit.
→ EMMC used as - Wattmeter, voltmeter & Ammeter.

Construction - (I) Fixed coil - The fixed coil connecte in series with the load. It is considered as a current coil because the load current flows through it. (Produced magnetic field ∝ current)
→ It produces the uniform magnetic field
(II) Moving coil - It's considered as the pressure coil. It parallel with the supply voltage. Note: Magnetic field produced by moving coil ∝ V
The flow of currents control with the help of resistor which connects in series with the moving coil
(III) Control - The control system provides the controlling torque to the instrument. Spring control is used for control the movement of the pointer.
(IV) Damping - Reduce the movement of the pointer/Prevent the oscillation/bring the pointer in rest position.
(V) Scales & pointers - The pointer point / indicates the deflection of the coil & the magnitude of their deviation is shown on the scale.

Working Principle :- When the supply is given to the circuit the line current passes through the fixed coils. And the supply voltage given to the moving coil producee a current. These two coil produced magnetic field.

The magnetic field produced by Fixed coil ∝ I
" " " Moving coil ∝ V

Due to interaction between these two magnetic fields, a deflecting torque is produced on the moving coil. Hence the moving coil rotates along with the pointer. The deflection of the pointer shows the readings on the measuring scale.

Deflection ∝ Power supplied to the load.

Error - (1) Pressure coil inductance -
(2) Pressure coil ~~inducta~~ capacitance -
(3) Error due to mutual inductance error
(4) Stray magnetic field error
(5) Temperature Error

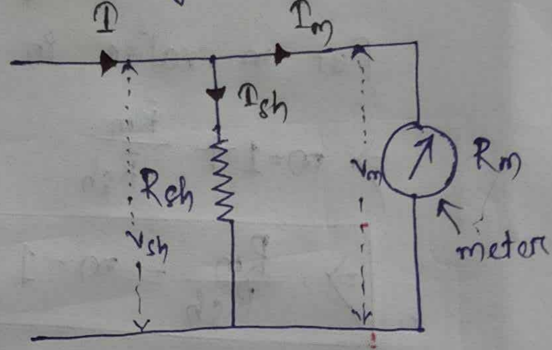
Advantages -
→ Can be used on both DC & AC system
→ good accuracy.
→ Used as Transfer instrument.

Disadvantages - Non uniform scale
→ Low sensitivity
→ More expensive / high cost

Extension of Range

Ammeter- A PMMC is used as indicating device. The current capacity of PMMC is small. It is impractical to construct a PMMC coil, which can carry a current grater than 100 mA. Therefore a shunt is required for large current measurement.

* Shunts are used for extension of range of Ammeter.



R_m = meter resistance (Ω)

R_{sh} = Shunt resistance (Ω)

I_m = meter Current (A)

I = current to be measured (A)

I_{sh} = Current through shunt (A)

V_m = voltage droop across meter (V)

V_{sh} = voltage droop across shunt resistance (V)

From the ckt diagram :-

$V_m = V_{sh}$ —— eq^n (1)

$V_m = I_m R_m$

$V_{sh} = I_{sh} R_{sh}$

Put the V_m & V_{sh} value in eq^n (1)

we get,

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

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

$$I_{sh} = I_m \left(\frac{R_m}{R_{sh}}\right) \quad \text{— eq}^n\ (2)$$

By applying KCL

$$I = I_m + I_{sh}$$

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

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

$$\Rightarrow \frac{I}{I_m} = 1 + \frac{R_m}{R_{sh}} \quad \text{—— eq}^n\ (3)$$

$$m = \frac{I}{I_m}$$

m = multiplying factor / Multiplication factor

Put m value in eqn (3), we get

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

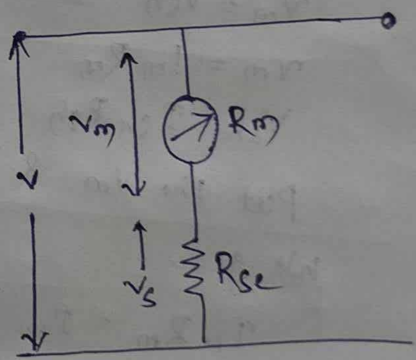
$$\Rightarrow \frac{R_m}{R_{sh}} = m - 1$$

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

$m > 1$, $R_{sh} << R_m$

Range Extension of voltmeter :-

We connect a resistance in Series with meter resistance for extension of voltmeter range.



$V = IR$

$R = R_m + R_{se}$

$V_m = I_m R_m$

$\Rightarrow V = I_m (R_m + R_{se})$

$\Rightarrow V = I_m R_m + I_m R_{se}$

$\Rightarrow V - I_m R_m = I_m R_{se}$

$$\Rightarrow R_{se} = \frac{V - I_m R_m}{I_m}$$

$$= \frac{V}{I_m} - \frac{I_m R_m}{I_m}$$

$$R_{se} = \frac{V}{I_m} - R_m$$

multiplying factor $m = \frac{V}{V_m} = \frac{I_m(R_m + R_{se})}{I_m R_m}$

$$M = 1 + \frac{R_{se}}{R_m}$$

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

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

Multi range voltmeter

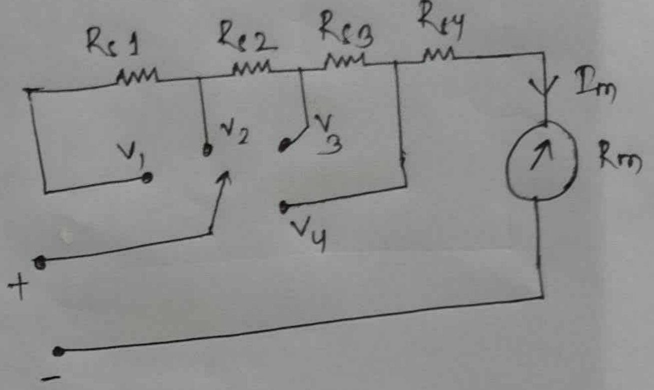
$R_{s1} = \frac{V_1}{I_m} - R_m$

$R_{s2} = \frac{V_2}{I_m} - R_m$

$R_{s3} = \frac{V_3}{I_m} - R_m$

$R_{s4} = \frac{V_4}{I_m} - R_m$

$$R_{sn} = \frac{V_n}{I_m} - R_m$$



, $m_1 = \frac{V_1}{V_m}$, $m_2 = \frac{V_2}{V_m}$, $m_3 = \frac{V_3}{V_m}$, $m_4 = \frac{V_4}{V_m}$

Multi Range Ammeter

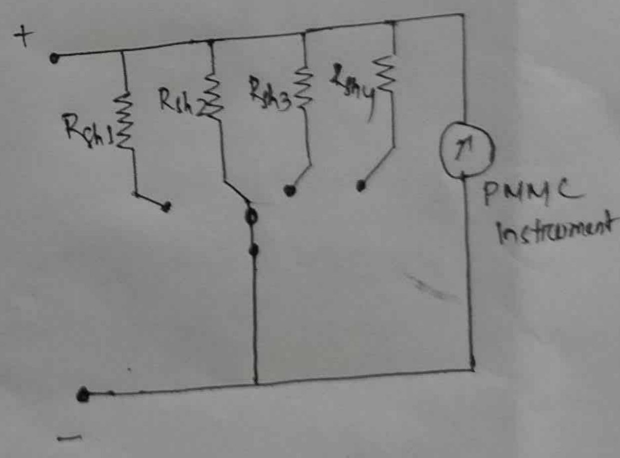
$R_{sh1} = \frac{R_m}{m_1 - 1}$

$R_{sh2} = \frac{R_m}{m_2 - 1}$

$R_{sh3} = \frac{R_m}{m_3 - 1}$

$R_{sh4} = \frac{R_m}{m_4 - 1}$

$$R_{shn} = \frac{R_m}{m_n - 1}$$



Magnin material is used for making ammeter shunt.
↳ Thin wire → Temp. coeffecient low → Less heating effect.

Unit -3

Dynamometer Type Wattmeter :-

Wattmeter is an instrument which is used to measure electrical power in Watts.

$$P = VI \quad \text{(Product of voltage \& current)}$$

A Dynamometer is a device which is used to measure force, torque & power.

Wattmeter

- Dynamometer Type (AC & DC power measurement)
- Induction type Wattmeter. (AC power measurement)

Dynamometer Type Wattmeter :-

→ The instrument whose working depends on the reaction bet^n the magnetic field of moving & fixed coil is known as the electro dynamometer wattmeter.

→ uses for measuring the power of both AC & DC circuit.

* Their working depends on the theory that the current carrying conductor placed in a magnetic field it experiences a mechanical force. This force deflects the pointer which is mounted on the calibrated scale.

Construction :- (1) Fixed coil - Fixed coil connects in series with the load. It is considered as a Current coil because the load Current flows through it. It produces uniform electric field.

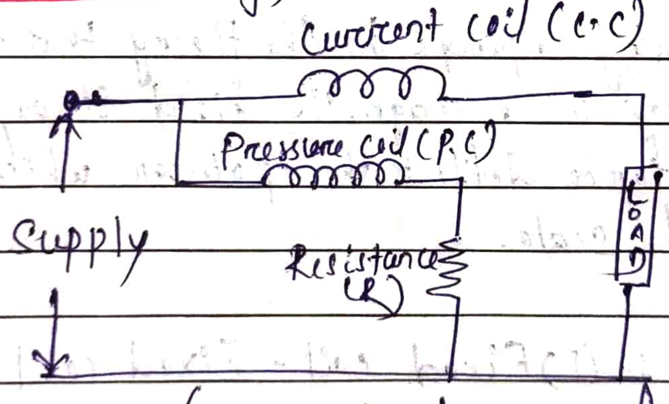
(2) Moving coil → It is considered as the pressure coil of instrument. It connects in parallel with the supply voltage. The current flows through them is directly propotional to the supply voltage.

The flow of currente control with the help of resistor which connects in series with the moving coil.

(3) Control → The control system provides the Controlling torque to the instruments. Spring control is used in this system.

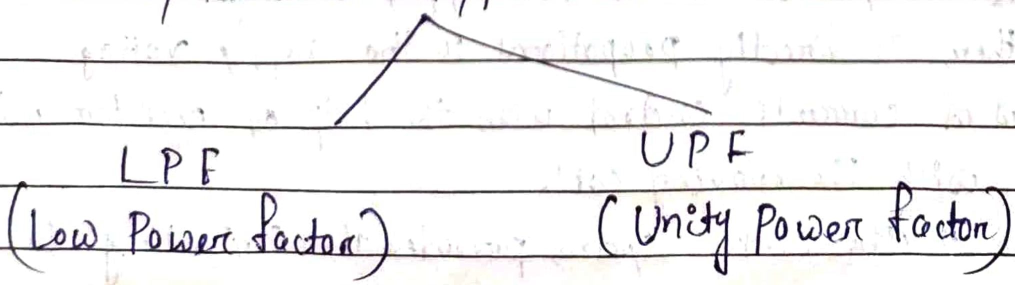
Spring control system is used for the movement of the pointer.
(4) Damping → It reduces the movement of the pointer. Air friction damping is used in this system.
(5) Scale & pointer – The instrument uses a linear scale because their moving coil moves linearly.

Working → when the supply voltage applies to the moving coil. The resistor controls the current across the moving coil & ~~the resistor~~ it is connected in series with it.
The pointer is fixed on the moving coil which is placed betⁿ the fixed coils. The current & voltage of the fixed & moving coil generate the two magnetic fields. Due to interaction betⁿ two magnetic fields the pointer will be deflects.
The deflection of pointer is directly propotional to the power flow through it. $T_d \propto P$

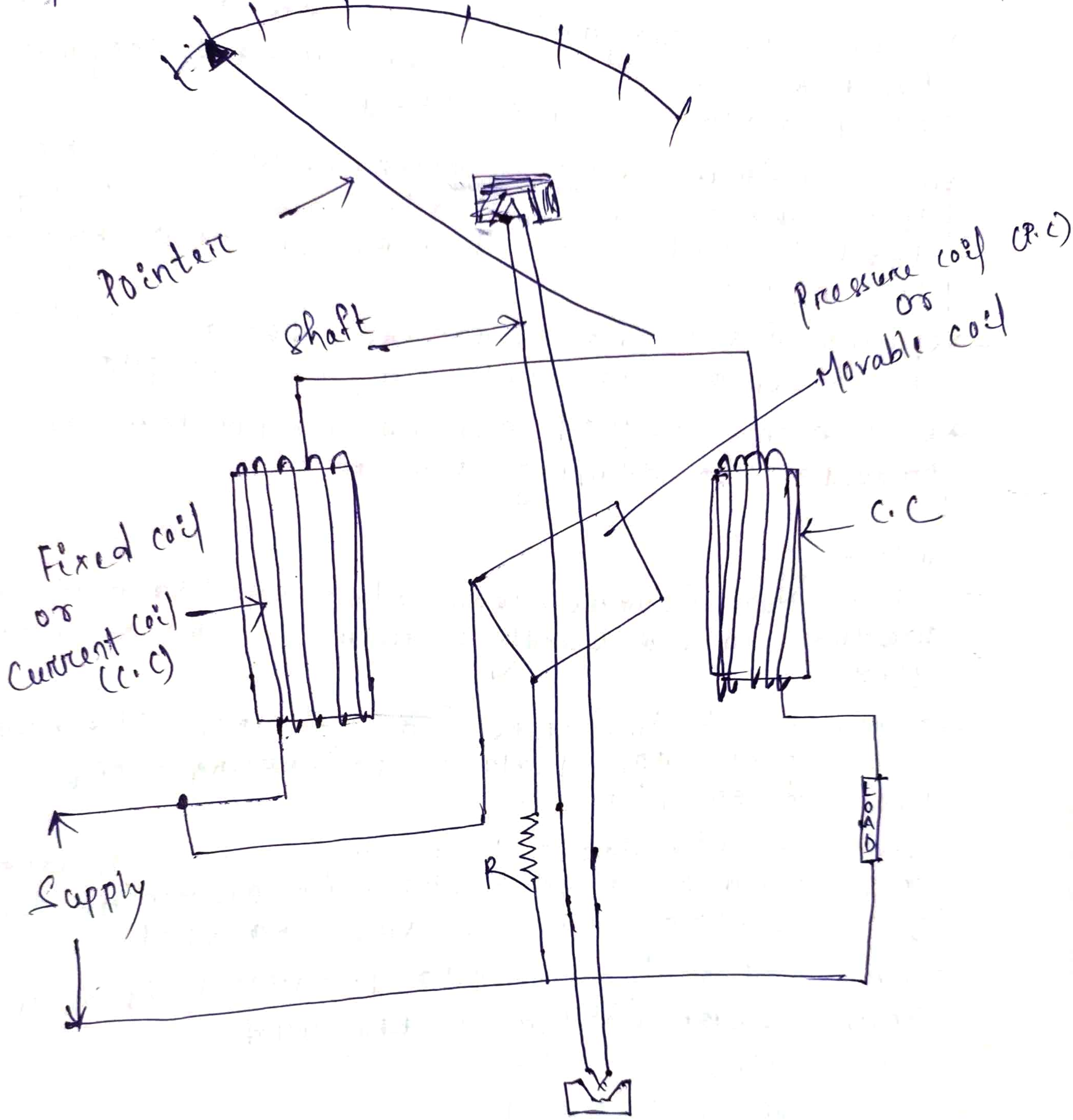


(Circuit diagram of Dynamometer type Wattmeter)

Dynameter Type Wattmeter



Dynamometer Type wattmeter :-



Low Power Factor Wattmeter :- The instrument that measures the low value of power factor accurately is known as Low power factor wattmeter.

→ Used for measuring the power of the highly inductive circuit.
→ This type of wattmeter is employed for power measurement in ckt whose power factor is less than (0.5).

Application → OC Test of Transformer

In ordinary wattmeter a circuit operating at low factors causes inaccurate in the reading because of two reason.

(1) In low power factor meter, the magnitude of deflecting torque on moving coil is small even after the full excitation of the pressure & current coil.

(11) The error occurs in the reading because of the pressure coil inductance.

* Less sensitivity more error.

To overcome these difficulties so that accurate reading can be obtained by the wattmeter when used in low power factor ckt.

Construction → Construction of a low power factor (LPF) wattmeter is the same as that of an electrodynamometer type wattmeter with slight modification for the compensation of errors.

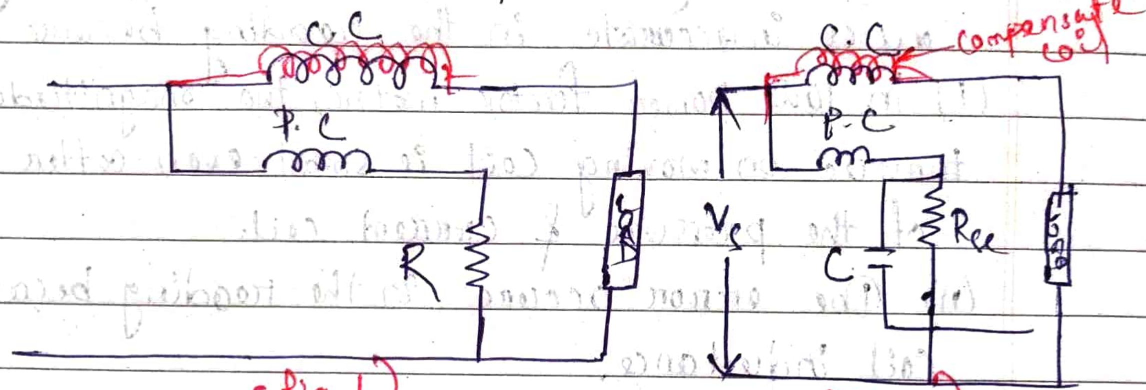
Modification :-

(1) Winding of the moving coil is made with low resistance material : The pressure coil is designed for having a low value of resistance so that the high value of current passed through it. This current produces the deflecting torque on the moving coil.

(2) Compensation for pressure coil :- (fig-1)

In low power circuit the value of current is high & that of the power is low. The high value current causes the error in wattmeter reading. For reducing the error, the compensation coil is used in the circuit.

The compensating coil compencate the error in the circuit which induces because of low power factor.
The compencating coil & the precceure coil are in series with each other. The coil is coordinate with the current coil.
The pressure coil (I_p) flows through it. The field induces is the compencating coil is because of the current (I_p).
The field of the compencating coil & the current coil opposes each other. Thus the pressure coil is neutralized.



(fig 1) (fig 2)

(3) Compensation for Inductance of pressure coil :- (fig 2)

The small amount of inductance is present in the pressure coil of the wattmeter. The inductance causes the error in the reading.
Compensating coil is used for compensating the inductance error occure in the wattmeter.
Along with compencating coil, the capacitor used in the ckt.
Capacitor placed in parallel with the pressure coil resistance.
The capacitor eliminates the error.

(4) Small controlling torque

The control torque of the low P.F wattmeter is kept small. So that the full scale deflection is obtained even for the small value of the power factor.

good deflection
full scale deflection.

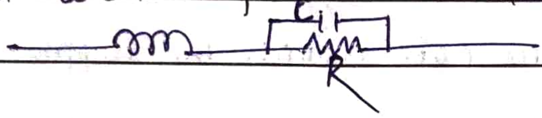
Error in Dynamometer Type Wattmeter & Methods of their Correction :-

$P = VI\cos\phi$

$V = \frac{P}{\downarrow I\cos\phi\downarrow}$

(1) Pressure coil inductance - Because of inductance the current of the pressure coils lag behind the voltage. Thus power factor of the wattmeter becomes lagging & the meter reads high reading.

* Correction → A capacitor must be added or connected in parallel with a portion of multiplier.



(2) Pressure coil capacitance - The P.C has capacitance which can cause increases the power factor hence it will be cause the error in the reading.

* Correction → It can be corrected by making inductive reactance equal to capacitive reactance ($X_L = X_C$) & the error = 0

(3) Error due to mutual inductance effect - Mutual inductance betn the P.C & C.C produces an error.

* Correction → By reducing the coupling between the coils.

(4) Eddy current error - The eddy current induces in the coil creates its own magnetic field. This field affects the main current flow through the coil. Thus the error occurs in the reading.

* Correction → By using a stranded conductors to minimize the eddy current flowing in the current coil itself.

(5) Stray Magnetic field - It disturb the main magnetic field. Thus affect their reading.

* Correction → The wattmeter must be properly shielded to reduce the magnetic effect.

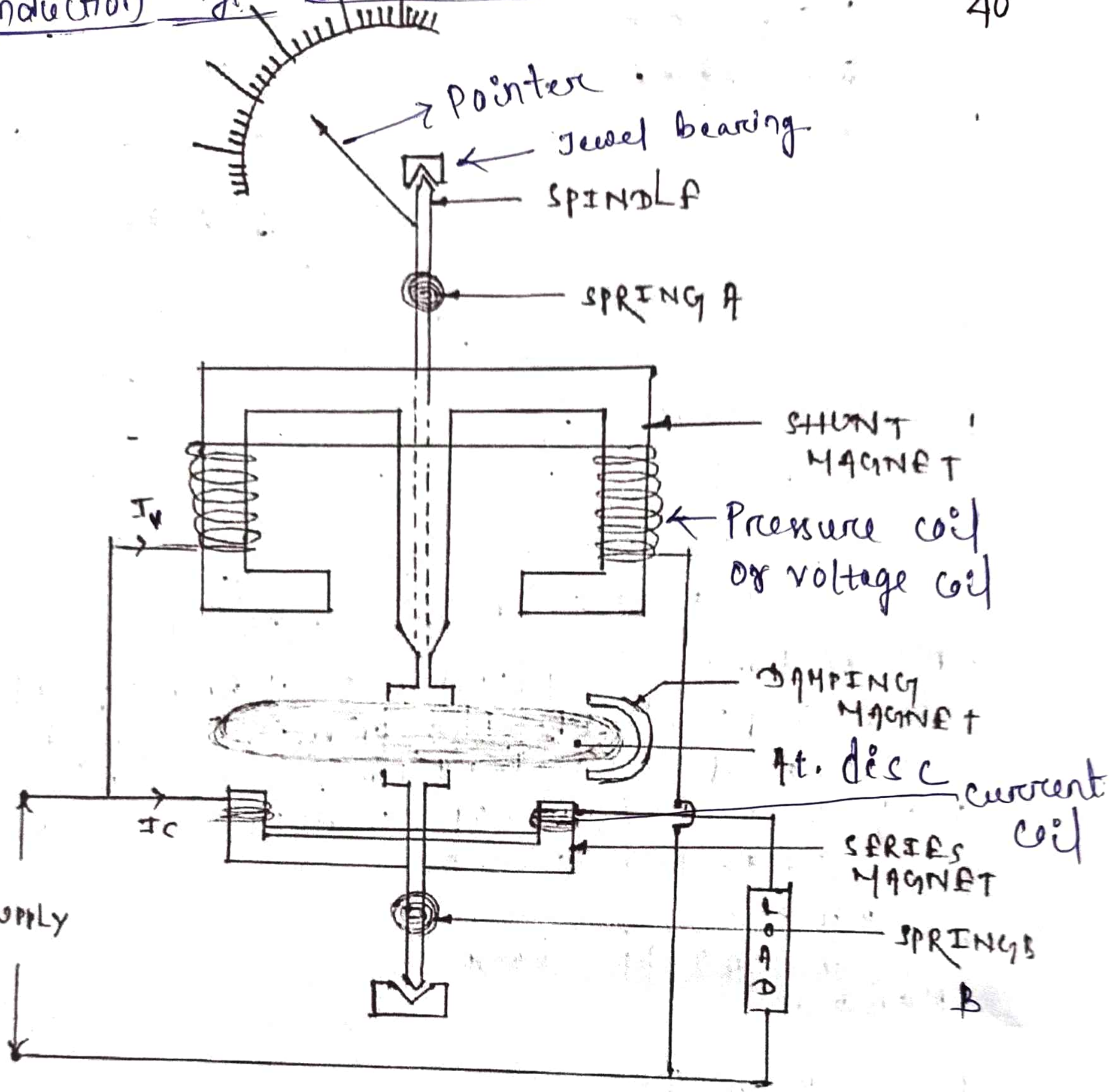
(6) Temperature error - the variation in temperature will change the resistance of the pressure coil (P.C). The P.C affect the spring then the spring affected the pointer. Hence the error will be occure.

* correction → Using a copper of resistance alloy which has temperature coefficient of 1:10.

(7) Error caused due to wrong connection.

Correction - Connecting Pressure coil across the supply & current coil in series with load.

Induction Type Wattmeter :-



→ The induction type wattmeter is used to measure only the AC power consume by the load.

→ It works on the same principle of as a induction type voltmeter & ammeter instrument.

Construction :-

→ The induction type wattmeter consists of two laminated electro magnets, known as shunt magnet or series magnet.

→ The series magnet is connected in series with the load and is excited by the load current.

- The shunt magnet is connected across the load & is excited by the current proportional to voltage across the load.
- An aluminium disc is mounted in between the two electro magnets in such a way that it cuts the fluxes produce by both the magnets.
- Spring A & B are connected to the spindle to provide the controlling the torque.
- A damping magnet can be connected to provide the damping torque.

Working:-

- The two fluxes generated by the electro magnet induce & eddy current in the aluminium disc.
- Due to the interaction between the fluxes & eddy current field a deflecting torque is produced on the disc.
- Due to the deflecting torque the spindle also rotates along with the aluminium disc & moves the pointer over the scale.
- The deflecting torque produced $T_d \propto VI\cos\theta$

$\cos\theta$ = power factor of the load

V = supply voltage

I = circuit current

Advantages:-

- The damping torque is produced is very effective.
- The induction type instrument has a very large scale range.

Disadvantages:-

Change in atmospheric temperature the resistance of the moving aluminium disc, which affects the deflecting torque.

Unit-5

Measurement of speed - Tachometer.

Tachometer use for measuring the rotational speed or angular velocity of the machine.

→ It works on the principle of relative motion between magnetic field & shaft of the coupled device.

→ The relative motion induces the EMF in the coil. The developed EMF is directly propotional to the speed of the shaft.

Tachometers

(1) Electrical Tachometer - It converts the angular velocity into an electrical voltage

(2) Mechanical Tachometer - It measure the speed of shaft reading revolution per minutes (RPM).

Electrical Tachometer is catagorized into 2 types

(i) AC Tachometer Generator - For reducing the problems related commutator & brushes AC tachometer will be designed.

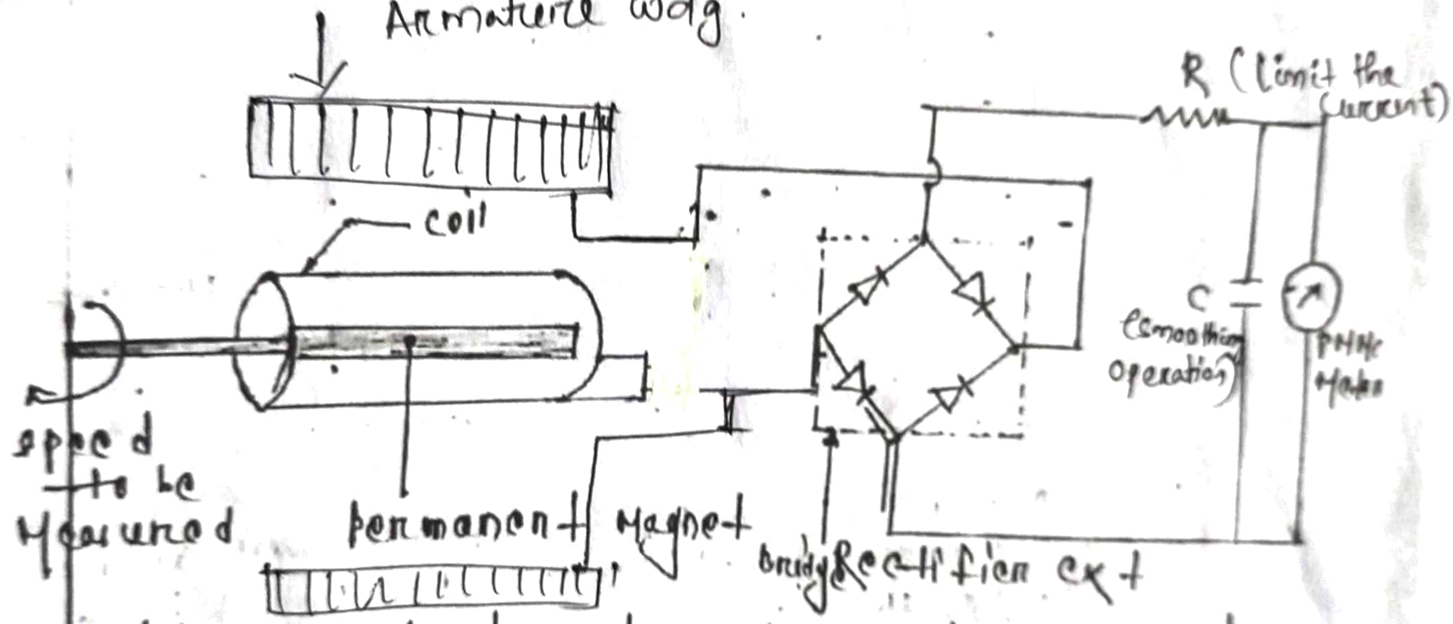
→ AC tachometer has stationary armature & rotating magnetic field.

→ The rotating magnetic field induces the EMF in the stationary coil of the stator. The amplitude & frequency of the induced emf are equivalent to the speed of the shaft.

Thus, either amplitude or frequency is used for measuring the angular velocity.

Induced voltage are rectified & then passes to the capacitor filter for smoothing the ripples of rectified voltages.

02



This AC tachometer generator generates

(II) DC Tachometer Generator :-

Permanent magnet, armature, commutator, brushes, variable resistor & the moving coil voltmeter are the main parts of the DC tachometer generator.

→ The machine whose speed is to be measured is coupled with the shaft of the DC tachometer generator.

→ It works on the Faraday's law of electromagnetic induction. The magnitude of the induced emf is directly proportional to the shaft speed.

→ Commutator converts the AC to DC with the help of brushes. Moving coil voltmeter measures the induced emf. The polarity of the induced dc voltage determines the direction of motion of the shaft. Resistance is used for controlling the heavy current of the armature.

$$E = \frac{P\phi ZN}{60A}.$$

$$\boxed{E \propto N}$$

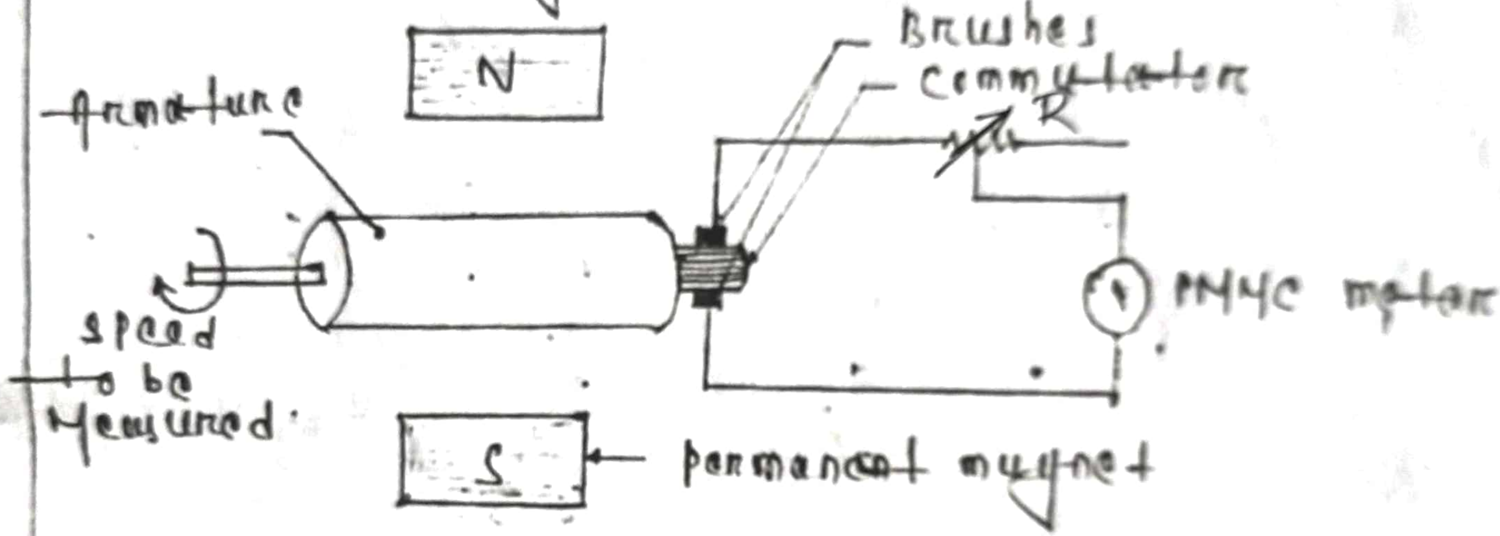
Advantages - a The polarity of the induced voltage indicates the direction of rotation of the shaft.

(b) It used for measuring the induced voltage.

Disadvantages → It require the periodic maintenance due to use of commutator & brushes.

(II) Resistance is high.

(4) DC Tachometer generator:-



Measurement of frequency → Instrument Frequency Meter

A Frequency meter is an instrument that displays the frequency of a periodic electrical signal.

It is 2 types
(1) Electrical Resonance type frequency meter
(2) Mechanical Resonance type frequency meter.

(1) Electrical Resonance type frequency meter.

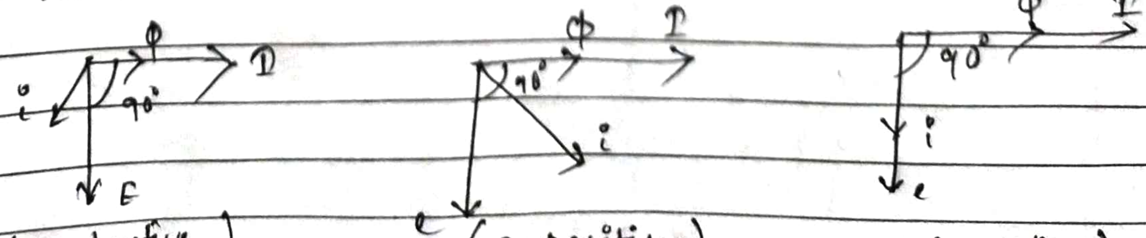
Electrical resonance occurs in an electric circuit at a particular resonance frequency where the imaginary parts of circuit element impedances or admittances cancel each other.
$X_L = X_C$ & the power factor will be close to 1 & Phase angle (ϕ) is zero. In resistive circuit it will be possible.

Construction :- It consist of a laminated Iron core a fixed Coil & moving coil with a pointer attached with it. The moving coil is connected across a capacitor C & the fixed coil is connected across the supply circuit, whose frequency is to be measured.

Working - when the magnetising coil is connected across the supply circuit current (I) flows through it & flux ϕ in phase with the current is set up in the iron core & emf is lagging behind the current by 90°.

→ Current in the moving coil be lagging or leading the induced emf depends on the it will be inductive or capacitive.

→ The current in the moving coil will be in phase with e when $X_L = X_C$



(Inductive) (Capacitive) (Resistive)

The torque of the moving system

$$T \propto I_1 I_2 \cos(90^\circ \pm \alpha)$$

At $X_L = X_C$ → Torque will be zero

High sensitivity can be obtained if the inductance of the moving coil changes slowly with the variation of the position on the core.

07 **Ferrodynamic type frequency meter:-**

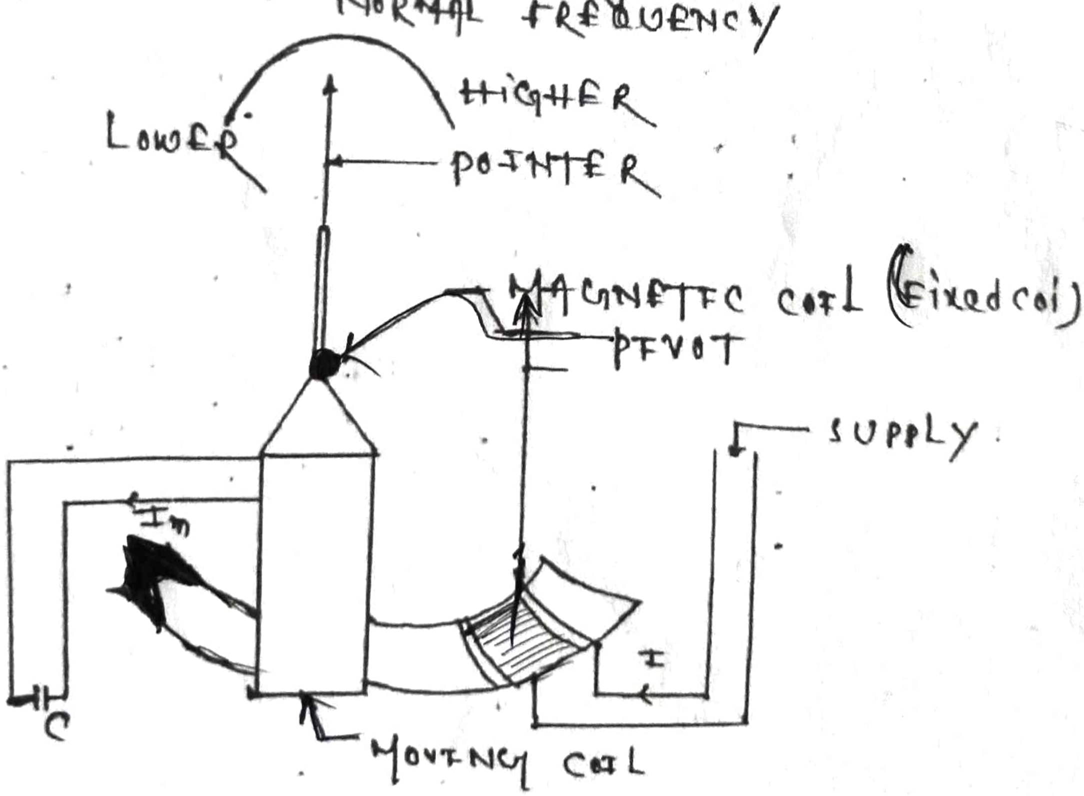
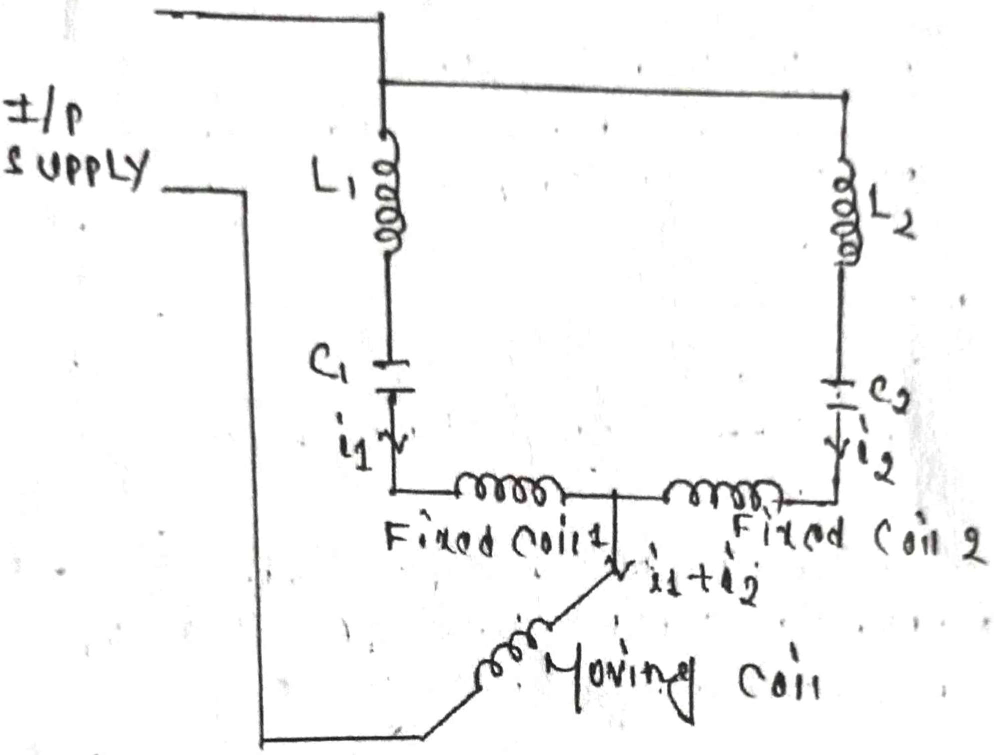


Fig: Ferrodynamic electrical resonance frequency meter.

Electrodynamometer type frequency meter :-



Construction :-

→ In this type frequency meter one fixed coil is present which is divided into 2 parts i.e. fixed coil 1 & fixed coil 2.

→ Fixed coil 1 is in series with & inductance L_1 & a capacitance C_1. The value of L_1 & C_1 are choosen that its resonant frequency F_1 is slightly lower than the instrument frequency.

9 → the fixed coil 2 is in series with and an inductance L_2 & a capacitance C_2. the value of L_2 & C_2 are so chosen that its resonant frequency of the circuit 'F_2' is slightly higher than the instrument frequency.

→ Ex:- If 50Hz is the middle scale of the instrument frequency then $F_1 \approx 40$Hz, $F_2 \approx 60$Hz

$$F_1 = \frac{1}{2\pi\sqrt{L_1C_1}} , \quad F_2 = \frac{1}{2\pi\sqrt{L_2C_2}}$$

→ one moving coil is connected in between the fixed coil 1 & fixed coil 2 through which $I_1 + I_2$ current flows.

Working:-

→ For an applied frequency of the ckt of fixed coil 1 operates above the resonant frequency, as $X_L > X_C$. so here current i_1 lags the voltage.

→ At that time the circuit of fixed coil 2 operates below the resonant frequency, as $X_C > X_L$. so here current i_2 leads the voltage.

→ since one circuit is inductive & the other is ~~capacitor~~ capacitive, therefore the 2 currents i_1 & i_2 generates to opposite torques on the moving coil.

→ the resultant torque which acts on the moving coil is a function of frequency of the applied voltage.

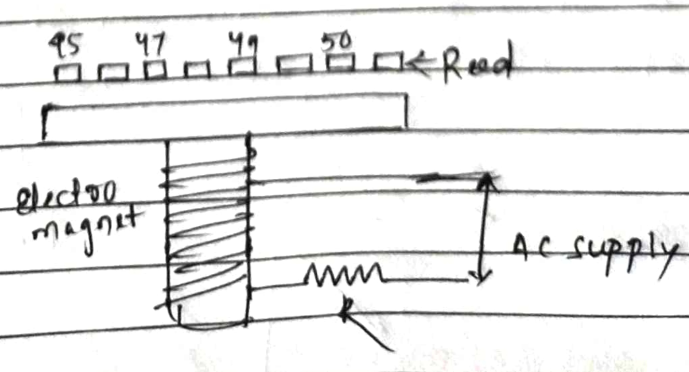
→ the movement of the moving coil can be calibrated over a scale in terms of frequency.

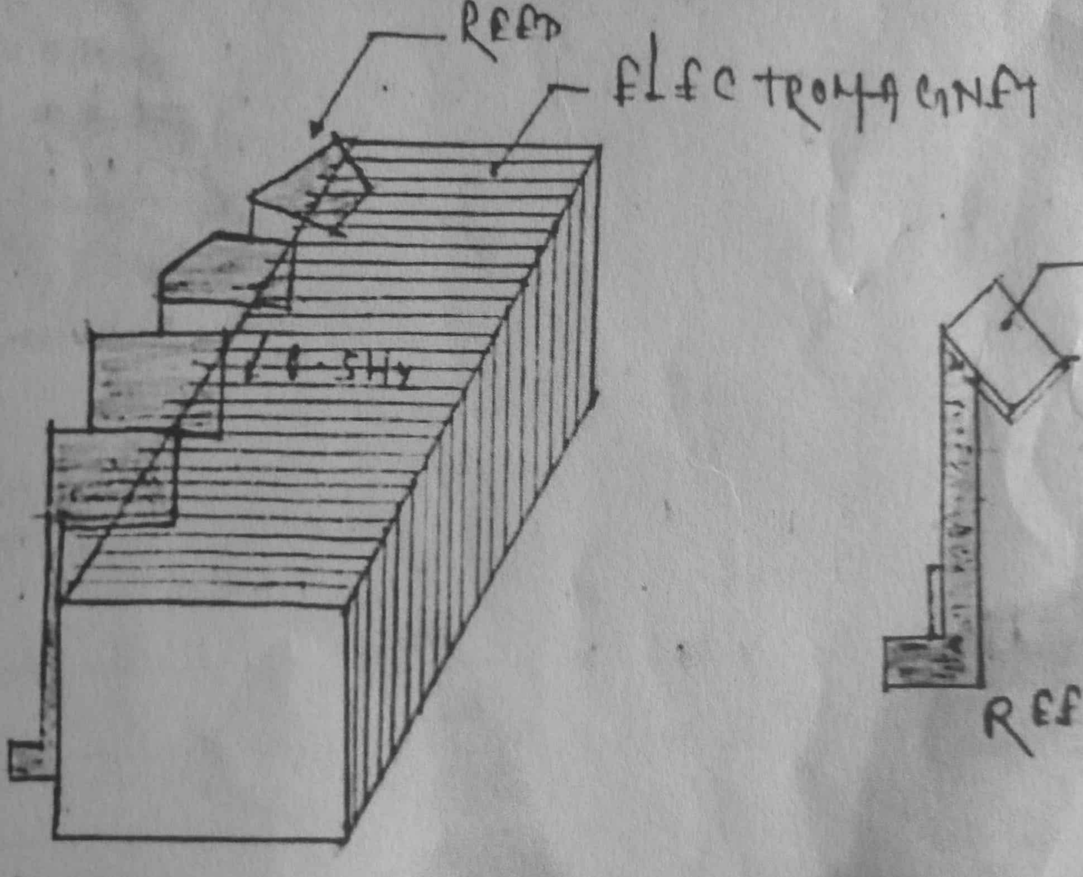
Mechanical Resonance type frequency Meter
(Vibrating Reed type frequency meter)

A mechanical resonance type frequency meter indicates the supply frequency of the circuit directly & is very convenient for most practical purpose.
It gives reading free from errors due to change in temperature, wave form & magnitude of applied voltage.

Construction - A vibrating reed frequency meter consist of a number of thin steel strips called reeds. These reeds are placed in a row alongside & close to an electromagnet. These electromagnet Consist of thin laminations & a coil is wound around it. The coil is connected in series with a resistance across the supply whose frequency is to be measured.
The reeds are fixed at the bottom end and are free at the top end. The flags at the top of reeds are painted white & the frequency is read directly from the instrument by observing the scale mark opposite to the reed which is vibrating most.

Working :- when the meter is connected across the supply whose frequency is to be measured an alternating current I flows through the coil of an electromagnet which produces a force of attraction on the reeds. The force of attraction is propotional to the square of the current there force it varies at twice the supply frequency. All the reeds thus tend to vibrate. Mechanical resonance is obtained in the case of this reed.





(Fig: vibrating reed type frequency meter)

Power Factor Meter - The instrument which indicates the power factor of a load circuit to which their connected is called as power factor meter.

→ The power factor is the cosine of the angle betn the voltage & current.

→ It determines the type of load using on the line & it also calculate the losses occur on it.

$$P = VI \cos\phi$$

where as, P = power, V = voltage & I = current, cos ϕ = power factor

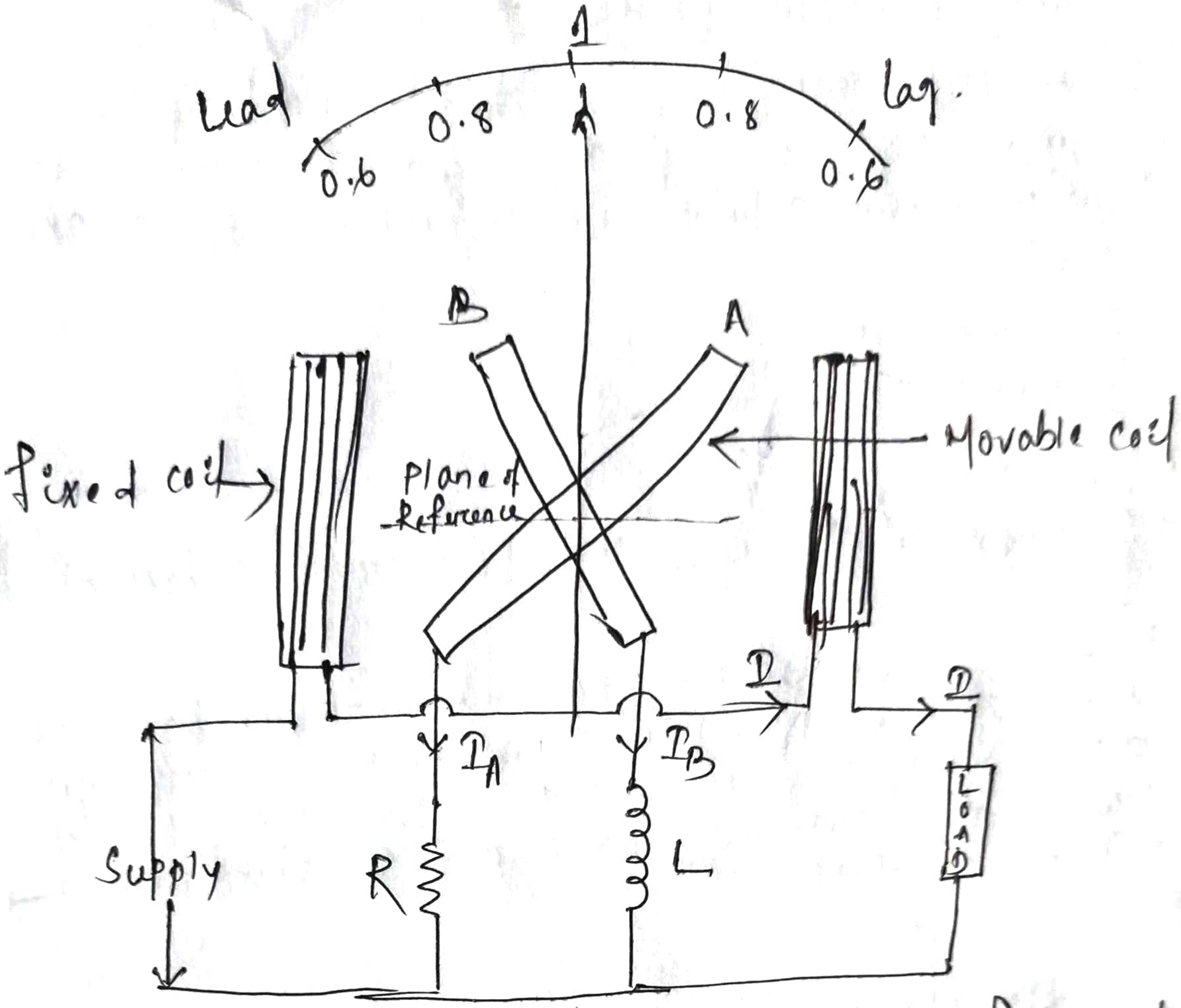
$$\cos\phi = \frac{P}{VI}$$

The power factor meter has the moving system called pointer which is in equilibrium with the two opposing forces.

The power factor meter is of 2 types

(1) single phase Electrodynamometer power factor meter

(2) Three phase " " "



(1 ϕ Electrodynamometer type power factor Meter)

Construction:-

→ The single phase electrodynamometer type power factor pressure coil consists of fixed coil &

→ The fixed coil splits into two parts and carries the current of the circuit which is supplied to the load.

→ The pressure coil also consists of two coils that is coil A & coil B.

→ These two pressure coil pivoted on a spindle

→ Which constitute the moving system.

→ Pressure coil 'A' is connected in series with a resistance 'R' and pressure coil 'B' is connected in series with inductance 'L'.

→ The current proportional to the voltage drop across the load flows through the pressure coil.

→ The value of R & L are so adjusted that $R = 2\pi f L$

→ The angle between the plane of the coil is made equal to 90°. The current I_B lags the voltage by 90°, current I_A is in phase with voltage. (is insame phase).

Working / operation:-

→ In this case two deflecting torque are produce which acts on coil A & coil B.

→ The coils are so design that the torque acting on it, are equal & opposite in direction so the pointer takes a position where the two torques are equal.

→ The deflecting torque acting on coil A proportional to $VI_A M \cos\phi \sin\theta$

$T_A \propto VI_A M \cos\phi \sin\theta$

$\Rightarrow T_A = KVI_A M \cos\phi \sin\theta$

$T_B = KVI_B \cos(90-\phi) \sin(90+\theta)$

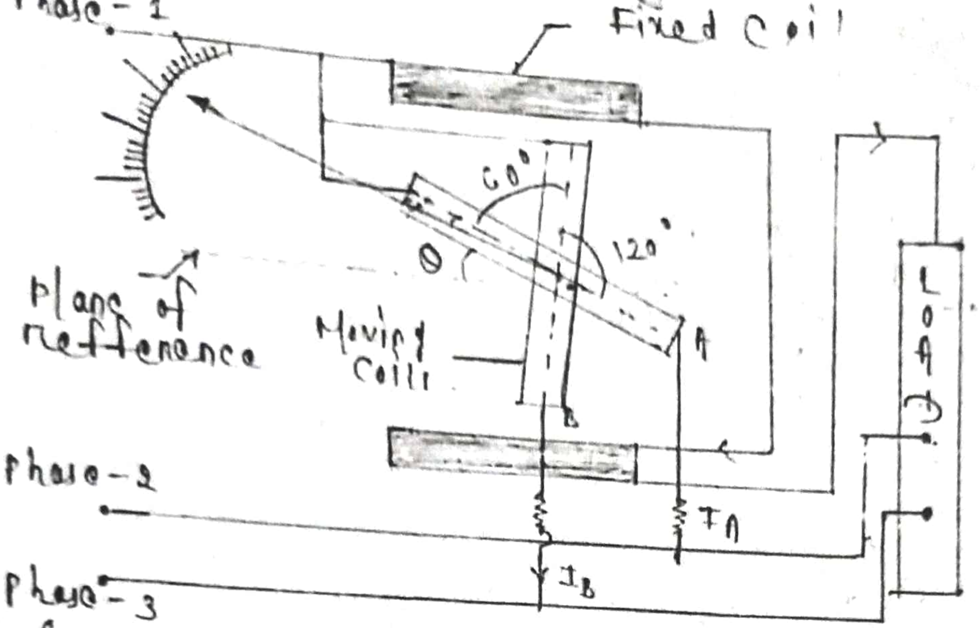
equilibrium cond? $T_A = T_B$

$\theta = \phi$

so the deflection of the instrument ~~which~~ w.r.t pressure coil A is the measure of phase angle of the circuit.

→ The scale of the instrument can be calibrated cosine of the phase angle that is power factor.

3-ϕ Electrodynamometer-type power factor meter:-



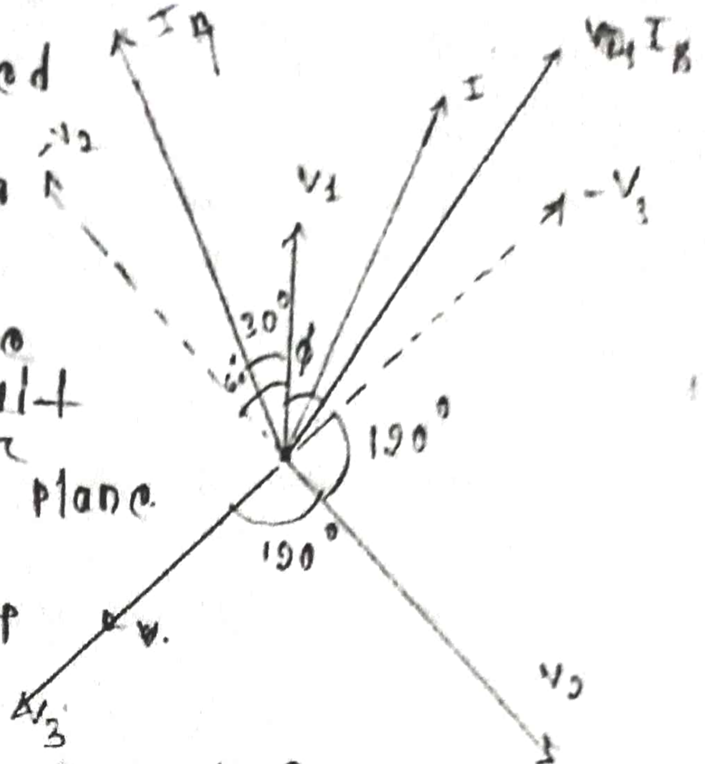
(Fig: 3-ϕ Electrodynamometer-type power factor meter)

Construction:-

- The above figure shows the construction & connection of a 3-ϕ electrodynamometer-type power-factor.
- The two moving coils of the meter are show placed that the angle between their place is 120°. This two coils are connected across two different phases of the supply circuit.
- Each of this two coils has series resistance through which it is connected to the phase angle.
- The voltage applied across coil 'A' is V_{12} & the current flowing through it is I_A.
- The voltage applied across coil 'B' is V_{13} & the current flowing throug it is I_B.
- This two moving coils are placed in between the segments of fixed coils.

Working :-

→ The torque developed in coil 'A' & coil 'B' are equal & opposite in direction.



→ Let 'ϕ' is the phase angle of the circuit & 'θ' is the angular deflection w.r.t plane of refference.

→ The torque develop in coil 'A' can be given by,

$T_A = K V_{12} I_A M \cos(30+\phi) \cdot \sin(60+\theta)$

→ The torque develop in coil 'B' can be given by,

$T_B = K V_{13} I_B M \cos(30-\phi) \cdot \sin(120+\theta)$

→ this two torque are equal in magnitude, so we can write, $T_A = T_B$

since the angular deflection of the pointer from the plane of refference is equal to the phase angle of the circuit, so the pointer movement can be calibrated interms of power factor (cosϕ).

CHAPTER - 6

MEASUREMENT OF RESISTANCE, INDUCTANCE & CAPACITANCE, RESISTANCE MEASUREMENT

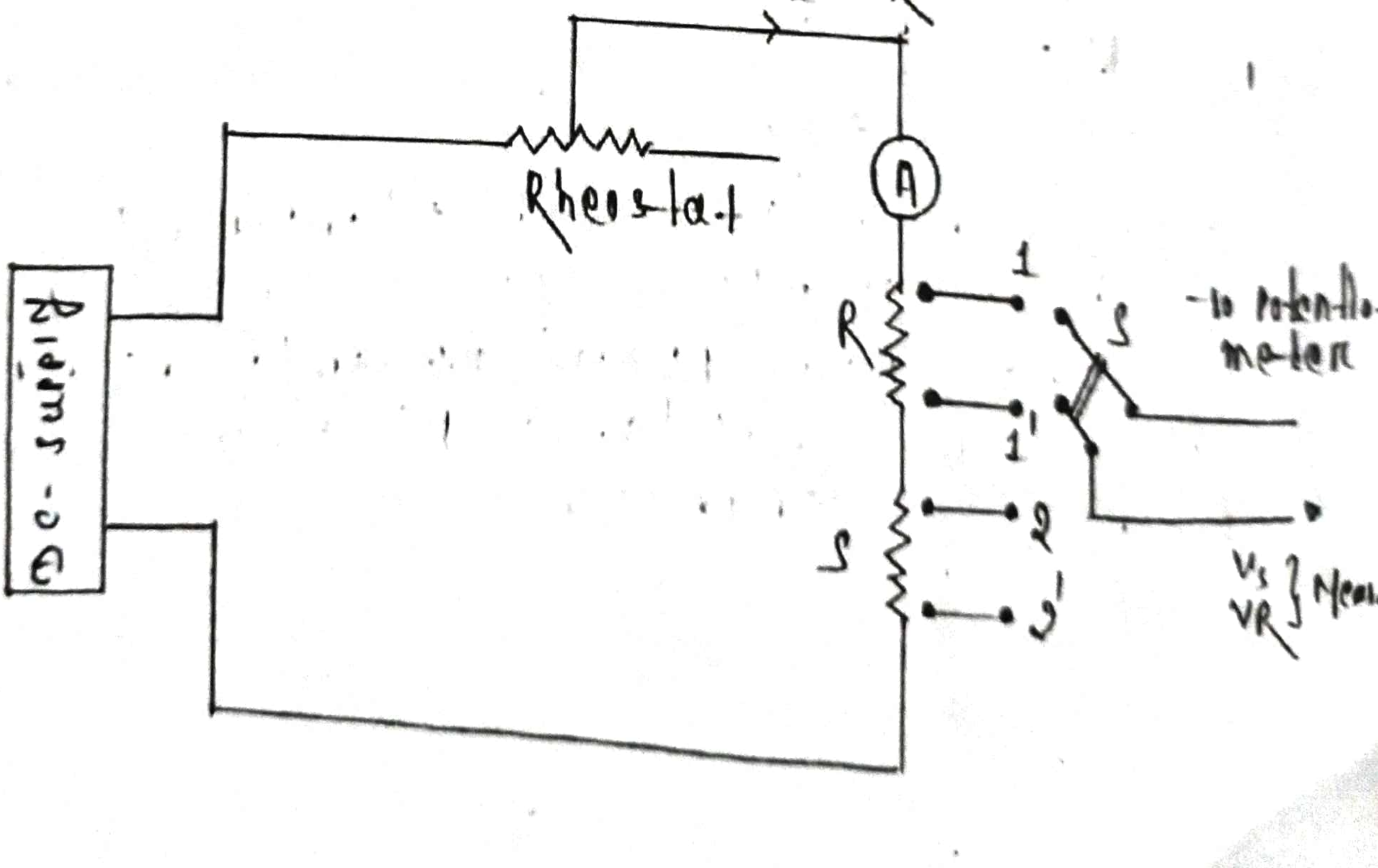
Resistance are catagorised into 3 catagory:-

1. Low resistance (Below 1 Ω or ≤ 1 Ω)
2. Medium resistance (1 - 100k Ω)
3. High resistance (More than 100 or >, 100k Ω)

Low resistance Measurement by potentiometer Method :-

$V_S = I \times S \Rightarrow I = \frac{V_S}{S}$ $\Rightarrow R = \frac{V_R \times S}{V_S}$

$V_R = I \times R \Rightarrow I = \frac{V_R}{R}$ $\frac{V_S}{S} = \frac{V_R}{R}$



→ the above ckt is used to measure the unknown resistance with the help of a potentiometer.

→ potentiometer is a device which can detect variable unknown voltages.

→ In the above ckt 'R' is the unknown resistance whose value is to be measured & 's' is the known standard resistor.

→ the ckt current is control with the help of a rheostat.

→ A double through switch is used to connected 1 1' or 2 2' points.

→ The double throw switch is connected to a potentiometer to measure the voltage drop in unknown resistor 'R' (V_R).

→ When the switch is connected 1 1' than voltage drop $V_R = I \times R \Rightarrow I = \frac{V_R}{R}$ —— eqn ①

→ When the switch is connected 2 2' than voltage drop '$V_s = I \times s \Rightarrow I = \frac{V_s}{s}$ —— eqn ②

→ From eqn ① & ② we get that,

$$\frac{V_s}{s} = \frac{V_R}{R}$$

$$\Rightarrow \boxed{R = \frac{V_R \times R_s}{V_s}}$$

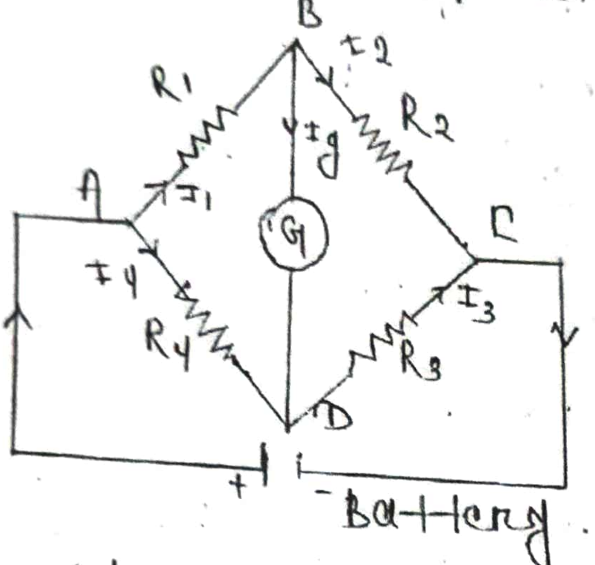
→ since the value of standard resistance 'Rs' is accurately known, V_R & V_s value can be detected from potentiometer, the unknown resistance 'R' value can be easily calculated.

Medium resistance Measurement by wheatstone bridge method:-

→ wheatstone is an electrical ckt in which 4 no. of resistors are connected in a bridge structure.

→ out of this 4 resistances, 3 resistance are known & 1 resistance is unknown.

→ The wheatstone bridge ckt can be used to calculate the value of unknown resistance.



→ Consider the 4 resistance R_1, R_2, R_3 & R_4 which are connected in the wheatstone bridge.

→ Let, R_1, R_2 & R_3 are known resistances & R_4 is unknown resistance.

→ Let I_1, I_1, I_3 & I_4 are the current flowing through the resistances.

→ A null type galvanometer is connected between B & D junction & 'I_g' is the current flowing through the galvanometer.

→ Consider 'R_3' is the variable resistor, whose value is show adjusted that the galvanometer show null deflection. At this condition $I_g = 0$.

→ At this balancing condition:-

At junction B,

$I_1 = I_g^{0} + I_2$

$\Rightarrow \boxed{I_1 = I_2}$ — eqn ①

R_g is the internal resistance of the galvanometer.

At junction D,

$I_4 + I_g^{0} = I_3$

$\Rightarrow \boxed{I_4 = I_3}$ — eqn ②

Applying KVL, in ABD Loop,

$I_1 R_1 + I_g R_g^{0} - I_4 R_4 = 0$

$\Rightarrow \boxed{I_1 R_1 = I_4 R_4}$ — eqn ③

Applying KVL in BCD Loop.

$I_2 R_2 - I_3 R_3 - I_g R_g^{0} = 0$

$\Rightarrow \boxed{I_2 R_2 = I_3 R_3}$ — eqn ④

Dividing eqn ③ with eqn ④ we get:-

$$\boxed{\frac{I_1 R_1}{I_2 R_2} = \frac{I_4 R_4}{I_3 R_3}}$$

Using eqn ① & ②

$$\frac{I_1 R_1}{I_1 R_2} = \frac{I_4 R_4}{I_4 R_3}$$

$$\Rightarrow \boxed{\frac{R_1}{R_2} = \frac{R_4}{R_3}}$$

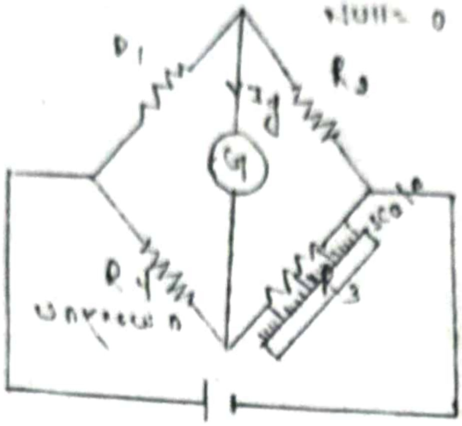
This condition is known as balancing condition of wheatstone bridge.

$$\boxed{R_4 = \frac{R_1 \times R_3}{R_2}}$$

From the above ~~experime~~ expression the value of unknown resistances R_4 can be calculated.

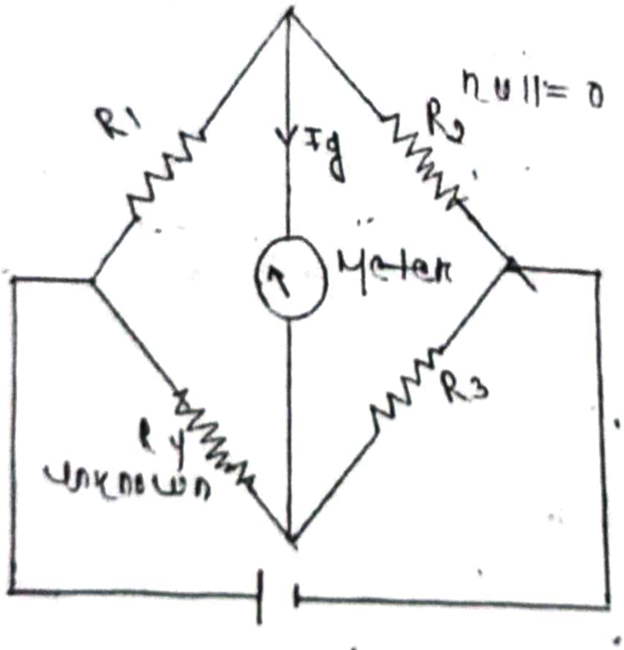
There are two types of wheatstone bridge ckt :-
1- Null balance type
2- Deflection type.

Null balance type :-



→ The adjustment of variable resistor R_3 is calibrated interms of unknown resistance R_4.

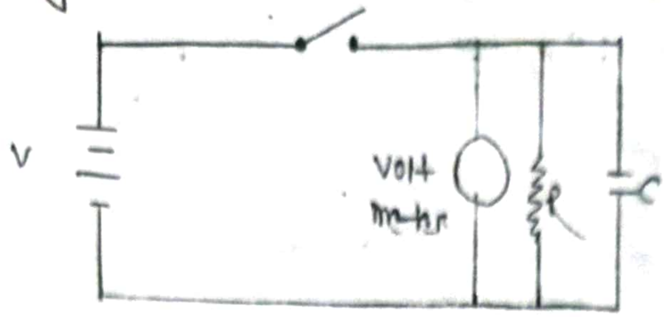
Deflection type :-



→ The current Ig is proportional to the unknown resistance R_4 when the bridge is unbalanced.

→ A PMMC type instrument can be connected to measure the 'Ig' current & the meter is calibrated interms of unknown resistance R_4.

High resistance measurement by loss of charge method:-



- The high resistance can be measured by using loss of charge method.
- The high resistance is also known as insulation resistance.
- In this method the insulation resistance are whose value is to be measured is connected in parallel with a capacitor 'C' & a voltmeter.

Working:-

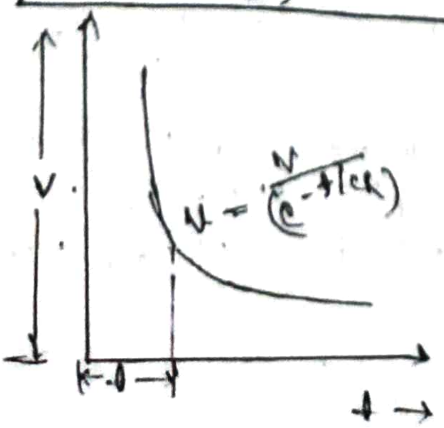
- The capacitor is charged to a suitable voltage by using a battery.
- After that the capacitor is allowed to discharge.
- During the discharge the terminal voltage across the capacitor or at any instant of time 't' can be given by.

$v = Ve^{(-t/CR)}$

$\Rightarrow \boxed{\frac{v}{V} = e^{(-t/CR)}}$

$\Rightarrow \ln\left(\frac{v}{V}\right) = -t/CR$

$\Rightarrow \boxed{R = \frac{-t}{C \ln\left(\frac{v}{V}\right)} = \frac{-t}{C \times 2.3 \log\left(\frac{v}{V}\right)} = \frac{0.434 t}{C \log\left(\frac{V}{v}\right)}}$



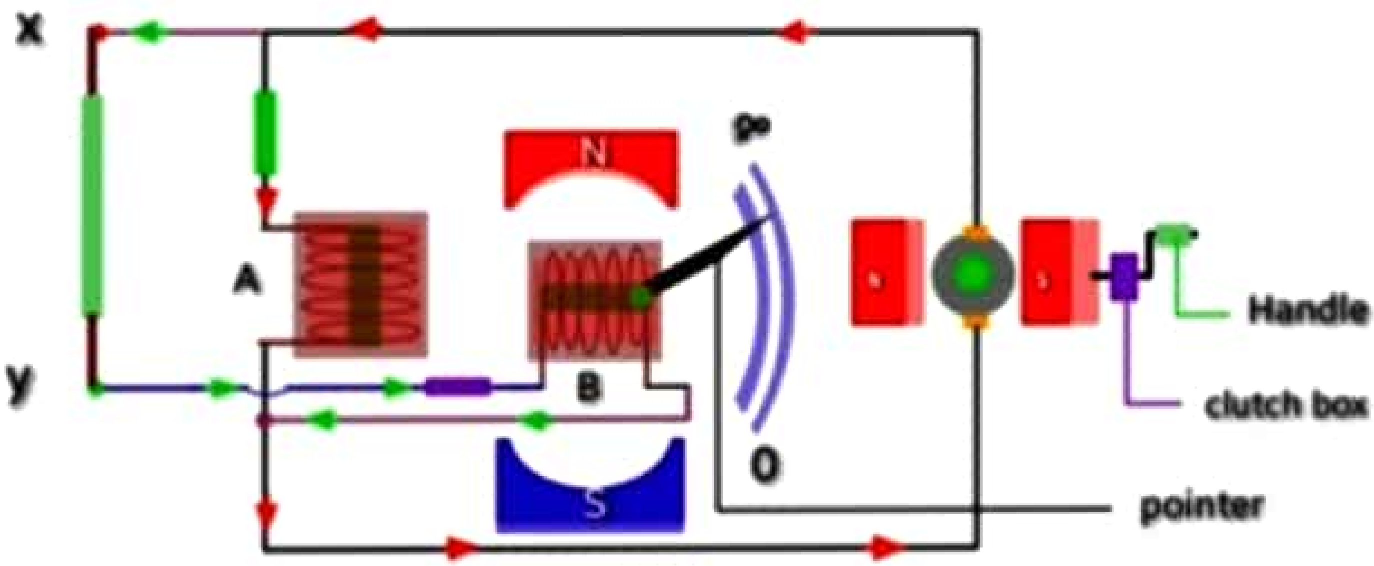
→ v is the instantaneous value of voltage across a capacitor at any instant of 't'.

$$R = \frac{-0.4343t}{C\log\left(\frac{V}{v}\right)} \quad \text{——— eqn (1)}$$

→ In eqn (1) if v, t, V & C values are known to us than the unknown resistance at can be calculated.

Megger :-

→ Megger is an instrument which is used to measure insulation resistance & very high resistance. It is also known as insulation tester.



x
y
A
N
B
S
∞
0
Handle
clutch box
pointer

→ It is a modified PMMC type instrument.

→ This instrument contains 1 current coil & 2 pressure coils.

→ The pressure coils are V_1 & V_2, this 2 coils are so located that when the magnetic field gradually become stronger the pointer moves from ∞ to 0.

→ The current coil also controls the pointer movement by its magnetic field.

→ When the current in the current coil in the large, than the pointer indicates '0', which means R_x is very small.

→ Similarly when the current in current coil is low, it indicates '∞' over than scale, which means R_x value is very large.

→ The voltage range of the instrument can be controlled by using variable resistor switch, which is connected in series with current coil.

→ The generator is use to generate the testing voltage while measuring the unknown resistance.

→ The unknown resistance R_x can vary the current flowing through 'P' coil & 'c' coil. So the movement of pointer can be affected by the unknown resistance 'R_x'.

→ When A & B ends are upon circuited than the pointer indicates '∞'.

→ When A & B end short circuited than the pointer indicates '0'.

→ The pointer movement can be calibrated in terms of resistance to measure the 'R_x' value.

→ A centrifugal clutch in incorporated in the generator to drive it at a constant speed while generate in the voltage.

Earth tester :-

→ Earth tester is an instrument which is used to measure earth resistance.

→ While earthing the earth electrode should be present in a low resistance soil, so that it can carry the excess current to the earth without any disturbance.

→ The earth soil resistance is affected by the moisture contain of the soil. So periodic testing of earth resistance is required to make the earthing system more effective.

Construction :-

→ The earth tester is a special type of megger with two additional features.

(i) current reversal
(ii) Rectifier → (commutator)

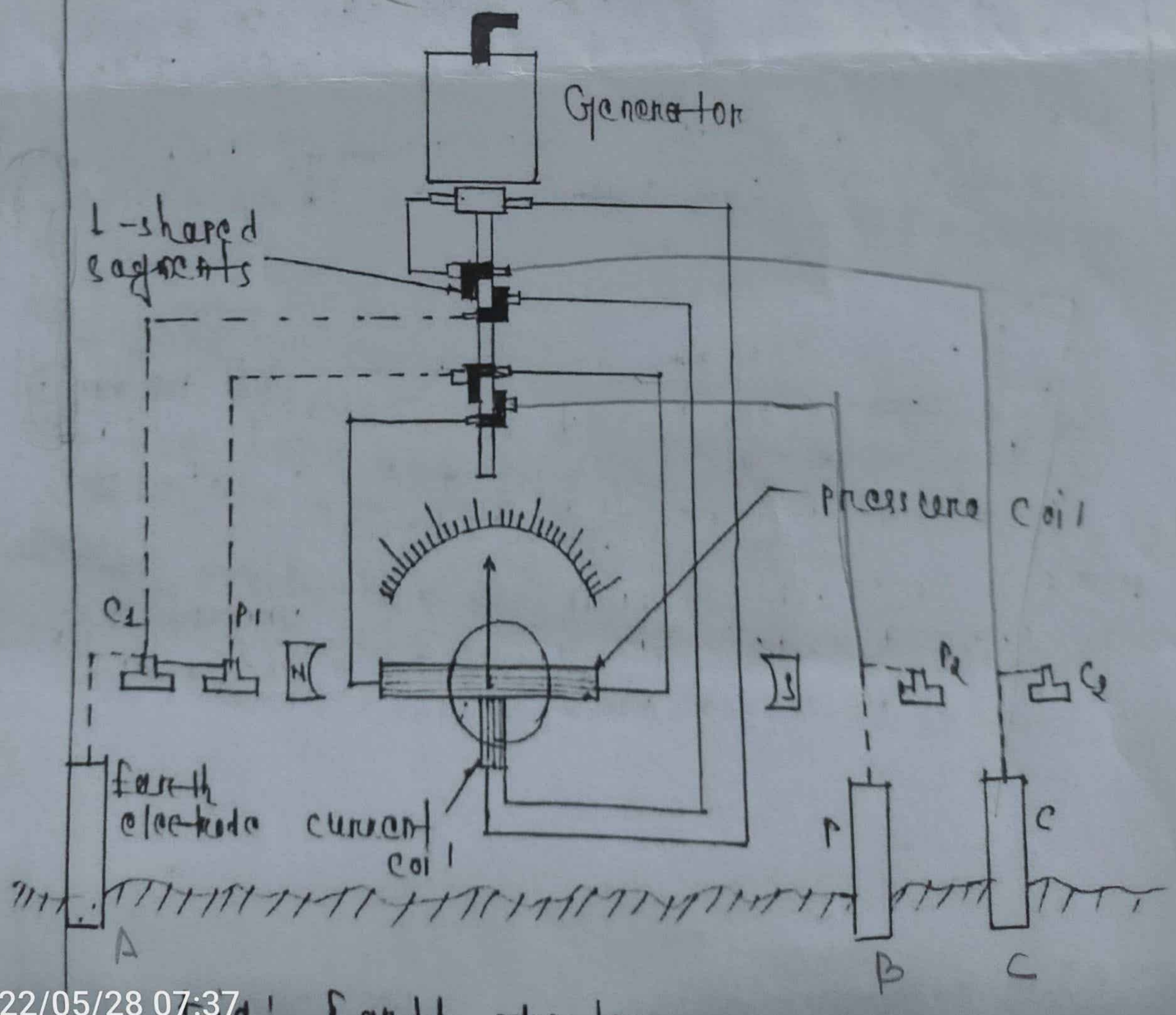


Fig : Earth tester.

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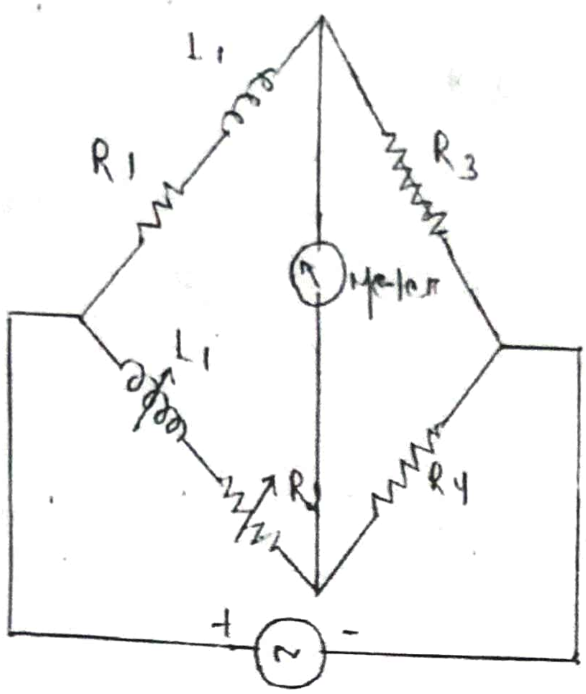
- This instrument consists of commutators made up of L-shaped segments.
- This segments are mounted on the shaft of the generator.
- Is commutator has four brushes, this brushes are position that one pair contact alternately with one segment, while the second pair fixedly contact to the same point, when the commutator rotates.
- The earth tester has four terminal P_1, P_2, C_1 & C_2.
- Two terminal P_1 & C_1 are shorted are connected to earth electrode.
- The other two terminal P_2 & C_2 are connected to auxiliary electrodes 'P' & 'C'.
- The indication of earth tester instrument depend upon the ratio of voltage across the pressure coil & the current flowing through it.
- The deflection of instrument pointer indicates the earth resistance directly.

Note:-

- When DC current is supplied to the earth for measurement of resistance, the back emf is generated in the soil, due to electrolytic effect.
- To avoid this condition AC current supply through the soil for the measurement of earth resistance.

Maxwell bridge for (Inductor Measurement):-



→ The maxwell bridge measures inductance by comparing with a variable standard inductance.

→ In the above circuit L_1 = unknown inductance
L_2 = variable inductance
R_1, R_3, R_4 = known resistance
R_2 = variable resistance.

→ The balancing condition of the bridge can be given by,

$$\frac{Z_1}{Z_3} = \frac{Z_2}{Z_4}$$

$\Rightarrow Z_1 Z_4 = Z_2 Z_3$

$\Rightarrow (R_1 + j\omega L_1) R_4 = (R_2 + j\omega L_2) R_3$

$\Rightarrow R_1 R_4 + j\omega L_1 R_4 = R_2 R_3 + j\omega R_3 L_2 R_3$

→ Equating the imaginary part of the above eqn we get,

$\Rightarrow j\omega L_1 R_4 = j\omega L_2 R_3$

$\Rightarrow L_1 R_4 = L_2 R_3$

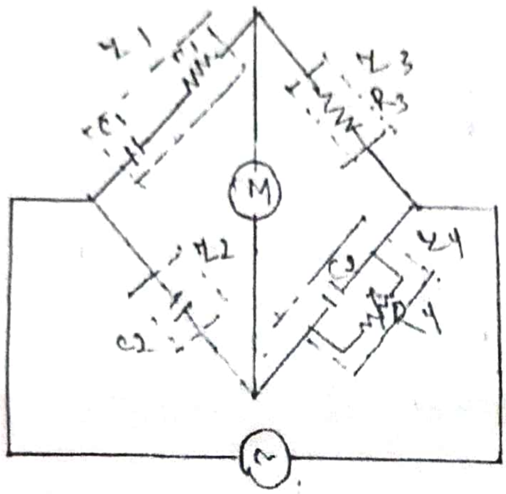
$$\Rightarrow L_1 = \frac{L_2 R_3}{R_4}$$

→ In the above eqn the value of L_2, R_2, R_3, R_4 are known, so the unknown inductance L_1 can be calculated.

→ By equating the real parts $R_1R_4 = R_2R_3$, this condition also has to be satisfy.

Measurement of capacitance by schering bridge:-

Schering bridge is used for the measurement of unknown capacitance.



C_1 = capacitor whose capacitance is to be measured.

r_1 = a series resistance representing loss in capacitor.

C_2 = standard capacitor

C_4 = variable capacitor

R_4 = variable resistor in parallel with C_4

R_3 = standard resistance

The balancing condition of the bridge can be give by,

$$\frac{Z_1}{Z_3} = \frac{Z_2}{Z_4}$$

$$\Rightarrow Z_1 Z_4 = Z_2 Z_3$$

$$\Rightarrow \left(r_1 + \frac{1}{j\omega C_1}\right)\left(\frac{R_4}{1 + j\omega C_4 R_4}\right) = \frac{1}{j\omega C_2} \times R_3$$

$$\Rightarrow \left(r_1 + \frac{1}{j\omega C_1}\right) = \frac{R_3}{j\omega C_2} \times \frac{(1 + j\omega C_4 R_4)}{R_4}$$

$$\Rightarrow r_1 - j\frac{1}{\omega C_1} = \frac{R_3 + j\omega C_4 R_3 R_4}{j\omega C_2 R_4}$$

$$= \frac{R_3}{j\omega C_2 R_4} + \frac{j\omega C_4 R_3 R_4}{j\omega C_2 R_4}$$

$$= -j \times \frac{R_3}{\omega C_2 R_4} + \frac{C_4 R_3}{C_2}$$

$$\Rightarrow r_1 - j\frac{1}{\omega C_1} = \frac{C_4 R_3}{C_2} - j\frac{R_3}{\omega C_2 R_4}$$

comparing the real part from the above eqn we get, $r_1 = \frac{C_4 R_3}{C_2}$ —— eqn (i)

comparing the imaginary part from the above eqn we get $\frac{1}{\omega C_1} = \frac{R_3}{\omega C_2 R_4}$

$\Rightarrow C_1 = \frac{\omega C_2 R_4}{\omega R_3}$

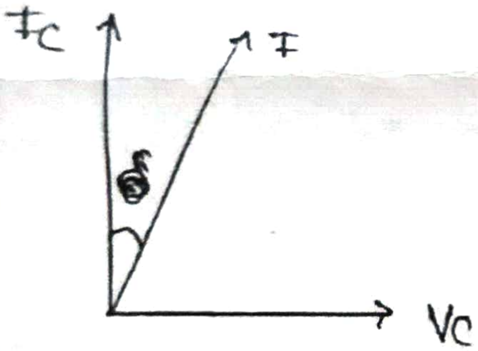
$$\Rightarrow \boxed{C_1 = \frac{C_2 R_4}{R_3}} \quad \text{—— (ii)}$$

so, the unknown resistance 'C_1' can be determin from eqn (ii). C_2, R_4 & R_3 values are known, so 'C_1' can be calculated.

This dissipation factor can be given by

$\tan\delta = \omega C_1 r_1$

$= \omega C_1 \times \frac{C_4 R_3}{C_2}$



Multimeter:-

→ This is a measuring instrument which is used for measurement of multiple quantit like voltage, current, resistance etc.

→ There are 2 types of multimeter availab

1. Analog multimeter.
2. Digital multimeter.

Analog Multimeter:-

→ An analog multimeter is an PMMC-type meter which works on 'd'-Arsonval' movement principle.

→ It consists of a needle or pointer to indicate the measured value over a graduated scale.

→ The PMMC-type meter acts as ammeter when shunt resistors are connected.

→ The meter acts as voltmeter when multiplier resistors are connected.

→ It acts as ohmmeter when a battery & a resistance network is connected.

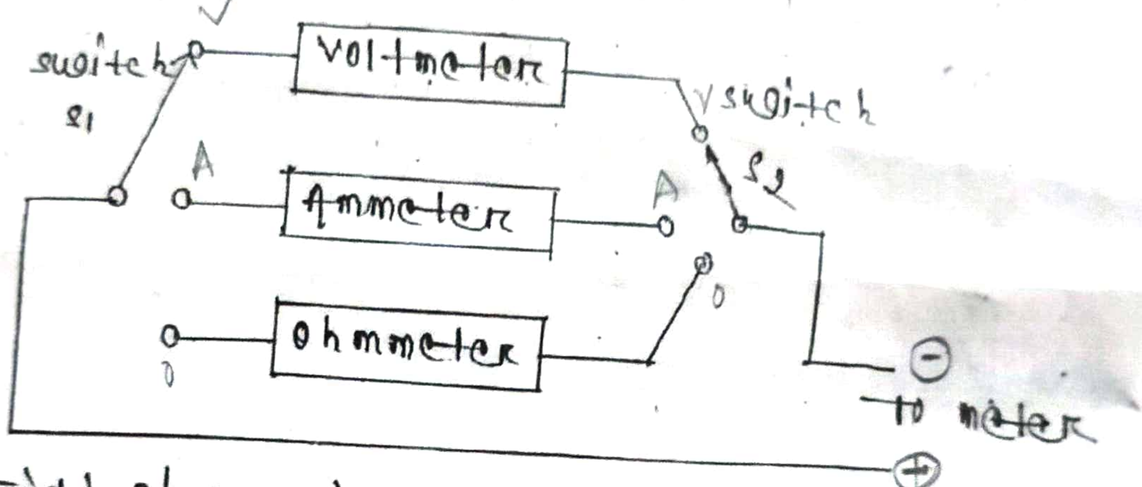
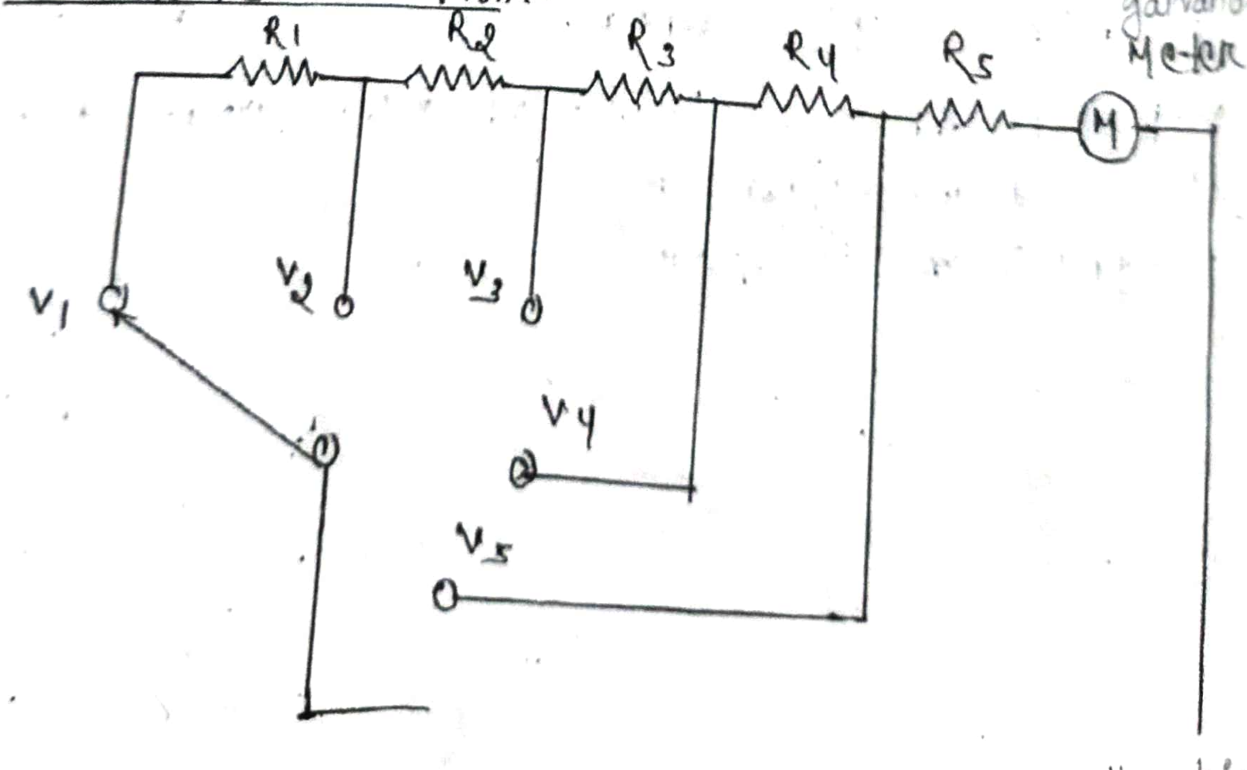


Fig: Block diagram of multimeter.

Voltmeter section:-

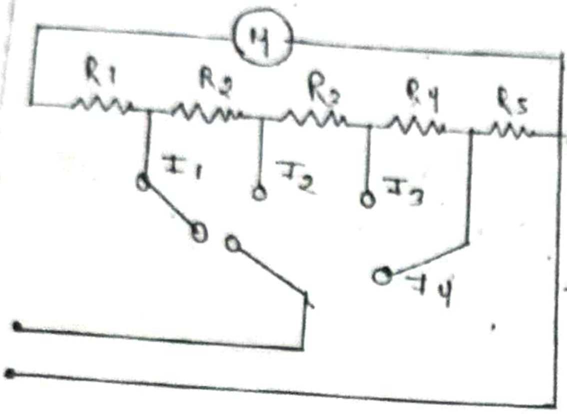


High volt measured by connecting high resistance

→ Multipliers are connected in series with the PMMC-type voltmeter.

→ In the above figure V_1, V_2, V_3, V_4 & V_5 are the different voltage ranges for measurement.

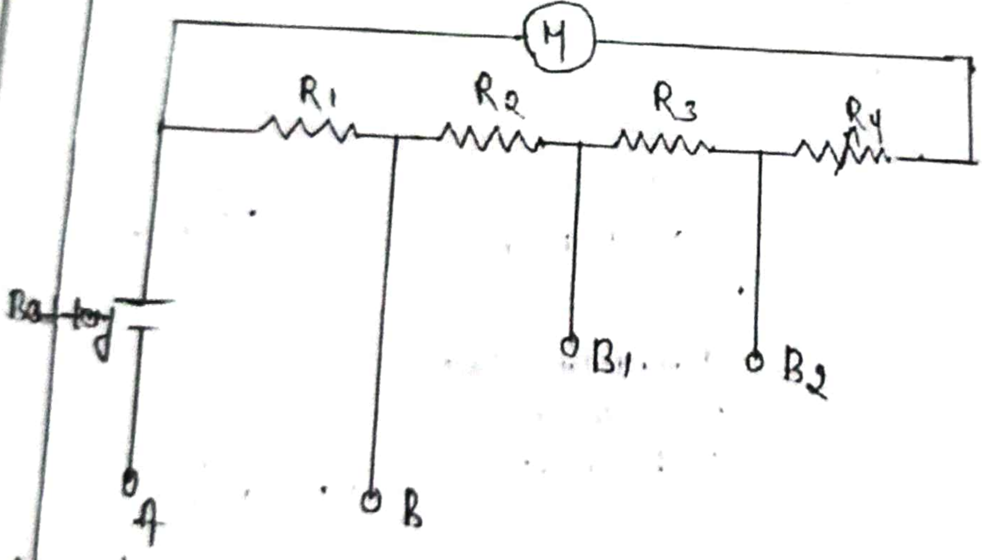
Ammeter section



Ammeter section

→ Shunt resistors are connected parallelly with the meter. In the above fig I_1, I_2, I_3 & I_4 are different current ranges for measurement.

ohm meter section:-



→ This instrument is short circuited A & B ends & the '0' adjustment control resistor are is so adjusted that the meter reads zero.

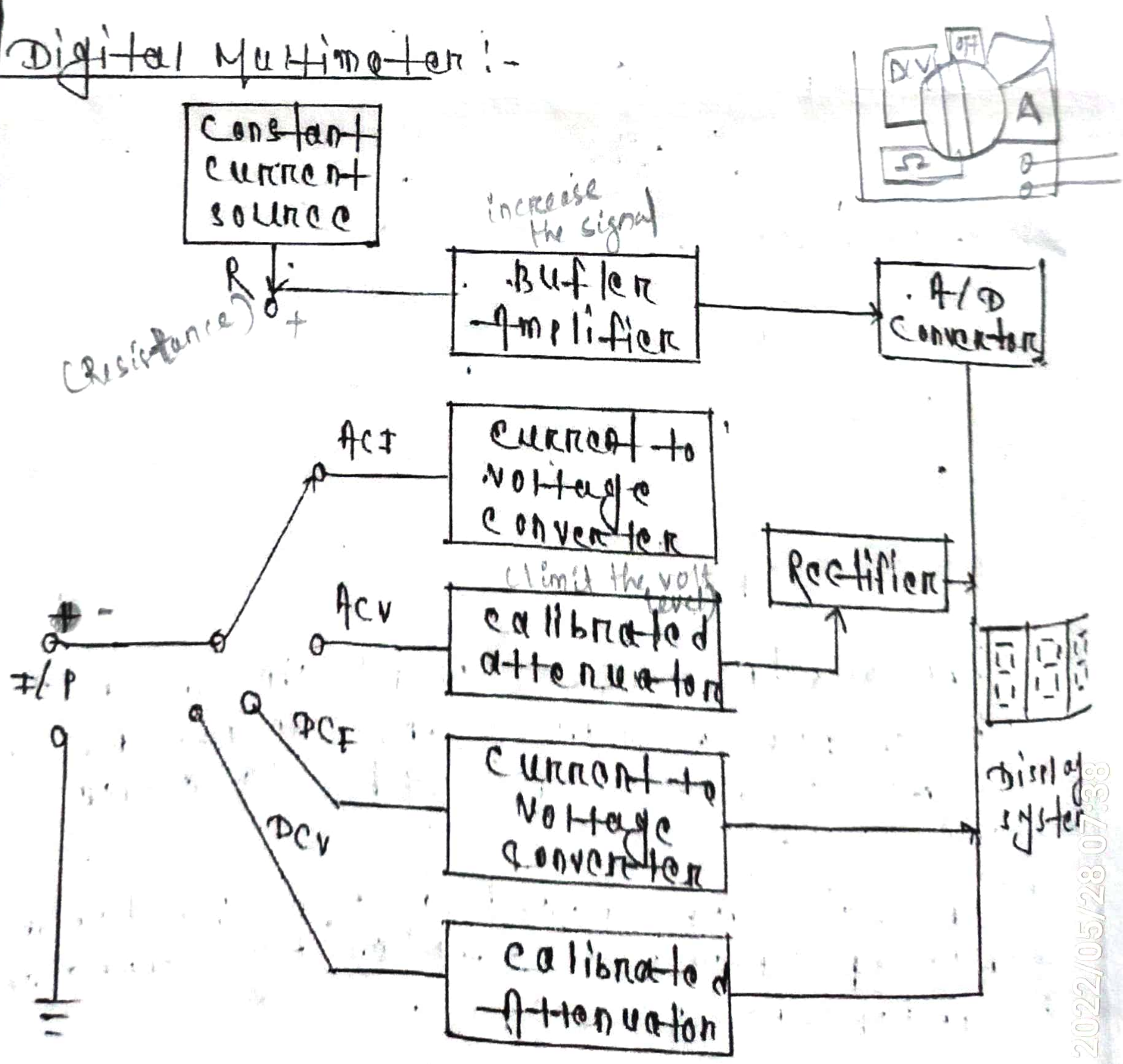
→ Then this instrument is use for the measurements of unknown resistor by connecting the resistor to A, B end.

→ The range of the measurement can be varied by varing the position of 'B' and . In the above figure B, B1 & B2 can be used to achieved different resistance range's from measurement.

→ A switch can be used to select AC/DC quantity for measurement. If DC quantity is selected by the switch than the input is direct fed to the PMMC meter for indication.

→ If AC quantity is selected than the input is passed through a rectifier ckt, which converts AC quantity to DC and the fed to PMMC meter for indication.

Digital Multimeter :-



→ Digital multimeter is the instrument which is used to measure multiple quantity like :- voltage, current, resistance etc & display the measure quantity interms of digits.

→ In digital multimeter the +ve input probe is connected to a rotary switch through which different measurements can be selected like:- resistance, DC current, AC voltage, AC current, & DC voltage.

→ The AC quantities after converting to perticular voltage range is passed through a rectifier ckt for AC to DC conversion.

→ AC current & DC current are passed through current to voltage converter ckt which converts the current into proporsional to voltage.

→ AC voltage & DC voltage are attenuated (decrease strength) with in a perticular voltage range before giving it to addy convertor.

→ A constant current source is used to generate equivalent voltage w.r.t. unknown resistance while resistance measurement.

→ All the quantities are converted to DC voltage from by using proper ckts & then it is given to addy convertor.

→ Addy convertor converts the analog signal into digital forms (0 to 1).

→ The digital data is than provided to display system.

→ A micro-controller chip is present with in the display system, which control the digit display on segment LEDS.

Chapter - 4

Energy Meter & Measurement of energy

Energy is defind as the power consume by the load over a particular interval of time.

Energy = power x time

$E = P \times t$

$E = \int_0^t P\,dt$

$E = \int_0^t VI\,dt$

→ If the voltage is measured in voltage & current 'I' is measured in ampere time 't' in second, than the energy consumed can be expressed in watt-second unit.

→ 1 watt-second = 1 joule

→ If the time interval 't' is in hour than the energy can be expressed, watt hour unit.

→ 1000 watt hour is also called as 1 unit in domestic energy meters.

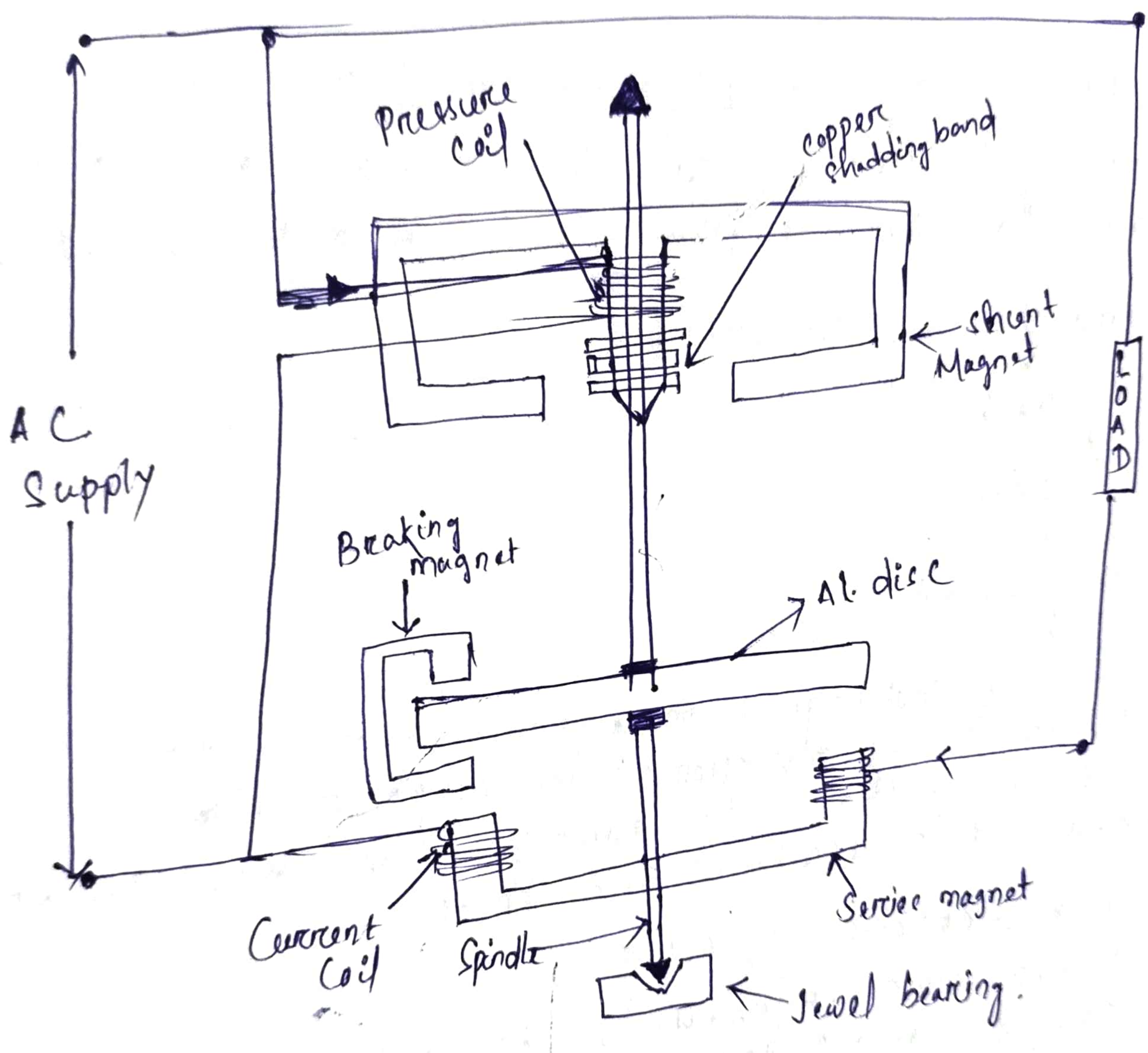
⇒ 1 KWH = 1 unit

→ Energy meter is the device or instrument which is used to measure the energy consume by the load.

→ Generally induction type energy meters are universally used for measurement of energy in domestic & industrial AC circuit.

(A)

Induction Type Energy Meter



Single Phase Induction type Energy meter :-

A single phase energy meter requires the electrical power calculation that measure accurate power consumption from current, voltage & time information.

The energy meter must have stable operation during a specified period of time.

* Construction :- The energy meter has 4 main parts they are :-

(1) Driving system

(2) Moving system

(3) Braking system

(4) Registering / Counting system

(1) Driving system - Electromagnet is the main component of the driving system. It is the temporary magnet which is excited by the current flow through their coil. The driving system has two electromagnets (shunt & series).

→ The series electromagnet is excited by the load current flow through the current coil. The coil of the shunt electromagnet is directly connected with supply & hence carry the current propotional to the shunt voltage. This coil is called the pressure coil.

Copper band is connected with the central limb. Main function of Cu. band is to align the flux produced by shunt magnet.

(2) Moving system - The moving system is the aluminium disc. The disc is placed in the air gap of the two electromagnets. The eddy current is induced in the disc because of the change of the magnetic field. Due to interaction between flux & eddy current the deflecting torque is produced.

(3) Breaking system - The permanent magnet is used for braking system.

→ It is used for reducing the rotation of the aluminium disc. The breaking torque opposes the movement of the disc, thus reduces their speed.

(4) Counting system - Used to record the number of rotation of the aluminium disc.

Their rotation is directly propotional to the energy consumed by the loads in Kwh.

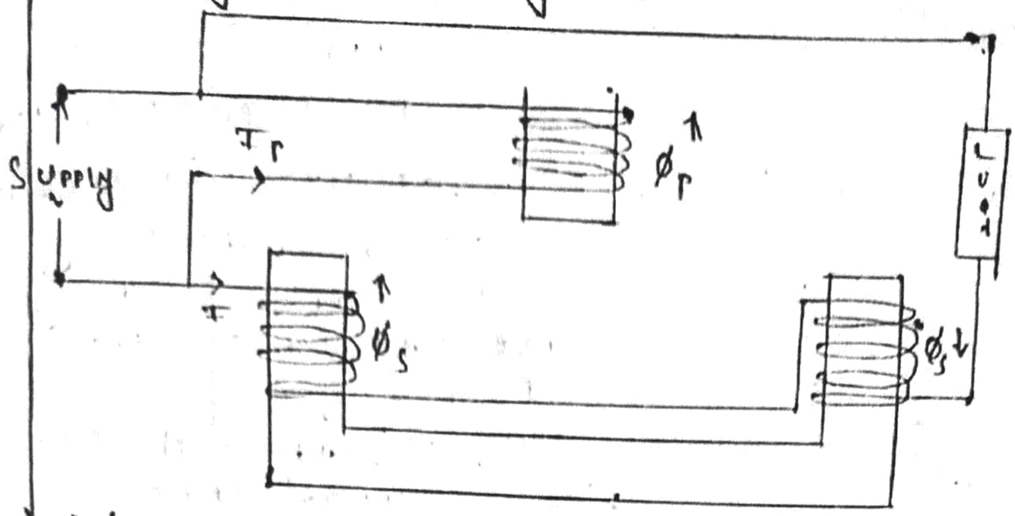
The rotation of the disc is transmitted to the pointers of the different dial for recording the different reading.

→ Cyclometer counts the rotation of the disc.

* Working

(5)

Theory & operating principle:-



→ The above diagram shows the functional driving system of induction type meter.

→ In the above diagram we can see the supply voltage is applied across the pressure coil.

→ The pressure winding is highly inductive as it has very large no. of turns.

→ Ip current flows in the pressure coil which is proportional to the supply voltage & this current lags the voltage by few degrees less than 90°.

→ This Ip current produces a flux ϕ_p which goes across the aluminium disc & responsible for the production of driving torque.

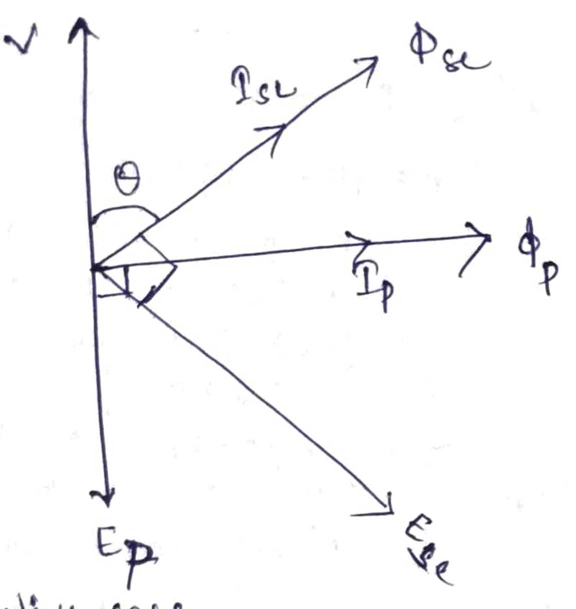
→ ϕ_p is inphase with Ip & the value is proportional to the current Ip.

→ The load current 'I' flow through the current coil & produces flux ϕ_s. This ϕ_s flux is proportional to load current 'I' & is inphase with it.

→ ϕ_p produces an eddy current Iep & ϕ_s produces an eddy current Ies in the aluminium disc.

→ ϕ_s interacts with Iep eddy current & ϕ_p interacts with Ies to produce two different torques. The net torque is the difference between the above two maintain torques.

Phasor diagram of Energy meter :-



V = supply voltage
I_{se} = eddy current due to flux Φ_{se}
Φ_{se} = flux at current coil
Φ_p = flux at pressure coil
I_p = current at pressure coil
E_{se} = Induced emf ~~due~~ in series magnet
E_p = EMF induced in shunt magnet

In Inductive case
Current (I) always lag behind the voltage by 90°
Produced EMF alway lag behind the current by 90°

As we know that

T_d = deflecting torque
T_c / T_B = controlling or Breaking torque

$\phi \propto I$

$\phi \propto V$

$T_d \propto \Phi_p \Phi_{se} \sin(90° - \theta)$

$T_d \propto \Phi_p \Phi_{se} \cos\theta$

$T_d \propto VI \cos\theta$

$T_d \propto$ Power (Electrical energy)

$T_c \propto N$ (speed)

Under balanced condn

$T_d \propto T_c$ or $T_d = T_c$

⇒ Electrical Energy ∝ Speed (N)

(7)

Energy compensations:-

1. Light load compensation / friction
2. creep compensation
3. overload compensation
4. temperature compensation
5. voltage compensation.

(a) Light load compensation:-

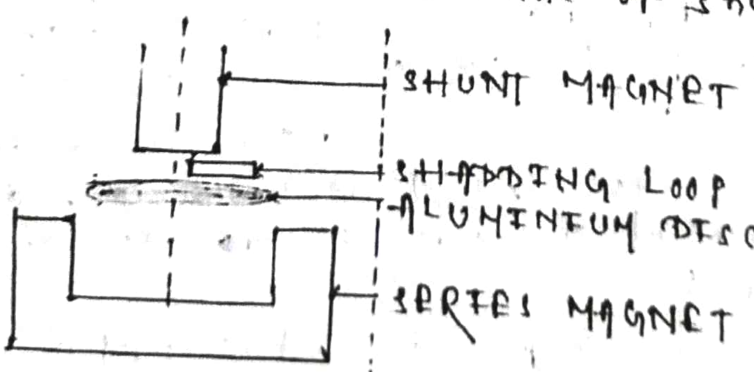
→ The jewelled pivot-bearings for the spindle provides sum friction to the movement of aluminium disc.

→ During low load & light load supply we need to generate an extra small torque to overcome this friction.

→ This is because during light load very small amount of driving torque is generated which is not sufficient to overcome the friction & move the aluminium disc.

→ To compensate this light load condition small shadding pole or loop is added in between the centre of the pole of the shunt magnet & the disc.

→ This shadding loop is slightly placed towards one side of the centre line of shunt magnet.



→ The interaction between the portion of shadded & unshadded flux & the current induced in the disc generates a torque which can be used for friction compensation.

(8)

(b) creep compensation:-

→ In sum meters a slow rotation of the disc is obtained even when there is no current flowing through the current coil. This is known as creeping.

→ In order to prevent this creeping to diamd diametrically holes are grilled in the disc.

→ The disc comes to rest when one of the holes in under the edge of the pole.

(c) overload compensation:-

→ During overload condition to compensate the driving & thi its proporsional to breaking torque an extra magnetic shunt are used in the device.

→ The magnetic shunt approches & saturate & divirt the series magnetic flux to the disc air gap. Due to this action the driving torque during the overload condition can be controlled.

(d) Temperature compensation:-

→ An increase in atmospheric temperature can increase the resistance of all copper & aluminium parts present in the device.

→ Due to this change in resistance the lag between the supply voltage 'V' & 'Øi' changes, eddy current flowing in the aluminium disc also varies.

→ In order to compensate the impact of increase in temperature the meter should be installed with proper sheiding.

→ A special material mutemp can be used to make different parts of the device which is very less sensitive to temperature.

→ If 'N' is the steady speed than the breaking torque can be given by.

$$T_B = K_4 \times N$$ — eqn (ii)

→ At steady speed the driving torque must be equal to the breaking torque.

$T_d = T_B$

$\Rightarrow K_3 \times \text{power} = K_4 \times N$

$\Rightarrow N = \frac{K_3}{K_4} \times \text{power}$

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

→ The total no. of revolution during a perticular time interval can be given by,

$\int N\,dt = \int K \times \text{power}\,dt$

$\Rightarrow \int N\,dt = K \int (\text{power})\,dt$

$\Rightarrow \int N\,dt = K \times \text{energy}$

→ Total no. of revolution of the Aluminium disc ∝ Energy consumed by the load.

(9) **Lag Adjustment of Energymeter device!-**

→ We have assume $\Delta = 90°$, so that speed of rotation 'N' will be proporsional to power.

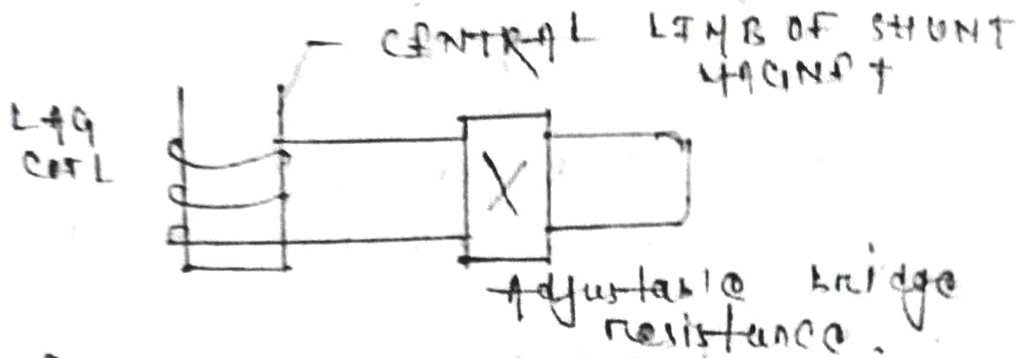
→ In this condition ϕ_p lags the supply voltage 'V' by 90°.

→ To acheive this the pressure coil winding should be design that it is highly inductive & has a low resistance.

→ This can be obtained by interducing a lag coil which is locatate on the central limb of the shunt magnet.

→ The mmf of the lag coil can be exhausted by the making following arrangements.

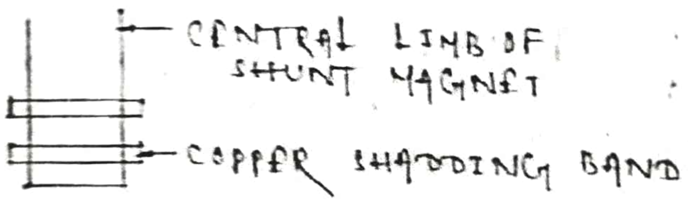
(i) Adjustable Resistance!-



→ A few turns of wires are placed around the central limb of the shunt magnet and the circuit is closed through a low adjustable bridge resistance.

→ This resistance value can be altered to adjust the phase angle of flux φp w.r.t supply voltage 'v'.

(ii) Shadding Bands!-



→ In this arrangement copper shadding bands are placed around the central limb of shunt magnet instead of lag coil.

→ The adjustment can be done by moving the shadding band along the axis of the limb.

→ As the shadding bands are move up the limb it can provide more amount of flux.

→ By the adjusting the position of shadding band the phase angle can be made approximately equals to 90°.

Note:-
This lag adjustment is also known as power factor adjustment, inductive lag adjustment & quadrature adjustment.

CHAPTER-7
SENSORS & TRANSDUCERS

What is transducers:-

→ Transducers is a device which can convert or transduce one from of energy into another form.

→ Sensors are special type of transducer which are used to sense or detect physical parameters & provides output generally used electrical form.

→ Ex:- speaker, potentiometer, turbine etc.

classification of transducers:-

Basic upon the output produced by transducers element, transducers are categorise into two type.

Mechanical Transducers:-

→ This transducers produced output in term of mechanical energy i.e. displacement speed.

→ Ex:- turbine, Bourdon tube

Electrical transducers:-

→ This transducer's produced output in terms of electrical energy.

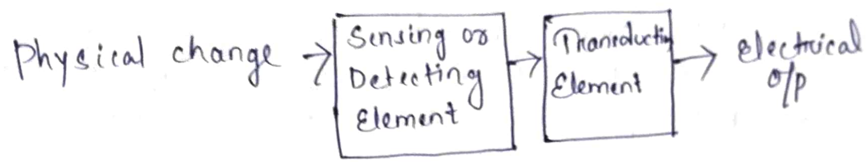
→ Ex:- LVDT transducer, strain gauge piezoelectric sensor etc.

Transducer :-

A transducer is defined as a device which converts one form of energy in to other.

It is referred to as energy converter.

A transducer combination of sensing & Transduction element has to change one form of energy into another form.



* It must have a component
  (1) Sensing / Detector element
  (2) Transduction Element

(1) Sensing Element - Sensor are special type of transducer which are used to sense or detected physical parameter & provide o/p generally electrical form.

→ It is also known as primary transducer.

→ It gives accurate reading.

e.g - LED, Temperature sensor, Thermistor, pressure switch.

(2) Transduction Element - It converts the o/p of sensing element into electrical signal.

→ It is also known as secondary transducer.

E.g → Microphones & loud speaker, strain gauge, piezoelectric transducer, linear transducer

Active Transducers:-

→ The transducers which can generate electrical output in terms of voltage or current without any external power supply are known as Active transducers.

→ Ex:- Thermocouple

Passive Transducers:-

→ The transducers which requires external power supply to generate output in terms of voltage & current are known as passive transducers.

→ Ex:- LVDT, strain gauge, potentiometer etc.

→ The passive transducers produces output in terms of resistance, inductance & capacitance w.r.t input parameter.
According to this the passive transducer are categorised into 3 types.

1- **Resistive Transducer:-**

→ The output resistance of this transducers changes w.r.t input parameters.

Ex:- (1) Potentiometer
(2) Thermistor
Resistance thermometer
strain gauge.

2. Inductive transducers:-
The o/p inductance of this transducer changes w.r.t input parameter.
Ex:- LVDT.

3. Capacitive transducers:-
The o/p capacitance of this transducers changes w.r.t input parameter.
(i) variable area type capacitive transducer
(ii) variable air gap type capacitive transducer

Note:-
→ The transducer which is directly connected to the physical parameter being measured is known as primary transducer & the transducer which are connected to the primary transducer are known as secondary transducer.

Resistive Transducer:- Already there
→ The resistance of this transducer changes w.r.t change in I/P parameter.
→ These are passive transducer i.e. external supply is required to generate voltage or current as O/P. $R = \frac{\rho L}{A}$
$\rho \rightarrow$ Resistivity of the Material

1. Potentiometer:-
→ Potentiometer is a type of displacement sensor.
→ simply it is turn as POT stands for potentiometer.
→ POT meter consists of a uniform resistive element & a sliding contact. this sliding contact is known as slider or wiper.

→ The motion of the sliding contact may be translattering or rotational.

→ Depending open the movement of the slider the potentiometer are classify into 2 category:-

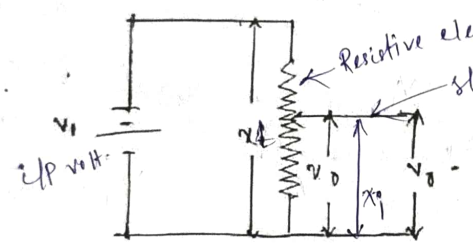
(i) Linear potentiometer
(ii) Angular potentiom

Note:-
→ 3rd type pot is also available where the slider can move in both translational & rotational direction. This pot is known as helipot.

Passive
Analog

A. Linear potentiometer:-

variable Resistance → POT



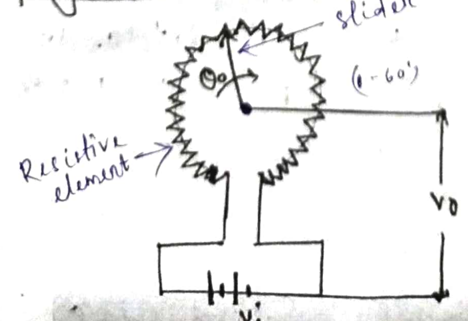
The variation of resistance leads change to the o/p voltage.

(Fig 1 - Linear potentiometer)

→ In this transducer the resistive element is lianear in shape so it is called as linear potentiometer.

→ Linear potentiometer is used to measure linear displacement.

B. Angular potentiometer:-



whenever slider is getting changed the i/p volt is also varied.
$R \propto \Delta V$
$R\uparrow = V\downarrow$

(Fig 2 - Angular potentiometer.)

→ In this transducer the resistive element is present in a circular shape.

→ This angular potentiometer is used to measure angular displacement.

$$V_o = \frac{x_o}{x_i} \times V_i$$

Theory:-

→ The resistive of the potentiometer is a very clean wire made up of platinum & nickel alloy.

→ If, from fig 1, if V_i is the I/P supply voltage,

V_o is the O/P voltage

x_i is the total length of resistive element.

→ x_o is the displacement made by the wiper then, the O/P voltage generated by the potentiometer can be given by

$$V_o = \frac{x_o}{x_i} \times V_i$$

$V_o \propto X_i$ sensitivity = $\frac{O/P}{I/P} = \frac{V_o}{X_i}$

$\frac{V_i}{X_t}$

→ For angular potentiometer the full turn of the wiper may be approximate 300°. If θ_i is the total angular turn by the wiper, then in fig 2 the O/P voltage developed by the potentiometer can be given by:

$$V_o = \frac{\theta_o}{\theta_i} \times V_i$$

→ The O/P of the potentiometer varies linearly w.r.t the I/P displacement. The characteristics of potentiometer can be given by.

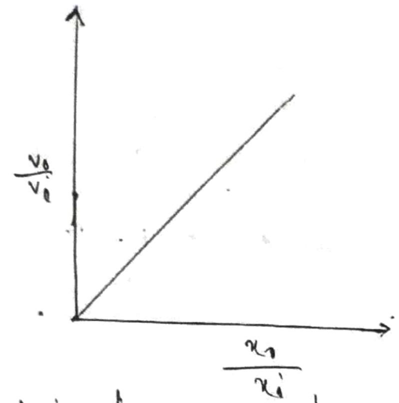


Fig :- characteristic of the potentiometer.

2. **Thermistor:-**

→ Thermistor is a temperature sensor.

→ It measures temp. & provides o/p in terms of resistance.

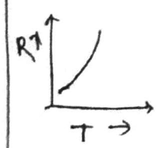
→ It is a passive transducers.

→ It is also called as thermal resistor.

→ Two types of thermistor are generally available.

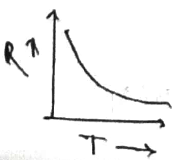
1- **PTC** (positive temp. coefficient)

→ When I/P temp. increases o/p resistance also increases.



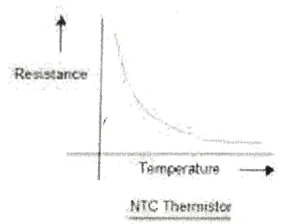
2- **NTC** (Negative temp. coefficient)

→ When I/P temp. increases o/p resistance decreases gradually.



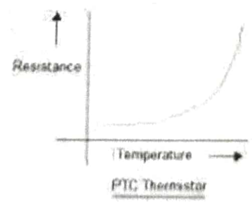
2. Thermistor:

- Thermistor is a resistive transducer whose resistivity depends upon surrounding temperature. For this reason it can be used as Temperature sensor.
- The term Thermistor is a combination of "thermal" and "resistor"
- It is made up of semiconductor material. Thermistor devices are generally made from oxides of certain metals like Manganese, Cobalt & Nickel etc.
- There are two types of thermistors: Negative Temperature Coefficient (NTC) and Positive Temperature Coefficient (PTC). With an NTC thermistor.
  - NTC Type:
    In this type when temperature increases, resistance decreases. Similarly, when temperature decreases, resistance increases. This type of thermistor is used the most.



$T \propto \frac{1}{R}$

  - PTC Type:
    In this type when temperature increases, the resistance increases, and when temperature decreases, resistance decreases.



$T \propto R$

- **Working Principle:**
  - As the temperature of a thermistor increases its resistance decreases exponentially.
  - The mathematical expression for the relationship between resistance of thermistor and temperature is

$$R_{T1} = R_{T2}\exp[\beta\left(\frac{1}{T1}-\frac{1}{T2}\right)]$$

Where,

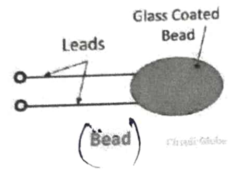
R_{T1}= resistance of the thermistor at temperature T1

R_{T2} = resistance of the thermistor at given temperature T2

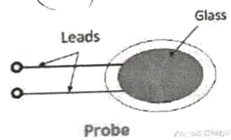
β = constant, its value depends upon the material used in the construction of thermistor, typically its value ranges from 3500 to 4500.

This above equation is known as characteristic equation of Thermistor

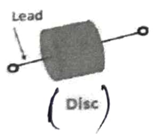
- Thermistor can be made in different shape and sizes. It is available in the form of the bead, probe, rod and disc etc. The different types of the thermistor are shown in the figure below.



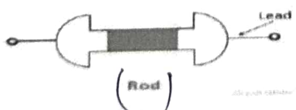
The bead form of the thermistor is smallest in shape.



Bead type is enclosed inside the solid glass rod to form probes.



The disc shape is made by pressing material under high pressure with diameter range from 2.5 mm to 25mm



It is shaped as a long vertical rod 0.250-2.0 inches (0.63-5.1 centimetres) long and 0.050-0.110 inch (0.13-0.28 centimetre) in diameter, of oxide-binder mix and sintered; ends are coated with conducting paste and leads are wrapped on the coated area.

- **Advantages**
  - They are compact and inexpensive.
  - They have good stability and high sensitivity.
  - Their response is very fast.

- They are not affected by stray magnetic and electric fields.

  Due to all these advantages, thermistors are preferred over other temperature detecting devices like RTDs and thermocouples.

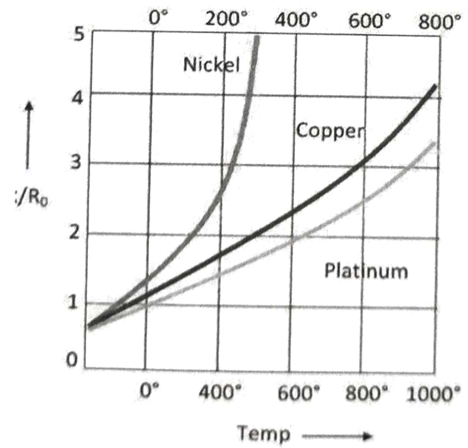
3. Resistance Thermometer:

- Resistance thermometers are based on the principle that the electrical resistance of a metal wire varies with temperature.
- The resistance thermometer is also known as Resistance Temperature Detector (RTD)
- It uses the resistance of electrical conductor for measuring the temperature.
- If R_0 is the resistance at 0 °C, then the resistance R_T at T °C is:

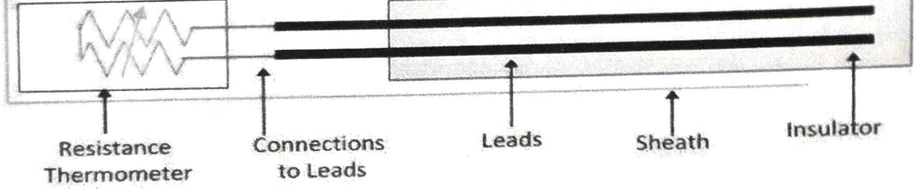
$$\mathbf{R_T = R_0 (1 + \alpha T)}$$

Where, α = temperature coefficient of resistance of a particular material.

- The resistance thermometer uses a sensitive element made of extremely pure metals like platinum, copper or nickel.
- RTD is a PTC type transducer.



- **Construction of Resistive Thermometer**



Resistance Thermometer

- The resistance thermometer is placed inside the protective tube for providing the protection against damage.
- The resistive element is formed by placing the platinum wire on the ceramic bobbin.
- This resistance element is placed inside the tube which is made up of stainless steel or copper steel.
- The lead wire is used for connecting the resistance element with the external lead. The lead wire is covered by the insulated tube which protects it from short circuit.
- The ceramic material is used as an insulator for high-temperature material and for low-temperature fibre or glass is used.

➢ **Advantages:**
- It provides highly accurate results.
- RTD provides a vast operating range.
- Due to its high accuracy
- RTD is used in all such applications where precise results are needed.

➢ **Disadvantages:**
- The sensitivity of platinum RTD is very less for the minor variation in temperature.
- RTD possess slower response time.

4. Strain Gauge:

➢ A strain gauge is a device used to measure strain on an object.

➢ Resistance of the device varies with respect to applied force. It converts force, pressure, tension, weight, etc., into a change in electrical resistance which can then be measured.

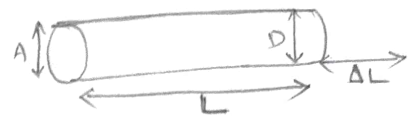
➢ When an external force is applied on an object, due to which there is a deformation occurs in the shape of the object. This deformation in the shape is both compressive or tensile is called strain, and it is measured by the strain gauge.

➢ **Working Principle:**

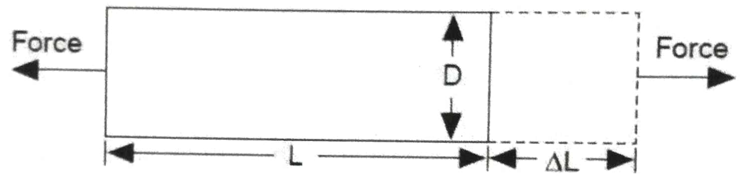
Resistance of any conductor wire is directly dependent on the length and the cross-sectional area of the conductor, given by:

$$R = \rho L / A$$

Where,
R = Resistance
L = Length
A = Cross-Sectional Area
ρ= Resistivity of the material



The change in the shape and size of the conductor also alters its length and the cross-sectional area which eventually changes its resistance.



If ΔL is the change in length of the wire by the application of force or stress then strain (ε) is given by:

$$\text{Strain } (\varepsilon) = \frac{\Delta L}{L}$$

- Sensitivity of the strain gauge material is given by a parameter known as **Gauge factor** (G). The Gauge Factor is the sensitivity coefficient of strain gauges
- **Gauge factor** is defined as the ratio of fractional change in electrical resistance to the fractional change in length (strain):

$$G = \frac{\Delta R / R}{\Delta L / L} = \frac{\frac{\Delta R}{R}}{\varepsilon}$$

Where,
R=original Resistance of wire
ΔR= change in Resistance
L=original Length of wire
ΔL= change in Length

$$\varepsilon = \frac{\Delta L}{L}$$

To measure dimension change.

- **Construction:**

The metallic strain gauge consists of a very fine wire or,
metallic foil arranged in a grid pattern.
The grid is bonded to a thin backing, called the carrier, which is attached directly to the test specimen (object). Therefore, the strain experienced by the test object is transferred directly to the strain gauge and changes the resistance of the strain gauge.

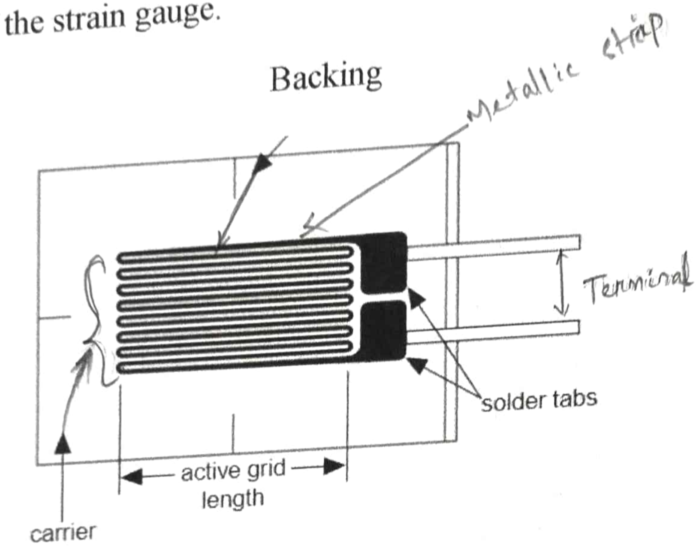
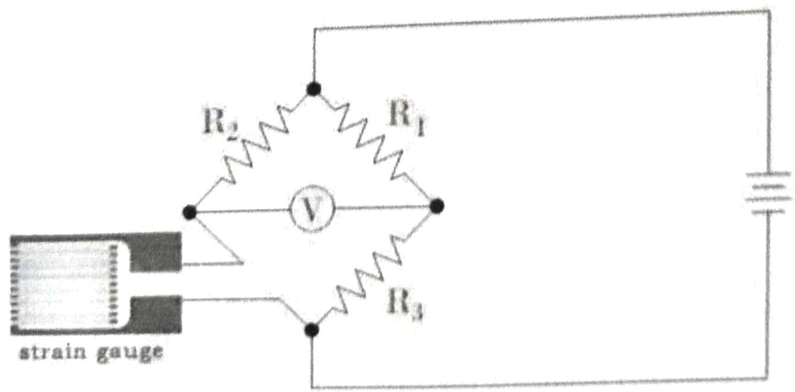


Figure: Wire type bonded strain gauge

- **Measurement by using Bridge circuit:**

The change in resistance in strain gauge can be measured in terms of change in voltage by connecting the strain gauge in a Wheatstone bridge circuit.



$R_1 = R_3$
R_2 = strain gauge resistance

- In this circuit, R1 and R3 arms are equal to each other, and R2 is the rheostat arm and its value equal to the strain gauge initial resistance.

- When no force is applied, the gauge is unstrained and the bridge is balanced. Voltmeter shows zero value at this condition
- When force is applied on the strain gauge resistance of the gauge changes. As there is a change in resistance of strain gauge, the bridge gets unbalanced and produces a voltage indication at the voltmeter.

➢ **Application:**

- It can be used as Weight, Force, Pressure or Stress sensor.

Testing of aircraft like linkages, structural damage etc

I. Inductive Transducers

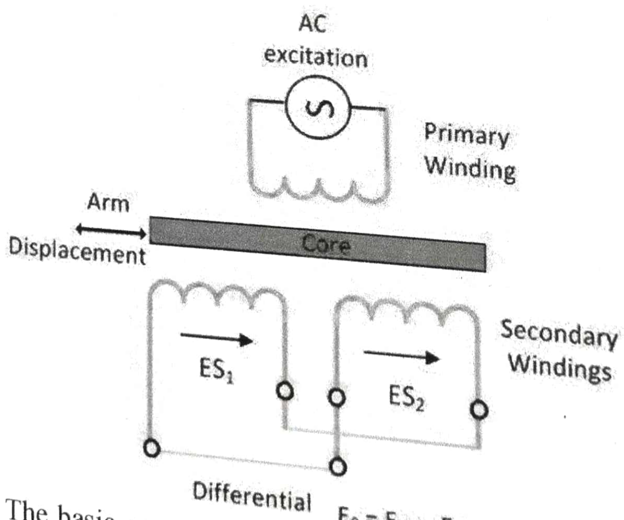
The transducer whose inductance changes with respect to change in input parameter is known as inductive transducer.

1. LVDT(Linear Variable Differential Transformer):

➢ The Linear Variable Inductive Transformer converts the linear displacement into an electrical signal.

➢ It works on the principle of mutual induction, i.e., the flux of the primary winding is induced to the secondary winding. The output of the transformer is obtained because of the difference of the secondary voltages, and hence it is called a differential transformer.

➢ **Construction of LVDT:**



➢ The basic construction of the LVDT is shown above in the figure. LVDT consist of a primary winding and two secondary windings S_1 and S_2. The secondary winding is wound on the cylindrical former.

➢ The secondary windings have an equal number of turns, and it is placed identically on both the side of the primary

- The output voltage of the secondary [illegible] the S_2 is ES_2.
- The secondary voltage signal is converted into an electrical signal by connecting the secondary winding in series opposition as shown in the figure above.
- The output voltage of the transducer is determined by subtracting the voltage of the secondary windings.

Output voltage (E_0) = $ES_1 - ES_2$

- **Working:**

The change in output voltage is directly proportional to the displacement of the core. Any displacement will increase the flux of one of the secondary winding and on the other hand, reduces the other which develops a differential voltage at the output. There could be three possible conditions which are described below:

Condition-I:

- When the soft core moved towards left, the flux linked in S_1 is more as compared to S_2.
- The output voltage of the winding S_1 is more than the S_2.
- Since **$ES_1 > ES_2$, E_0 is positive.** So E_0 is in phase with the primary voltage.

Condition-II:

- When the soft iron core move towards right the magnitude of the flux linked S_2 is more than S_1.
- The output voltage of the winding S_1 is less than the S_2.
- Since **$ES_1 < ES_2$, E_0 is negative.** The output voltage E_0 is 180° out of phase with the primary winding.

Condition-III:

- When the soft iron core is at the centre of S_1 and S_2, the flux linked in S_1 and S_2 are same.
- The output voltage of the winding S_1 is equal to S_2.
- So **$E_0 = ES_1 - ES_2$**

  $= 0$ V

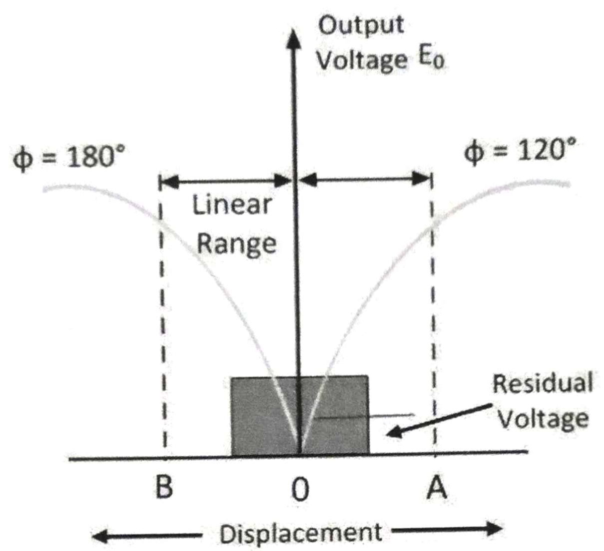


Figure: LVDT Characteristics

The curve between the output voltage and the input displacement is shown in the figure above.
The curve is linear for small displacement between A & B.

- **Uses of LVDT:**
  - It is used for measuring the displacement having a range from few mm to cm. The LVDT directly converts the displacement into an electrical signal.
  - The LVDT is used as a device for measuring the force, weight and pressure. Some of the LVDT used for measuring the load and pressure.

II. Capacitive Transducers

The transducer whose capacitance changes with respect to change in input parameter is known as capacitance transducer.

- The working principle of a capacitive transducer is variable capacitance. It consists of two parallel metal plates which are separated by dielectric medium (such as air).

- The capacitance of the variable capacitor can be measured by this formula.

$$C = A\frac{\epsilon_0\epsilon_r}{d}$$

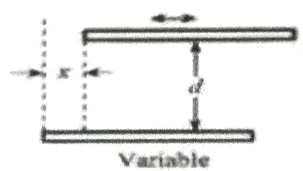
$$C = A\frac{\epsilon}{d}$$

C = capacitance of the variable capacitor
ϵ_0 = permittivity of free space
ϵ_r = relative permittivity
$\epsilon = \epsilon_0\epsilon_r$
A = overlapping area between the two plates
d = distance between the two plates
By varying the parameters like **A, d** & ϵ_r of the variable capacitor the capacitance can be changed.
So the capacitive transducer is of three types:

1. Variable Area(**A**) Capacitive Transducer
2. Variable distance between two plates (**d**) type capacitive Transducers
3. Variable dielectric constant (ϵ)type capacitive Transducers

1. Variable Area Capacitive Transducer:

- ➢ In this type capacitive transducer the overlapping area (A) between the two plates changes due to the application of Displacement, Force or Pressure.
- ➢ Since parameter 'A' changes, the capacitance 'C' also changes, as 'C'is directly proportional to 'A'.



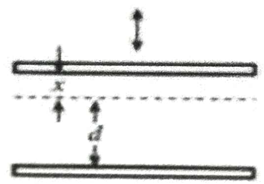
$$C = \frac{\epsilon\,(A - wx)}{d}$$

Where, ‘x’ is the displacement of the plate and ‘w’ is the width of the plate

- It can be used as Displacement, Force or Pressure sensors.

2. Variable distance between two plates type capacitive Transducers

In this type capacitive transducer the distance (d) / separation between the two plates changes due to the application of Displacement, Force or Pressure.



- Since parameter ‘d’ changes, the capacitance ‘C’ also changes, as ‘C’ is inversely proportional to ‘d’.

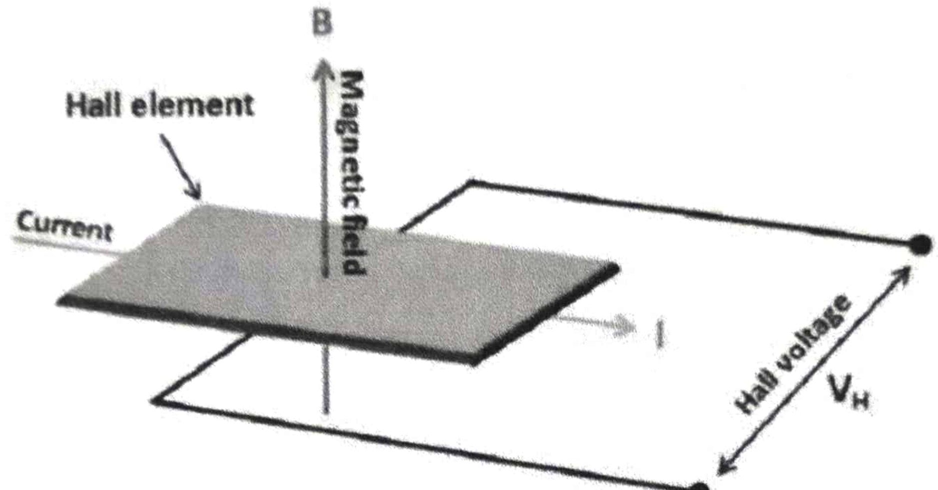
$$C = A\frac{\epsilon}{d+x}$$

Where, ‘x’ is the displacement of the plate

- It can be used as Displacement, Force or Pressure sensors.

response to a magnetic field.

- This transducer works on the principle of Hall Effect.
- **Hall Effect**: If a current carrying strip of the conductor is placed in a transverse magnetic field, then an EMF is developed on the edge of the conductor. The magnitude of the developed voltage depends on the density of flux. This property is known as Hall Effect.



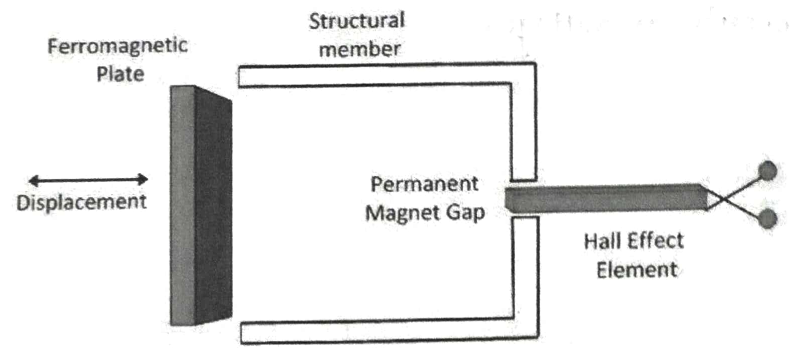
Hall effect

The output voltage of Hall Effect sensor $V_H = K\frac{B \times I}{t}$

Where, K= Hall Effect coefficient
B=Magnetic flux density
I= Circuit current
t = Thickness of the conductor strip (Hall Element)
The strip of the conductor is called as Hall element.

Applications of Hall Effect Transducer:

a. **Magnetic to Electric Transducer** – The Hall effect element is used for converting the magnetic flux into an electric signal.
b. **Measurement of Displacement** – The Hall Effect element measures the displacement of the structural element



Measurement of Displacement Using Hall Efect Transducer

Circuit Globe

Consider the ferromagnetic structure which has a permanent magnet. The hall effect transducer placed between the poles of the permanent magnet. The magnetic field strength across the Hall Effect element changes by changing the position of the ferromagnetic field. So output voltage of the transducer changes with respect to input displacement.

c. **Measurement of Current** – The Hall Effect transducer is also used for measuring the current.
The AC or DC is applied across the conductor for developing the magnetic field. The strength of the magnetic field is directly proportional to the applied current. The magnetic field develops the EMF across the strips.

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Chapter-8: OSCILLOSCOPE

CATHODE RAY OSCILLOSCOPE (CRO)

- The cathode ray oscilloscope (CRO) is an electrical instrument which is used for display, measurement and analysis of waveforms and others and electrical phenomenon.
- A cathode ray oscilloscope is a very fast X-Y plotter that can display an input voltage signal versus time.

Working:

- The CRO has the cathode ray tube which acts as a heart of the oscilloscope.

- In an oscilloscope, the CRT produces the electron beam which is accelerated, decelerated and focus with the help of accelerating and focusing anode at a high velocity and brings to the focal point on a fluorescent screen.
- After the collision of the electron on the screen, it produces a visible spot where the electron beam strikes with it and this spot is seen on another side of the screen.
- This collision or bombarding of electrons continually done on the screen which shows the electrical signal, this electron beam like an electrical pencil of light which produces a light where it collides with the screen.

Major Components of Cathode Ray Oscilloscope

The main blocks of CRO are

- Cathode Ray Tube (CRT)
- Vertical amplifier
- Delay Line
- Trigger circuit
- Time base generator
- Horizontal amplifier
- Blanking circuit
- Power supply

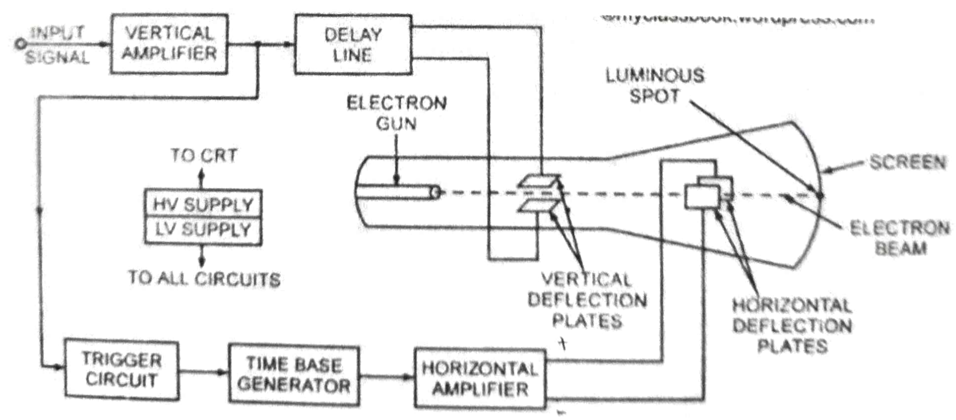
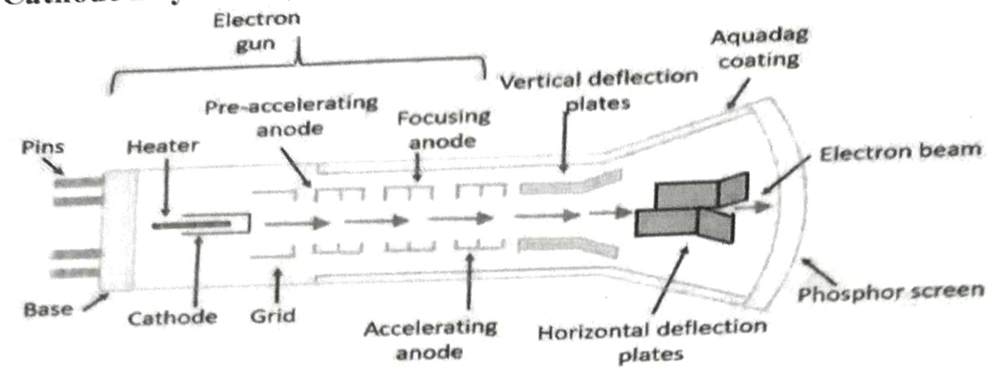


Figure: Block diagram of CRO

Working :- CRT depende on the movement of electrons beams. The electron guns generate sharply focused electrons which are accelerated at high voltage. This high velocity electron beam when strikes on the fluorescent screen creats luminous spot.

After ~~exiting~~ exiting from the electron gun, the beam passes through the pairs of electrostatic deflection plates.



Internal structure of CRT Electronics Coach

- CRT Produces a sharply focused beam of electrons and accelerate it to a very high velocity.
- CRT consist of the following parts:
  - Electron gun
  - Deflection plate assembly
  - Glass envelope
  - Fluorescent screen
  - Base, for connections
- This electron beam travels from the electron gun to the screen. The electron gun consists of a filament, cathode, control grid, accelerating anodes and focusing anode.
- While travelling to the screen, electron beams passes between a set of vertical deflecting plates and a set of horizontal deflection plates. Voltages applied to these plates can move the beam in vertical and horizontal plane respectively.
- The electron beam then strikes the fluorescent material (phosphor) deposited on the screen with sufficient energy to cause the screen to light up in a small spot.

Vertical Amplifier:

ie input signal is applied to the vertical amplifier. The gain of this amplifier n be controlled by VOLT/DIV knob. Output of this amplifier is applied to : delay line.

Delay Line:

e delay Line delays the arrival of the input waveform at the vertical lection plates until the trigger and time base circuits start the sweep of the

4. Trigger Circuit:

A sample of the input waveform is fed to a trigger circuit which produces a trigger pulse at some selected point on the input waveform. This trigger pulse is used to start the time base generator.

5. Time base (Sweep) Generator:

- This produces a saw-tooth waveform that is used as horizontal deflection voltage of CRT.
- The rate of rise of a positive going part of the sawtooth waveform is controlled by TIME/DIV knob.
- The sawtooth voltage is fed to the horizontal amplifier if the switch is in the INTERNAL position. If the switch is in EXT. position, an external horizontal input can be applied to the horizontal amplifier.

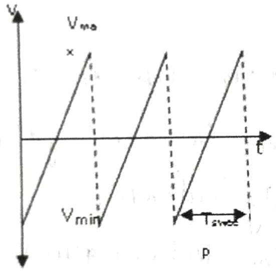


Figure: Sawtooth Waveform

- It is responsible for horizontal sweep of CRT spot from left hand side of the screen to right hand side.
- When a sawtooth voltage is applied to horizontal plates and an input signal is applied to vertical plates, display of vertical input signal is obtained on the screen as a function of time.

6. Horizontal Amplifier:

This amplifies the saw-tooth voltage. As it includes a phase inverter two outputs are produced. Positive going sawtooth and negative going sawtooth are applied to right – hand and left – hand horizontal deflection plates of CRT.

7. Blanking Circuit:

The blanking circuit is necessary to eliminate the retrace that would occur when the spot on CRT screen moves from right side to left side.

This retrace can cause confusion if it is not eliminate. The blanking voltage is produced by sweep generator. Hence a high negative voltage is applied to the control grid during retrace period.

Cathode Ray Tube (CRT):

The CRT is a display screen which produces images in the form of the video signal. It is a type of vaccum tube which displays images when the electron beam through electron guns are strikes on the phosphorous surface/screen so that the beam becomes visible.

Construction :- The electron gun assembly, Deflection plate assembly, fluorescent screen, glass envelope, Base are the important parts of the CRT.

(1) Electron Gun Assembly - The electron gun emits the electron beams. The electron gun has a heater, cathode, grid. The electrons are emitted from the highly emitted cathode.
The electron which is emitted from the electron gun & passes through the control grid have high potential which is applied across the pre accelerating & accelerating anodes. The beam is focused by focusing anode. After exiting the focusing anode the beam passes through the vertical & horizontal deflection plate.

(2) Deflection plates - It produces the uniform electrostatic field only in one direction. Hence the electrons will not move in the other directions.

(3) Screen for CRT - The phosphorous screen converts the electrical energy into light ~~ligh~~ energy.

(4) Aquadag - It collects the secondary emitted electrons which are necessary for keeping the CRT screen in the state of equilibrium.

8. **Power Supply:**

A high voltage (HV supply) section is used to operate CRT and a low voltage section (LV supply) is used to supply electronic circuit of the oscilloscope.

Measurement of Voltage, Current, frequency, phase by CRO

Measurement of Voltage:

- The oscilloscope is mainly a voltage measuring device.
- The number of divisions on the voltage axis (Y-axis) is measured and it is multiplied by the value indicated by the Volts/Div knob on the CRO.

Voltage measured= Total no of Y-axis division × Volts/Div

AC Voltage:

- It is measured from peak-to-peak amplitude which measures the absolute difference between the maximum point of signal and its minimum point of the signal
- The sine wave is supplied to the Y input of CRO. By adjusting the Volt/div knob, obtain a sufficiently large display of signal on the CRO screen.
- The vertical length of the waves from the negative maximum to the positive maximum is read on the graphic scale of the screen.
- This reading (in div.) is multiplied by the volt/div knob reading to give peak to peak voltage Vp-p.
- The voltage Vp-p is divide by 2 to give peak ac voltage of the signal.

DC Voltage:

- The DC power supply is connected to Y input of CRO taking care that positive lead of the cable is connected to +ve terminal and negative to the –ve of the dc power supply.
- The Volt/div knob is set and the dc power supply is switched ON. A sufficiently large display of signal (vertical line) on the CRO screen is obtained by setting Volt/div knob.
- The vertical length of the waves is read on the graphic scale of the screen.
- This reading (in div.) is multiplied by the volt/div knob reading to get the DC voltage.

Measurement of Current :

- Electrical current cannot be measured directly by an oscilloscope. However, it could be measured indirectly within scope by attaching probes or resistors.

- Resistor measures the voltage across the points and then substituting the value of voltage measured and resistance in Ohm's law formula and calculates the value of electrical current.

$$Current = \frac{Measured\ Voltage}{Resistance}$$

Measurement of frequency (Direct Method):

- The sine wave is given to the Y input of CRO whose frequency is to be measured.
- By adjusting the **time/div** knob, obtain a sufficiently large display of signal on the CRO screen.
- Measure the width of one full wave in no of divisions.
- Multiply this measured division with reading of time /div knob. This gives the time period of applied signal.
  Time Period= Total no of X-axis division × Time/Div
- Reciprocal of time period will be the frequency of the applied signal.

$$\boldsymbol{Frequency = \frac{1}{Time\ period}}$$

Measurement of Phase & frequency by Lissajous figure method

- A Lissajous figure is displayed pattern on the screen when sinusoidal signals are applied to both horizontal & vertical deflection plates of CRO.
- This Lissajous figure pattern can be used for the measurement of Phase difference and frequency of applied signals.
  Measurement of Phase:
- When two equal voltages of equal frequency but with a different phase shift (ϕ) are applied to a CRO we obtain different patterns of Lissajous figure in the below figure.

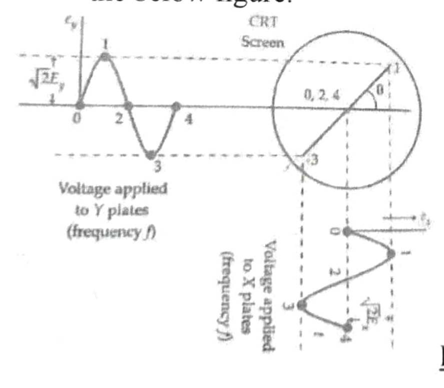


Figure: Lissajous figure for 0° phase shift

- When two sinusoidal voltages of equal frequency which are in phase with each other are applied to the horizontal and vertical deflection plates, the pattern appearing on the screen is a straight line.

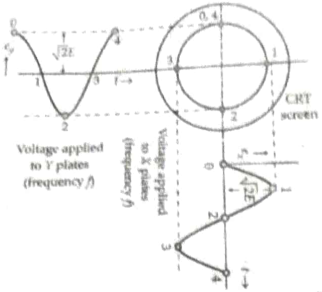
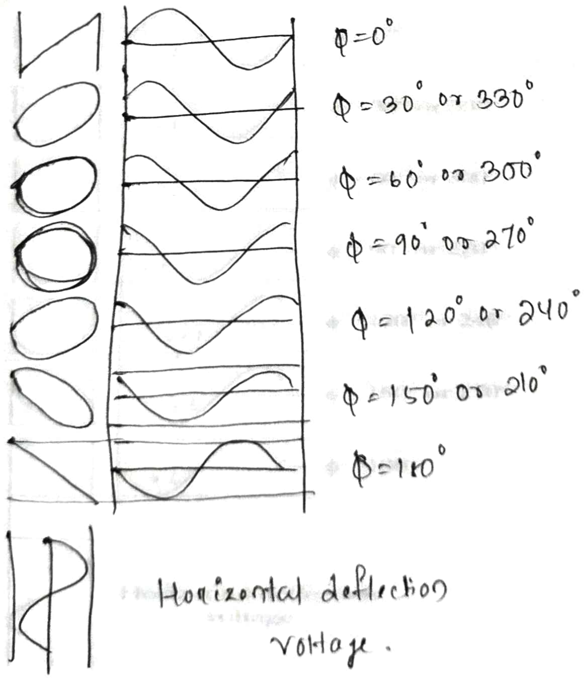
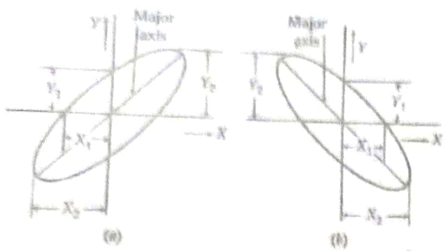


Figure: Lissajous figure for 90° phase shift

- Thus when two equal voltages of equal frequency but with 90° phase difference are applied to a CRO, the trace on the screen is a circle
- Similarly for different phase differences different type of pattern appears. Some of them are given below.



- The ellipse pattern of Lissajous figure provides a simple means of measuring phase difference between two voltages.



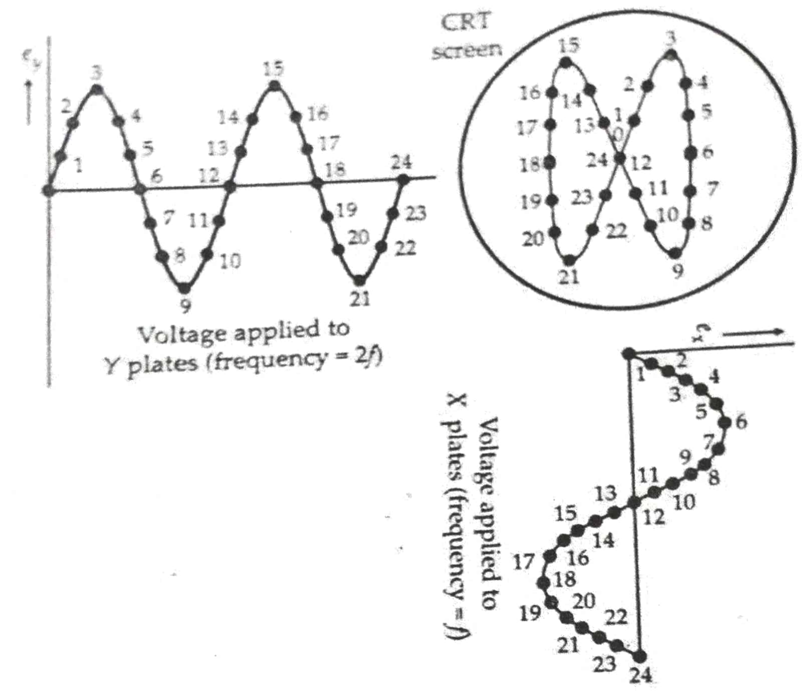
Referring to figure, the sine of the phase angle between the voltages is given by:

$$Sin\phi = \frac{Y_1}{Y_2} = \frac{X_1}{X_2}$$

$$\Rightarrow \phi = \sin^{-1}(\frac{Y_1}{Y_2}) = \sin^{-1}\frac{X_1}{X_2}$$

Measurement of Frequency Lissajous Patterns

- Lissajous patterns may be used for accurate measurement of frequency.
- The signal, whose frequency is to be measured, is applied to the Y plates. An accurately calibrated standard variable frequency source is used to supply voltage to the X plates.
- Suppose sine waves are applied to X and Y plates as shown in the figure below. Let the frequency of wave applied to Y plates is twice that of the voltage applied to X plates. This means that the CRT spot travels two complete cycles in the vertical direction against one in the horizontal direction.



- In the above case Frequency of Y signal is 2 times (twice) of the X signal so two loop of pattern appear on the CRO screen.
- Similarly number of loop increases if Y signal frequency increases, which is indicated below.

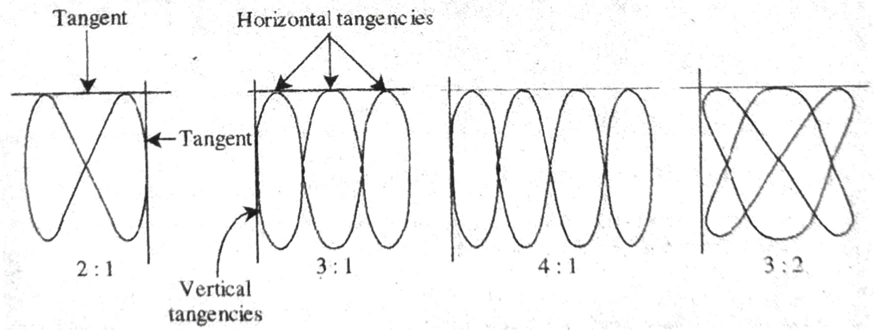


fig 6.2 Lissajous patterns allowing different frequencies ratios

The ratio of frequency can be calculated by drawing tangent at top/bottom and left/right sides.

The ratio of the two frequencies can be given by:

$$\frac{f_x}{f_y} = \frac{Number\ of\ times\ tangent\ touches\ top\ or\ bottom}{Number\ of\ times\ tangent\ touches\ either\ left\ or\ right\ side}$$

$$\Rightarrow \frac{f_x}{f_y} = \frac{Number\ of\ horizontal\ tangencies}{Number\ of\ vertical\ tangencies} \quad \frac{(N_x)}{(N_y)}$$

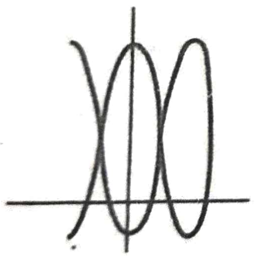
Where, f_x = frequency of signal applied to X

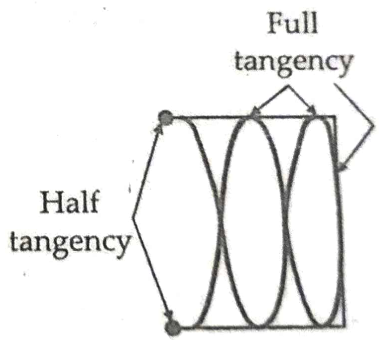
f_y = frequency of signal applied to Y

- The ratio of frequencies when open-ended Lissajous patterns are obtained can also be found by treating the open ends as half tangencies as shown in the below

$$\therefore \frac{f_y}{f_x} = \frac{\text{number of horizontal tangencies}}{\text{number of vertical tangencies}}$$

$$= \frac{2 + 1/2}{1} = \frac{5}{2}$$





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