Module-II (SAT)

Sensing Elements

1. Resistive sensing element

- Potentiometer
- Thermistor
- Helipot
- Resistance Thermometer or, RTD (RTD- Resistance temp. Detector)
- Strain Gauge

It can sense temperature, strain, displacement, heat, loss etc.

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

Potentiometer [POT]

Passive transducer: Those transducer which requires external power for energy conversion is known as passive transducer.

Active transducer: Those transducer which don't require external power sources for energy conversion, known as active transducer.

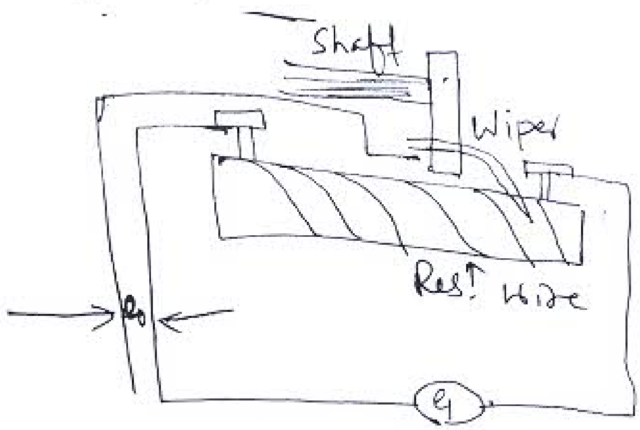
Ex: - Piezo-electric Crystal, Thermocouple

Potentiometer is used for displacement measurement.

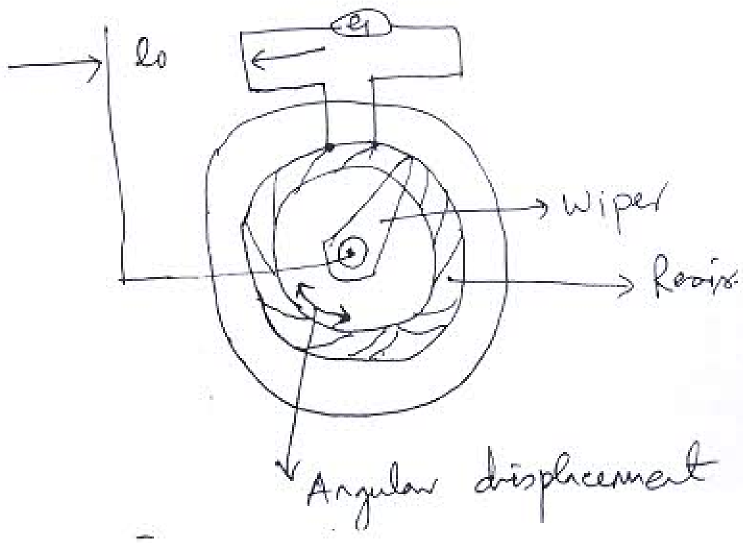
- Strain→ Strain Gauge
- Temperature→ Thermistors

It is a potential divider called POT and it is a passive sensing element.

It measures linear as well as angular displacement.

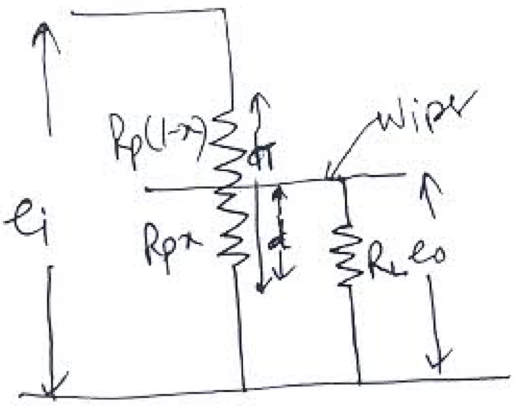


(1) Translational POT



(2) Rotational POT

Schematic Diagram:



d→length covered by the wiper

dT→Total length of the resistive element

R_P→Total Resistance of the POT

$d/dt = x$=Fractional Displacement

$$E_{th} = \frac{e_i \times R_p x}{R_p}$$

$$E_{th} = e_i.x$$

$$R_{Th} = R_p(1-x) \parallel R_p x = \frac{R_p(1-x).R_p x}{R_p} = R_p.x.(1-x)$$

$$V_L = \frac{E_{th} R_L}{R_{th} + R_L} = \frac{e_i x R_L}{R_p x(1-x) + R_L}$$

$$V_L = \frac{e_i x R_L}{R_p x(1-x) + R_L} \rightarrow Non - Linear\ Equation$$

when R_L is large linearity can be obtained

$$V_L = \frac{e_i x R_L}{R_L\left[\frac{R_p}{R_L}x(1-x)+R_L\right]} \Rightarrow V_L = \frac{e_i x}{\frac{R_p}{R_L}x(1-x)+1}$$

$When\ R_L = \infty$

$$V_L = e_i x \rightarrow Linear\ property\ of\ potentiometer$$

→ POT are of two types: -

i) *Wire Wound type*: - In this type 0.01 mm diameter of platinum or nickel alloy each wounded over an insulated former.

ii) *Plastic thin film type*: - These have zero resolution but have higher temperature co-efficient of resistance. This covers displacement span from 25-250mm with Non-linearity up to ±0.04% and resistance value from 500 ohm- 80 K ohm.

Resistance Thermometer (RTD)

It is made up of metal like Nickel, Cr and Pt.

→Platinum (Pt) is suitable metal for construction of RTD's because it is chemically inert and the range of temperature it can withstand is very large.

→Characteristics of Pt. with respect to temperature is linear. General relationship between change in resistance and change in temperature of any metal is given by

$$R_T = R_0\,[1 + \alpha T + \beta T^2 + \Upsilon T^3 + \ldots\ldots]$$

R_T= Resistance at T °C

R_0= Resistance at 0 °C

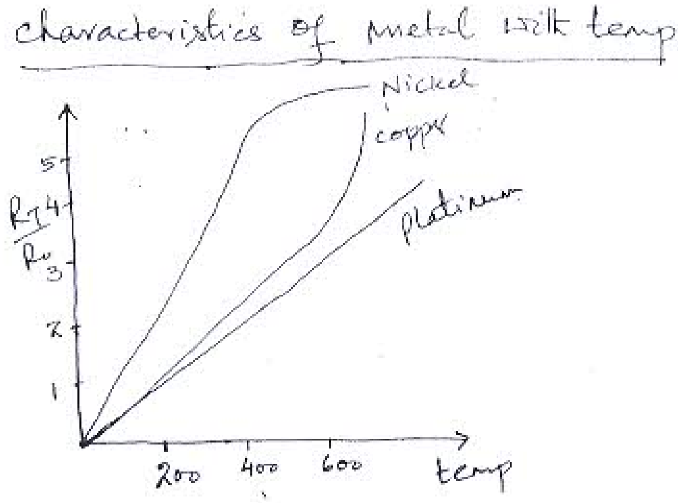
α, β, Υ = Temperature co-efficient of resistance of the metal

→ β, Υ are Non-linear terms and values are very small.

$$R_T = R_0\,[1 + \alpha T]$$

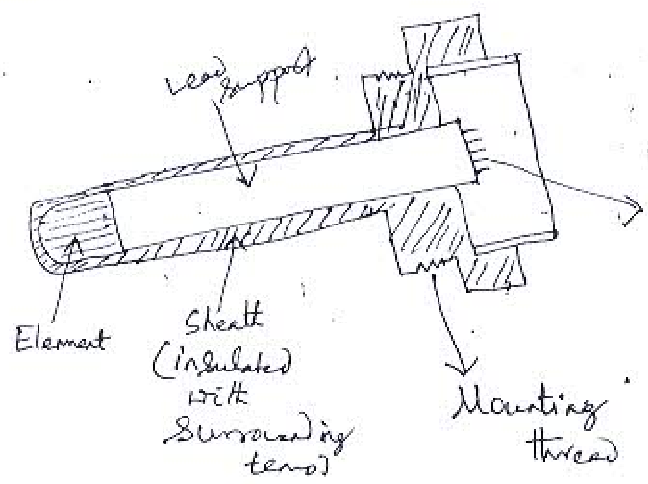
→A typical Platinum element has R_0=100 ohm and R_{100}=138.5 ohm

→[R_{100}-R_0]= Fundamental Interval



Requirement of Conductivity material to be used in RTD:

1) A change in resistance of material for unit change in temp should be as large as possible (sensitivity is High)
2) Resistance of material should have continuous and stable relationship with temperature.

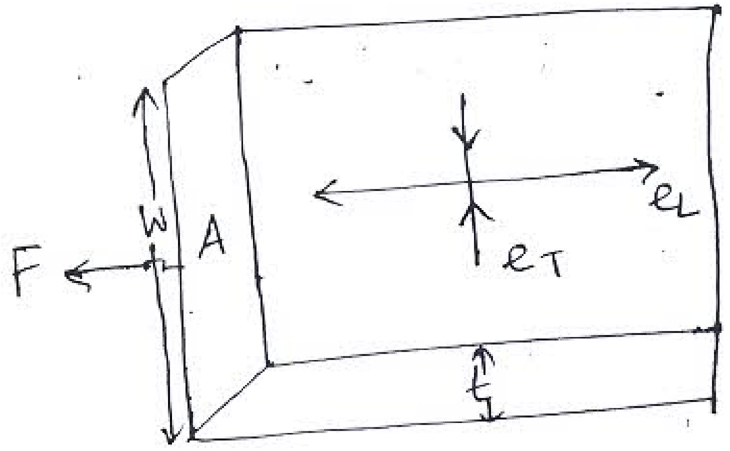


Thermistor (Thermal Resistor)

→These are resistive sensing element made up of semiconductor material used for measurement of temperature.

→The material used are metallic oxide of Cu, Ni, Fe, Co, Cr, Mn etc.

Derivation of Gauge Factor:



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

$$\Delta R = \left(\frac{\partial R}{\partial L}\right)\Delta L + \left(\frac{\partial R}{\partial A}\right)\Delta A + \left(\frac{\partial R}{\partial \rho}\right)\Delta \rho$$

$$= \frac{\rho}{A}\Delta L + \frac{\rho L}{-A^2}\Delta A + \frac{L}{A}\Delta \rho$$

$$A = w \times t$$

$$\Delta A = \frac{\partial A}{\partial w}.\Delta w + \frac{\partial A}{\partial t}.\Delta t$$

$$= t\,.\Delta w + w.\Delta t$$

$$\frac{\Delta A}{A} = \frac{\Delta w}{w} + \frac{\Delta t}{t} = e_T + e_T$$

$$\Rightarrow \frac{\Delta A}{A} = 2e_T$$

$$\Delta R = \rho \frac{\Delta L}{A} - \frac{\rho L}{A} 2e_T + \frac{L}{A}\Delta \rho$$

$$\frac{\Delta R}{R} = \frac{\Delta L}{A} - 2e_T + \frac{\Delta \rho}{\rho}$$

$$\frac{\Delta R}{R} = e_L - 2(-ve_L) + \frac{\Delta \rho}{\rho} = e_L + 2ve_L + \frac{\Delta \rho}{\rho}$$

$$\Rightarrow \frac{\Delta R / R}{e_L} = 1 + 2\nu + \frac{\Delta \rho}{e_L \rho}$$

Gauge Factor is the change in unit resistance per strain

$$GF = \frac{\Delta R / R}{e} = \frac{\Delta R / R}{\Delta L / L}$$

$$\boxed{GF = 1 + 2\nu + \frac{1}{e_L} \frac{\Delta \rho}{\rho}}$$

- 1 → Due to change in length
- 2ν → Due to change in Area
- $\frac{1}{e_L}\frac{\Delta\rho}{\rho}$ → Due to change in Piezo-resistive effect (very small)

  Only for semiconductor gauge we have to consider this effect

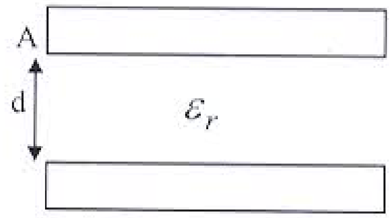
→For most of the metals Poisson ratio is approximately equals to 0.3 and the Piezo-resistive effect is 0.4.

→So, metal gauge factor is around 2.

→For semiconductor strain gauge Piezo-resistive effect term is very large. So gauge factor (GF) of Semiconductor strain gauge is very large. Hence Sensitivity is high for semiconductor type strain gauge.

→Disadvantages of semiconductor strain gauge is its resistance decreases with increase in temperature and consequently there is a decrease in gauge factor of strain gauge i.e. decrease in sensitivity.

2. *Capacitive Sensing Elements*

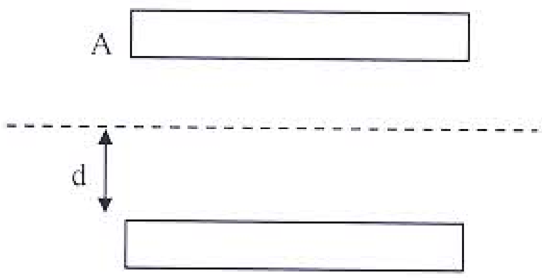


$$e = \frac{\varepsilon_0 \varepsilon_r A}{d}$$

ε_0 =Permittivity of free space ($8.85 \times 10^{-12}\ F/m$)

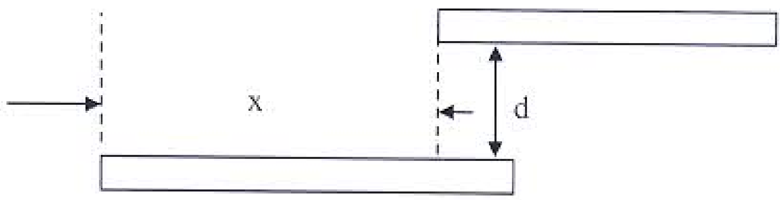
ε_r =Permittivity of relative medium

a) *Variable displacement Sensor*



$$e = \frac{\varepsilon_0 \varepsilon_r A}{d + x}$$

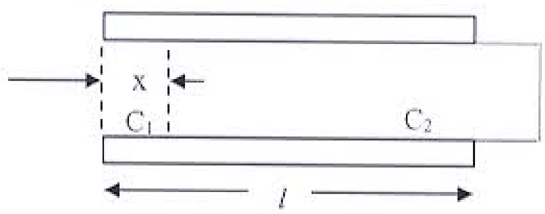
b) *Variable Area Sensor*



W=width of the plate

$$e = \frac{\varepsilon_0 \varepsilon_r (A - wx)}{d}$$

c) *Variable Di-electric type sensor*

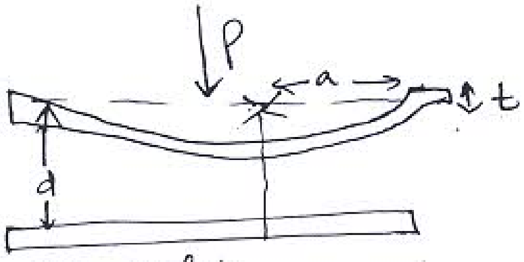


$$C = C_1 + C_2$$

$$C = \frac{\varepsilon_0 \varepsilon_{r1} wx}{d} + \frac{\varepsilon_0 \varepsilon_{r2} w(l-x)}{d}$$

$$\Rightarrow C = \frac{\varepsilon_0 w}{d}\left[\varepsilon_{r2} l - x(\varepsilon_{r2} - \varepsilon_{r1})\right]$$

d) *Capacitive Pressure Sensor*



$$y = \frac{3}{16} \cdot \frac{(1-\nu^2)}{Et^3}\left(a^2 - r^2\right)\rho$$

$$\frac{\Delta C}{C} = \frac{(1-\nu^2)a^4}{16Edt^3}$$

Where, P→Applied Pressure

ΔC→Change in Capacitance

a→Radius of the Diaphragm

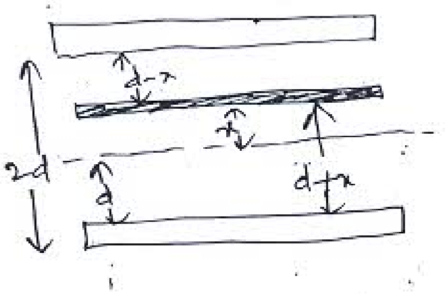
r→Radius in which we are applying pressure to generate displacement

t→Thickness of Diaphragm

E→Youngs modulus of Material

ν→Poisson's Ratio

C→Original Capacitance of capacitor before application of pressure *e) Three Plate Differential or, Push Pull Displacement Sensor*

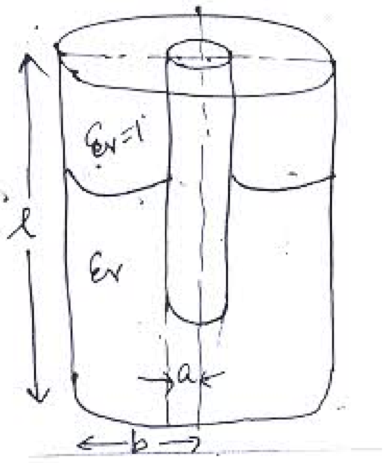


$$C_1 = \frac{\varepsilon_0 \varepsilon_r A}{d + x}$$

$$C_2 = \frac{\varepsilon_0 \varepsilon_r A}{d - x}$$

For avoiding non-linearity we have to incorporate this with a bridge circuit.

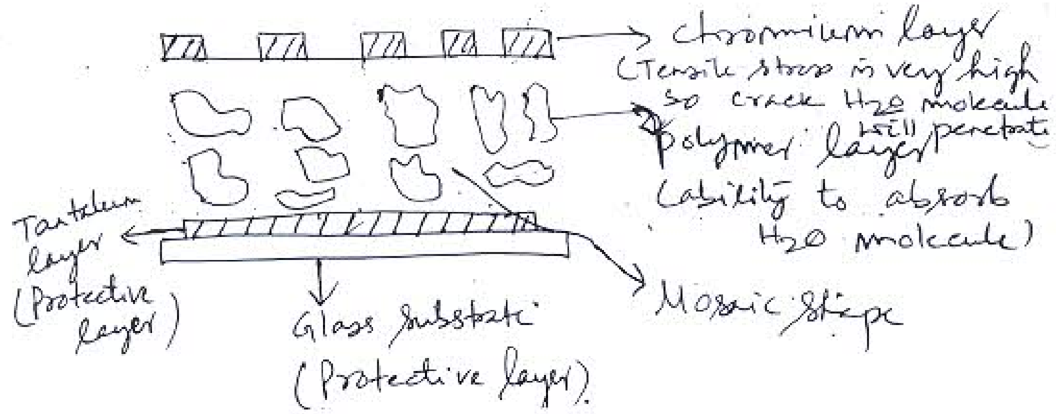
f) Capacitive level Sensor



$$\text{Capacitance / length} = \frac{2\pi\varepsilon_0\varepsilon_r}{\log_e\left(b/a\right)}$$

$$C = \frac{2\pi\varepsilon_0\varepsilon_r h}{\log_e\left(b/a\right)} + \frac{2\pi\varepsilon_0\varepsilon_r (l-h)}{\log_e\left(b/a\right)}$$

g) Thin Film Capacitance Humidity Sensor



→If all the H_20 molecule is not going to be absorbed by the polymer layer, then it won't go down.

$\Delta C \propto$ Relative Humidity

C = (375+1.7 RH) pF

RH→Relative Humidity

pF→Pico Farad

→The humidity sensor has an input range of 0 to 100% RH and a capacitance of 370 pico-Farad which RH is 0% and a linear humidity of 1.7pF per percent RH.

→The di-electric medium is characterised by a word called **loss tangent**.

$$\tan\delta = \frac{1}{\omega CR}, Q = R\sqrt{\frac{L}{C}}$$

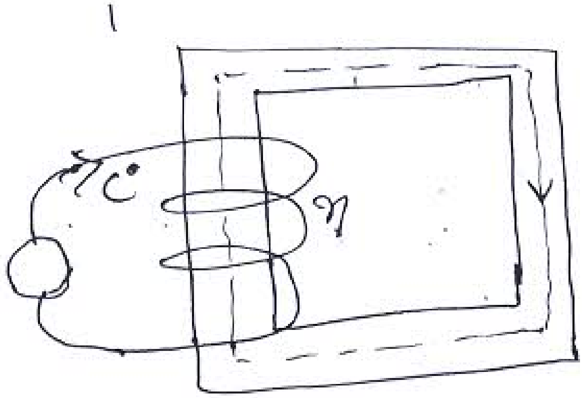
3. Inductive Sensing Element

Inductive sensing element

Variable Inductance/reluctance → LVDT

Variable Inductance/reluctance

Displacement Sensor



$$mmf = \phi \times R \quad (\text{R} \rightarrow \text{Reluctance})$$

$$\phi = \frac{ni}{R}, \; N = \frac{n^2 i}{R}$$

$$L = \frac{n^2 i}{R_i} = \frac{n^2}{R}, \quad \text{Inductance(L)} = \frac{Total\ flux}{Current}$$

$$R = \frac{l}{\mu\mu_0 A}$$

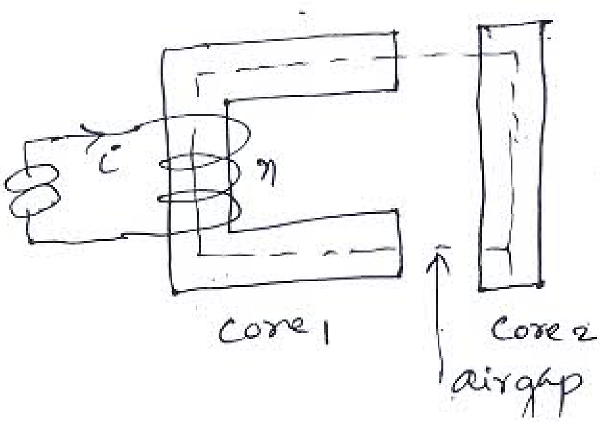
Where, l= Total length of flux path

A=Cross-sectional area of flux path

μ_0 =Permeability of Free space

$\mu_0 = 4\pi \times 10^{-7}\ Henery/m$

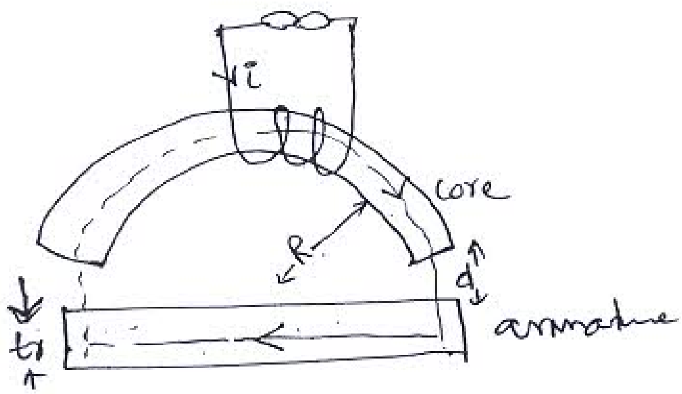
μ =Relative Permeability



$R_{total}=R_{core1}+R_{air\ gap}+R_{core2}$

Variable inductance/reluctance displacement Sensor

- Variable reluctance displacement Sensor
- Push pull or, Differential displacement sensor



$R_{total} = R_{core} + R_{air\ gap} + R_{armature}$

$$R_{core} = \frac{\pi R}{\mu_0 \mu_c \pi r^2} = \frac{R}{\mu_0 \mu_c r^2}$$

$$R_{air\ gap} = \frac{2d}{\mu_0 \pi r^2}$$

$$R_{armature} = \frac{2R}{\mu_0 \mu_A 2 r t_r} = \frac{R}{\mu_0 \mu_A r t_r}$$

$$R_{total} = \frac{R}{\mu_0 \mu_c r^2} + \frac{2d}{\mu_0 \pi r^2} + \frac{R}{\mu_0 \mu_A r t_r}$$

$$= \frac{R}{\mu_0 r}\left[\frac{1}{\mu_c r} + \frac{1}{\mu_A t_r}\right] + \frac{2d}{\mu_0 \pi r^2}$$

$$R_T = R_0 + kd$$

$$\Rightarrow R_0 = \frac{R}{\mu_0 r}\left[\frac{1}{\mu_c r} + \frac{1}{\mu_A t_r}\right]$$

$$k = \frac{2}{\mu_0 \pi r^2}$$

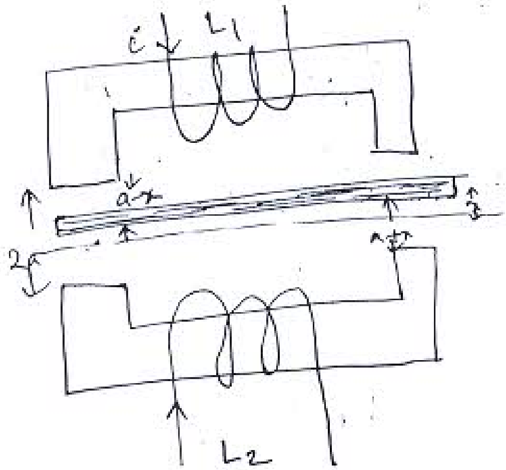
[k value depends upon the structure of the material]

$$L_T = \frac{n^2}{R_T} = \frac{n^2}{R_0 + k.d} = \frac{n^2 / R_0}{R_0/R_0 + k.d/R_0} = \frac{L_0}{1 + \alpha d}$$

$$\left[\therefore L_0 = n^2/R_0 \ \ and \ \ \alpha = k/R_0\right]$$

L_0→Inductance of sensor at zero air gap, k & α depends upon the structure of the sensor.

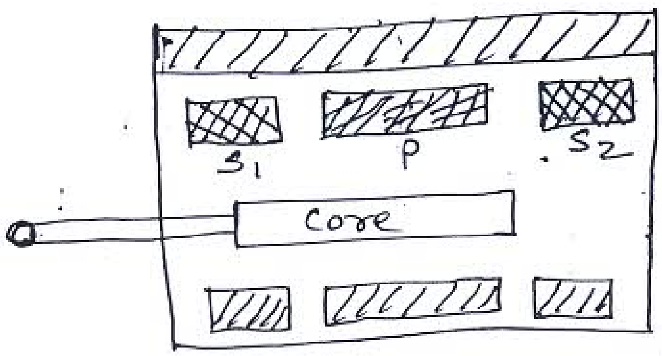
Push pull or, Differential displacement sensor



$$L_1 = \frac{L_0}{1+\alpha(a-x)}, \quad L_2 = \frac{L_0}{1+\alpha(a+x)}$$

→In order to avoid non-linearity, we design this type of sensor. We have to incorporate this with bridge circuit.

LVDT (Linear Variable Differential Transformer)



→ The soft iron core makes a flux linkage between the primary winding and the two secondary winding.

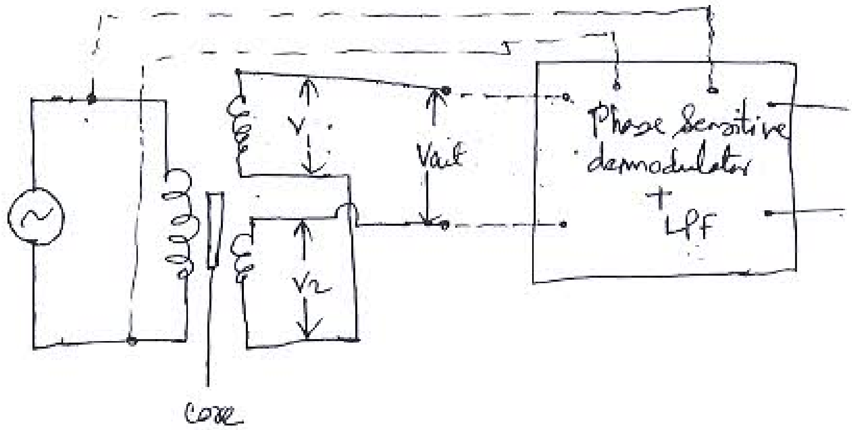
→The two secondary windings are identically placed either side of the primary windings.

→Number of turns of two secondary windings are equal.

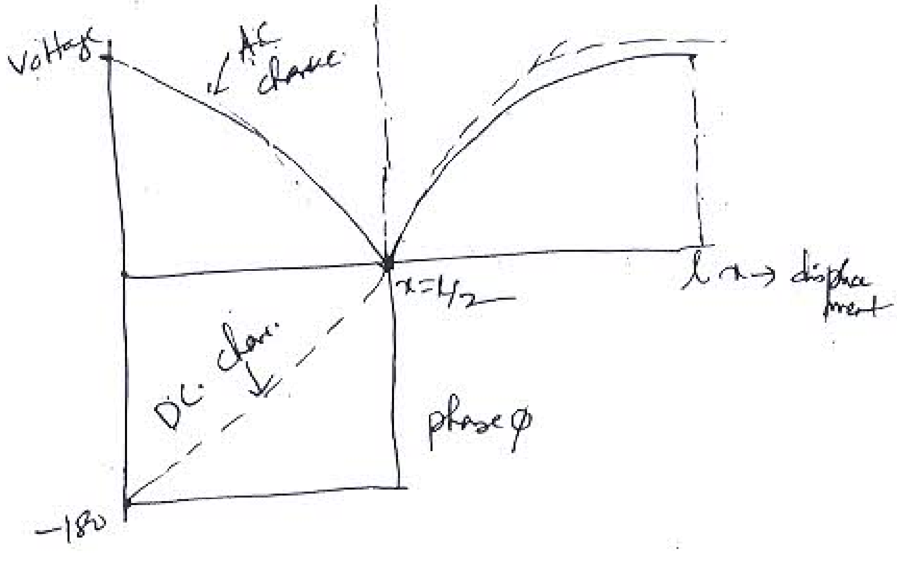
→The core is made up of high permeability (unwanted fizzer component) Nickel iron which is having low harmonics, low null voltages and is of high sensitivity.

→The core is slotted longitudinally to reduce the eddy current loss. (Current due to the back e.m.f.)

LVDT Electrical equivalent Circuit:



→The two secondary coils are connected in series so as to get one output.



→Phase sensitive demodulator- to produce positive voltage and negative voltage.

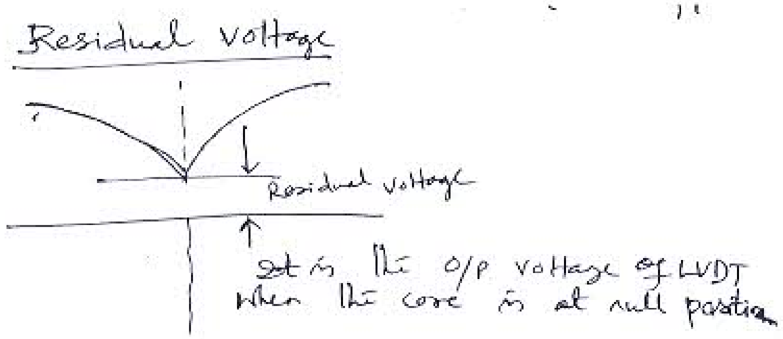
Note

Low Pass Filter (LPF)

→The Band width B.W. of LPF is less than the sampling frequency to filter out the carrier signal and more than maximum frequency not to filter out the measurement signal.

→Frequency of AC applied to primary winding is in the range of 50Hz-20KHz. The Primary winding is excited by AC source produce an alternating magnetic field which includes A.C voltage in the two secondary winding.

→To represent the output from the two secondary's in to a single voltage, the two secondaries are connected in series opposition.



Reason for Occurrence of Residual Voltage in LVDT

- This may be due to an account of presence of harmonics in the input supply voltage and also the harmonics present or produced in the output voltage.
- The Residual voltage may be due to either an incomplete magnetic or, electrical unbalance.

4. *Electromagnetic Sensing Element*

→Eg: - Velocity Sensor

Variable Reluctance Tacho generator for measurement of angular velocity

→These sensors are based on Faraday's laws for measurement of linear and angular velocity.

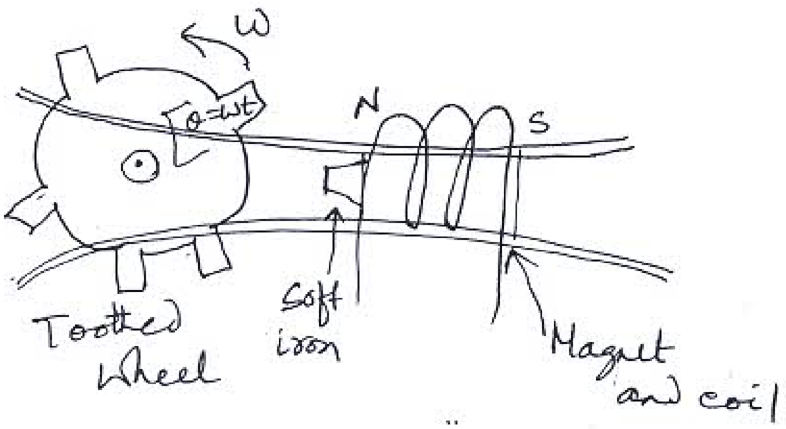
→The induced emf in a conductor depends on the rate of change of flux linking with conductor.

$$E = -\frac{dN}{dt} \quad N \rightarrow Total\ \ flux$$

Construction:

→It consists of a toothed wheel of ferro-magnetic material and a coil wounded on a permanent magnet extended by a soft iron pole piece.

→When the tooth is close to the pole piece reluctance is minimum but the reluctance increment with the tooth moves away from the pole piece.



→Reluctance is maximum when the gap is adjustant to the pole piece and falls again as the next tooth approaches to pole piece.

The total flux linked by a core of 'n' turn coil is

$$N(\theta) = a + b\cos m\theta$$

Where, a= mean flux

b= amplitude

m= no. of teeth

$$E = -\frac{dN}{dt} = -\frac{dN}{d\theta} \times \frac{d\theta}{dt}$$

$$= bm\sin(m\theta)\frac{d\theta}{dt}$$

$$= bm\sin(m\theta)\omega_r$$

$$E = bm\omega_r \sin(m\omega t) \quad [\because \theta = \omega t]$$

$$\hat{E} = bm\omega_r \quad f = \frac{m\omega}{2\pi}$$