Transducer :-

⇒ Topic :-

- Introduction.
- Measurement of Displacement.
  - * variable 'R' transducer.
  - * variable 'L' transducer
  - * variable 'C' transducer.
- Measurement of Pressure.
  - * Pressure measurement using passive transducer.
  - * Pressure measurement using Active transducer.
- Measurement of strain.
  - * Theory of strain guage.
  - * Strain guage ckt.
  - * Temperature compensation.
- Measurement of Temperature.
  - * RTD
  - * Thermistor.
  - * Thermo-couples.

⇒ Introduction :-

- Transducer is a device that convert one form of energy to the other generally non-electrical to electrical by undergoing a change in one of its physical characteristic specifically used for the purpose of measurement.

- Fundamentaly transducers are classified as :-

(i) Primary and Secondary transducer :-

- Primary transducer are those devices which actually sense the parameter under measurement. In most cases these are mechanical transducer which convert sensed parameter into proportional mechanical signal.

  Ex→ Ballow's, Diaphragam, Bourdon type and Capusule.

- Secondary transducer are those devices which take the o/p of the primary transducer and converts it into an analogous electrical signal.

  Ex→ LVDT used in pressure measurement.

(ii) Active and passive transducer :-

- Active transducer are those devices whose o/p is an electrical signal like a charge, voltage or a current and hence they do not require any external source of power for their operation.

- They are also known as self generating Devices.

  Ex→ Thermo-couples, piezoelectric crystal, Photo-voltaic cell, etc.

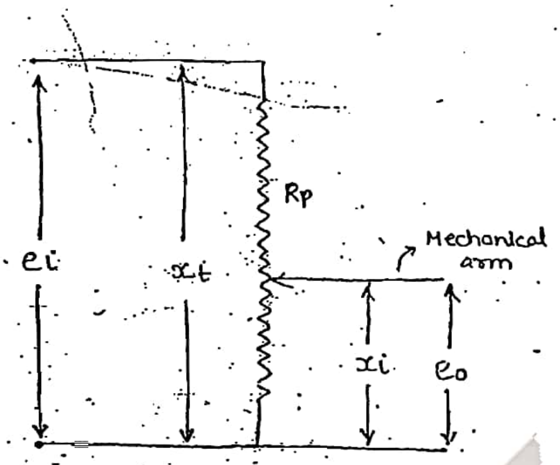
- Passive transducer are those devices which require an ~~electric~~ external source of electric supply for their operation.

Ex⇒ Strain guages, thermistor, LVDT, potentiometer, etc.

Measurement of Displacement :-

(1) Variable 'R' Transducer (Potentiometer) :-

- Variable 'R' transducer based their operation on the change in resistance due to displacement.
- ~~One of the simplest and efficient method for sensing~~ displacement is the potentiometer.
- Depending on how its resistive element is designed it can be used to measure both linear and angular displacement.
- A simple schematic of linear potentiometer is shown below :-
- It basically consist of a resistive element R_p of length $x(t)$ on which a mechanical arm is placed.
- The displacement under measurement is applied to mechanical arm which get displaced on the resistive element resulting in a voltage 'e_o' is introduced between its terminal.
- The relationship b/w the O/P voltage e_o and I/P displacement x_i is given below :-



Here,

x_t = Length of resistive eleme[nt]

R_p = Total Resistance.

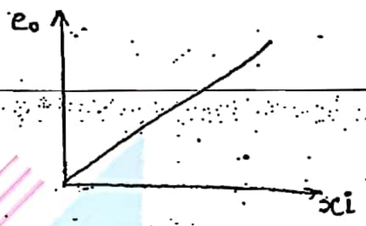
$\frac{R_p}{x_t}$ = Resistance per unit length

$\frac{R_p}{x_t} \times x_i$ = Resistance of element under mechanical arm

The o/p voltage e_o can be written by take the voltage divider rule, where

$$e_o = \frac{e_i \times R_p/x_t \cdot x_i}{R_p}$$

$$e_o = \frac{e_i}{x_t} \times x_i$$



calculating the displacement sensitivity we have

$$\frac{\partial e_o}{\partial x_i} = \frac{e_i}{x_t} = K \quad \text{(potential gain)}$$

$$\therefore \boxed{e_o \propto x_i}$$

* The various characteristic of potentiometer are :—

(i) They are simple to operate and measure large values of displacement.

(ii) As their electrical efficiency is high, these devices will not require any amplification at their output stage.

(iii) As the mechanical arm has a finite mass, a large force is required to displace it over resistive element. The moving part of this device are subjed to wear and tear.

Q) A Linear resistance potentiometer is 100 mm long and it is uniformly wound with a wire of total resistance 10,000 Ω under normal condⁿ the slider is at the centre of potentiometer. Determine the linear displacement when resistance of the potentiometer as measured by the wheatstone bridge is 3700 Ω. If it is possible to measure a minimum value of a ~~50~~ 5 Ω resistance with above arrangement. Determine the resolution of potentiometer in mm.

Ans→ Resistance of potentiometer = 10000 Ω

Length of element = 100 mm

Resistance per unit length = $\frac{10,000}{100} = 100\ \Omega/mm$

(a) Resistance of potentiometer under normal condition

$$= \frac{10,000}{2} = 5000\ \Omega$$

change in Resistance of pot = 5000 − 3700 = 1300 Ω

∴ Displacement will be $\frac{1300\ \Omega}{100\ \Omega/mm} = 13\ mm$

(b) The resolution of pot. for a 5 Ω change in resistance will be,

100 ⟶ 1 mm

5 ⟶ ?

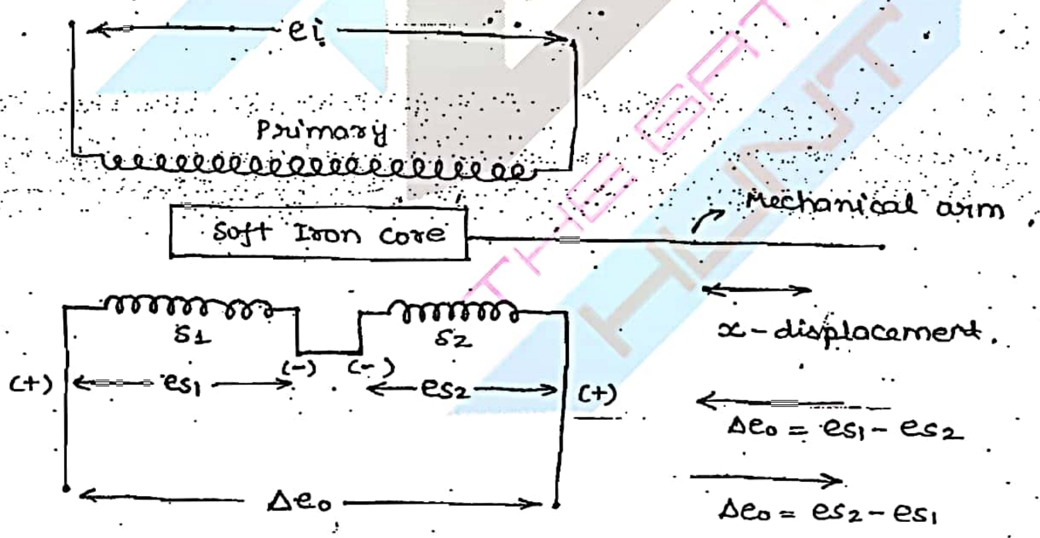
$$= \frac{5\times1}{100} = 0.05\ mm$$

(Ans)

(2) Variable 'L' transducer :-

⇒ Linear variable differential Transformer (LVDT) :-

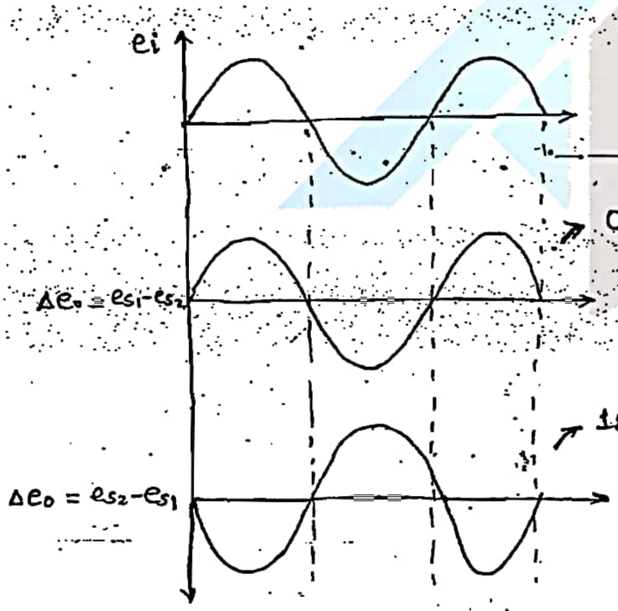
- variable 'L' transducer based their operation on change in the inductance due to displacement.
- Most of these transducers are based on the change in mutual inductance due to displacement due to the simplicity of their design.
- One of the most commonly used transducer for sensing displacement is a LVDT whose ~~is~~ simple schematic is shown below :-



- The LVDT basically consist of a simple ~~on~~ primary and two secondary winding with a soft iron core placed symmetrically b/w the two ~~bo~~ winding.
- The displacement under measurement is applied to the soft iron core through a mechanical arm, resulting

in the change in the flux linkage of the primary and individual secondary winding.

- This causes voltages to be introduced across the two Individual secondary winding and in order to obtain a differential voltage, the two secondary winding are connected in the series oposition methodology.
- The magnitude of a differential voltage depend on the direction in which the core move and its phase relationship with the Input is shown below:-

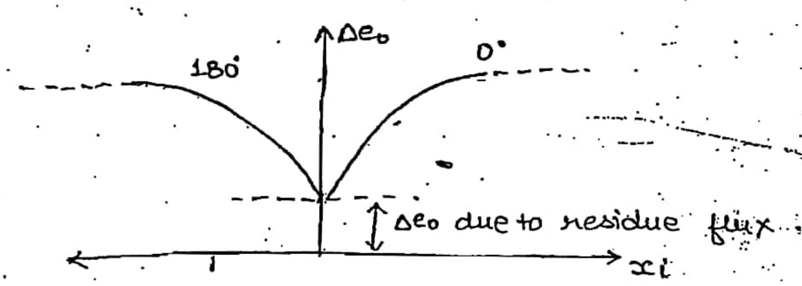


- If the core is symmetrically placed b/w S_1 and S_2, then $es_1 = es_2$

Hence, $\Delta e_0 = 0$.

- But in practical LVDT is, a small voltage always exist across the differential terminal due to presence of a stray flux.

- The effect of which can be seen from the I/P output characteristic of the LVDT shown in figure:-



- The effect of this stray voltage can be minimized by ~~replacing~~ the soft iron core with a core made up of a Nickle Iron alloy.

⇒ Major advantage :- (LVDT)

(1) It exihibit a high degree linearity and can be used to measure a large value of displacement.

(2) As there is no physical contact b/w core and winding so it is complete frictionless device.

(3) There is a ~~ele~~ complete electrical isolation b/w the excitation voltage e_i and differential o/p Δe_o.

(4) The sensitivity of this device is very high, typically upto 40 V/mm.

Q) An AC LVDT is given a 6.3 V I/p and produces 5.2 V for a range of + 0.5 inches. When the core is − 0.25 inch from the centre what is the o/p produced.

(a) −2 V (b) +2 V (c) −2.6 V (d) +2.6 V

Ans

5.2 V ⟶ + 0.5 inches

? ⟶ − 0.25 inches.

$$= \frac{-0.25 \times 5.2}{0.5} = -2.6\,V \quad \text{(option−c)}$$

Q) The O/P of LVDT is connected to a 5 V voltmeter to an amplifier having an amplification factor of 250. An O/P of 2mV appear across the terminals of the LVDT, when the core moves at a distance of 0.5 mm. Calculate the sensitivity of the LVDT and that of the whole setup. The milli-voltmeter has ~~1000~~ 100 division and scale can read to half of the direction. Calculate the resolution of the instrument in mm.

Ans→ O/p of LVDT = 2 mV

I/p of ~~LVDT~~ LVDT = 0.5 mm

Amplification factor = ~~200~~ 250.

voltage range = 5V

No. of division = 100.

(a) Sensitivity of the LVDT $= \frac{\text{output}}{\text{Input}}$

$= \frac{2 \text{ mV}}{0.5 \text{ mm}} = 4 \text{ mV/mm}$

(b) Sensitivity of the whole setup will be,

$= S_{LVDT} \times \text{Amp. factor}$

$= 4 \text{ mV/mm} \times 250$

$= 1000 \text{ mV/mm}$

(c) voltage per division $= \frac{\text{range}}{\text{No. of division}}$

$= \frac{5}{100} = 0.05 \text{ V} = 50 \text{ mV}.$

As voltmeter can clearly read to ~~1/2 of a division~~.

Minimum voltage read by voltmeter $= \frac{50}{2} = 25 \text{ mV}$.

Resolution of LVDT in mm is,

$$= 25\times10^{-3} \times \frac{1}{1000\times10^{-3}} = 25\times10^{-3}\ \text{mm} \quad \text{(Ans)}.$$

(iii) Variable 'C' Transducer :→

- Variable 'C' transducer based their operation on the capacitance of the parallel plate capacitor where

$$\boxed{C = \frac{A\varepsilon_0}{d}}$$

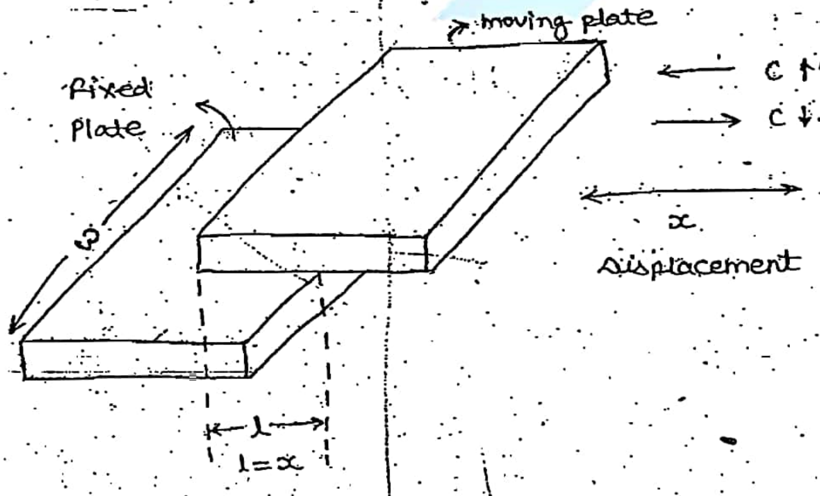
ε_0 = Dielectric strength (F/m)

A = Surface area (m^2)

d = distance b/w the plates (m)

- As both the area and distance b/w the plates are varied, these transducer can be configured for both change in area as well as the change in distance b/w the plates.

(a) Variable 'C' transducer based on change in area :-



Here,

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

where, $A = l \times w$

$w =$ width (m)

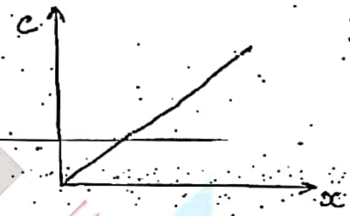
$l =$ overlapping distance b/w fixed & moving plates.

If initially $l=0$, then due to displacement $l=x$.

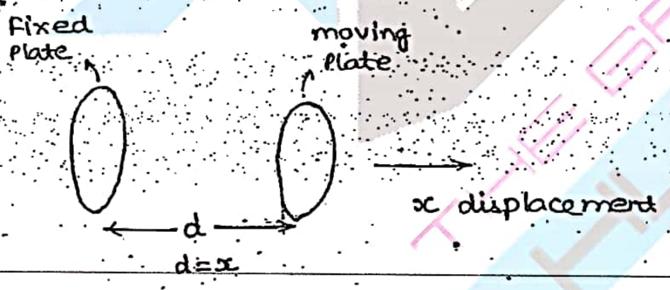
$$C = \frac{\epsilon w}{d} \cdot x$$

Displacement sensitivity will be:-

$$\frac{\partial C}{\partial x} = \frac{\epsilon w}{d} = K.$$



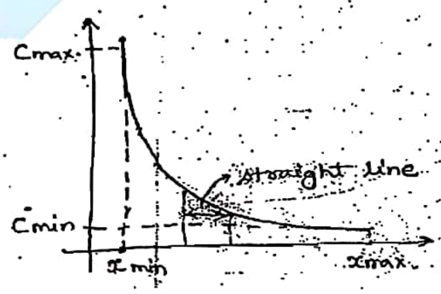
(b) variable 'C' transducer based on change in distance:-



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

as $d = x$

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



Calculating the displacement sensitivity, $\boxed{\frac{\partial C}{\partial x} = -\frac{\epsilon A}{x^2}}$

• variable 'C' transducer which based on operation on the change in area b/w the plates exhibit a highly linear input - output relationship and Hence are used for measuring ~~larger~~ value of displacement.

- variable 'C' transducer based on the change in distance b/w the plates exhibit a highly non-linear input - output characteristic but are characterized by high sensitivity.
- As they exhibit a straight line relationship b/w the input and output over a small ~~loro~~ range, these devices are generally used for measuring small Axial displacement.

Q) A capacitive transducer consist of two circular plate of ~~diameter 3cm each separated~~ by an air gap of 1mm. Calculate the displacement sensitivity of the transducer for small Axial load.

Ans→ we know,

$$\text{displacement sensitivity} = \frac{-\epsilon A}{x^2}$$

$$\epsilon = 8.854 \times 10^{-12} \text{ F/m}$$

$$A = \pi/4 (0.03)^2$$

$$x = 1\text{ mm} = 10^{-3}$$

$$\frac{-\epsilon A}{x^2} = \frac{-8.854 \times 10^{-12} \times \pi \times (0.03)^2}{4 \times (10^{-3})^2}$$

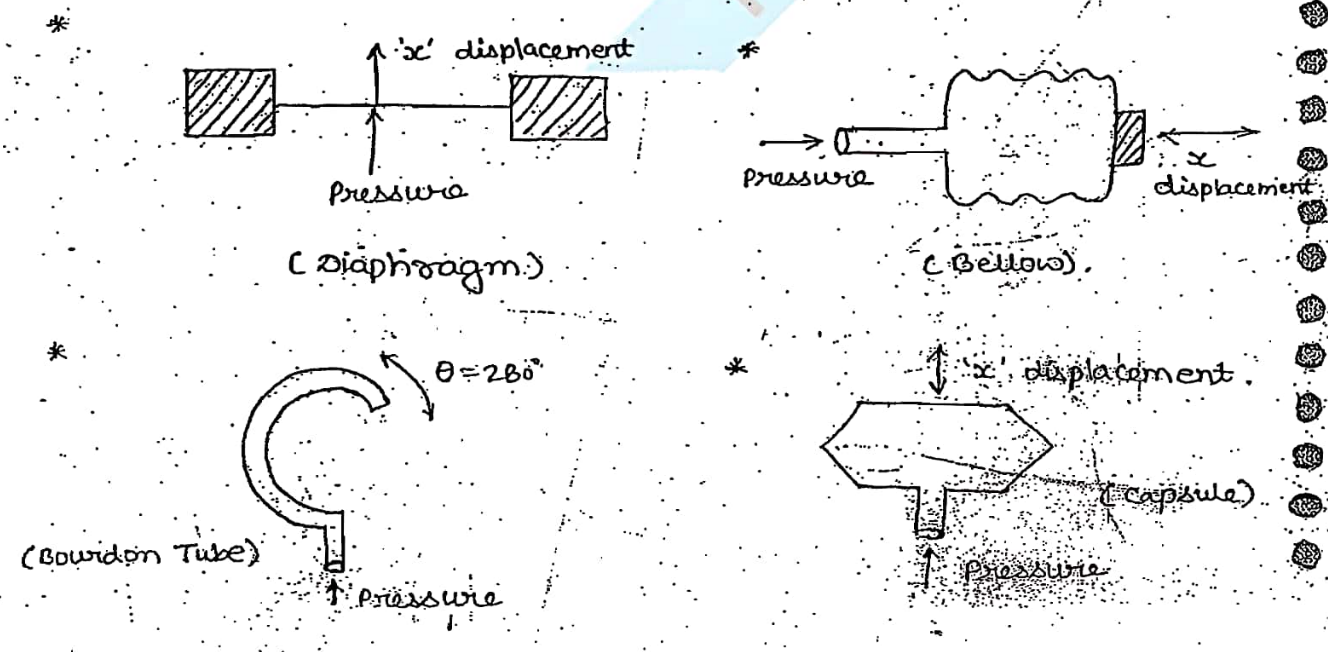
$$= -6.25 \text{ nF/m} \quad \text{(Ans.)}$$

(PTO)

Measurement of Pressure :~

(1) Pressure measurement using passive transducer :

- Pressure measurement using passive transducer is a two stage process in which in the first stage the pressure is sensed by a primary transducer which convert this sensed pressure into a proportional displacement signal.
- In the second stage a secondary transducer sences the displacement and converts it into an analogous electrical signal.
- The various secondary transducer used in the measurement of pressure could be variable 'R', variable 'L' or variable 'C' transducer.
- The various primary transducer used for the measurement of the pressure are shown below:-

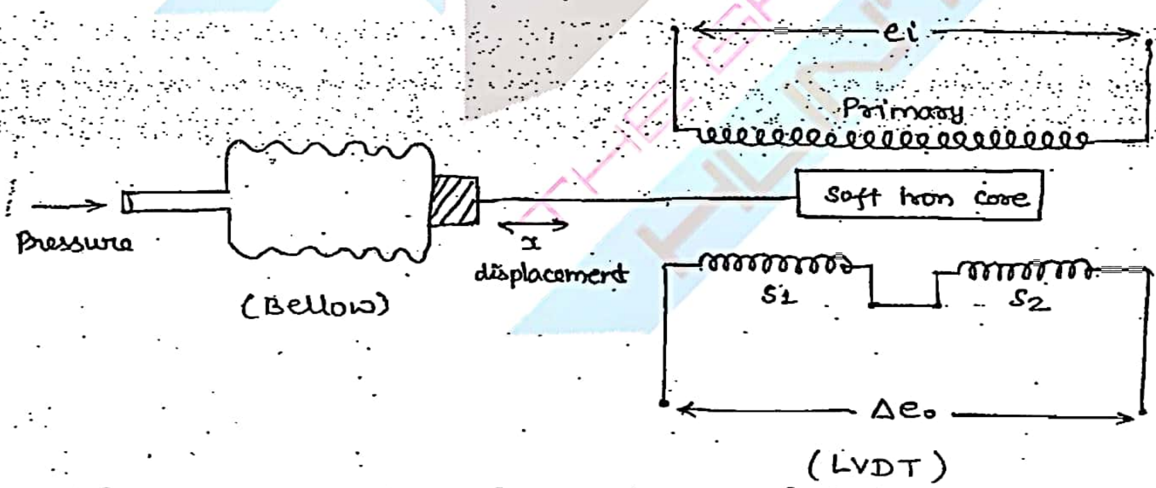


- The primary transducer shown above can sense pressure ranging from a few mm Hg to a several atmosphere. They are generally fabricated with materials like BeCu, phospher bronze or stainless steel.

- The output of a ~~Bored~~ Bourdon tube is angular displacement signal whereas the o/p of the remaining transducer are linear displacement signal.

- The capsule is used for measurement of dynamic pressure where as the other transducer can sense static pressure only.

⇒ Typical pressure measurement ~~sys~~ setup using a Bellow and LVDT :-



Since, $x \propto$ Pressure (P) ------(i)

Here, $\Delta e_o \propto x$ ------(ii)

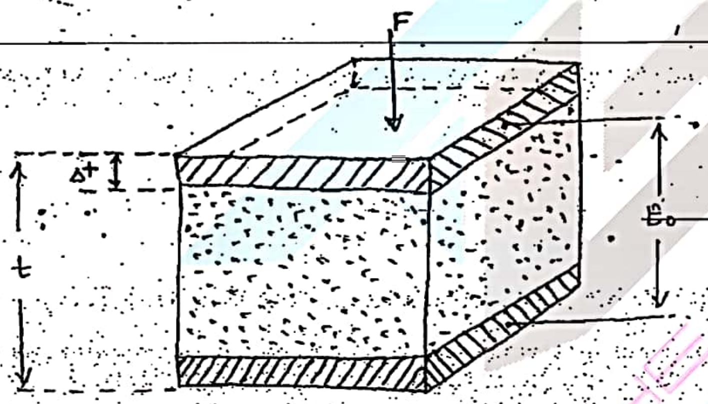
from (i) & (ii),

$$\boxed{\Delta e_o \propto \text{Pressure (P)}}$$

(2) Pressure Measurement using Active Transducer :-

(Piezoelectric crystal)

- Piezoelectric effect is defined as " the property of a crystal by the virtue of which charges are induced across its certain surface when its mechanical dimensions are changed due to application of pressure.
- This is reversible effect and the various materials that exhibit this property are Quartz crystal, Barium Titanate and Roschell's salt.



By definition of piezoelectric effect,

$$Q \propto F$$

$$Q = dF \quad ----- (1)$$

where d = charge density

As we know, that the charges induced can be expressed as :-

$$Q = CV$$

In this case,

$$Q = C_p E_0$$

$$\text{or} \quad E_0 = \frac{Q}{C_p} \quad ---- (2)$$

where; C_p = capacitance of the crystal.

The capacitance C_p can also expressed in terms of capacitance of a parallel plate capacitor where,

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

and in this case,

$d = t$, the unstrained thickness.

$$C_p = \frac{\epsilon A}{t} \quad \text{----- (3)}$$

substituting eq^n (3) and (1) in (2) we have,

$$E_0 = \frac{d \cdot F \cdot t}{\epsilon \cdot A} \quad \text{----- (4)}$$

Here; $\frac{d}{\epsilon} = g$ (voltage sensitivity)

$\frac{F}{A} = P$ (Pressure)

$t =$ unstrained ~~thickness~~

$$E_0 = g \cdot P \cdot t \quad \text{----- (5)}$$

as 'g' and 't' are constant

$$\boxed{E_0 \propto P} \quad \text{----- (6)}$$

Q) A Quartz piezoelectric transducer $0.5\ cm^2$ area and 1 mm thick is connected to charge amp^r having at feedback capacitor of 30 pF. The columb sensitivity of transducer is 2 pC/N. If the freq. range of operation of transducer, the amp^r can be assumed to have infinite I/P impedance and negligible O/P impedance. A sinusoidal force of $30 \times 10^{-3} \sin 150t$ N is applied on the transducer. What is peak to peak voltage swing at the amp^r O/P?

Ans: $A = 0.5\ cm^2 = 0.5 \times 10^{-4}\ m^2$

$t = 1\ mm = 10^{-3}\ m$.

charge sensitivity $= 2\,pC/N = 2\times10^{-12}\ C/N$.

$f_{max} = 30\times10^{-3}\ N$

$\epsilon = 8.854\times10^{-12}\ F/m$.

we know,

$$E_{0(max)} = \frac{d \cdot f_{max} \cdot t}{\epsilon A}$$

$$= \frac{2\times10^{-2}\times30\times10^{-3}\times10^{-3}}{8.854\times10^{-12}\times0.5\times10^{-4}}$$

$$= 0.135\ V.$$

Peak to peak voltage swing at o/p will be,

$$= 2\times E_{0(max)}$$

$$= 2\times0.135$$

$$= 0.270\ V \quad \text{(Ans)}$$

(3) Measurement of strain :—

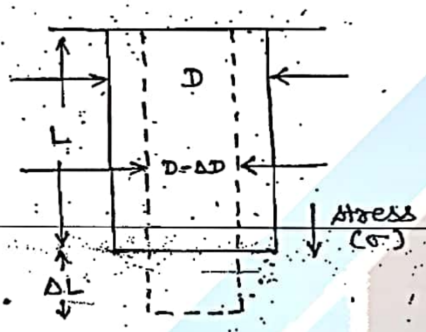
- Generally strain is defined as the change in the mechanical dimension wrt to its original dimension, specifically strain is a ratio b/w the change in the longitudinal dimension of the body wrt its original longitudinal dimension".
- Strain gudge base their ~~princip~~ operation on the fact that whenever a metallic wire is stressed it undergoes strain which results in increased resistance.

Mathematically,

$$\boxed{\frac{\Delta R}{R} = \frac{K \cdot \Delta L}{L}}$$

- The proportionality 'K' in the abv expression is known as the ~~strain~~ guage factor of the strain guage which explain several characteristic of the strain guage.

⇒ Derivation for the expression of the guage factor of a strain guage :-



Here,

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

μ strain

Here resistance of wire can be written as,

$$R = \frac{\rho L}{A}$$

Apply log on both side,

we have,

$$\log R = \log L - \log A + \log \rho$$

differentiate the abv exp. wrt stress (σ) we have

$$\frac{1}{R}\cdot\frac{dR}{d\sigma} = \frac{1}{L}\cdot\frac{dL}{d\sigma} - \frac{1}{A}\frac{dA}{d\sigma} + \frac{1}{\rho}\cdot\frac{d\rho}{d\sigma} \quad \text{---- (1)}$$

As $A = \frac{\pi D^2}{4}$, the term $\frac{1}{A}\cdot\frac{dA}{d\sigma}$ can be expressed as,

$$\frac{1}{A} = \frac{4}{\pi D^2}$$

$$\frac{dA}{d\sigma} = \frac{\pi D}{2}\cdot\frac{dD}{d\sigma}$$

$$\frac{1}{A}\cdot\frac{dA}{d\sigma} = \frac{4}{\pi D^2}\cdot\frac{\pi D}{2}\cdot\frac{dD}{d\sigma}$$

$$= \frac{2}{D}\cdot\frac{dD}{d\sigma}$$

substituting the abv exp. in eq^n (1),

$$\frac{1}{R}\cdot\frac{dR}{d\sigma} = \frac{1}{L}\frac{dL}{d\sigma} - \frac{2}{D}\cdot\frac{dD}{d\sigma} + \frac{1}{\rho}\frac{d\rho}{d\sigma}.$$

for small variation we have,

$$\frac{\Delta R}{R} = \frac{\Delta L}{L} - \frac{2\Delta D}{D} + \frac{\Delta \rho}{\rho} \quad \text{------ (2)}$$

from the possion ratio,

$$V = \frac{-\Delta D/D}{\Delta L/L}$$

$$\frac{\Delta D}{D} = -V\cdot\frac{\Delta L}{L}.$$

substituting the abv in exp. (2),

$$\frac{\Delta R}{R} = \frac{\Delta L}{L} + 2V\frac{\Delta L}{L} + \frac{\Delta \rho}{\rho}$$

$$\boxed{\frac{\Delta R}{R} = \left\{1 + 2V + \frac{\Delta\rho/\rho}{\Delta L/L}\right\}\cdot\frac{\Delta L}{L}} \quad \text{---- (3)}$$

↳ In the abv expression, the term $\left\{1 + 2V + \frac{\Delta\rho/\rho}{\Delta L/L}\right\}$ is known as the gauge factor of strain guage.

- In metal wire strain guages where change in resistance is due to the change in the mechanical dimension of the body. The term $\frac{\Delta\rho/\rho}{\Delta L/L} = 0$ and

Hence,

$$\boxed{\frac{\Delta R}{R} = \{1 + 2V\}\cdot\frac{\Delta L}{L}} \quad \text{---- (4)}$$

- The typical value of the ~~gate~~ guage factor of metal wire strain guages are b/w -3 and $+5$.

- In semi conductor strain guages which based their operation on piezoelectric effect. The change in resistance is due to change in resistivity of the material and Hence,

$$\boxed{\frac{\Delta R}{R} = \frac{\Delta \rho}{\rho}} \quad \text{----} (5)$$

- The typical value of the guage factor will be for semi-conductor strain guage are b/w 500 to 3000.

Q) A strain guage with a nominal resistance of 120 undergoes a strain of 10^{-5}. What is the change in resistance in response to this strain. (Gauge factor = 2)

Ans→ $R = 120\,\Omega$

$GF = 2$

$\frac{\Delta L}{L} = 10^{-5}$

$\therefore \frac{\Delta R}{R} = GF \times \frac{\Delta L}{L}$

$\Delta R = 2 \times 10^{-5} \times 120$

$\Delta R = 240 \times 10^{-5}\,\Omega$ (Ans)

Q) The guage factor of material of strain guage is such that the resistance changes from $1000\,\Omega$ to $1009\,\Omega$ when subjected to a strain of 0.0015. The poison's Ratio of the material of guage wire is :-

(a) 1.75 (b) 2 (c) 2.5 (d) 6.

Ans→ $R = 1000\,\Omega$

$\therefore \Delta R = 9\,\Omega$

$\frac{\Delta L}{L} = 0.0015$

we have,

$$\frac{\Delta R}{R} = (1+2V)\frac{\Delta L}{L}.$$

$$1+2V = \frac{\Delta R/R}{\Delta L/L}.$$

$$= \frac{9/1000}{0.0015}$$

$1+2V = 6$

$V = 2.5$ (option - C).

Q). A strain guague has a guage factor of 4. If this strain guage is attached to a metal bar that stretches from 25 cm to 25.2 cm, calculate % change in resistance. If the unstrained value of resistance is 120 Ω what could its value after ~~the strain~~ is applied.

Ans→ Given,

$L = 25$ cm

$\Delta L = 0.2$ cm.

Hence, strain $= \frac{\Delta L}{L} = \frac{0.2}{25}$.

Since, $GF = 4$.

but,
$$\frac{\Delta R}{R} = GF \times \frac{\Delta L}{L}.$$

$$\frac{\Delta R}{R} = 4 \times \frac{0.2}{25} = 0.032$$

$$\% \text{ change in } R = \frac{\Delta R}{R} \times 100 = 3.2\%.$$

If $\frac{\Delta R}{R} = 0.032$.

$\Delta R = 0.032 \times R$

$= 0.032 \times 120 = 3.84\ \Omega$.

∴ The resistance of the strain guage after strain

$= 120 + 3.84\ \Omega$

$= 123.84\ \Omega$ (Ans).

Q) A resistance strain guage of GF = 2 is fastened to a steal bar subjected to a stress of 1050 kg/cm². The modulus of elasticity of sheet is $2.1 \times 10^{+6}$ kg/cm². calculate % change in resistance of the strain guage due to applied stress ?

Ans→ stress = 1050 Kg/cm²

$E = 2.1 \times 10^{+6}$ Kg/cm²

GF = 2

Here, $E = \dfrac{\text{stress}}{\text{strain}}$

$\text{strain} = \dfrac{\Delta L}{L} = \dfrac{\text{stress}}{E} = \dfrac{1050}{2.1 \times 10^6} = 5 \times 10^{-4}$

but, $\dfrac{\Delta R}{R} = GF \times \dfrac{\Delta L}{L} = 2 \times 5 \times 10^{-4} = 10^{-3}$

$\% \text{ change in } R = \dfrac{\Delta R}{R} \times 100 = 10^{-3} \times 100 = 0.1\,\%$ (Ans).

⇒ Strain Gauge ckt :~

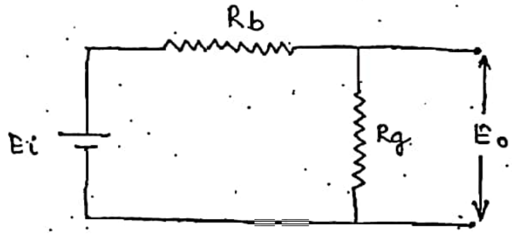
- The two most commonly used ckt for measuring strain are :-

(1) The Ballast ckt.

(2) The wheatstone bridge ckt.

(1) The Ballast Ckt :→

The value of E_0 at zero strain, $E_0 = \dfrac{R_g \cdot E_i}{R_g + R_b}$.



If the strain guage is stressed then its resistance change due to which Eo changes,

so, $\dfrac{\partial E_o}{\partial R_g} = E_i \left\{ \dfrac{R_b}{(R_b+R_g)^2} \right\}$

$$\Delta E_o = E_i \left\{ \frac{R_b}{(R_b+R_g)^2} \cdot \Delta R_g \right\}$$

$$= E_i \left\{ \frac{R_b R_g}{(R_b+R_g)^2} \cdot \frac{\Delta R_g}{R_g} \right\}$$

As $\dfrac{\Delta R_g}{R_g} = G.F. * \dfrac{\Delta L}{L}$

we have,

$$\Delta E_o = E_i \left\{ \frac{R_b R_g}{(R_b+R_g)^2} * GF * \frac{\Delta L}{L} \right\} \text{ ----- (1)}$$

As $\dfrac{E_i R_b R_g}{(R_b+R_g)^2}$ and GF are constant,

$$\boxed{\Delta E_o \propto \frac{\Delta L}{L}} \text{ --- (2)}$$

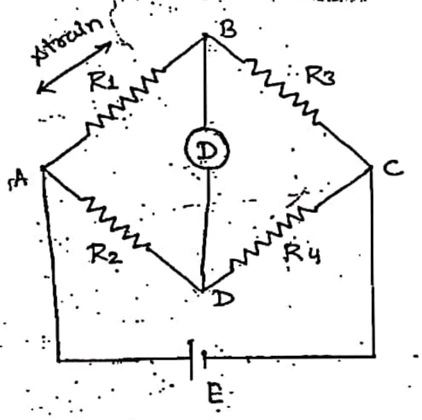
maximum sensitivity is obtained when $R_g = R_b$.

$$\Delta E_o = \frac{E_i \cdot R_g^2}{4R_g^2} * GF * \frac{\Delta L}{L}$$

$$\boxed{\Delta E_o = \frac{E_i * GF}{4} * \frac{\Delta L}{L}} \text{ --- (3)}$$

↳ As a ballast ckt consist of a voltage sensitive device across which a strain guage is connected.

(2) The wheatstone bridge ckt :–



(fig–1)

- One of the most commonly used ckt for the measurement of strain is the wheatstone bridge ckt.
- One or more than one arm of the bridge can consist strain guages and the strain can be measured either by balancing the bridge or detecting the unbalanced condition.

- Thus the wheatstone bridge can be used in two ways:-
  (a) The null deflection bridge.
  (b) The deflection type of a bridge.

(a) The null deflection type of a bridge :–

- This bridge measures strain in terms of the magnitude change in the variable resistance required to bring bridge to balance when strain guage is undergoes strain. (Fig–1)

→ The magnitude of the strain guage (R_1) at zero strain,

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

As R_1 is stressed due to which it changes its resistance and R_2 is varied till the bridge is re balanced.

$$(R_1+\Delta R_1) = \frac{R_3}{R_4}\cdot(R_2+\Delta R_2)$$

$$R_1+\Delta R_1 = \frac{R_3 R_2}{R_4} + \Delta R_2 \cdot \frac{R_3}{R_4}$$

$$\therefore \cancel{R_1}+\Delta R_1 = \cancel{R_1} + \Delta R_2 \frac{R_3}{R_4}$$

$$\Delta R_1 = \frac{R_3 \cdot \Delta R_2}{R_4}$$

Expressing the abov in terms of ΔR_2;

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

Intially, if $R_1 = R_2 = R_3 = R_4 = R_g$

then $\Delta R_2 = \Delta R_g$.

we ~~know~~, $\Delta R_g = GF \times \frac{\Delta L}{L} \times R_g$

So, $\Delta R_2 = GF \times \frac{\Delta L}{L} \times R_g$

As GF and Rg are constant

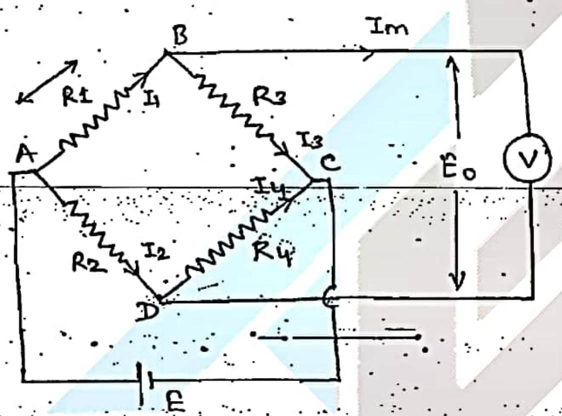
$$\boxed{\Delta R_2 \propto \frac{\Delta L}{L}}$$

* **Note**:- As a finite amount of time is required to bring the bridge back into the balance condition, this bridge ~~qui~~ finds limited application in the measurement of static strain only.

(b) Deflection type of a bridge :-

- It is one of the most commonly used ckt for measurement of dynamic strain is the deflection type of wheatstone bridge.

- When resistance of strain guage changes, the voltage appear across a point which a detector is connected and the deflection of any voltmeter can be directly calibrated in terms of strain.
- In most of case the o/p of bridge is feed to a high impedance amplifier and hence this bridge is known as voltage sensitive bridge.



→ Assuming the voltagmeter is to have infinite input impedance,

So, $I_m = 0$

and

$E_0 = I_1 R_1 - I_2 R_2$

but as $I_m = 0$

$$I_1 = I_3 = \frac{E}{R_1+R_3}$$

$$I_2 = I_4 = \frac{E}{R_2+R_4},$$

$$E_0 = E\left\{\frac{R_1}{R_1+R_3} - \frac{R_2}{R_2+R_3}\right\}$$

$$= E\left\{\frac{R_1R_4 - R_2R_3}{(R_1+R_3)(R_2+R_3)}\right\}$$

If R_1 is strained then its resistance changes by ΔR_1 and E_0 changes by ΔE_0,

$$\therefore E_0 + \Delta E_0 = E\left[\frac{(R_1+\Delta R_1)R_4 - R_2R_3}{(R_1+\Delta R_1+R_3)(R_2+R_4)}\right].$$

Initially $R_1 = R_2 = R_3 = R_4 = R_g$, then the bridge is balanced and $I_m = 0$,

$$\Delta E_0 = E\left\{\frac{R_g^2 + R_g\cdot\Delta R_g - R_g^2}{(2R_g+\Delta R_g)\cdot 2R_g}\right\}$$

$$= E\left\{\frac{\Delta R_g}{4R_g + 2\Delta R_g}\right\}$$

$$= E\left\{\frac{\Delta R_g/R_g}{4+2\Delta R_g/R_g}\right\}$$

as $4 >> 2\Delta R_g/R_g$.

$$\Delta E_0 = \frac{E}{4}\left\{\frac{\Delta R_g}{R_g}\right\}.$$

As $\frac{\Delta R_g}{R_g} = GF \times \frac{\Delta L}{L}$ we have,

$$\Delta E_0 = \frac{E}{4}\left\{GF * \frac{\Delta L}{L}\right\}$$

(or)

$$\boxed{\Delta E_0 \propto \frac{\Delta L}{L}}$$

↳ from the abv analysis it can be seen that any voltmeter connected across the o/p of bridge can have its scale directly calibrated in terms of the strain.

⇒ <u>Temperature compensation in strain guages</u> :-

(1) Error due to temperature variation in strain guages occur b/c of :-

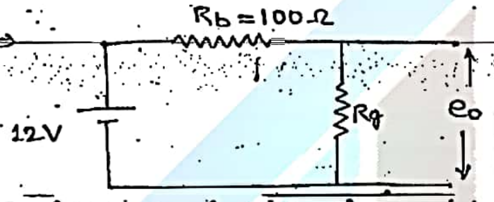
(a) The change in resistance of strain guage due to ambient temperature.

(b) Differential expansion of the strain guage wrt surface with which it attached.

(2) These occur can be compensated by introducing dummy guages in one or more than one arm of the wheat stone bridge.

Q) A strain guage having a resistance of 100Ω and a guage ~~factor~~ of 2 is connected in series with ballast resistance of 100 Ω and across a supply of 12V. Calculate the difference b/w the output voltage with no stress applied and a stress of 140 MN/m². The modulus of elasticity is 200 GN/m².

Ans →



→ e_o at zero strain,

$$= \frac{100 \times 12}{100 + 100} = 6V.$$

$$\text{stress} = 140 \times 10^6 \ N/m^2$$

$$E = 200 \times 10^9 \ N/m^2$$

$$\text{strain} = \frac{\Delta L}{L} = \frac{\text{stress}}{E}$$

$$= \frac{140 \times 10^6}{200 \times 10^9} = 0.7 \times 10^{-3}.$$

we know,

$$\frac{\Delta R}{R} = GF \cdot \frac{\Delta L}{L}$$

$$= 2 \times 0.7 \times 10^{-3}$$

$$= 1.4 \times 10^{-3}.$$

$$\Delta R = 1.4 \times 10^{-3} \times R = 1.4 \times 10^{-3} \times 100 = 0.14\Omega$$

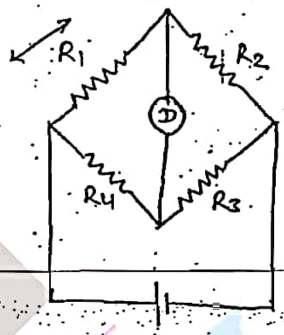
the changed R will be $= 100 + 0.14 = 100.14$.

$$E_o = \frac{12 \times 100.14}{100 + 100.14} = 6.0042V.$$

change in E_o due to stress $= 6.0042 - 6V$

$= 0.0042 \ V$ (Ans)

Q) A strain guage shown in fig, has two resistance R_2 and R_3 of 125 Ω each. A variable resistor R_4 which is 120 Ω without strain and 120.75 Ω with strain. If the guage factor of the strain guage of 2.04, Determine the strain in the beam where the guage is attached.



Ans: Resistance of R_1 without strain,

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

$$= \frac{125 \times 120}{125} = 120\ \Omega$$

Resistance of R_1 with strain,

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

$$= \frac{125 \times 120.75}{125} = 120.75\ \Omega$$

We know,

$$\frac{\Delta R}{R} = GF \times \frac{\Delta L}{L}$$

$$\frac{0.75}{120} = 2.04 \times \frac{\Delta L}{L}$$

$$\frac{\Delta L}{L} = \frac{0.75}{120 \times 2.04} = 3.06 \times 10^{-3} \quad \text{(Ans)}$$

Q) The resistor in the four arm of a bridge with dc supply across A and C are $R_{AB} = R_{BC} = R_{CD} = R_{DA} = 350\ \Omega$. R_{BC} constitute the active guage (unstrained resistance = 350 Ω). R_{CD} is the dummy guage, of the same value. The Detector is connected across B and D and supply voltage is 10 V. The active guage has a guage factor of 2.03. If the guage is in the arm BC is subjected to a strain of 1450 um/m. find the Bridge off set voltage.

Ans→ H.W.

Measurement of Temperature :-

- The most commonly used transducer for detecting temperature are :-

  (a) Resistance temp. detector.

  (b) Thermistor.

  (c) Thermo-couple.

(a) Resistance temp. detector (RTD) :-

- An RTD bases its operation that the resistance of pure metal increases with in rise in temperature due to their positive temp. coefficient of Resistance.
- Constructionally, an RTD is a wire made up of pure metal enclosed in a glass bead and subjected to the temperature under measurement.
- The resistance of wire increases due to temperature, and this increase in resistance is detected by a suitable ckt like a wheatstone bridge.
- The most important characteristic of any metal used as an RTD are :-

  (a) The temp. coefficient of the metal should be high, which results in a detector with high sensitivity.

(b) The resistivity of the metal should be large, as it give a detector which is large in size.

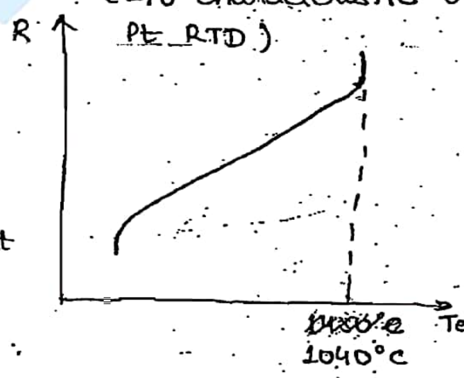
(c) The temp. coefficient of Resistance (α) of the detector should be fairly constant over a wide range of temperature, resulting in increased linearity.

- The most preferred material used for fabricating RTD is platinum (Pt) whereas most commonly used is Nickle (Ni).
- 'copper' is generally used below 120° range where as 'Tungstun' is used for high temp. measurement.
- 'Gold' and '~~Silver' are~~ not used to fabricate RTD due to their low resistivity.
- The mathematical relationship b/w temp. and resistance and a typical Input-output relationship of platinum RTD are shown below:-

$$\boxed{R_T = R_{T_0}(1+\alpha\Delta T)}$$

where, $\boxed{\Delta T = T - T_0}$

(I/O characteristic of Pt RTD)



$T \rightarrow$ Temp. under measurement (°C)

$T_0 \rightarrow$ Reference temp. (°C)

$\alpha \rightarrow$ Temp. coefficient of Resistance

$R_{T_0} \rightarrow$ Resistance at reference temp.

$R_T \rightarrow$ Resistance at temp. T.

Q) A platinum resistance thermameter has a resistance of ~~200 Ω at~~ 20°c. what is it resistance at 100°c, if the temp. coefficient of resistance of thermameter at 20°c is 0.004.

Ans. $T = 100$

$T_0 = 20°$

$\Delta T = T - T_0 = 80$

$\alpha = 0.004$

$R_{T0} = 200\ \Omega$

$R_T = 200(1 + 0.004 \times 80)$

$R_T = 264\ \Omega$. (Ans)

(b). Thermistor :-

:- The thermistor which is also known as 'thermal resistor' is a semi-conducting device that exhibit a change in resistance due to temperature.

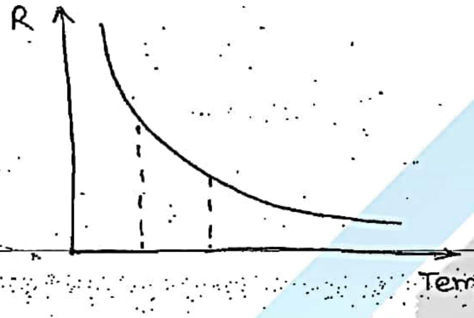
- depending on the temp. coefficient of the resistance (α) these devices can be further classified as :-

(i) PTC thermistor → which exhibit a positive temp. coefficient of resistance. And generally used in automobile engineering.

(ii) NTC thermistor → which exhibit a negative temp. coefficient of resistance. and are extensively used for temperature measurement and control.

- NTC thermistor are fabricated with metal oxide of either Magnese or cobalt and exhibit very high sensitivity and highly non-linear Input-output characteristic.

- The relationship b/w its resistance and temperature and typical Input-output characteristic of a thermistor are shown below :-



$$\boxed{R_T = R_{T_0} e^{\beta\left(\frac{1}{T} - \frac{1}{T_0}\right)}}$$

↳ In the above expression,

T_0 = Reference temp. (in °K)

T = Temp. under measurement (°K)

R_{T_0} = Resistance at reference temp. T_0

R_T = Resistance at temp. under measurement.

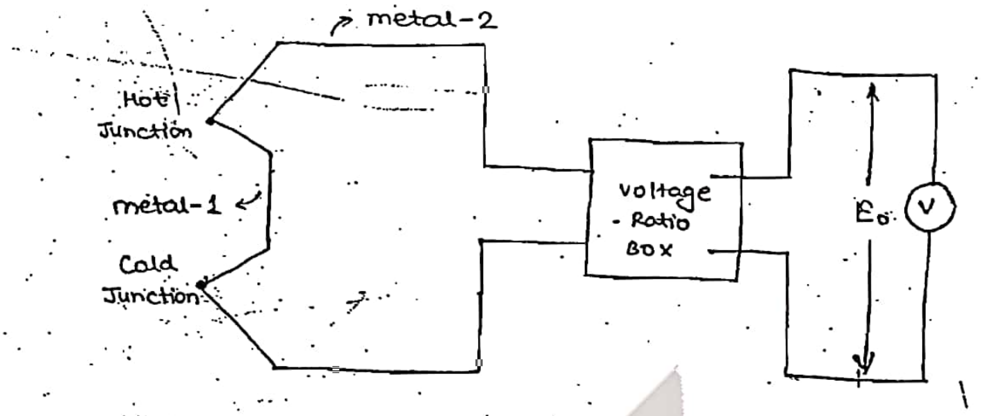
β = constant = 4000.

* <u>Note</u> :- The resistance-temperature relationship of a thermistor is same as that of RTD upto a range of 75°C.

- Typical range of thermistor ~~RTD~~ is b/w − 90°C to + 150°C

(c) <u>Thermo-Couple</u> :~

- Thermo-couple is an active transducer which bases its operation on See back of electric current which states that ' whenever a temperature difference exist



across the junction of two dis-similar metal, an EMF E_0 is induced across its output terminal.

- The relationship b/w output ~~E_0~~ voltage E_0 and temp. under measurement T is given below:-

$$\boxed{E_0 = S(\Delta T)}$$

where, $\Delta T = T - T_0$.

T = temp. of Hot junction.

T_0 = temp. of cold junction.

S = Seeback coefficient.

- Depending on the metal used in fabrication, thermo-couple can be further classified as :-

(i) <u>Base ~~[illegible]~~ metal thermo-couple</u> :- which are fabricated with metals like copper, constanten, iron, etc and can measure temp. upto 1400 °C.

(ii) <u>Rare-earth thermo-couple</u> :- with are fabricated with metal and metal alloy of platinum, irridium and Rodium and can measure temp. upto 2700°C.

Q) A Copper-constanten thermo-couple was found to have a linear calibration b/w 0 to 400°C with EMF at max. temp. (reference j^n at 0°C) is equal to 20.68 mV.

Determine :-

(a) The correction which was to be made to the indicated emf if the cold junction temp. is 25°C.

(b) If the indicated emf is 8.92 mV in the thermo-coupled ckt, determine the temp. of hot junction.

Ans→ $T = 400°C$

$T_0 = 0°C$

$\Delta T = T - T_0 = 400°C$

$E_0(max) = 20.68 \text{ mV}$.

$\therefore S = E_0/\Delta T = \frac{20.68 \times 10^{-3}}{400} = 5.17 \times 10^{-5} \text{ V/°C}$

(a) Correction provided if cold j^n is kept at 25°C.

Here, $T = 400°C$

$T_0 = 25°C$.

$\Delta T = 375°C$.

$S = 5.17 \times 10^{-5} \text{ V/°C}$

$\therefore E_0 = S \cdot \Delta T$

$= 5.17 \times 10^{-5} \times 375$

$= 19.38 \text{ mV}$.

therefore correction to be provided $= E_{0max} - E_0$,

$= 20.68 - 19.38$

$= 1.3 \text{ mV}$.

(Ans)

(b) If $E_0 = 8.92$ mV, then $T = ?$

Here, $T_0 = 0°C$; $S = 5.17 \times 10^{-5}$ V/°C.

$$\Delta T = \frac{E_0}{S} = \frac{8.92\times10^{-3}}{5.17\times10^{-5}}$$

$$\Delta T = 172.53$$

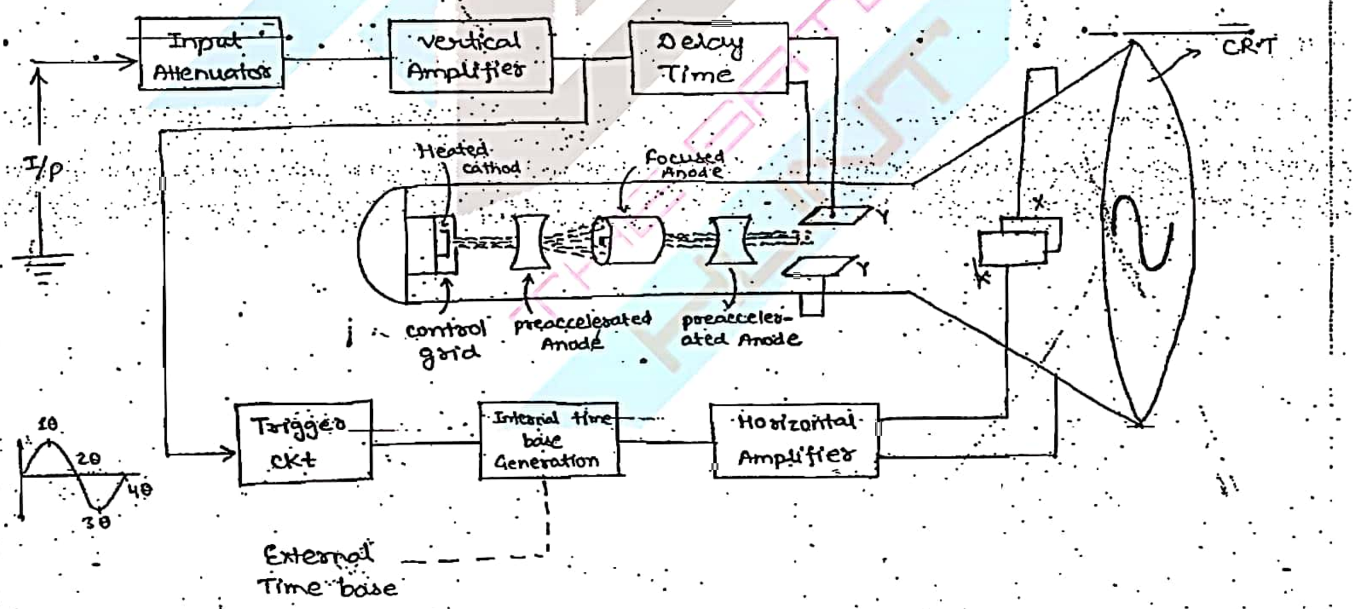
$$\therefore T = 172.53\,^\circ C \quad (b/c\ T_0 = 0^\circ C) \quad \text{(Ans)}$$

⊙ Cathod Ray Oscilloscope (CRO) :~

⇒ Topic :-

1. Block diagram of CRO.
2. Pattern formation of CRO.
3. Measurement of phase.
4. Measurement of frequency.

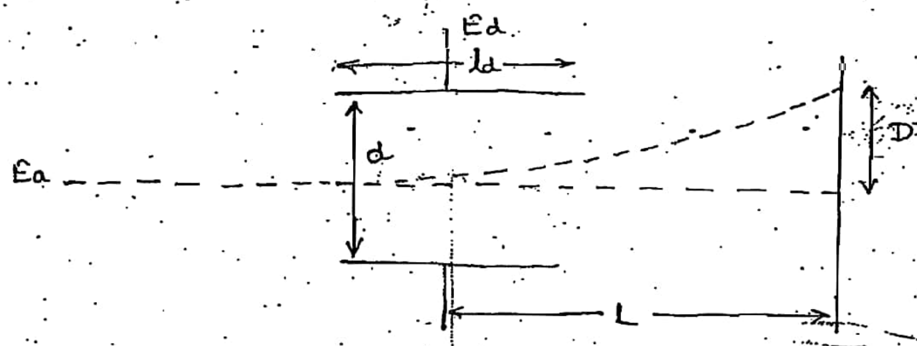
⇒ Block diagram of CRO :~



- The vertical component of the signal in the o/p of a CRO represents the volts per division where as a horizontal component of signal represent time per division.
- High I/P impedance of CRO is due to presence of buffer amplifier in the vertical Amplifier ckt.

- The utility of delay line is to synchronise the o/p of vertical and horizontal deflection plate to appear at the same time there by avoiding the loss in the leading edge of signal.
- The internal time base generation basically consist of a UJT based sweep signal generator.
- The potential difference across the control grid is controlled by the intensity control on the front panel of the CRO.
- The potential difference across the electrostatic focusing mechanism (the set of 3 anode) is controlled by the focusing control on the front panel of CRO.
- The CRT of CRO uses a electrostatic deflection system as the area of sweep is small and image is generally formed on the centre of screen and also b/c accuracy requirement in CRO are very high in comparison to sensitivity requirements.

→ Electrostatic deflection due to Y plates :-



$$\boxed{D = \frac{L\,l_d\,E_d}{2\,d\,E_a} \text{ metre}}$$

$$\boxed{S = \frac{D}{E_d} = \frac{L\,l_d}{2\,d\,E_a}}$$

$$\boxed{G = \frac{1}{S} = \frac{2dE_a}{L\,l_d}}$$

- The electrostatic deflection in the beam of e^-s due to Y-plate is given by the expression,

$$\boxed{D = \frac{L\,l_d\,E_d}{2dE_a} \text{ metres}}$$

- The deflection sensitivity is defined as the deflection per volt of deflecting voltage.

$$\boxed{S = \frac{D}{E_d} = \frac{L\,l_d}{2dE_a}}$$

- ~~The deflection factor is the reciprocal of deflection~~ sensitivity and given by expression,

$$\boxed{G = \frac{1}{S} = \frac{2dE_a}{L\,l_d}}$$

where, L = distance of screen from the centre of reflecting plates in meter

l_d = length of deflecting plates in meters

E_d = potential difference across the deflecting plates in volts

d = distance b/w plates in metre

E_a = The anode voltage / the accelerating voltage in volts.

Q) The X deflection plate of a CRT are 20mm long and 5mm apart, the centre of plate is 25cm away from screen and accelerating voltage is 3000 V. Calculate deflection sensitivity of CRT.

Ans→ $l_d = 20\text{ mm} = 20 \times 10^{-3}\text{ m}$

$L = 25\ cm = 25 \times 10^{-2} m$

$d = 5\ mm = 5 \times 10^{-3} m$

$E_a = 3000\ V$.

$S = \frac{L l_d}{2 d E_a} = \frac{25 \times 20 \times 10^{-5}}{2 \times 5 \times 3} = \frac{50}{3} \times 10^{-5} = 0.1667\ mm/V.$

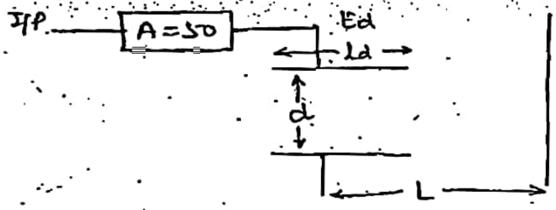
Q) A CRT as an anode voltage of 2KV and parallel deflecting plates are 2 cm long and 5 mm apart. The screen is 30 cm away from the centre of the plate. The I/p voltage is applied to the deflecting plate through amp. having an overall gain of 50. The I/p ~~voltage required to deflection the beam through~~ 3 cm is ?

Ans→ $l_d = 2 \times 10^{-2}$, I/P = 2

$d = 5 \times 10^{-3}$, I/P = $\frac{E_d}{A}$

$L = 30 \times 10^{-3}$

$D = 3 cm$



$D = \frac{l_d \cdot L \cdot E_d}{2 d E_a}$

$3 \times 10^{-2} = \frac{2 \times 10^{-2} \times 30 \times 10^{-3} \times E_d}{2 \times 5 \times 10^{-3} \times 2 \times 10^{3}}$

$\therefore 3 = 3 \times 10^{-3} \cdot E_d$.

$E_d = 100\ V$.

I/p applied = $\frac{100}{50} = 2V$.

Q) An unknown voltage is applied to the horizontal deflection plate of a CRO, which shifts the spot by 5 mm towards the right. If the deflection sensitivity is 0.05 mm/V then the applied unknown voltage :-

(a) 25 V (b) 10 V (c) 100 V (d) 50 V

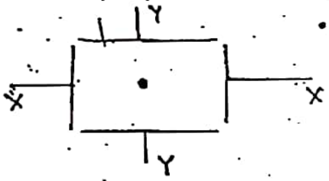
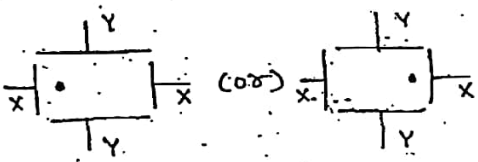
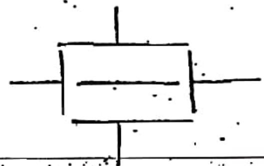
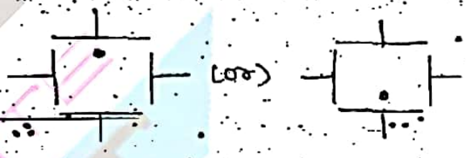
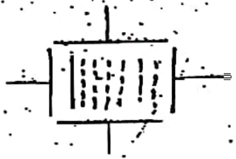
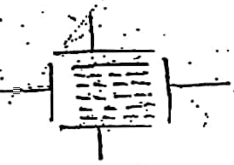
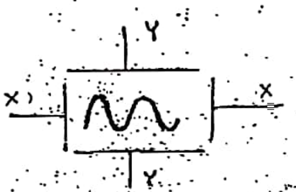
Ans→ $D = 5\ mm$

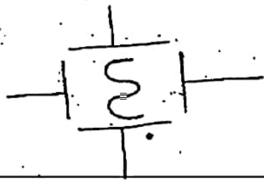
$S = 0.05\ mm/V$

$S = D/E_d$

$E_d = \frac{5 \times 10^{-3}}{0.05 \times 10^{-3}} = 100$ Volts.

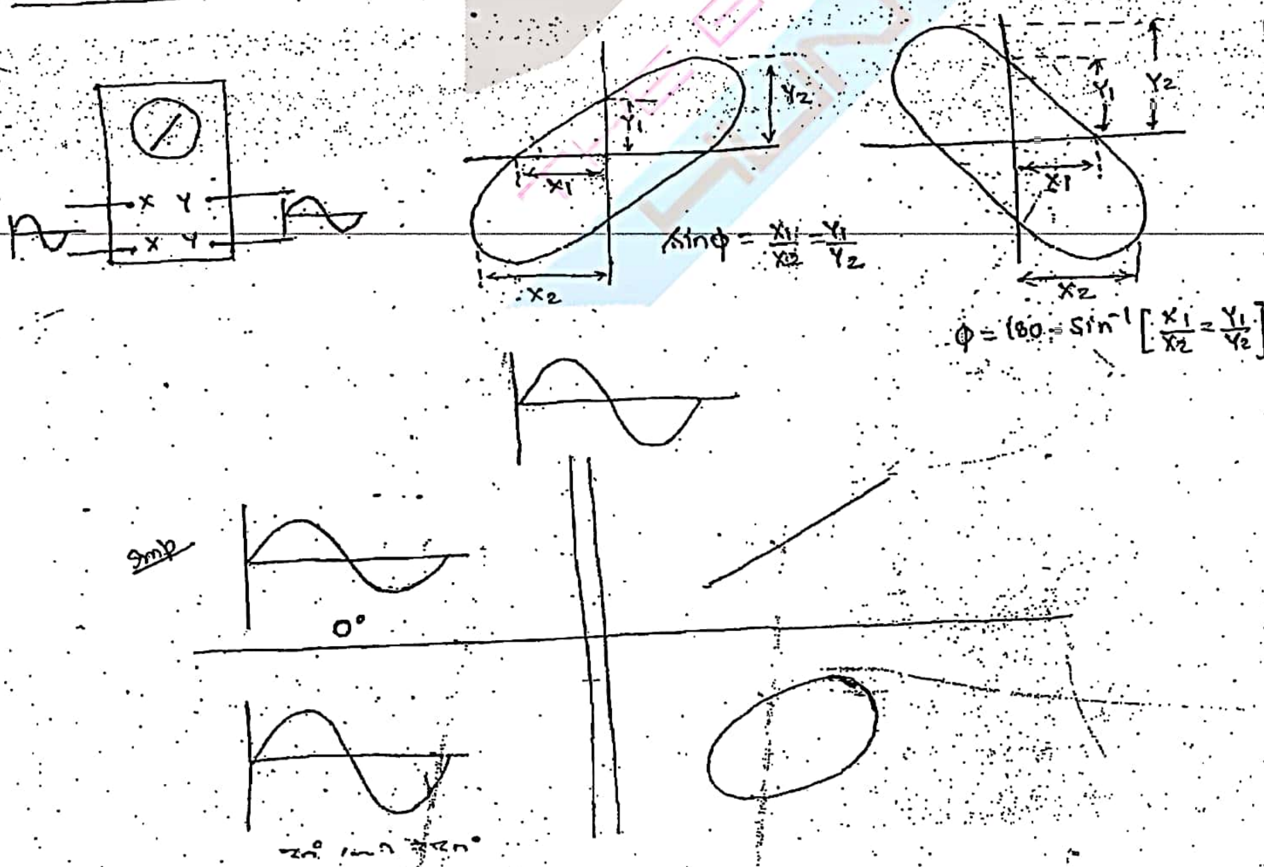
⇒ Pattern formation in CRO :-

Case	Pattern description	Pattern
(1) Case-1 :- XX → grounded, YY → grounded	Pattern is a spot on the centre of the screen.	
* Case-2 :- XX → DC, YY → grounded	Pattern is a spot at in the centre shifted in the horizontal plane.	
* Case-3 :- XX → AC, YY → Gnd	Pattern is a horizontal line at the centre.	
* Case-4 :- XX → Gnd, YY → DC	Plot at centre shifted in vertical plane.	
* Case-5 :- XX → Gnd, YY → AC	Pattern is vertical line at centre.	
* Case-6 : XX → DC, YY → AC	Pattern is vertical straight line shifted in Horizontal plane.	
* Case-7 :- XX → AC, YY → DC	Pattern is a horizontal straight line shifted in vertical plane.	
* Case-8 :- XX → DC, YY → DC	A spot on any point on screen. In the diagonal plane if $V_{xx} = V_{YY}$	
* Case-9 :- XX → time base, YY → Sinusoidal	A sinusoidal in a horizontal plane	

* Case-10 :- XX → Sinusoidal YY → time base	A Sinusoidal in a vertical plane	
* Case-11 :- XX → Sinusoidal YY → Sinusoidal.	When two sinusoidal are applied at XX & YY plate of CRT the pattern formed on screen are known as Lissajous pattern. Lissagous pattern are used for accurate measurement of phase & frequency.	

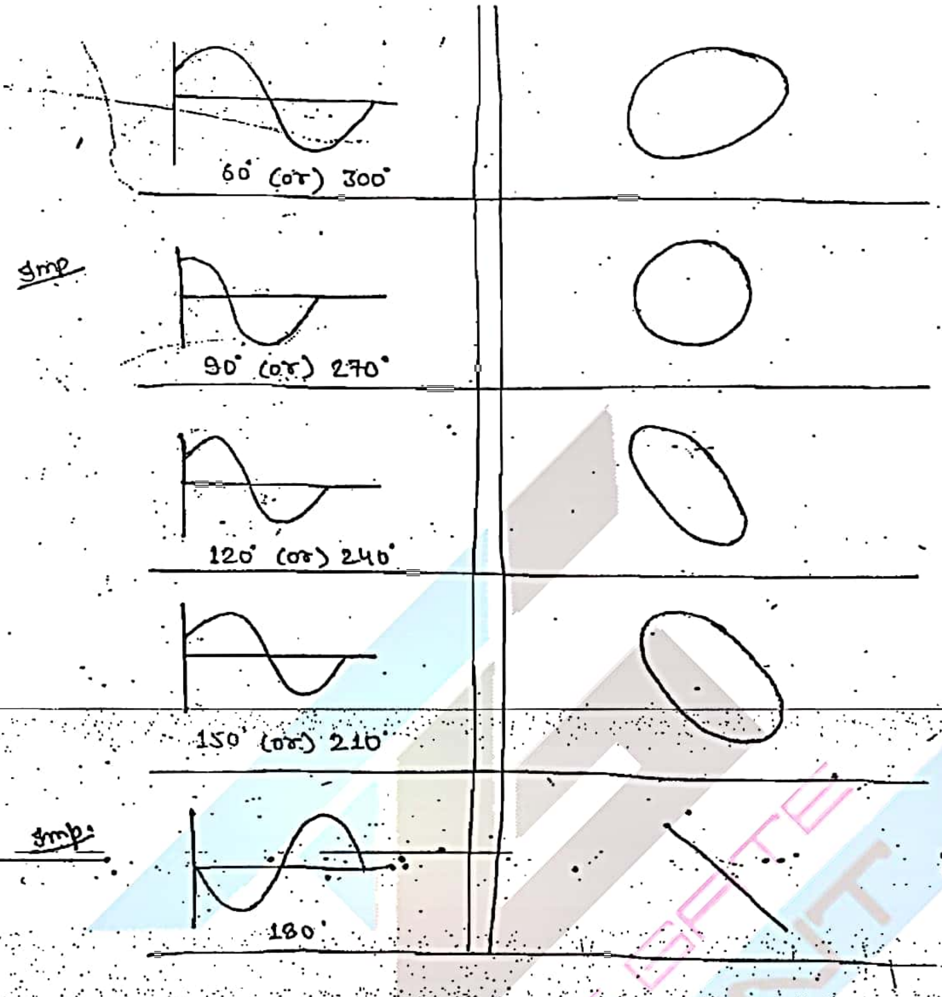
* Measurement of phase using Lissagous pattern method:-

Precondition:- Freq. of both the signal should be same.



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

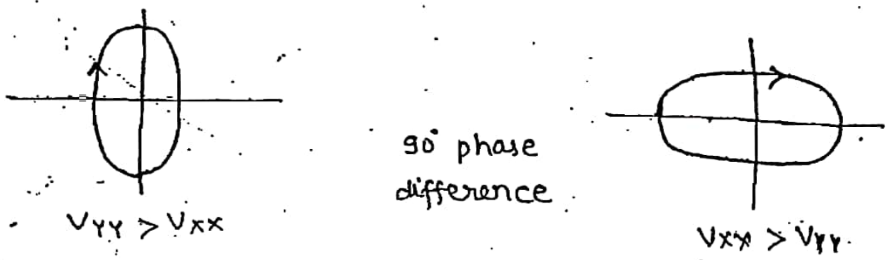
$\phi = 180 - \sin^{-1}\left[\frac{X_1}{X_2} = \frac{Y_1}{Y_2}\right]$



#

↳ Direction of arrows indicate the direction of trace.

#

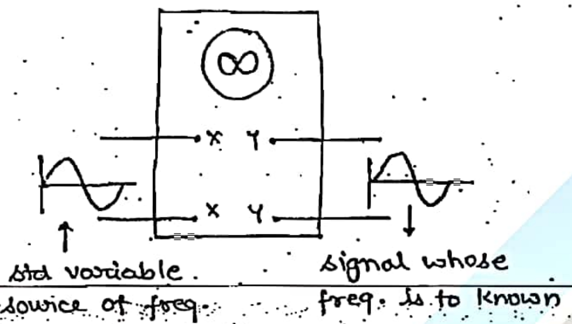


(PTO)

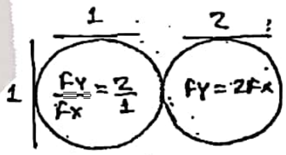
Measurement of frequency using ~~Kiss~~ Lissajous pattern method :-

* for closed Lissajous pattern :-

$$\left\{ \frac{f_Y}{f_X} = \frac{\text{No. of tangencies in horizontal plane}}{\text{No. of tangencies in vertical plane}} \right\}$$



1)



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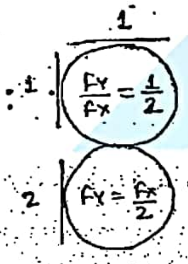

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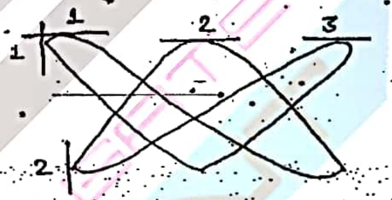


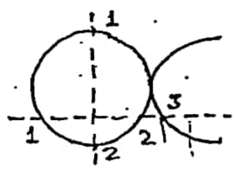
$\frac{f_Y}{f_X} = \frac{3}{2}$

$f_Y = \frac{3f_X}{2}$

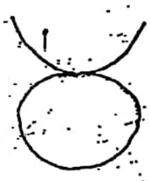
* for openended Lissajous pattern :-

$$\left\{ \frac{f_Y}{f_X} = \frac{\text{max. no. of inter section in Horizontal plane}}{\text{max. no. of inter section in vertical plane}} \right\}$$

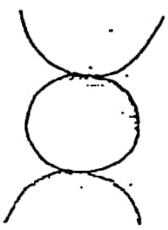
1)



2)

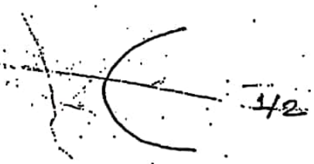


3)



4)

5)



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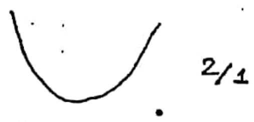

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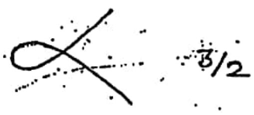

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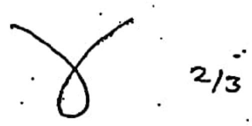
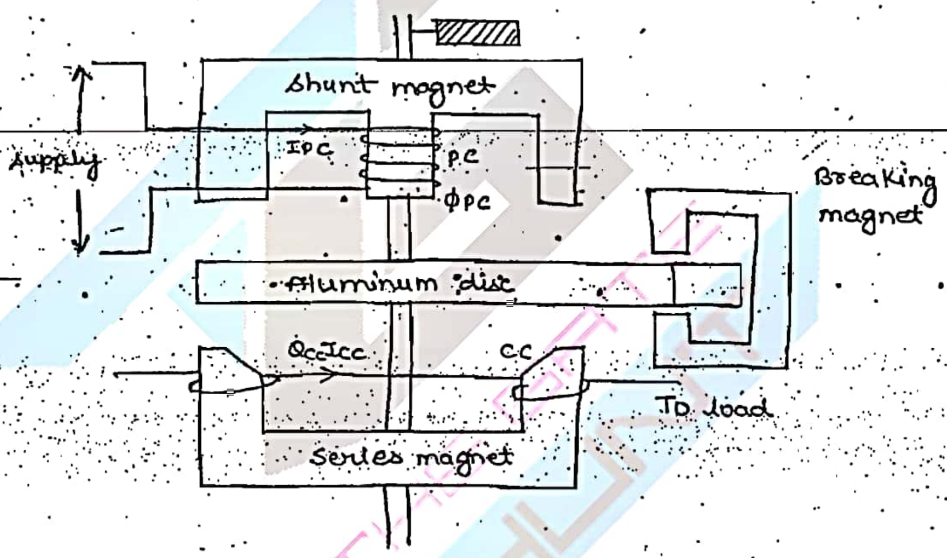


⇒ Energy Meter :~



(End)