§ Measurement of displacement:

Using
- → potentiometer
- → LVDT
- → optical Encoder.

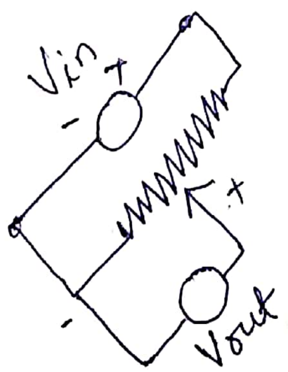
Potentiometer:

✓ A potentiometer is a three-terminal resistor with a sliding or rotating contact that forms an adjustable voltage divider. If only two terminal are used, one end and the wiper, it act as a variable resistor or rheostat.

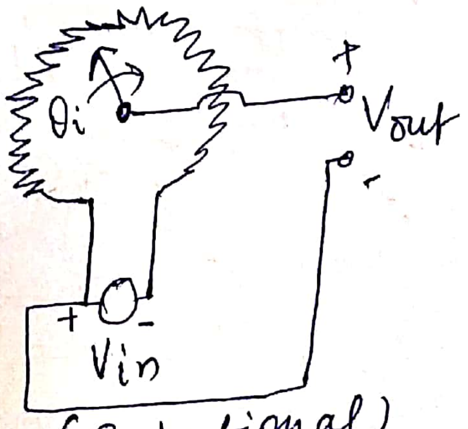
✓ Generally use for Audio control, TV brightness control, Motion control of motor (angle, speed, displacement)

✓ Potentiometers are widely used as a part of displacement transducer.

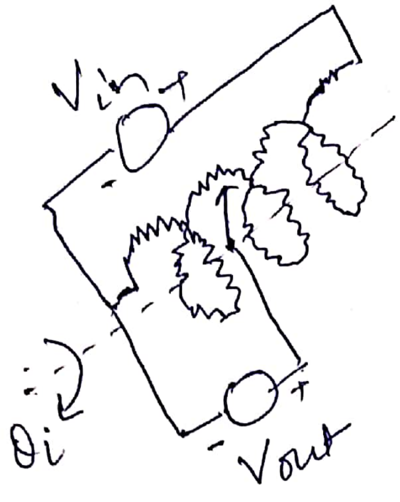
✓ Basically a resistance potentiometer, or simply a POT. (a resistive potentiometer used for the purpose of voltage division called POT).



(Linear)

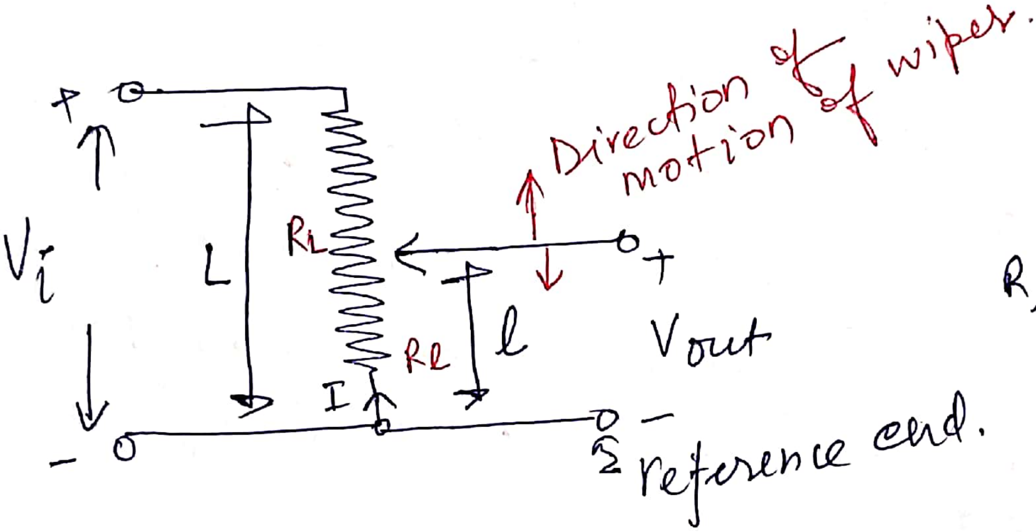


(Rotational)



(Helical)

✓ The POT is passive transducer since it require external power source for its operation.



$$\rho_L = \left(\frac{R}{L}\right)$$

$$R_l = \rho_L \cdot l$$

$$= \left(\frac{R_L}{L}\right) l$$

$$V_{in} = i R_L \quad \text{—} \; (I)$$

$$V_{out} = i R_l \quad \text{—} \; (II)$$

$$= i \left(\frac{R_L}{L}\right) l$$

II/I

$$\boxed{\frac{V_{out}}{V_{in}} = l/L}$$

$$\boxed{V_{out} = \left(\frac{l}{L}\right) V_{in}} \quad \text{—} \; (III)$$

$$\boxed{V_{out} = V_{in} \left(\theta_i / \theta_t\right)}$$

for rotatory

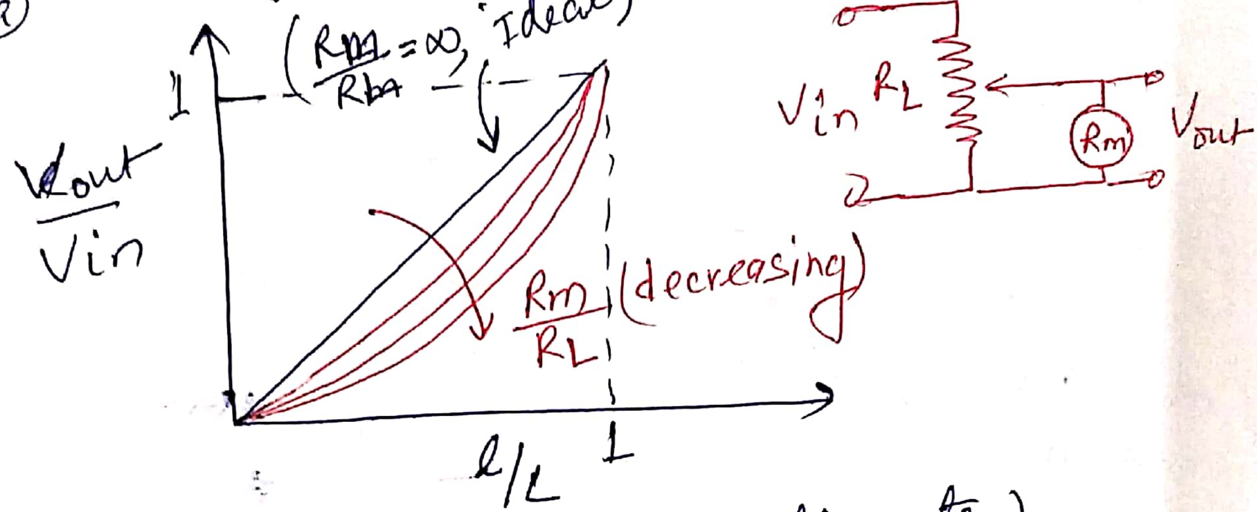
θ_i – input angular displacement (degree)

θ_t – Total travel of the wiper in degree

Scanned by CamScanner

Characteristics of potentiometer ;

Under ideal circumstances, the o/p voltage varies linearly with displacement as shown in fig (a)

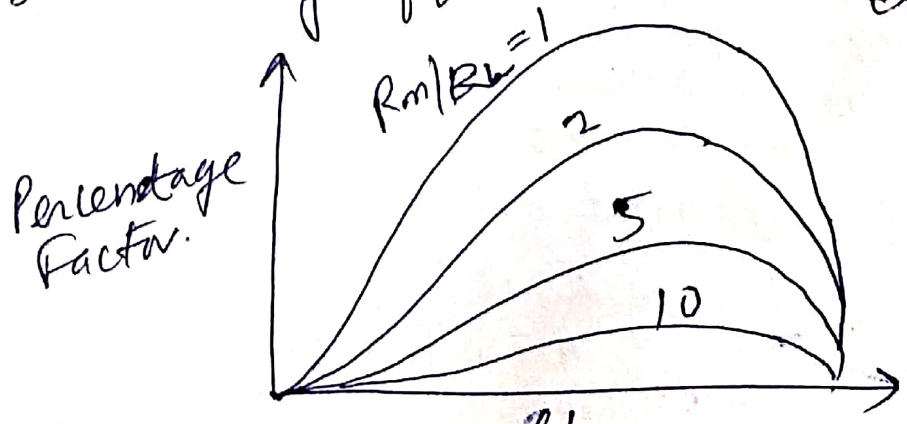


(Characteristics of potentiometer)

✓ In order to keep linearity the value of R_m/R_L should be as large as possible.

✓ The output of the POT are connected to a device whose impedance is finite (in practice) which form a load for the POT. Thus at the o/p indicated voltage is less than that given by $V_{out} = \left(\frac{l}{L}\right) V_{in}$, which is refered as loading effect.

error = (o/p voltage under load) − (o/p voltage under no load)



(variation of error due to loading effect)

✓ if R_L is made small, linearity improves and the sensitivity will decrease.

Advantage & disadvantage of potentiometer -

Adv. -

✓ They are inexpensive.
✓ Simple to operate.
✓ Useful for the measurement of large amplitude of displacement.
✓ o/p is sufficient, so no amplification is required.
✓ Having hig resolution.

DisAdv -

✓ Require large force to move their sliding contact.
✓ Contact can be contaminated.

Material used for potentiometer - May be classified as.

→ 1 - **Wire wound potentiometer** :-
These are platinum, nickel chromium, nickel coper or some other precious resistance elements { temp coefficient of order 20×10^{-6} /°c
resolution = 0.025 to 0.05 mm

→ 2 - **Non-wire potentiometer** :- called continous potentiometer.
Material used for this is:
cement, Hot moulded carbon, carbon film, Thin metal film,

Note - cement is very useful for A.C. Applications

LVDT (Linear Variable Differential Transformer)

This is an inductive motion transducers are replacing potentiometers as they have superior reliability. Two important inductive motion transducers are

- LVDT (Linear Variable differential Transducers)
- RVDT (Rotatory Variable differential Transducers)

Principle of operation

Variable inductance transducers are based on Faraday's law of Induction in a coil. The law specifies that the induced voltage is equal to the rate at which the magnetic flux through the ckt. changes.

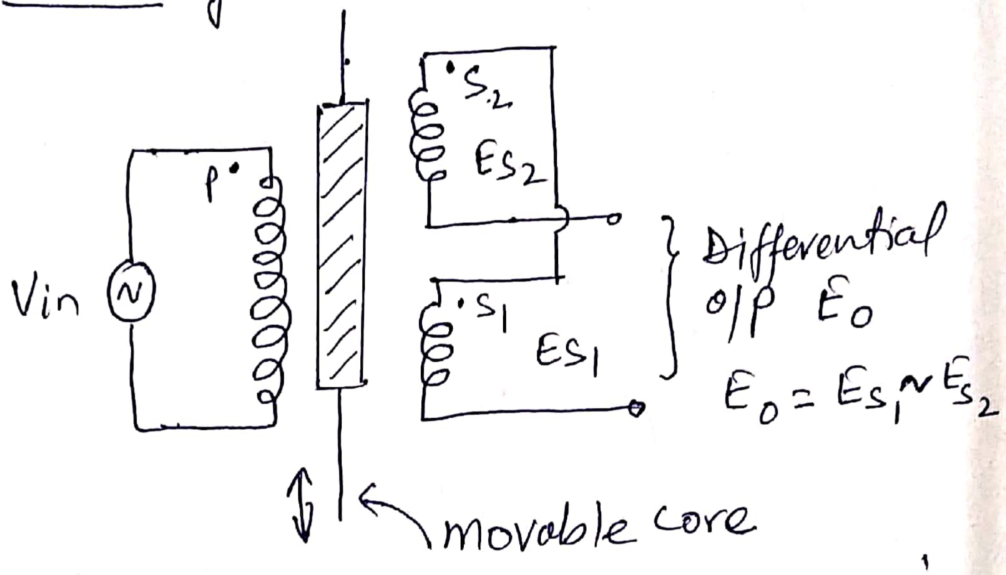
The induced voltage is given by $V = N\frac{d\phi}{dt}$.

$\phi = B \cdot A$, B is magnetic field, A is area of coil.

Application

- LVDT are mostly used transducer to translate linear displacement into electrical signal.
- LVDT find a number of application in both measurement & control systems.
- High resolution, High accuracy, Good reliability, and stability make them an ideal device for application involving short displacement measurement.

Construction & working -



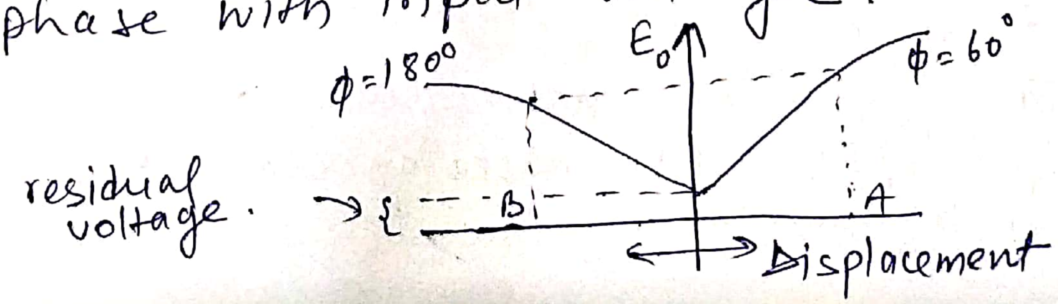
{ S_1 & S_2 are secondary winding connected in series.
P - Primary ~~W~~inding.

Position of movable core determine the flux linkage between the primary and each of two secondary windings.

Let E_{S1} = output of secondary S_1
E_{S2} = ouput of secondary S_2

then, $\boxed{E_0 = E_{S_1} - E_{S_2}}$

✓ In bothe the direction we will get differential voltage but in one direction it will be in phase to input voltage and in other direction it will be out of phase with input voltage.



✓ Linear range = 2 × Full Scale deflection

Slope of the curve = $\frac{|E_0|}{\text{Core displacement from centre}}$.

$$m = \frac{|V_0|}{x}$$

LVDT equation is characterised by $|V_0| = mx$

✓ Sensitivity of LVDT = $\frac{\text{output voltage}}{\text{Displacement}}$.

✓ Sensitivity of measurement

= Amplification factor × Sensitivity of LVDT.

Advantage:

1- High range (1.25 mm to 250 mm)
2- Give high o/p (mostly no need of amplifire)
3- Posses high sensitivity (up to 40 V/mm)
4. Repeatability is excellence (because low hysterisis)
5. Consume less power (less than 1 W)
6. Less friction, so less noise (absence of sliding contact)
7. Tolerate high degree of sock & Vibration.
8. ~~Cap~~ Can operate at −265°c to 600°C

Disadvantage:

1- Sensitive to stray magnetic field.
2- Displacement must be large for appreciable o/p.
3- Dynamic response is limitted ~~to~~ due to mass of core.

Optical Encoder :—

Encoder
- Linear
  - Absolute
  - Increamental
- Rotatory
  - Absolute
  - Increamental

Technology
- Magnetic
- Optical
- Inductive
- Capacitive
- Laser.

Encoder provides an information about the position information.

→ An Absolute Encoder provides specific location information

→ Increamental Encoder provide distance travelled and direction information. Machine needs to be referenced or homed.

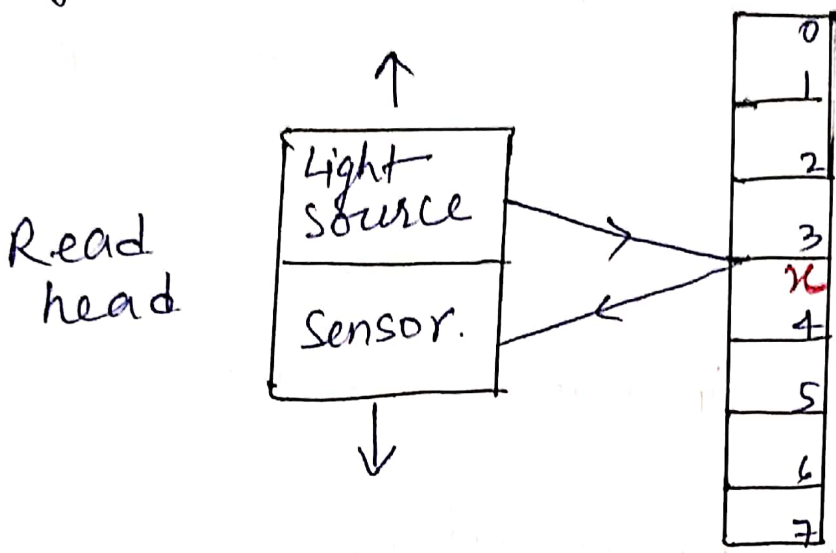
<u>Optical encoder</u> is composed of the "read head" and the scale.

The read head travel with the axis while the scale is stationary (In case linear encoder)

The scale can be made of either glass or metal.

In the encoder to the left, the metal scale has reflective marking.

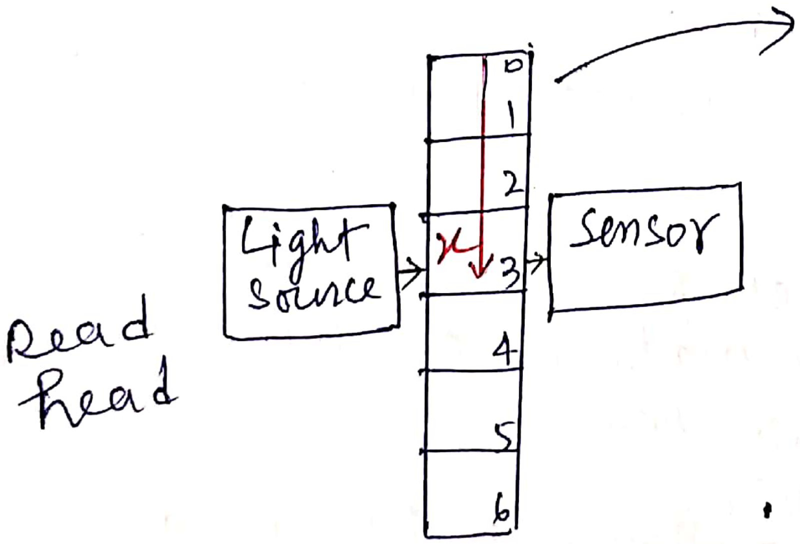
The light from the source in the read head, reflects on the marking and are picked up by the sensor.



metal Scale with reflective marking.

X (Position) can be read on the scale Through Sensor

<u>Note</u> In similar way Glass scale can be used.

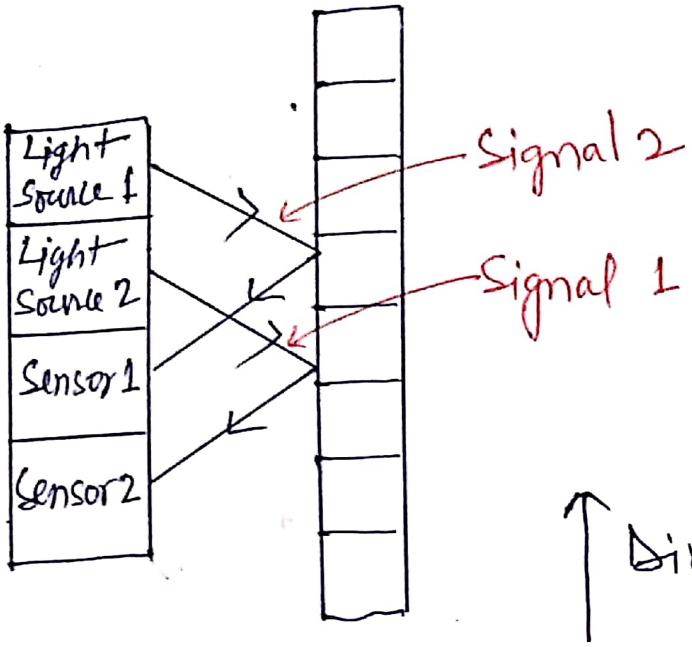


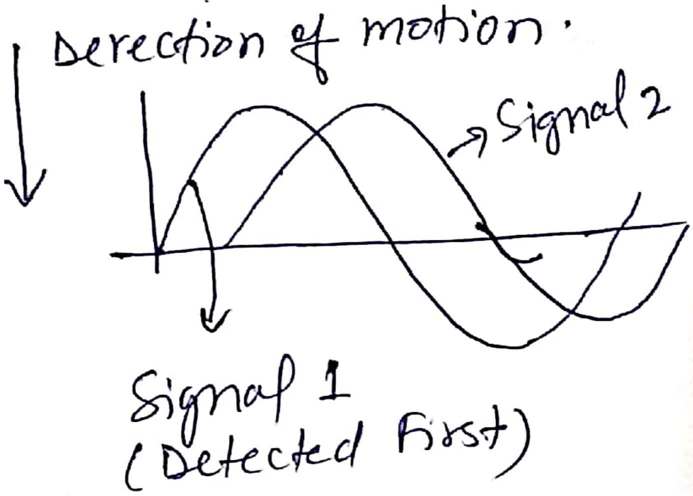
- Glass scale
- A read head travels, light passes through the glass to the sensor. Some area are blackend to prevent the light
- X (position) can be read on the scale through sensor.

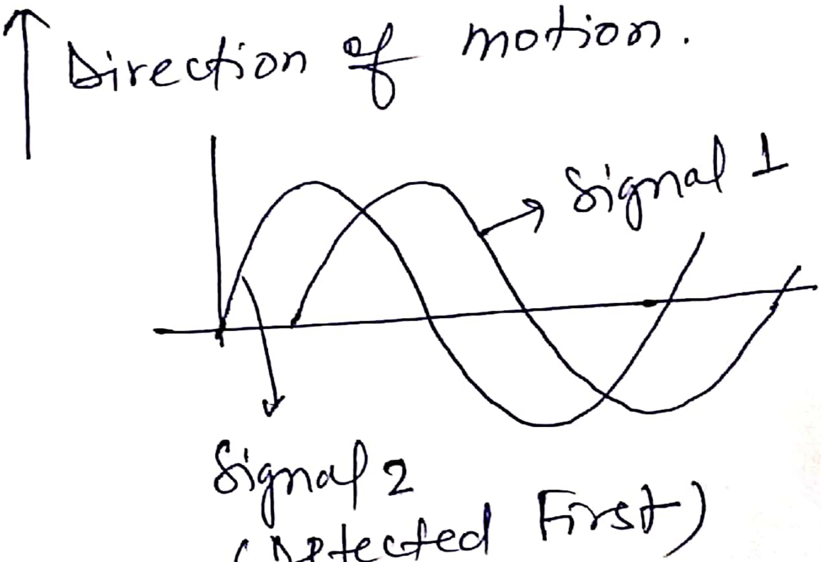
(Linear & absolute optical encoder)

<u>Note</u> An additional light source and sensor can be added to determine the direction.

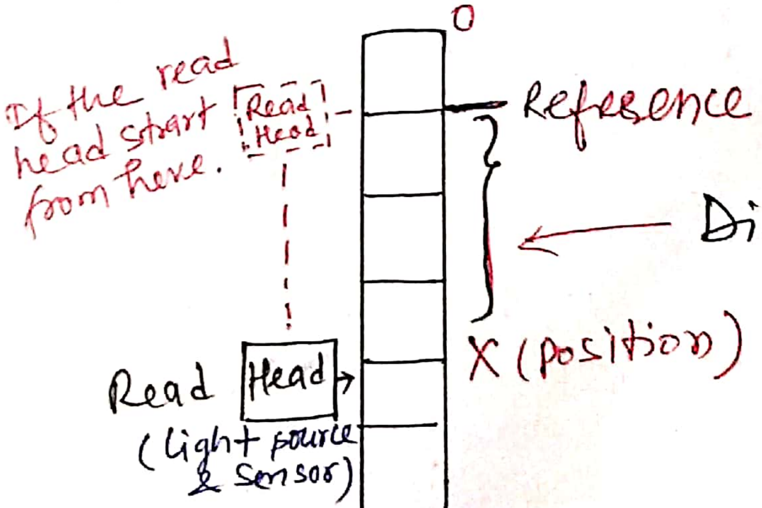
Scanned by CamScanner







Note: For the increamental Encoder we have to assume the refrence point (It may be home)



(optical Linear & increamental Encoder)

optical rotatory encoder.

§ Measurement of Force Using strain gauge.

Strain Gauge:

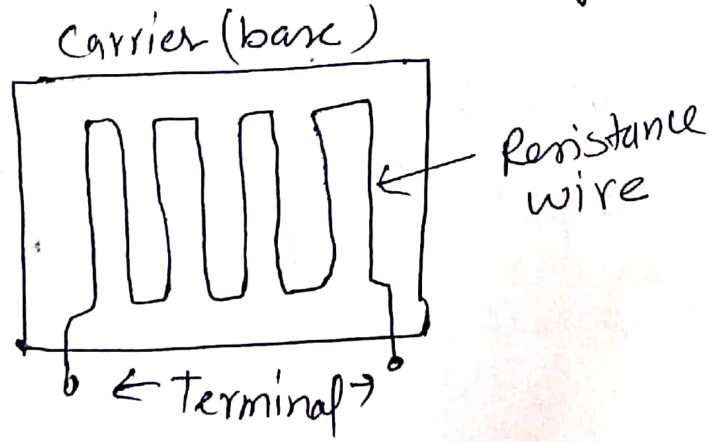
When a metal conductor is streched or compresed, its resistance changes on account of the fact that both length and diameter of the conductor change. The value of resistivity of conductor also changes.

When it is strained its property is called piezo-resistance. Therefore, resistance strain gauge are also known as piezo-resitive gauses.

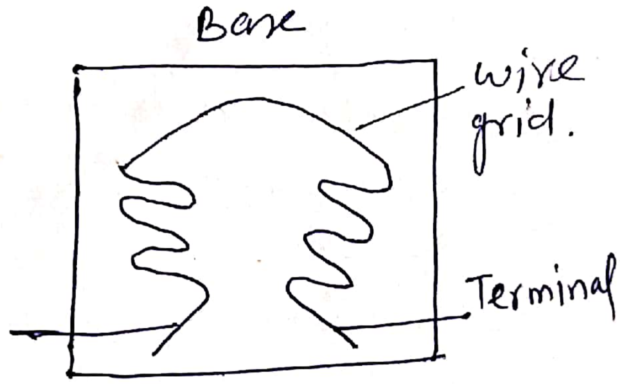
Type of strain Gauge -

1 - Wire-wound strain gauge < Bonded / Unbonded.
2 - Foil type strain gauge
3 - Semiconductor strain gauge
4 - Capacitive strain gauge.

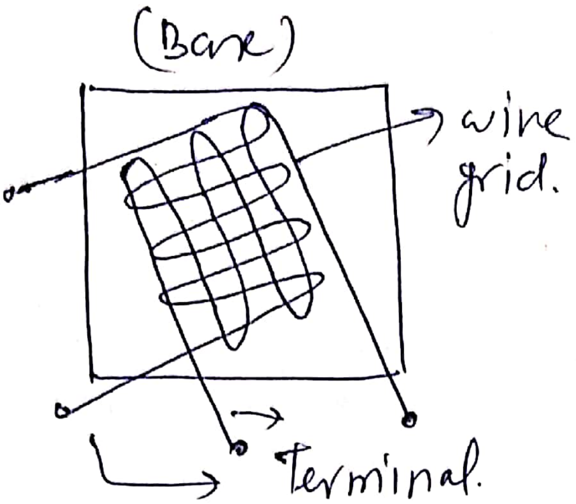
① Note Wire strain Gauge -
Bonded strain gauge, wire wound and cemented or a resilient insulating support, usually a wafer unit.



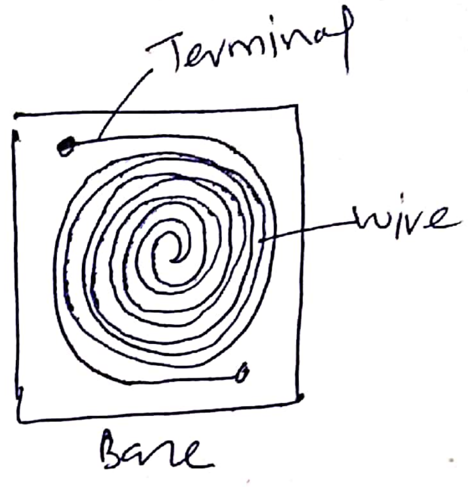
(Linear Strain Gauge)
(a)



(Torque Gauge)
(b)



(Ressetter) (C)

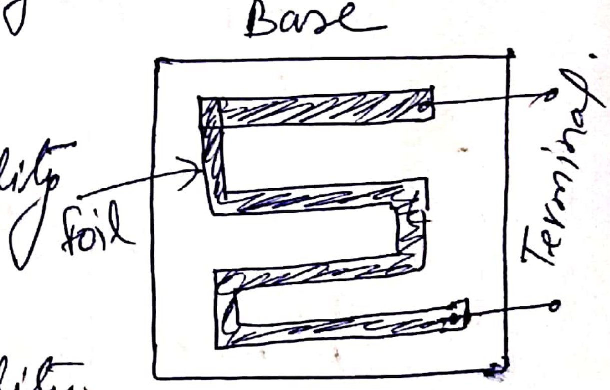


(Helical gauge)
(d).

(Resistance wire strain gauge)

② Foil strain gauge.

In these gauses the strain is sensed with the help of metal foil. Foil gauge have a much greater dissipation capacity as compared with wire wound gauge on account of their greater surface area for the same volume. Due to this reason they can be employed for higher operating temperature range.



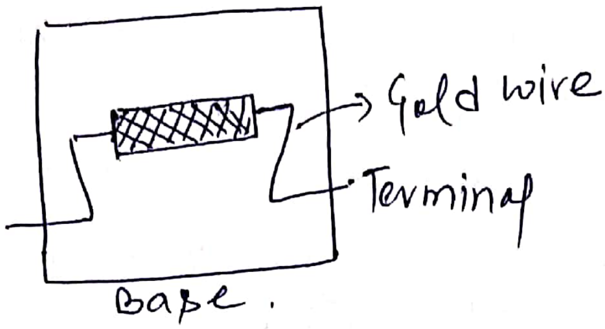
Advantage.

- excellent strain reproducibility
- low hysteresis and creep effect.
- Excellent mechanical stability.
- longer life
- Fabrication is easy.

Use: stress analysis & transducers.

(17)

③ Semiconductor strain Gauge -



(Semiconductor strain Gauge)

The resistance of semiconductors changes with change in applied strain. The semiconductor strain gauge depend on their action upon piezo-resistive effect ie change in the value of the resistance due to change in resistivity.

*(Unlike in the case of metallic gauge where the change in resistance is mainly due to change in dimensions (L, and A) when strained).

Advantage:

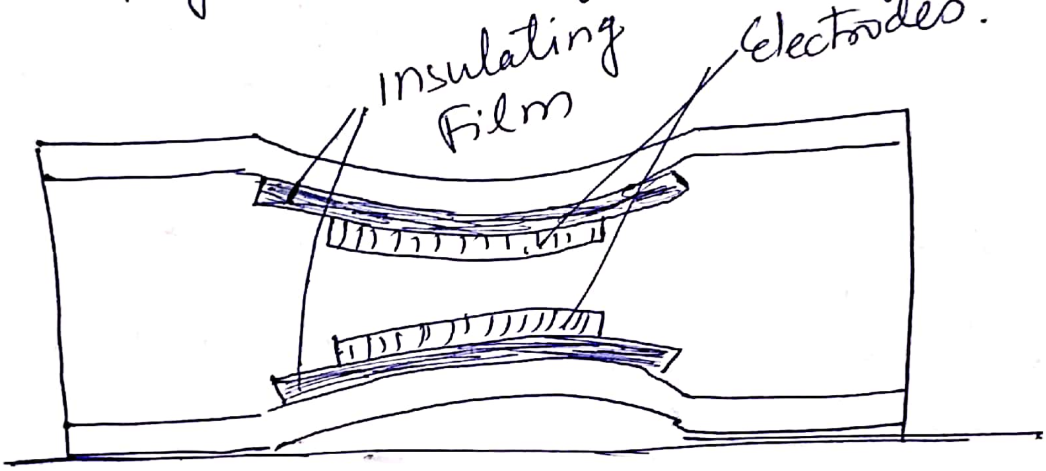
- ✓ Having high gauge factor
- ✓ They are chemically inert and have low cross-sensitivity.
- ✓ Almost free from hysterisis & creep effect.
- ✓ Fatigue life is in excess (10×10^5 operation)
- ✓ Range is small (0.7 to 7 mm) and used for local strains.

Disadvantage:-

- ✓ Very sensitive to change in temperature.
- ✓ linearity is poor.

(4) Capacitive strain gauge:-

- Use the principle of variation of capacitance with variation in distance between electrodes. The electrodes are flexible metal strips of about 0.1 mm thickness. The strain to be measure is applied to top plate. This changes the distance between curved electrodes resulting in change of capacitance.
- Use a polyamide film of insulating material electrodes.



(Capacitive Strain Gauge)

Application of strain Gauge –

* Amount of stress on plane wings, bridge, railway track etc can be measure to take preventive action.

Property of Gauge Material:

High sensitivity, High gauge factor, high mechanical strength, High electrical stability, Low temperature sensitivity, low hysterisis, low thermal emf when joined with other material.

18

Theory of Strain Gauge:

- when a strain gauge is subjected to tension (ie +ve strain) its length increases while its ~~length and~~ crossectional area decreases.

$$\boxed{R = \rho L/A} \quad -(1)$$

R changes when → { L changes & A changes. if ρ change then R will also change this property is known as piezoresistive effect.

- Strain gauge are most commonly used in wheatstone bridge circuit to measure the change in resistance of grid of wire.

$$\text{Gauge factor} = \frac{\text{Per unit change in resistance}}{\text{Per unit change in length.}}$$

$$\boxed{G_f = \frac{\Delta R/R}{\Delta L/L}} \quad -(II)$$

ΔR - Change in resistance
ΔL - Change in length.

In order to find ΔR, depends upon the material physical quantity.
differentiate wrt stress (S)

$$\frac{dR}{ds} = \frac{\rho}{A}\frac{\partial L}{\partial s} - \frac{\rho L}{A^2}\frac{\partial A}{\partial s} + \frac{L}{A}\frac{\partial \rho}{\partial s} \quad (II)$$

Scanned by CamScanner

Divide the eqn (III) by $R = \rho L/A$,
we get $$\frac{1}{R}\frac{dR}{ds} = \frac{1}{L}\frac{\partial L}{\partial s} - \frac{1}{A}\frac{\partial A}{\partial s} + \frac{1}{\rho}\frac{\partial \rho}{\partial s} \quad \text{— (IV)}$$

$$A = \frac{\pi}{4}D^2, \quad \frac{\partial A}{\partial s} = 2\frac{\pi}{4} \cdot D\frac{\partial D}{\partial s} \quad \text{— (V)}$$

$$\Rightarrow \frac{1}{A}\frac{\partial A}{\partial s} = \frac{(2\pi/4)D}{(\pi/4)D^2}\frac{\partial D}{\partial s} = \frac{2}{D}\frac{\partial D}{\partial s} \quad \text{— (VI)}$$

eqn (IV) can be written as:

$$\frac{1}{R}\frac{dR}{ds} = \frac{1}{L}\frac{\partial L}{\partial s} - \frac{2}{D}\frac{\partial D}{\partial s} + \frac{1}{\rho}\frac{\partial \rho}{\partial s} \quad \text{— (VII)}$$

Now
Poissons ratio $\nu = \frac{\text{Lateral strain}}{\text{Longitudinal strain}} = \frac{\partial D/D}{\partial L/L}$ — (VIII)

or, $$\frac{\partial D}{D} = -\nu\frac{\partial L}{L}$$

$$\therefore \frac{1}{R}\frac{dR}{ds} = \frac{1}{L}\frac{\partial L}{\partial s} + \nu\frac{2}{L}\frac{\partial L}{\partial s} + \frac{1}{\rho}\frac{\partial \rho}{\partial s} \quad \text{— (IX)}$$

For small variations, the above relationship can be written as,

$$\frac{\Delta R}{R} = \frac{\Delta L}{L} + 2\nu\frac{\Delta L}{L} + \frac{\Delta \rho}{\rho} \quad \text{— (X)}$$

We know, $$G_f = \frac{(\Delta R/R)}{(\Delta L/L)}$$

$$\therefore \quad G_f = \frac{\Delta R/R}{\Delta L/L} = 1 + 2\nu + \frac{\Delta\rho/\rho}{\epsilon}$$

$$\boxed{G_f = 1 + 2\nu + \frac{\Delta\rho/\rho}{\epsilon}} \quad -(81)$$

where, ϵ = strain = $\frac{\Delta L}{L}$

$$G_f = \underbrace{1}_{\substack{\text{Resistance change} \\ \text{due to change} \\ \text{of length.}}} + \underbrace{2\nu}_{\substack{\text{Resistance} \\ \text{Change due} \\ \text{to change in} \\ \text{area}}} + \underbrace{\frac{\Delta\rho/\rho}{\epsilon}}_{\substack{\text{Resistan change} \\ \text{due to piezo-} \\ \text{resistive effect.}}}$$

$$\boxed{G_f = 1 + 2\nu}$$

valid only when change in resistance due to change in resistivity is negligible i.e. Piezoresistive effect is negligible.

—o—

Measurement of pressure

Using
- → Piezoelectric sensor
- → LVDT based diaphragm.

Piezoelectric Sensor :

"A piezoelectric material" is one in which an electric potential appears across certain surface of a crystal if the dimension of the crystal changed by the application of mechanical force.

This potential is produced by displacement of external charges. The effect is reversible, i.e., conversely, if a varying potential is applied to the proper axis of the crystal, it will change the dimensions of the crystal thereby deforming it. This effect is known as piezoelectric effect.

Some time it is also called electroresistive element.

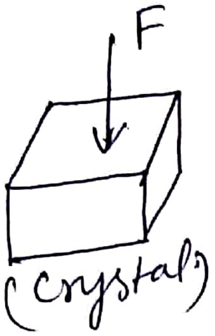
There are two main group of piezoelectric crystal:

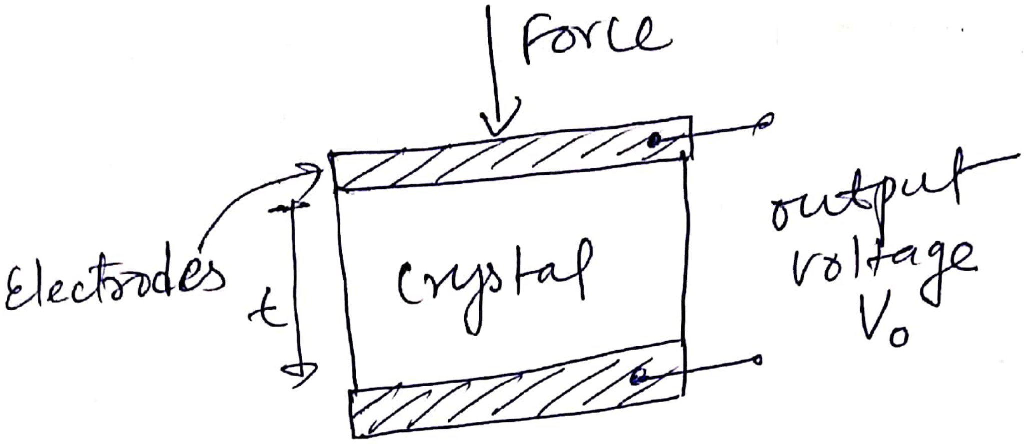
1- Natural Crystal: eg. quartz & tourmaline

2- Synthetic Crystals: eg. Rochelle salt, Lithium sulphate, dipotassium tartrate etc.

Desirable property are
Sensitivity, stability, High output, insensitivity to temp and humidity, ability to form into most desirable shape.

working.





The polarity of induced charge will depends on the direction of applied Force

$$Q = \underbrace{d}_{\text{charge sensitivity}} \times \underbrace{F}_{\text{applied Force}} \quad \text{— (I)}$$

$$\underbrace{g}_{\text{voltage sensitivity of crystal}} = \frac{V_o}{tP} = \frac{V_o/t}{P} \quad \text{— (II)}$$

but V_o/t = Electric fied strength; V/m.

Let $\epsilon = V_o/t$ = Electric field.

$$\therefore \boxed{g = \frac{\text{Electric field}}{\text{Stress}} = \frac{\epsilon}{P}} \quad Vm/N.$$

$$\boxed{V_o = \frac{gtF}{A} = gtP}$$

F = Force in Newton.
A = Area of crystal, m^2
P = F/A, N/m^2.

Advantage:

✓ High frequency, small size, High output, rugged construction, Negligible phase shift.

Disadvantage:

✓ temperature affect.
✓ can not measure static condition.

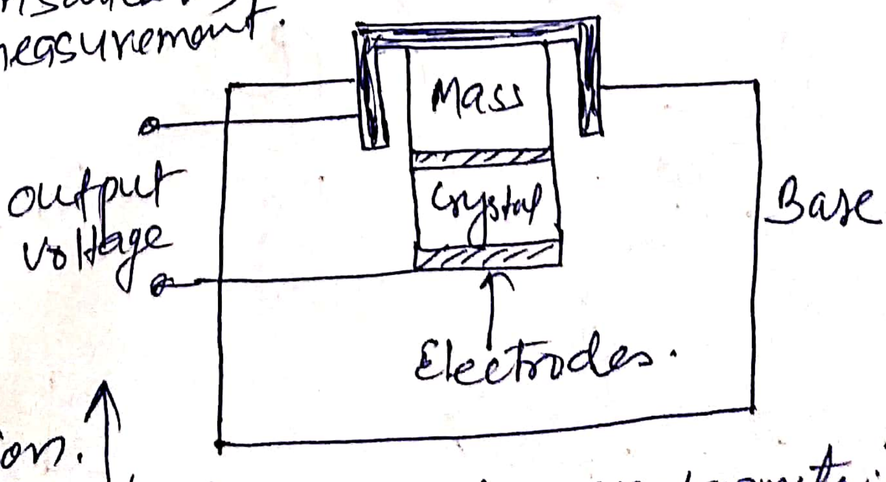
Application:

1- Accelerometer
2- Pressure cell
3- Force cell
4- Ceramic microphones
5- phonograph pick-up
6- Cartridges
7- Industrial cleanging apparatus.
8- Under water detection systems

Piezoelectric Accelerometer -

Commonly used transducers for acceleration measurement.

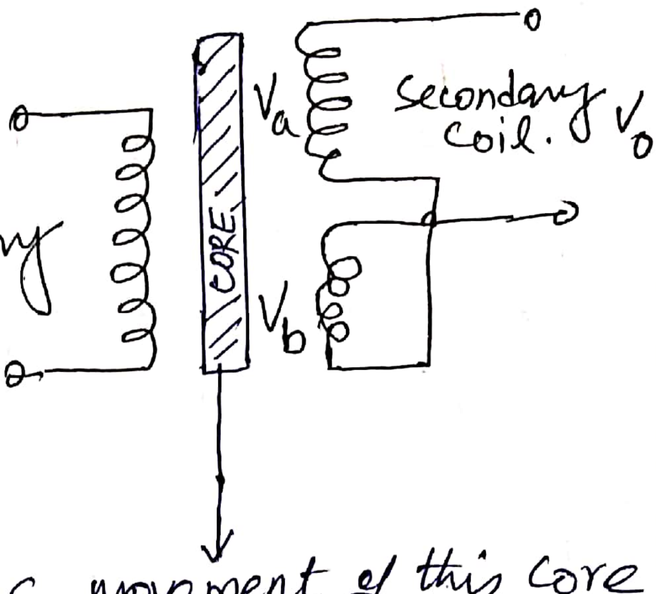
- High sensitivity
- small size.
- High O/P
- Sensitive to temp.
- Hysterisis error.



acceleration.

(Piezoelectric accelerometer)

Pressure using LVDT based on diaphragm



* The fluid whose pressure is to be measured is made to press the pressure sensitive device

Movement of this core can be done using primary pressure sensitive devices.

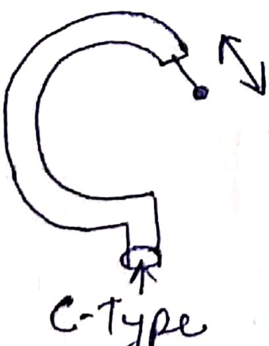
Pressure sensitive primary device:

The commonly used pressure sensitive devices are as below:

1- Bourdon tubes
- c type
- spiral
- Twisted tube
- Helical.

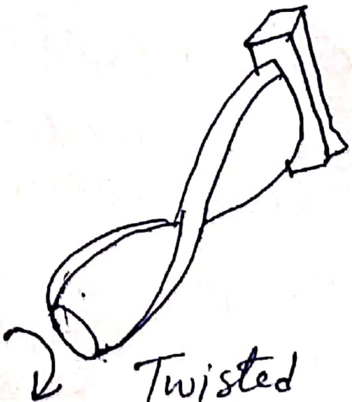
2- Bellows

3- Diaphragms

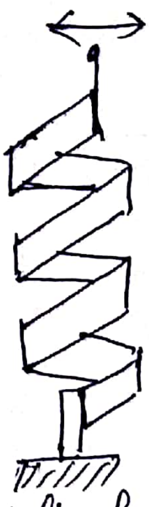


C-Type

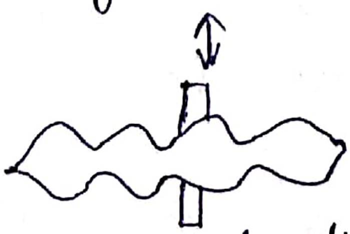
spiral



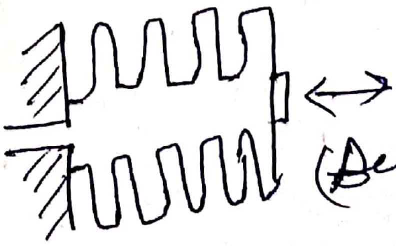
Twisted Tube



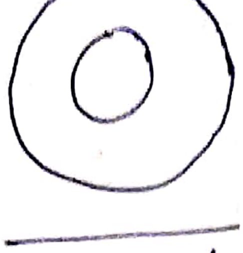
Helical



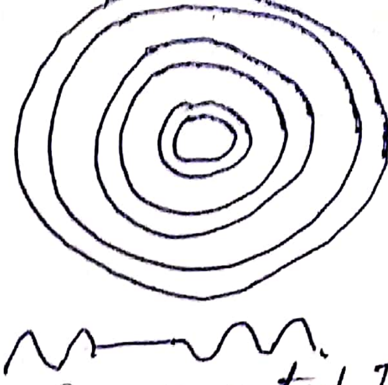
capsule diaphragms



(Bellows)



Flat Type Diaphragm



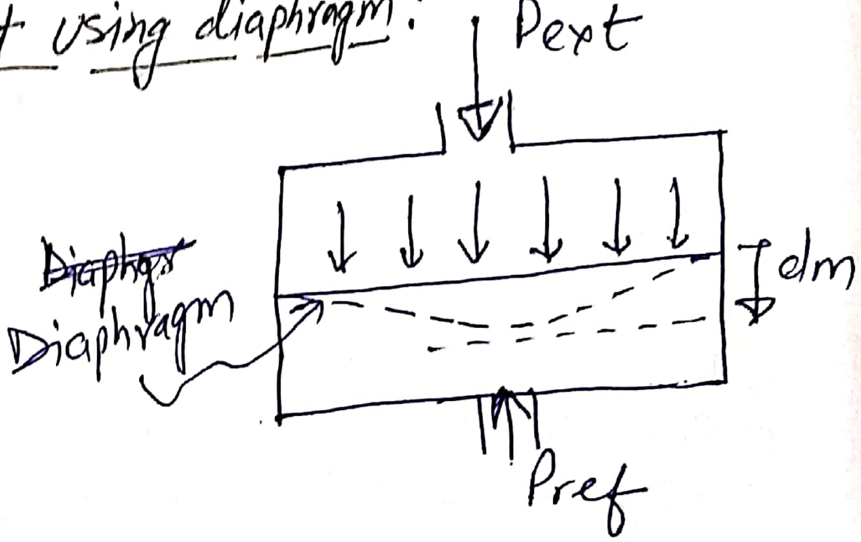
Corrugated Type diaphgram

(Diaphragm)

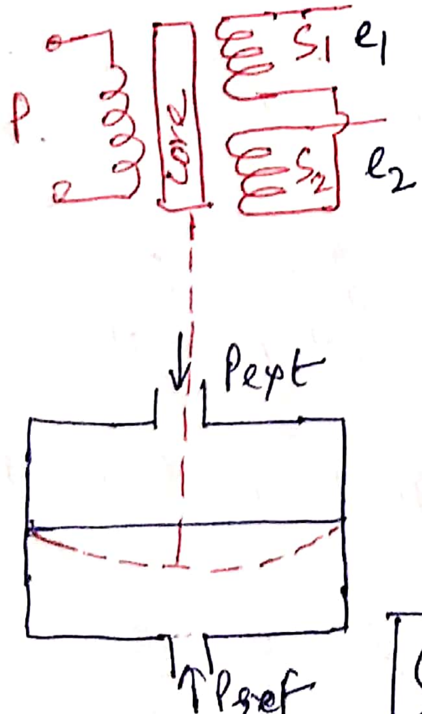
Pressure measurement using diaphragm:

$P_{ext} - P_{ref} = P$

$\boxed{P \propto dm}$



Pressure (P) $\propto$ dm (deflection of diaphragm)

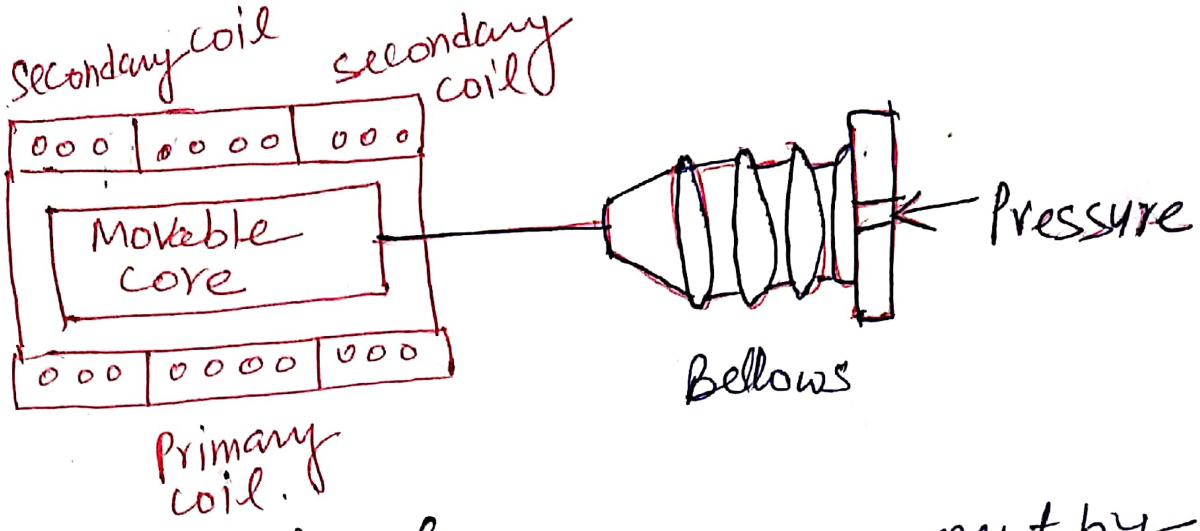


Deflection of diaphragm can be detected by:

- → Using LVDT
- → Using strain gauge
- → Mechanically coupled indicating needle.
- → Other velocity or displacement sensor.

$$\boxed{(e_2 \sim e_1) \propto P(P_{ext} - P_{ref}) \propto dm.}$$

Potential difference — Pressure — displacement



(LVDT) (Pressure measurement by LVDT using bellow as primary sensing element.)

Advantage:

- ✓ It gives high output (no need of Ampʳ.)
- ✓ Sensitivity is high.
- ✓ shows low hysterisis
- ✓ Repeatability is excellent
- ✓ Consume power less than 1 W.
- ✓ Less friction, less noise
- ✓ Tolerate high degree of sock.
- ✓ operate over −265°c to 600°c range

Disadvantage:

- ✓ Sensitive to stray magnetic field
- ✓ Relatively large displacement is required
- ✓ Affected by vibrations.
- ✓ Dynamic response is limitted due to core mass.

Application:

- ✓ Measurement of material thickness
- ✓ In accelerometer.
- ✓ Jet engine control.