R.N.G.P.I.T, Bardoli
Electrical Engineering Department

# Subject: EMMI

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# CH: Transducer & Sensors

- This Lecture contain
  - Resistive (Strain gauge..), Inductive (LVDT)and capacitive transducer

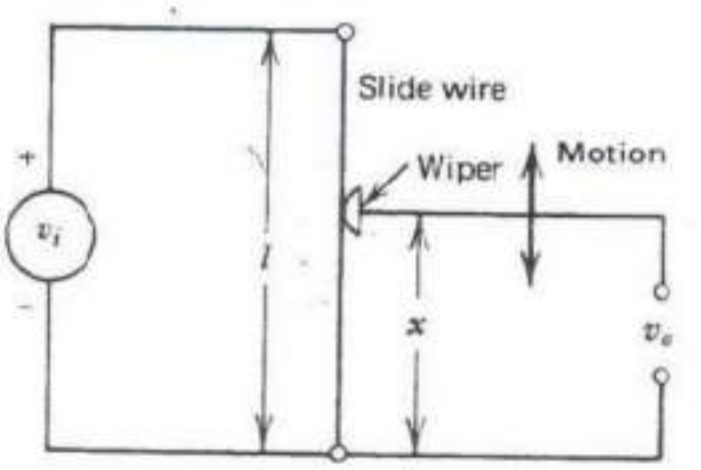
| | |
|---|---|
| **Transducers and Sensors :**<br>Definition, different types of transducers, criteria for selection, general characteristics and dynamic characteristics, transducers for measurement of temperature ((Thermocouple and RTD), transducers for measurement of pressure,  strain, transducers for measurement of displacement, speed, torque, Hall Effect transducer<br>Sensors – basic concept – Speed and position sensors | **10** |

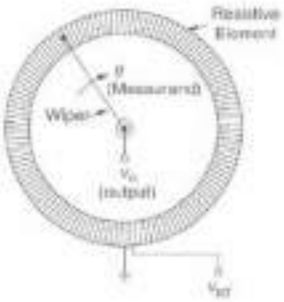
- RESISTIVE TRANSDUSERS:
- It is clear from the equation that, the electrical resistance can be varied by varying,

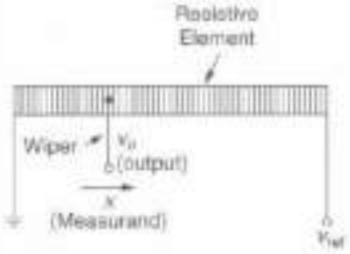
$$R = \frac{\rho l}{A}$$

- (i) Length
- (ii) Cross-sectional area and
- (iii) Resistivity or combination of these.
- Method of changing resistance Length - Resistance can be changed varying the length of the conductor,(linear and rotary).
- Dimensions - When a metal conductor is subjected to mechanical strain, change in dimensions of the conductor occurs, that changes the resistance of the conductor.
- Resistivity -When a metal conductor is subjected to a change in temperature and change in resistivity occurs which changes resistance of the conductor.
- Resulting device:-
- Resistance potentiometers or sliding contact devices displacements ,Electrical resistance strain gauges, Thermistor and RTD
- Use:-
- the resistive transducer used for the measurement of linear and angular, and used for the
- temperature mechanical strain measurement

- **Potentiometer:**
- A potentiometer is a resistive sensor used to measure linear displacements as well as rotary motion.
- In a potentiometer an electrically conductive wiper slides across a fixed resistive element. A voltage is applied across the resistive element. Thus a voltage divider circuit is formed. The output voltage(Vout) is measured as shown in the figure. The output voltage is proportional to the distance travelled.
- There are two types of potentiometer, linear and rotary potentiometer. The linear potentiometer has a slide or wiper. The rotary potentiometer can be a single turn or multi turn.

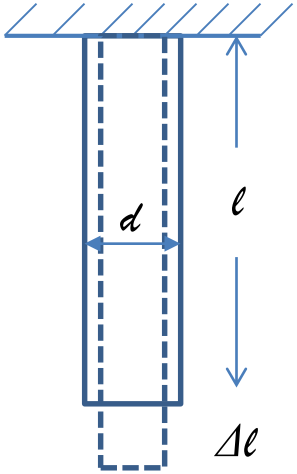


- Potentiometer:
- Some of the applications of the potentiometer are
- Linear displacement measurement
- Rotary displacement measurement
- Volume control
- Brightness control
- Liquid level measurements using float

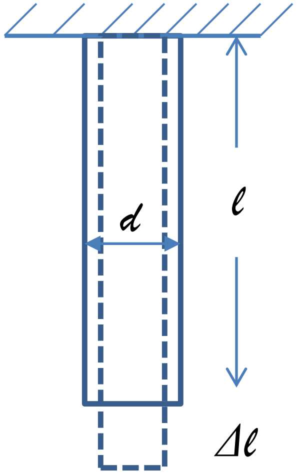
- **Strain Gauge:**
- Strain gauge is one of the most popular types of transducer. It has got a wide range of applications. It can be used for measurement of force, torque, pressure, acceleration and many other parameters. The basic principle of operation of a strain gage is simple: when strain is applied to a thin metallic wire, its dimension changes, thus changing the resistance of the wire.




- Gage Factor: Let us consider a long straight metallic wire of length l circular cross section with diameter d. When this wire is subjected to a force applied at the two ends, a strain will be generated and as a result, the dimension will change (l changing to $l+\Delta l$, d changing to $d-\Delta d$ and A changing to $A+\Delta A$). For the time being, we are considering that all the changes are in positive direction. Now, the resistance of the wire:

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

- Strain Gauge:
- When metal conductor experience a force not only dimension but its resistivity is also changed, this effect is called piezoresistive effect.




- Strain= Change in dimension/original dimension = Δℓ/ℓ

$$\frac{dR}{dS} = \frac{d}{dS}\left(\frac{\rho L}{A}\right)$$

$$\frac{dR}{dS} = \frac{\rho}{A}\frac{\partial L}{\partial S} - \frac{\rho L}{A^2}\frac{\partial A}{\partial S} + \frac{L}{A}\frac{\partial \rho}{\partial S}$$

$$\frac{dR}{dS} = \frac{\rho}{A}\frac{\partial L}{\partial S} - \frac{\rho L}{A^2}\frac{\partial A}{\partial S} + \frac{L}{A}\frac{\partial \rho}{\partial S}$$

$$\frac{1}{R}\frac{dR}{dS} = \frac{1}{R}\frac{\rho}{A}\frac{\partial L}{\partial S} - \frac{1}{R}\frac{\rho L}{A^2}\frac{\partial A}{\partial S} + \frac{1}{R}\frac{L}{A}\frac{\partial \rho}{\partial S}$$

$$\frac{1}{R}\frac{dR}{dS} = \frac{1}{L}\frac{\partial L}{\partial S} - \frac{1}{A}\frac{\partial A}{\partial S} + \frac{1}{\rho}\frac{\partial \rho}{\partial S}$$

$$A = \frac{\pi}{4}d^2$$

$$\frac{\partial A}{\partial S} = \frac{\pi}{2}d\frac{\partial d}{\partial S}$$

$$\frac{1}{R}\frac{dR}{dS} = \frac{1}{L}\frac{\partial L}{\partial S} - \frac{1}{\pi/_{4}d^2}\frac{\pi}{2}d\frac{\partial d}{\partial S} + \frac{1}{\rho}\frac{\partial \rho}{\partial S}$$

$$\frac{1}{R}\frac{dR}{dS} = \frac{1}{L}\frac{\partial L}{\partial S} - \frac{2}{d}\frac{\partial d}{\partial S} + \frac{1}{\rho}\frac{\partial \rho}{\partial S}$$

$$\text{Poisson ratio} = -\frac{\text{Lateral strain}}{\text{Longitudenal strain}}$$

$$\gamma = -\frac{\partial d / d}{\partial \mathrm{L}/\mathrm{L}}$$

$$\frac{\partial d}{d} = -\gamma \frac{\partial L}{\mathrm{L}}$$

$$\frac{1}{R}\frac{dR}{dS} = \frac{1}{L}\frac{\partial L}{\partial S} - \frac{2}{d}\frac{\partial d}{\partial S} + \frac{1}{\rho}\frac{\partial \rho}{\partial S}$$

$$\frac{1}{R}\frac{dR}{dS} = \frac{1}{L}\frac{\partial L}{\partial S} + \frac{2\gamma}{L}\frac{\partial L}{\partial S} + \frac{1}{\rho}\frac{\partial \rho}{\partial S}$$

$$\frac{1}{R}\frac{dR}{dS} = \frac{1}{L}\frac{\partial L}{\partial S}(1 + 2\gamma) + \frac{1}{\rho}\frac{\partial \rho}{\partial S}$$

$$\text{Gauge factor} = -\frac{\Delta \mathrm{R}/\mathrm{R}}{\Delta \mathrm{L}/\mathrm{L}}$$

$$\frac{\Delta \mathrm{R}}{R} = \mathrm{G.f.}\frac{\Delta \mathrm{L}}{L}$$

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

$$\frac{\Delta R / R}{\Delta L / L} = 1 + 2\gamma + \frac{\Delta \rho / \rho}{\Delta L / L}$$

$$\frac{\Delta R / R}{\Delta L / L} = 1 + 2\gamma + \frac{\Delta\rho / \rho}{\Delta L / L}$$

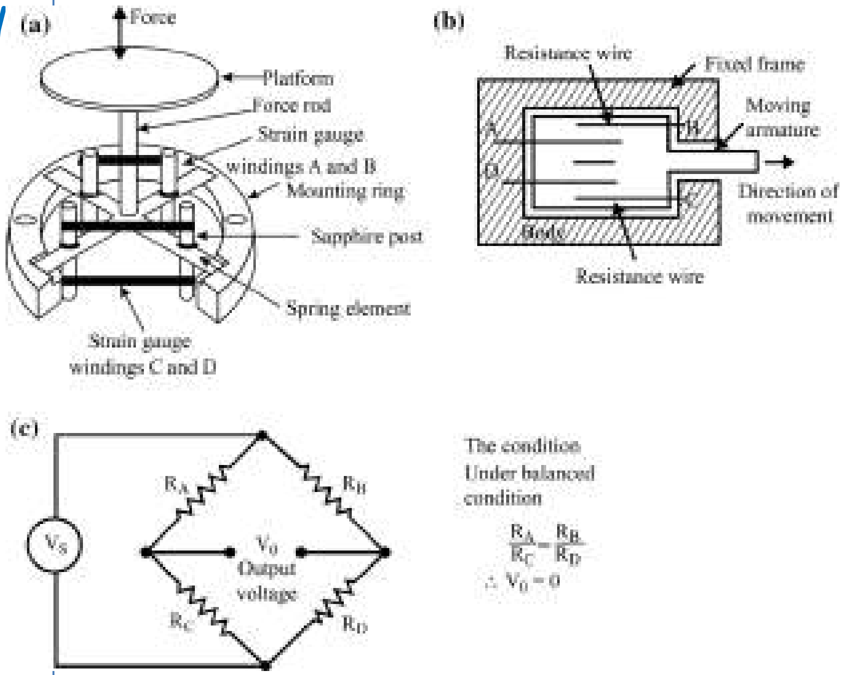
$$\text{Gauge factor} = -\frac{\Delta \mathrm{R}/\mathrm{R}}{\Delta \mathrm{L}/\mathrm{L}}$$

$$G.F. = 1 + 2\gamma + \frac{\Delta\rho / \rho}{\Delta L / L}$$

$$G.F. = 1 + 2\gamma + \frac{\Delta\rho / \rho}{\varepsilon}$$

$$\varepsilon = \text{strain} = \Delta \mathrm{L}/\mathrm{L}$$

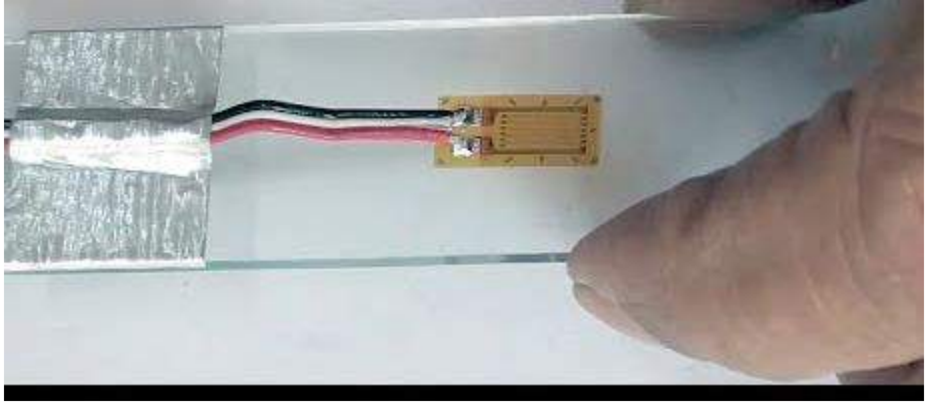
- Types of strain gauge:
- Types:
- 1) Wire wound (Unbonded and Bonded strain guage)
- 2) Foil Type
- 3) Semiconductor

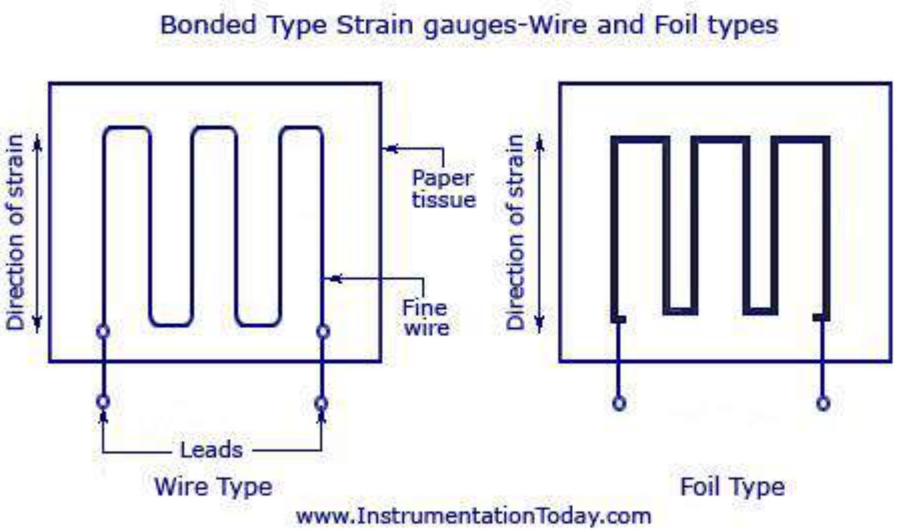



- Unbonded strain gauge:

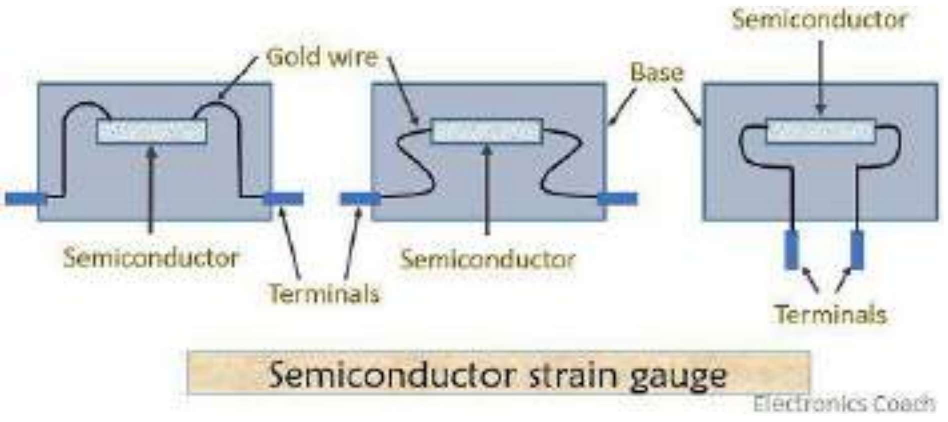
- Types of strain gauge:
- Types:
- 1)Bonded strain gauge
- 2) Foil type strain gauge

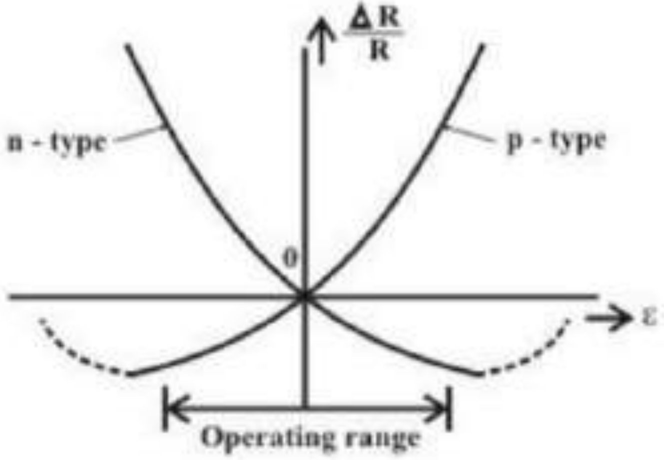
- Features:
- High Gauge factor
- Strain gauge resistance should be high
- Low resistance thermal coefficient
- Should Not effected by hysteresis
- Linear characteristics
- Good frequency response



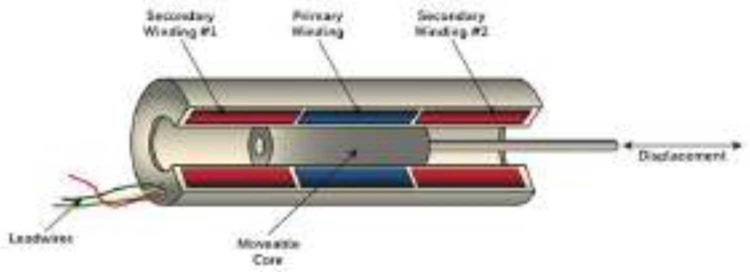


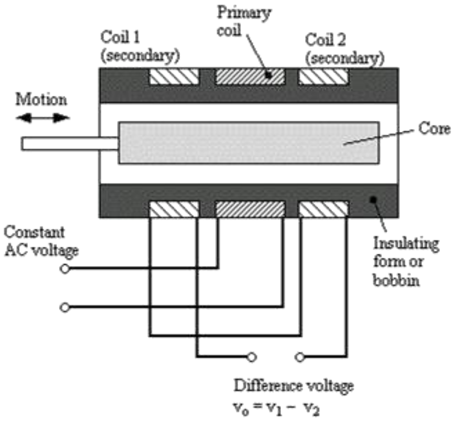
- Types of strain gauge:
- Types:
- 3)Semiconductor strain gauge
- They can be of two types: p-type and n-type. In the former the
- resistance increases with positive strain, while, in the later the resistance decreases with temperature.
- The construction and the typical characteristics of a semiconductor strain gage are shown in figure
- Features:
- High Gauge factor
- Low hysteresis loss
- Size small
- High fatigue life
- Highly affected by temperature
- Not linear
- Costly

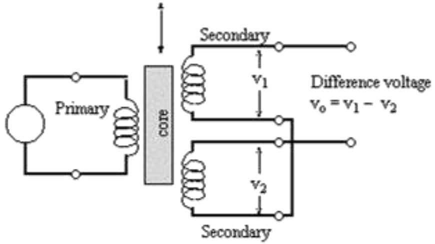


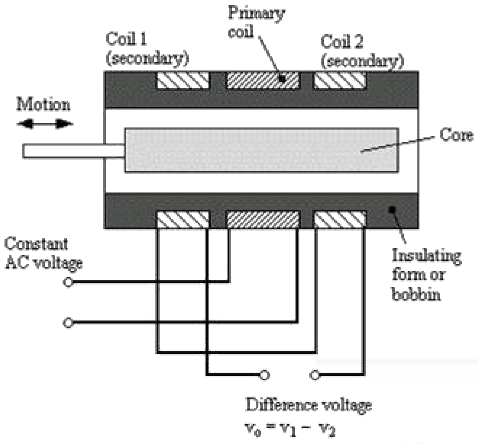
- Linear Variable Differential Transducer (LVDT):
- LVDT is inductive transducer:
- Inductive transducers work on the principle of inductance change due to any appreciable change in the quantity to be measured
- It measures displacement in terms of voltage difference between its two secondary voltages. Secondary voltages are nothing but the result of induction due to the flux change in the secondary coil with the displacement of the iron bar.

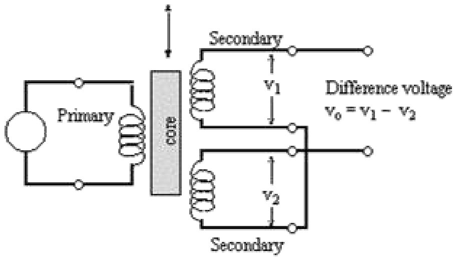


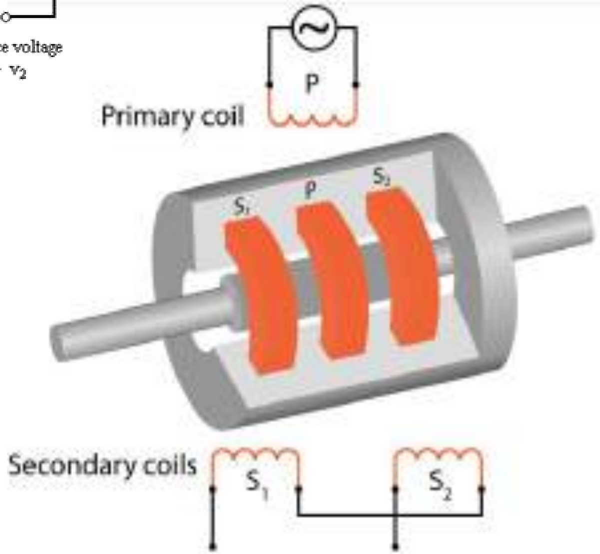



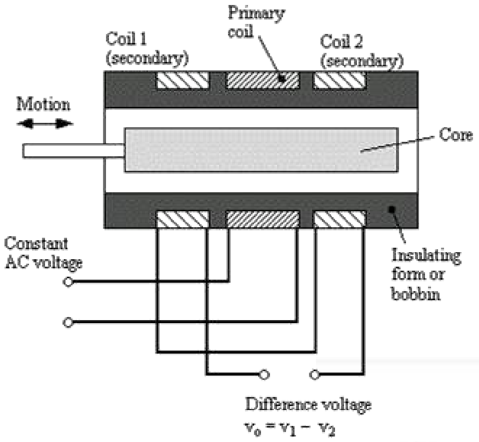
- **Linear Variable Differential Transducer (LVDT):**
- Construction:
- The transformer consists of a primary winding P and two secondary winding $S_1$ and $S_2$ wound on a cylindrical former(which is hollow in nature and will contain core).
- Both the secondary windings have equal number of turns and are identically placed on the either side of primary winding
- The primary winding is connected to an AC source which produces a flux in the air gap and voltages are induced in secondary windings.

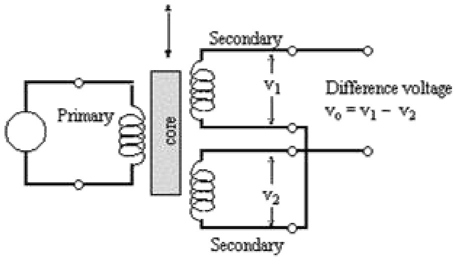


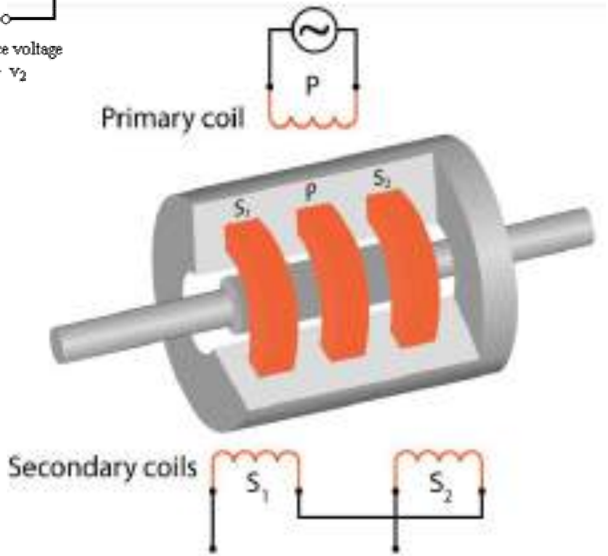



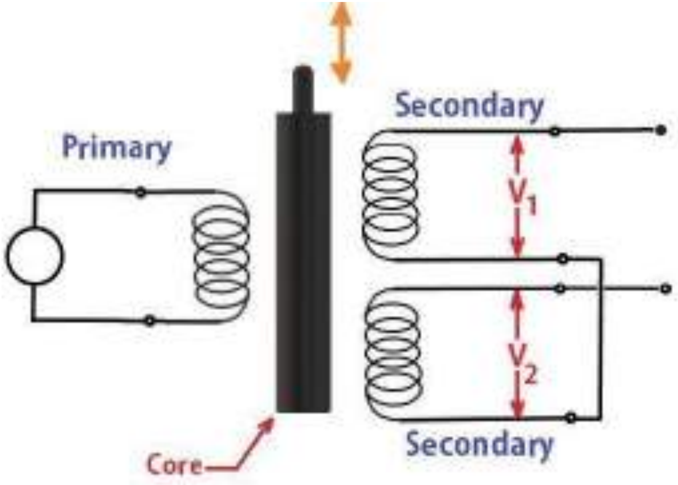
- Linear Variable Differential Transducer (LVDT):
- Construction:
- A movable soft iron core is placed inside the former and displacement to be measured is connected to the iron core.
- Soft iron core (nickel-iron alloy) slotted to reduce eddy current loss.
- The iron core is generally of high permeability which helps in reducing harmonics and high sensitivity of LVDT.
- The LVDT is placed inside a stainless steel housing because it will provide electrostatic and
- electromagnetic shielding.
- Secondary Windings are series opposition connected.

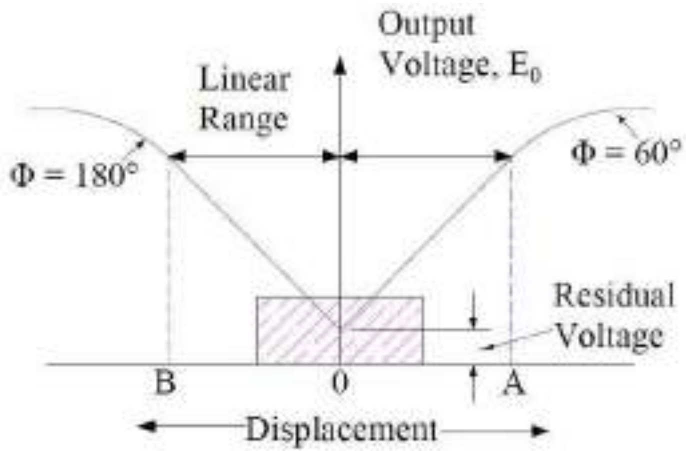


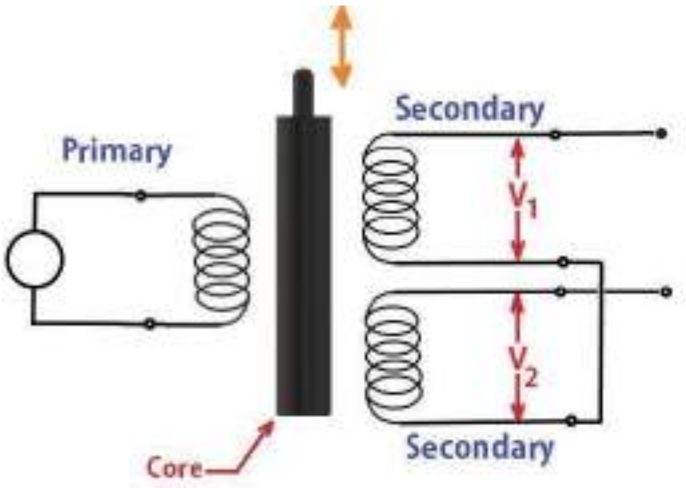



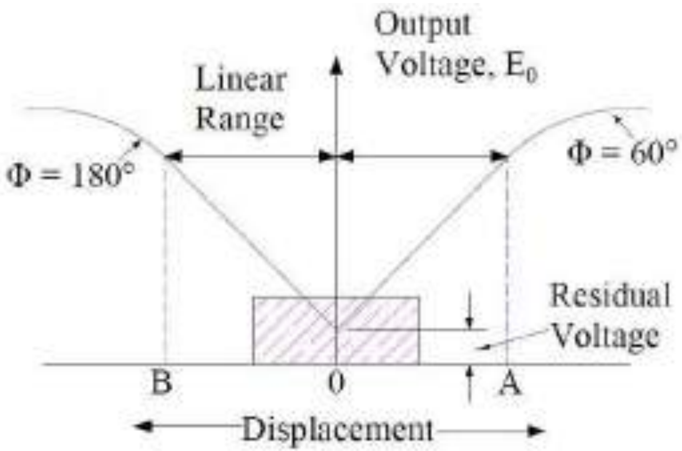
- Working of LVDT:
- As the primary is connected to an AC source so alternating current and voltages are produced in the secondary of the LVDT. The output in secondary $S_1$ is $V_1$ and in the secondary $S_2$ is $V_2$. So the differential output is, $V_{out} = V_1 - V_2$, This equation explains the principle of Operation of LVDT.
- When the core is at null position (for no displacement) When the core is at null position then the flux linking with both the secondary windings is equal so the induced emf is equal in both the windings. So for no displacement the value of output $V_{out}$ is zero as $V_1$ and $V_2$ both are equal. So it shows that no displacement took place.



- *Working of LVDT:*
- *When the core is moved to upward of null position (For displacement to the upward of reference point) In the this case the flux linking with secondary winding $S_1$ is more as compared to flux linking with $S_2$. Due to this $V_1$ will be more as that of $V_2$. Due to this output voltage Vout is positive.*
- *When the core is moved to downward of Null position (for displacement to the downward of reference point) In this case magnitude of $V_2$ will be more as that of $V_1$. Due to this output $V_{out}$ will be negative and shows the output to downward of reference point.*



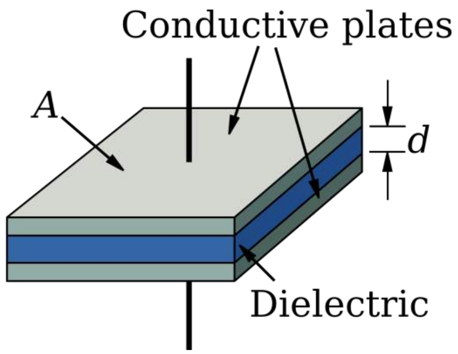



- LVDT:
- Advantages:
- Linear
- Low hysteresis loss, eddy current loss and frictional loss
- High resolution
- Disadvantages:
- For appreciable output large displacement is required
- Highly affected with vibration, temperature, stray magnetic field

- Application:
- They are used in applications where displacements ranging from fraction of mm to few cm are to be measured. The LVDT acting as a primary Transducer converts the displacement to electrical signal directly.
- They can also acts as the secondary transducers. E.g. the Bourbon tube which acts as a primary transducer and covert pressure into linear displacement. then LVDT coverts this displacement into electrical signal which after calibration gives the ideas of the pressure of fluid.

- Capacitive Transducer:
- A capacitor consists of two conductors (plates) that are electrically isolated from one another by a nonconductor (dielectric). When the two conductors are at different potentials (voltages), the system is capable of storing an electric charge. The storage capability of a capacitor is measured in farads. The principle of operation of capacitive transducers is based upon the equation for capacitance of a parallel plate capacitor
- Where, A = Overlapping area of plates; $m^2$,
- d = Distance between two plates; m,
- ε = Permittivity (dielectric constant); F/m.

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




- ## Capacitive Transducer:
- The capacitive transducers work on the principle of change in capacitance of the capacitor. This change in capacitance could be caused by change in overlapping area A of the plates, change in the distance d between the plates and change in dielectric constant ε.
- In most of the cases the above changes are caused by the physical variables, such as, displacement, force or pressure. Variation in capacitance is also there when the dielectric medium between the plates changes, as in the case of measurement of liquid or gas levels. Therefore, the capacitive transducers are commonly used for measurement of linear displacement.

i) Change in capacitance due to change in overlapping area of plates.
ii) Change in capacitance due to change in distance between the two plates.
iii) Change in capacitance due to change in dielectric between the two plates

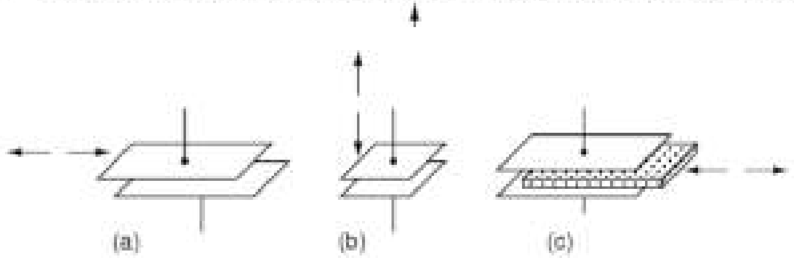
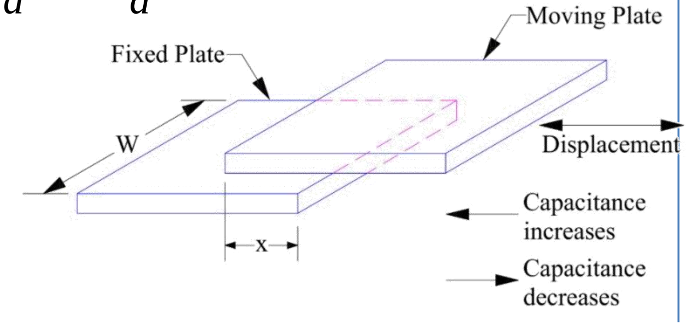
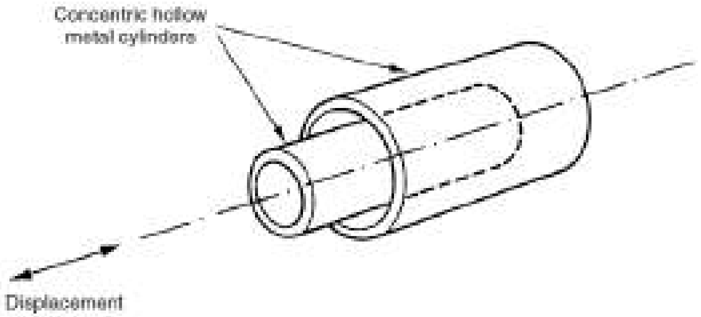


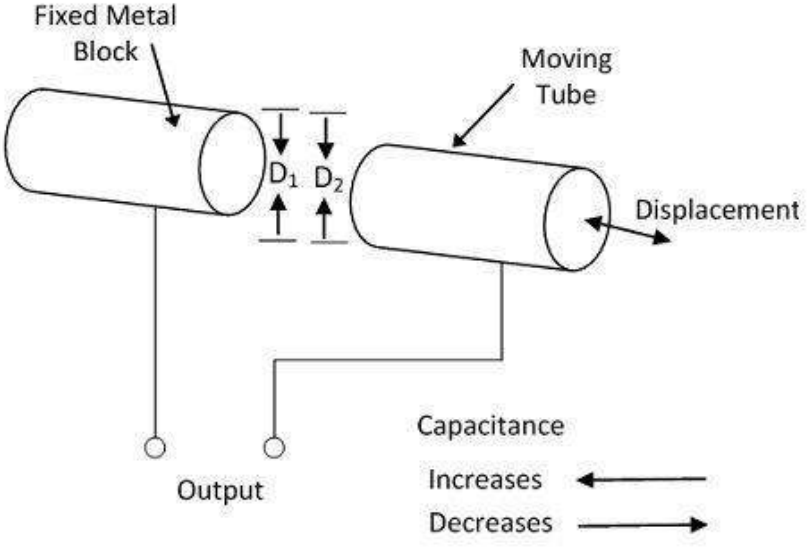

Fig.a Variable capacitive transducer varies; (a) area of overlap, (b) distance between plates, (c) amount of dielectric between plates

- Transducers Using Change in Area of Plates:
- capacitance changes linearly with change in area of plates. Hence this type of capacitive transducer is useful for measurement of moderate to large displacements say from 1 mm to several cm. The area changes linearly with displacement and also the capacitance.

$$C = \frac{\varepsilon A}{d} = \frac{\varepsilon \cdot l \cdot w}{d}$$

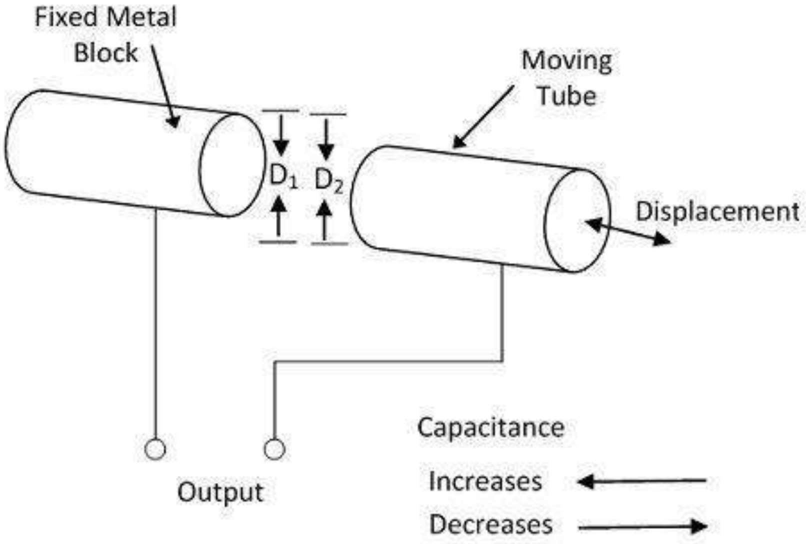


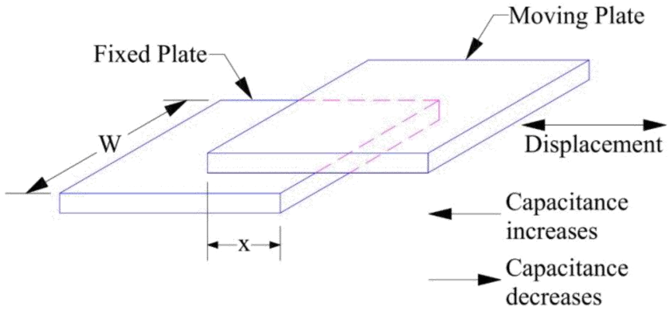



- *Transducers Using Change in Area of Plates:*
- *The sensitivity is constant and therefore there is linear relationship between capacitance and displacement.*

$$Sensitivity = \frac{\partial C}{\partial L}$$



- Transducers Using Change in Area of Plates:
- Fig. (b) shows the basic form of a capacitive transducer employing change in distance between the two plates to cause the change in capacitance. One plate is fixed and the displacement to be measured is applied to the other plate which is movable. Since, the capacitance, C, varies inversely as the distance d, between the plates the response of this transducer is not linear. Thus this transducer is useful only for measurement of extremely small displacements.

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

$$Sensitivity = \frac{\partial C}{\partial L} = -\frac{\varepsilon A}{d^2}$$

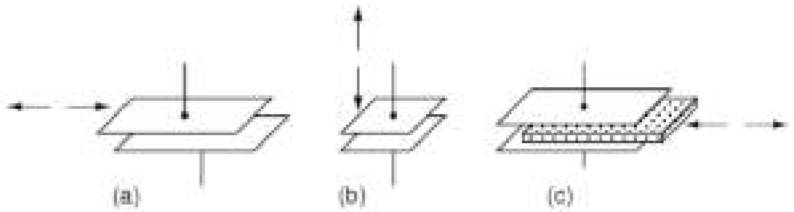
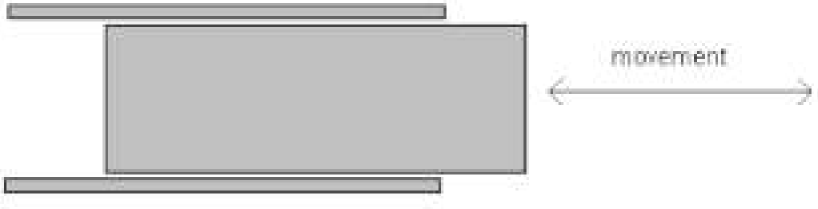



Fig.a Variable capacitive transducer varies; (a) area of overlap, (b) distance between plates, (c) amount of dielectric between plates

- *Transducers Using Change in Area of Plates:*
- *If the area (A) of and the distance (d) between the plates of a capacitor remain constant, capacitance will vary only as a function of the dielectric constant (ε) of the substance filling the gap between the plates. If the space between the plates of a capacitor is filled with an insulator,*
- *the capacitance of the capacitor will change compared to the situation in which there is vacuum between the plates. The change in the capacitance is caused by a change in the electric field between the plates*




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

$$Sensitivity = \frac{\partial C}{\partial L} = -\frac{\varepsilon A}{d^2}$$

- Capacitive Transducers Advantages and disadvantages:
- The major advantages of capacitive transducers are that they require extremely small forces to operate them and hence are very useful for use in small systems. They are extremely sensitive and require small power to operate them. Owing to their good frequency response they are very useful for dynamic studies.
- The disadvantages of capacitive transducers include their non-linear behaviour on account of edge effects and the effects of stray capacitances especially when the transducers have a low value of capacitance. Therefore guard rings must be used to eliminate this effect. The metallic parts of the capacitive transducers must be insulated from each other. In order to reduce the effects of stray capacitances, the frames must be earthed.

- Capacitive Transducers Application:
- Capacitive transducers can be used for measurement of both linear and angular displacements. The capacitive transducers are highly sensitive and can be used for measurement of extremely small displacements down to the order of molecular dimensions, i.e., $0.1 \times 10^{-6}$ mm. On the other hand, they can be used for measurement of large displacements up to about 30 m as in aeroplane altimeters. The change in area method is used for measurement of displacements ranging from 10 to 100 mm.
- Capacitive transducers can be used for the measurement of force and pressure.
- The force and pressure to be measured are first converted to displacement which causes a change of capacitance. Capacitive transducers can also be used directly as pressure transducers in all those cases where the dielectric constant of a medium changes with pressure. They can be used for measurement of humidity in gases and moisture content in soil / food products etc.

# End

# THANK YOU