UNIT-V
SENSORS AND TRANSDUCERS

1. Introduction to Transducers
   - definition, classification, advantages, transducer selection factors

2. Displacement Transducers
   Potentiometric Resistive Transducer → linear & angular DISP
   Capacitive displacement Transducer → Change in C due to change in d, A, Ɛ
   Inductive displacement Transducers → change in L due to change in N, R
   LVDT

3. Strain gauges → Measurement of Force :
   Bonded, Unbonded, Semiconductor strain gauges

4. Measurement of Temperature
   - Thermometer
   - Thermistor
   - Thermocouples

5. Measurement of Pressure
   - Piezo-electric pickup

6. Measurement of velocity, acceleration, vibration

7. pH Measurement Signal Conditional Circuits

1. INTRODUCTION TO TRANSDUCERS:

Definition:

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- An electrical transducer (or simply transducer) may be defined as a device which converts a non-electrical quantity into an electrical signal.
  Ex: Strain gauge, Thermometer, Thermistor, displacement transducers……

- An inverse transducer is defined as a device which converts an electrical quantity in to non-electrical quantity.
  Ex: Piezo-electrical crystal → when a voltage is applied across its surface it changes its dimension causing a mechanical displacement.

Classification of Transducers:

(1) Active transducers: These are self-generating type transducers.

These transducer do not require external power source for its operation.

These transducers develop an electrical signal, which is proportional to the quantity under measurement.

Ex: *Piezo electric pick-up: → generates charge corresponding to Pressure.*

Photo voltaic cell → generates voltage in response to light illumination.

Thermo couples → generates current in response to Temp change.

(2) Passive transducers: These are called as externally-powered transducers. These transducers do not generate electrical signals themselves.

To obtain an electrical signal from passive transducer, an external power source is essential.

Ex: Thermistor → resistance change corresponding to Temperature variations

Strain gage → resistance change in response to pressure.

Note that Passive transducers depend on the charge in electrical parameters like R, L, C.

Transducers may further classified in to different categories depends on their applications, method of energy conversion, nature of the output signal, principle of operation and so-on.

The following table gives the different types of transducers classified according to their principle of operation and applications:

S. No.	Electrical parameter & class of Transducers	Principle of operation	Applications
(A) RESISTANCE TRANSDUCERS:			
1	Potentiometric Resistance Transducers	Positioning of the slides by external force varies the resistance of potentiometer (or) bridge ckt.	Displacement Pressure
2	Strain guage	Resistance of a wire (or) s.c is changed by elongation (or) compression due to externally applied tress.	Force Torque Stress
3	Thermometer	Resistance of a metal wire with +ve temp, co-efficient varies with temp.	Temperature Radiant heat

4	Thermistor	Resistance of some metal oxides with –ve temp.co-efficient varies with temp.	Temperature
(B)	**CAPACITANCE TRANSDUCERS:**		
1	Variable capacitance Transducer	Distance between two parallel plates is varied by externally applied force.	Displacement Pressure
2	Capacitor microphone	Sound pressure varies the gap between fixed plate & a movable diaphragm.	speech music noise
3	Dielectric gage	Variation in capacitance by changes in dielectric.	liquid level thickness
(C)	**INDUCTANCE TRANSDUCERS:**		
1	Variable inductance	Self (or) mutual inductance of ac-excited coil is varied by changes in magnetic ckt.	Displacement Pressure
2	Variable Reluctance pick-up.	Reluctance of the magnetic ckt is varied by changing the position of the iron core of a coil.	Displacement Pressure Vibration
3	Differential transformer(LVDT)	The differential voltage of two secondary windings of a transformer is varied by positioning the magnetic core through an externally applied force.	Displacement Pressure Vibration force
	ACTIVE TRANSDUCERS		
1	Thermocouples	An emf is generated across the junctions of two dissimilar metals when any one of the junction is heated.	Temperature Heat flow Radiation
2	Piezo electric pick up	An emf is generated when an external force is applied to certain crystalline materials such as quartz.	Sound, vibration, acceleration, pressure, changes.
3	Photo voltaic cell	A voltage is generated in a semiconductor junction when radiant energy stimulates the cell.	Light meter, solar cell
4	Moving coil generator	Motion of a coil in a magnetic field generates a voltage	Velocity.

Transducer selection factors:

In any measurement system, the transducer is the first element which converts physical quantity in to electrical signal. Picking the right transducer for a given measurement application involves considering the transducer characteristics, desired system performance, i/p requirements.

The following parameters are to be considered while selecting transducers for the measurement of particular quantity.

1. **Linearity** : The relationship b/w input physical parameter & o/p electrical signal must be linear. The ability to reproduce the input characteristics symmetrically is called Linearity. Linearity property indicates the straight line nature of the calibration curve.
2. **Sensitivity**: High sensitivity is desirable

   Sensitivity is defined as the ratio of *change in o/p of an instrument* to *change in i/p quantity*. *Mathematically,*

   $$\text{Sensitivity } S = \frac{change\ in\ of\ output\ of\ instrument}{change\ in\ input\ quatity} = \frac{qo}{qi}$$

3. **Dynamic range**: The operating range of transducer should be wide.

   The minimum and maximum values of a quantity for which an instrument is designed to measure is called its *range.*
4. **Repeatability**: The input-output relationship for a transducer should be predictable over long period of time. This ensures reliability of operation.

   Precision is the ability of an instrument to reproduce its readings again and again in the same manner for a constant input. Precision is defined as a measure of consistency/repeatability of measurements. i,e, successive readings do not differ.
5. **Accuracy**: must be high.

   It is defined as the degree of closeness / conformity to the true value of the quantity It indicates the ability of the instrument to indicate the true value of the quantity.
6. **Environmental capability**: There should be no effects of external temp, pressure, shocks, fields, interaction. Transducer should work under specified environment conditions for satisfactory operation like temp. range, pressure, shock, EM interference etc.
7. **Insensitive to unwanted signals**: Measurement system doesn’t distributive Existing conditions.
8. **Speed of response:** must be high
   a. It is the rapidity with which an instrument responds to the changes in the i/p quantity
   b. It gives information about how fast the system reacts to changes in the input.
   c. It indicates the activeness of the system.
   d. The measurement system should respond very quickly to the changes in input.
9. **Physical size**: The transducer must have minimum weight and volume.

2. MEASUREMENT OF DISPLACEMENT:

(2.1) POTENTIOMETRIC RESISTANCE TRANSDUCER:

Principle*:*

The resistance transducers are a type of electrical transducers where the physical quantity to be measured changes the resistance of sensing element

The resistance of conductor is given by,

$R = \rho \frac{l}{a}$ ohms. *Where* ρ *= resistivity of conductor* (Ωm).

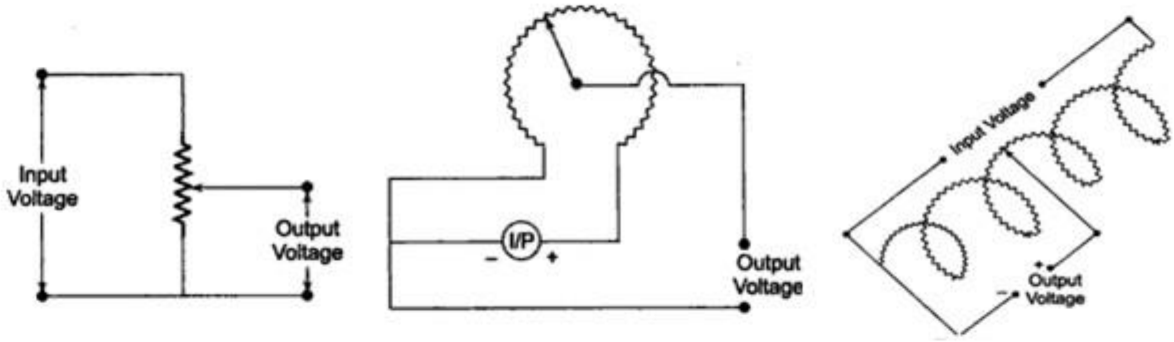
l = length of the conductor (m).

a = cross sectional area of conductor (m^2).

The quantity to be measured changes any one of the above parameter and hence the resistance R will be changed.

The Potentiometric Resistive Transducer is used for the measurement of linear and angular displacement as shown in below figure.

1. Linear/Translator type POT → used to measure linear displacement.
2. Angular/Rotational POT → used to measure angular displacement.



(a) Linear/ translatory type *(b) Rotational /angular* *(c) Helical type*

1. Resistance POT consists of a resistance element along with a sliding contact called as wiper.

2. The motion of the sliding contact may be translating (or) rotational.

   Translator resistive elements are linear (straight line) & used for linear DISP measurement.

   Rotational resistance elements are circular & used for angular DISP measurement.

   Helical resistive elements are multi turn rotational devices which can be used for the measurement of either translational (or) rotational motion.

3. The movement of sliding contact (wiper) on resistance element causes change in resistance and it is converted into voltage.

The output voltage $e_0 = \dfrac{\text{resistance of output terrminals}}{\textit{total resistance}} * e_{in}$

$$= \frac{R_p(x_i/x_t)}{R_p} * e_{in}$$ Where R_p = total resistance of POT.

$$= \frac{x_i}{x_t} * e_{in}$$ x_t = total length of translational POT.

$$= S\,x_i$$ x_i = displacement of wiper from initial position

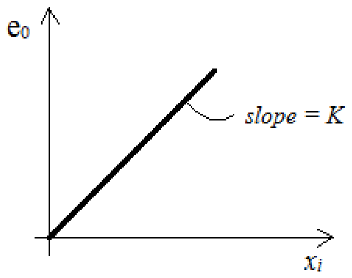
$S = \dfrac{e_{in}}{x_t}$ = constant.

Hence, $e_0 \;\alpha\; x_i$ (linear displacement) for Translational POT.

lly We have $e_0 \;\alpha\; \theta_i$ (angular displacement) for Rotational POT

Characteristics of POT:

Under ideal conditions,
the o/p voltage varies linearly with displacement of sliding contact.



Sensitivity S = e_{in}/x_t *Volts/m*

Power dissipation = e_{in}^2/R_P *Watts*

Advantages of POT:
(1) Simple to operate
(2) High electrical efficiency
(3) Inexpensive

Applications : → For the measurement of Linear & angular displacement

(2.2) CAPACITANCE DISPLACEMENT TRANSDUCER:

Principle:

The principle of operation of capacitive transducer is based on the equation of capacitance of parallel plate capacitor.

The capacitance of parallel plate capacitor is given by,

$$C = \epsilon \frac{A}{d} \text{ Farads}$$ *where* ϵ = *Permittivity of medium (F/m)*

A = *overlapping area of plates* (m^2)

d = *distance between two plates (m)*

The capacitance transducer works principle of change of capacitance caused by

(i) Change in overlapping area A

(ii) Change in distance between the plates

(iii) Change in dielectric constant

These changes are caused by physical variables like Displacement, Force, Pressure,etc. The change in capacitance can be measured by using bridge circuits.

(i). Capacitance Transducer using change in area of plates:

From the above eqn, the capacitance changes linearly with change in overlapping area of plates. The area changes linearly with Displacement and hence capacitance changes.

The capacitance of parallel plate capacitor is given by,

$$C = \epsilon \frac{A}{d} = \epsilon \frac{w\,x}{d}$$

Where w = width of overlapping part of plates (m)

x = length of overlapping part of plates which is equal to the DISPLACEMENT.

$$C = S * x \quad \text{where } S = \text{sensitivity} = \epsilon \frac{w}{d} \text{ F/m}$$

Since the Sensitivity S is constant, the capacitance changes linearly with Displacement x.

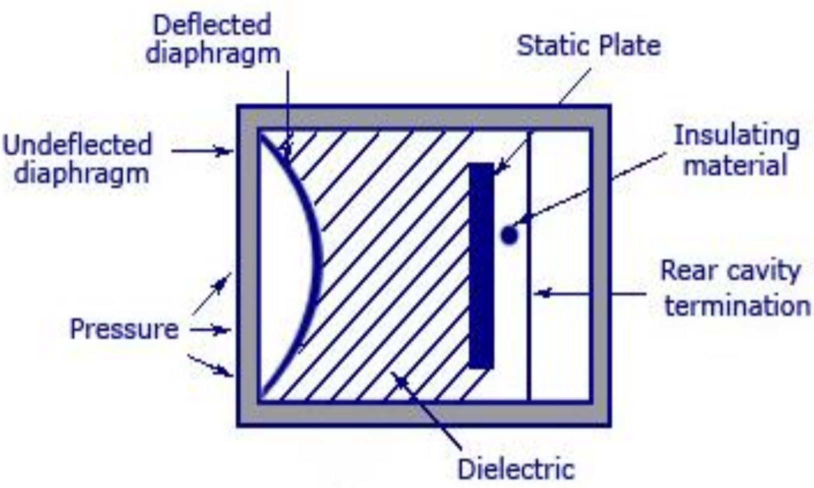
(ii). Capacitance Transducers using change in distance between plates:

Figure shows the basic form of a capacitance transducer in which change of capacitance occurs due to change in distance between two plates - One is **fixed plate** and the other is **movable plate.**

The displacement to be measured is applied to the **movabl plate**.

The capacitance of parallel plate capacitor is given by,

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



Since dielectric medium **Є** and overlapping area of plates **A** are kept constant, the capacitance **C** varies inversely to the distance of separation **d**.

$$C \propto \frac{1}{d}$$

This transducer is useful only for measurement of externally small displacements.

(iii). Capacitance Transducers using change in dielectric constant:

From the capacitance equation, the capacitance changes due to change in dielectric constant. The capacitance of parallel plate capacitor is given by,

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

iv) Variation of dielectric constant for measurement of liquid level:

- The capacitive transducers using the principle of change of capacitance with change of dielectric are normally used for measurement of liquid level.
- The non-conductive liquid acts as a dielectric between two parallel electrodes forms a parallel plate capacitance.
- As the liquid level increases, the dielectric increases and thus Capacitance increases. Hence the capacitance is proportional to the liquid level in the tank.

Advantages:

- High sensitivity.
- The force requirement is very small, hence power required to operate is small.
- Good frequency response and very high input impedance.
- Less loading effect
- They are use full in applications, where stray magnetic fields affect performance of inductive transducers.

Disadvantages:

- Proper insulation is required between metallic parts of the capacitive transducer.
- The stray capacitance affects the performance of the transducer.
- Non-linear behaviors due to edge effects and stray electric fields.
- For low value capacitances, the impedance tends to high value which causes loading effect.

(2.3) INDUCTANCE DISPLACEMENT TRANSDUCER:

Principle:

The principle of operation of inductance transducer is based on the change in self inductance of coil due to variation of the quantity under measurement.
The self inductance of the coil is given by

$$L = \frac{N^2}{R} \text{ Henry} \quad \textit{where } N = \textit{No. of turns}$$

R = *Reluctance of the Magnetic circuit (A/Wb)*

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

l = *length of the magnetic circuit (m)*

A = *Area of magnetic circuit through which flux is passing* (m^2)

μ = *Permeability of the Core (H/m)*

$$\boxed{L = \frac{N^2 \mu A}{l} \text{ Henry}}$$

From the above equation, The variation in Inductance may be due to

(i) Change in Number of Turns (N)

(ii) Change in Permeability (μ)

(iii) Change in Reluctance – Variable Reluctance type

i) Change in L due to change in Number of Turns (N)

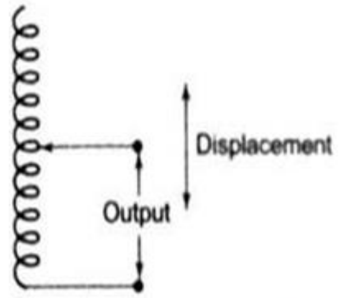


Fig a) Linear inductive Transducer

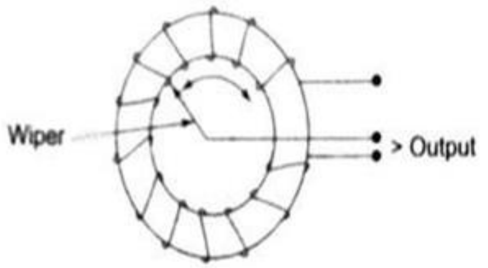


Fig b) angular inductive transducer

Fig a and b are transducers used for the measurement of displacement of linear and angular movement respectively.

Fig a. is an air cored transducer for measurement of linear displacement.

Fig b. is an iron cored coil used for the measurement of angular displacement.

In both cases as the number of turns are changed, the self inductance and the output also changes.

(ii) Change in L due to change in Change in Permeability (μ)

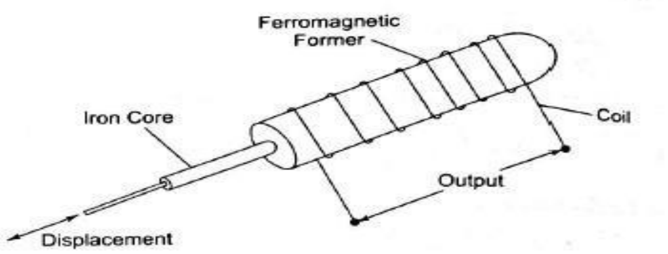
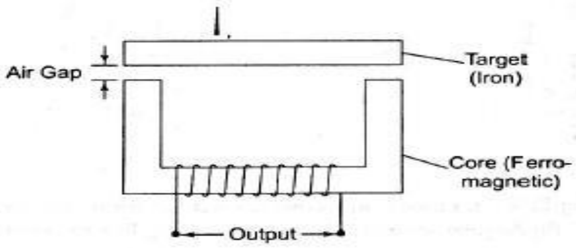


Fig shows an inductive transducer which works on the principle of the variation of permeability causing a change in self inductance.

The iron core is surrounded by a winding. If the iron core is inside the winding, its permeability is increased, and so is the inductance. When iron core is moved out of the winding, the permeability decreases. Resulting in a reduction of the self inductance.

iii) Change in L due to change in Reluctance(R)



A transducer of the variable type consists of wound on a ferromagnetic core. The displacement which is to be measured is applied to a ferromagnetic target. The target does not have any physical contact with the core on which it is mounted. The core and the target are separated by an air gap, as shown in figure.

The reluctance of the magnetic path is determined by the size of the air gap. The inductance of the coil depends upon the reluctance of the magnetic circuits.

The self inductance of the coil is given by

$$L = \frac{N^2}{R_i + R_g}$$

where N = number of turns
R_i = reluctance of iron parts
R_g = reluctance of air gap

The reluctance of the iron part is negligible compared to that of the air gap. Therefore

$$L = N^2/R_g$$

But reluctance of the air gap is given by

$$R_g = \frac{l_g}{\mu_o \times A_g}$$

Where l_g = length of the air gap

A_g = area of the flux path through air.

μ_0= Permeability.

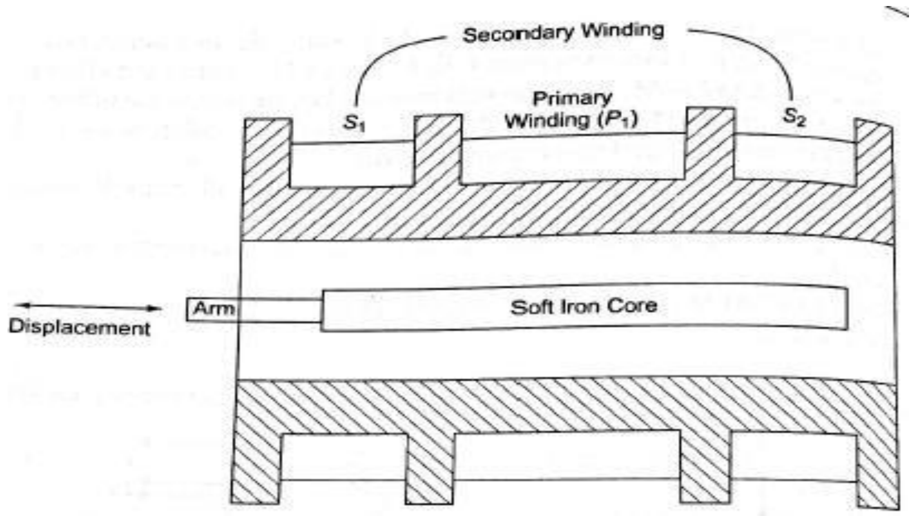
R_g is proportional to l_g, as μ_0 and A_g are constant. Hence L is proportional to $1/l_g$ i.e. the self inductance of the coil is inversely proportional to the length of the air gap.

When the target is near to core, the length is small and therefore the self inductance large.When target is away from core, the reluctance is large, resulting smaller self inductance value. Hence the inductance of the coil is a function of the distance of the target from the core, i.e. the length of the air gap.

Since it is the displacement which changes the length of the air gap, the self inductance is a function of displacement.

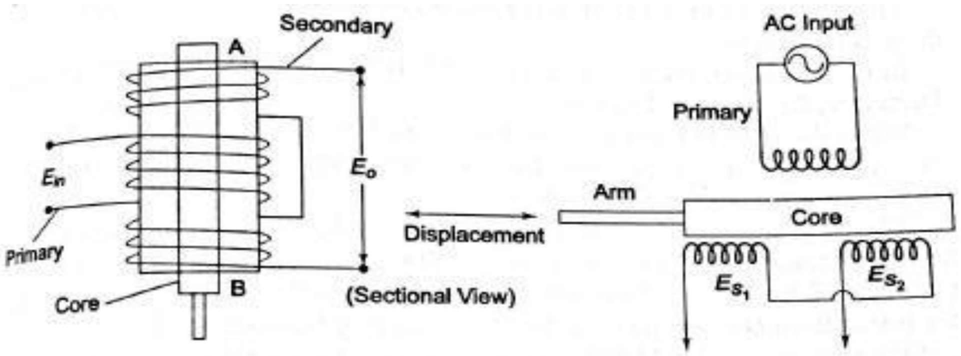
(2.4) LINEAR VARIABLE DIFFERENTIAL TRANSDUCER (LVDT):

- The LVDT is a passive transducer used for the measurement of Displacement.
- LVDT consists of a single Primary winding and two Secondary windings S_1 and S_2 wound on a cylindrical former.
- The secondary windings have equal number of turns and they are identically placed on either side of the primary winding.
- A movable soft iron core is placed inside the former.
- The displacement to be measured is applied to the arm attached to the soft iron core.



- The primary winding is excited by an ac source and it produces an alternating magnetic field which in turn induces ac voltages in the two secondary windings.
- Since the two Secondary windings are connected in series opposition, the **emfs** induced in the secondary coils oppose each other. Hence the output voltage of the transducer is the difference of the two secondary voltages.

$$E_0 = E_{S1} - E_{S2}$$



- The displacement to be measured is applied to the arm attached to the soft iron core.
- The position of the iron core affects the magnetic coupling between primary and two secondary windings.
- When the core is at NULL position (i.e., at centre)

  The flux linking with both secondary windings is equal and hence equal **emfs** are induced. Hence at NULL position, $\mathbf{E_{S1} = E_{S2}}$

  Therefore the output differential voltage $E_0 = 0$.

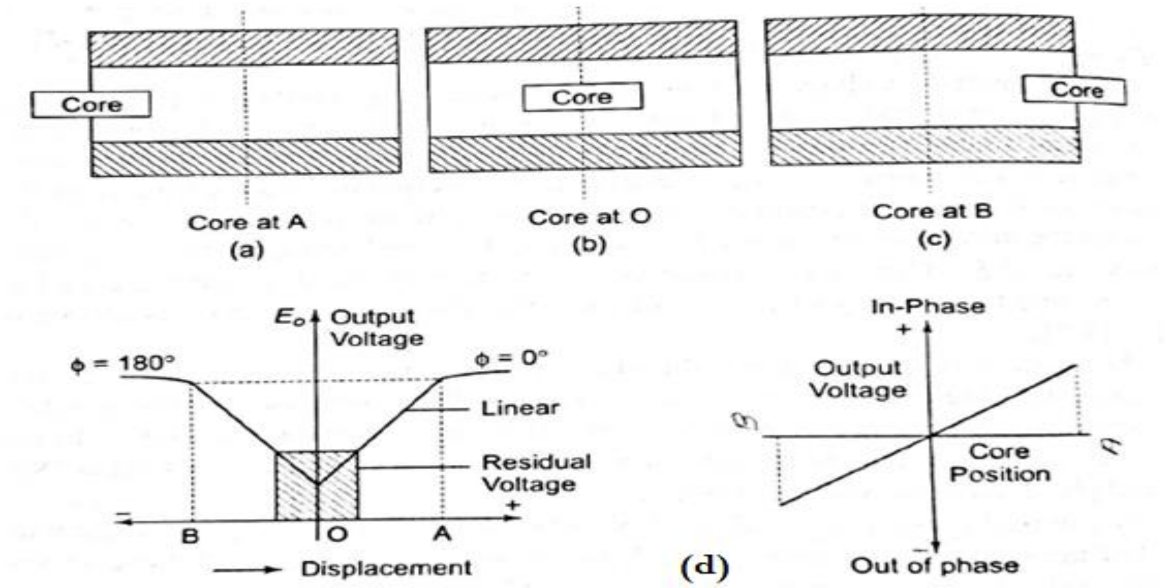


Fig: a),b),c)Various core positions of LVDT
d) Variation of output voltage vs displacement

- When the core is moved towards LEFT (i.e., at A)
  more flux links with S_1 and less with S_2 and hence E_{S1} increases and E_{S2} decreases. Hence the output differential voltages E_0 **increases.**
- When the core is moved towards RIGHT (i.e., at B)
  less flux links with S_1 and more with S_2 and hence E_{S1} decreases and E_{S2} increases. Hence the output differential voltages E_0 **decreases.**
- Hence the output voltage of LVDT is a linear function of the core displacement within a limited range of motion.

Advantages:

- Linearity
- High resolution
- High sensitivity (about 40V/mm)
- Ruggedness (tolerate to vibration and shock)
- Less friction
- Low hysteresis
- Low power consumption

Disadvantages:

- Sensitive to stray magnetic fields
- Dynamic response is limited
- Temperature affects the operation of transducer
- Large displacements are required for appreciable output.

3. STRAIN GAUGES:

Principle:

The basic principle of operation of a strain gauge is that the resistance of a wire (or) metal foil is changed as a function of strain (increases with tension & decreases with compression) and the change in resistance is measured with a Wheatstone bridge.

The resistance of conductor is given by,

$$R = \rho \frac{l}{a} \text{ ohms.} \qquad Where\ \rho = resistivity\ of\ conductor\ (\Omega\, m).$$

$$l = length\ of\ the\ conductor\ (m).$$

$$a = cross\ sectional\ area\ of\ conductor\ (m^2).$$

If a metal conductor is stretched (or) compressed, its resistance changes as both length & diameter of the conductor changes. Also there is a change in the *resistivity* of the conductor when subjected to strain. This property is known as *Piezo-resistive effect.*

When a gauge is subjected to +ve stress, its length increases and cross-sectional area decreases.

Since $R = \rho \frac{l}{a}$ *as 'l' increases & 'a' decreases, R increases with positive stress.*

Applications of Strain gauges:

→ In the measurement of strain, stress, pressure ….etc

→ Used in Load cells, Torque meters, Pressure gauges as secondary transducers.

Types of Strain gauges:

1. Resistance wire gauges → Unbonded , Bonded
2. Foil type strain gauges
3. Semiconductor strain gauges / Piezo-resistive strain gauges.

3.1. **Resistance Wire Strain gauges:**

1(a) Unbonded Resistance wire strain gauge:

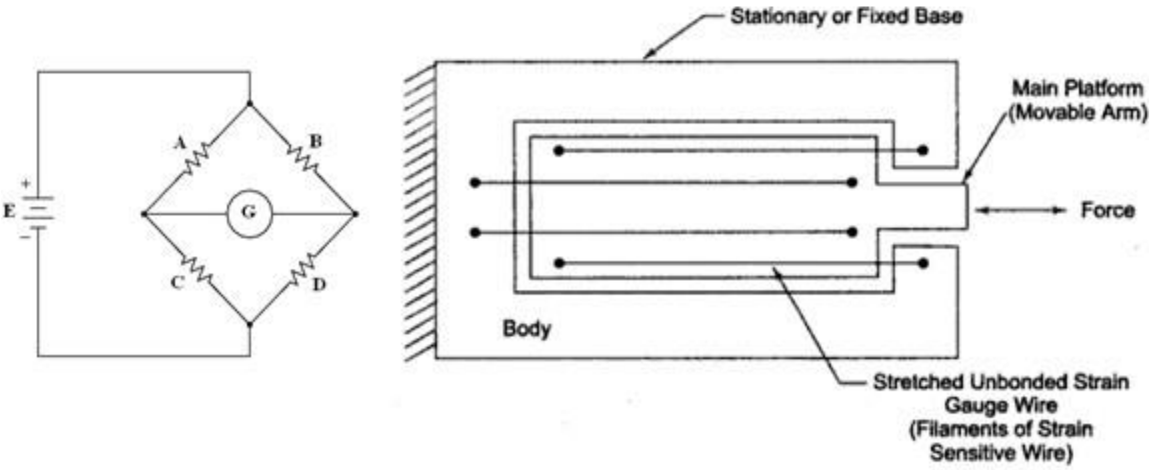


Fig. Unbonded Strain Gauge

→ The unbonded strain gauges consist of a wire stretched between two points in an insulating medium such as air. The diameter of the wire is about 25 μm.

→It has a stationary base and a movable armature that is supported in the centre of the frame.

→ The armature can move in two directions and its movement is limited by 4-filaments of strain sensitive wires mounted on the stationary frame & movable armature as shown in figure.

→ Since wires are kept under tension, there is no sag and no free vibration

→ The unbonded strain gauges are usually connected in a Wheatstone bridge which is initially balanced when no load applied.

→ If an external force is applied to the armature, it moves in one direction and hence lengths of gauges A, B, C, D changes.

→ As length of wires change, the resistance changes and hence the bridge is unbalanced.

→ The unbalanced current indicated by the detector is proportional to the magnitude of displacement of armature (or) which is proportional to the applied strain.

1(b) Bonded Resistance wire strain gauge:

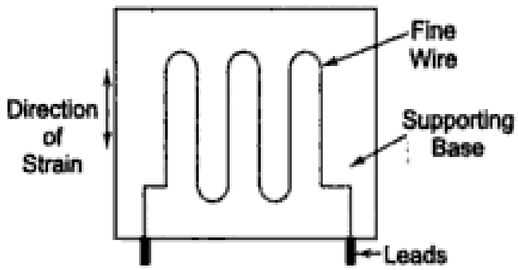


Fig. Bonded resistance Wire Strain Gauge

→ In unbonded strain gauges, the resistive element wires are exposed to air/environment. In bonded strain gauges, the resistive element is covered on the top of the material such as a sheet of Teflon (or) Bakelite so that it is not damaged mechanically.

→ The spreading of the wire permits uniform distribution of stress.

→ The carrier (thin sheet of Teflon or Bakelite) is bonded to the member being studied. This permits good transfer of strain from carrier to wire.

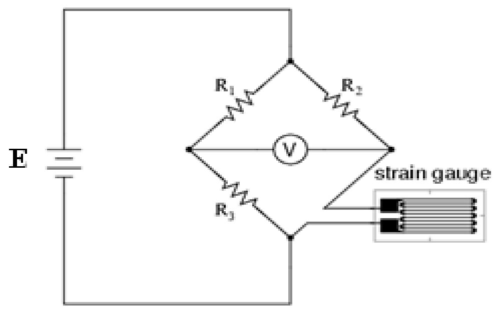
→ The resistive element may be in the form of wire, foil (or) film of the material.

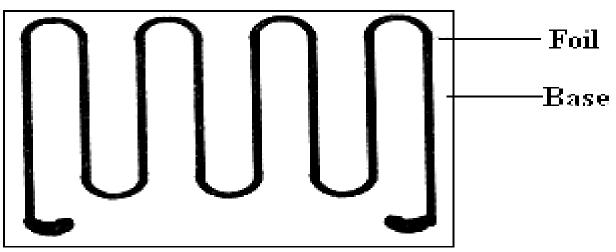
$$R=\rho\frac{l}{a}$$

→ A tensile stress tends to elongate the wire and thereby increase in length and decrease in cross sectional area. The combined effect is an increase is resistance.

Other types of wired Strain gauges:

3. 2. Foil strain gauges:





→ In this gauges, the strain is sensed with the help of metal foil. Because of the larger surface area, foil gauges have much greater dissipation capacity then wire gauges. Hence they can be used at a high operating temperature range.

→ The metals and alloys used for the construction of Foil strain gages are Nichrome (Ni + Cr), Constantan (Ni +Cu), isoelastic (Ni+ Cr + Mo)

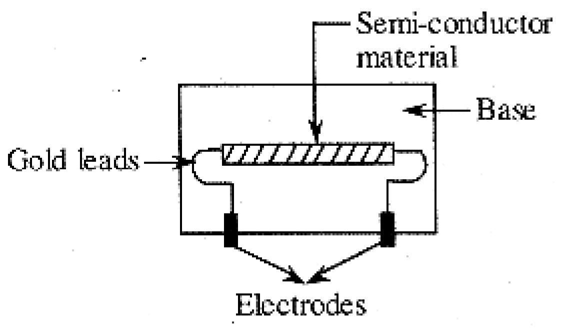
→ Foil type strain gauges have similar characteristics of wire strain gauges. Their gauge factors are typically the same.

→ The advantage of foil type strain gauges are,

- They can be fabricated on large scale and in any shape.
- The foil can be etched on the base.
- Large surface area leads to better bonding.
- High dissipation capacity.
- High operating temperature range.
- Low hysteresis.
- High longitudinal sensitivity.
- Longer life.

3.3. Semi conductor strain gauges / Piezo-resistive transducer:

- Semi conductor strain gauges are used when a high value of gauge factor is desired. Their gauge factor is 50 times greater than that of resistive wire gauges.
- The materials used in Semiconductor strain gauges are Silicon and Germanium.
- The Semiconductor wafer (or) filament has a thickness of 0.05mm is bonded on suitable insulating substrates such as Teflon. Gold leads are used for making contacts.
- The basic principle of operation of Semiconductor strain gauge is the piezo-resistance effect i.e., the change in resistance due to change in resistivity of Semiconductor when strained.



Advantages:

- High gauge factor about 130.
- High sensitivity (can measure externally small strains of the order of 0.01µ strains)
- Good hysteresis characteristics.
- Longer life: $10*10^6$opreations.
- Small in size, ranging in length from 0.7 to 7mm.

Disadvantages:

- Sensitive to temperature changes.
- Linearity of Semiconductor strain gauges is poor.

Desirable characteristics of strain gauges:

- High gauge factor → large change in resistance for particular strain → High sensitivity
- Resistance of the strain gauges should be as high as possible to minimize the effects of a undesirable variations of resistance.
- Low resistance temperature co-efficient.
- Should not have any hysteresis effect in its response.
- Should have linear characteristics i.e., resistance should be is linear factor of strain.
- Leads used must be of materials which here low and stable resistivity and low R temperature co-efficient.

4. MEASUREMENT OF TEMPARATURE:

4.1. THERMOMETER:

Principle: The resistance of a conductor changes with Temperature. Thermometers are also called as Resistance Temperature Detectors (RTD).

The relationship between Temperature and Resistance of a conductor is given by

$$R_T = R_{ref} [1 + \alpha (\blacktriangle T)]$$

where R_T = Resistance of conductor at temperature T ^{0}C

R_{ref} = Resistance of conductor at reference temperature 0 ^{0}C

α = Temperature coefficient of resistance

$\blacktriangle T$ = change in Temperature

Desirable characteristics of temperature transducers:

- The change in resistance of material per unit change in temperature must be as large as possible.
- The resistance of material must have a continuous and stable relationship with temperature.
- Liner change in R with change in temperature.
- The speed with which a resistance element responds to changes in temperature must be high.
- The materials used for the construction of Thermometer are Platinum, Copper, and Nickel.
- These metals have positive temperature coefficient of resistance.
- As Temperature increases, Resistance increases
- Produces linear characteristics.
- The change in resistance is measured by bridge circuit.
- Temperature range : -200 ^{0}C to +650 ^{0}C
- Sensitivity – medium (0.2 ohms / ^{0}C)
- Speed of response – medium (2 to 10 sec)

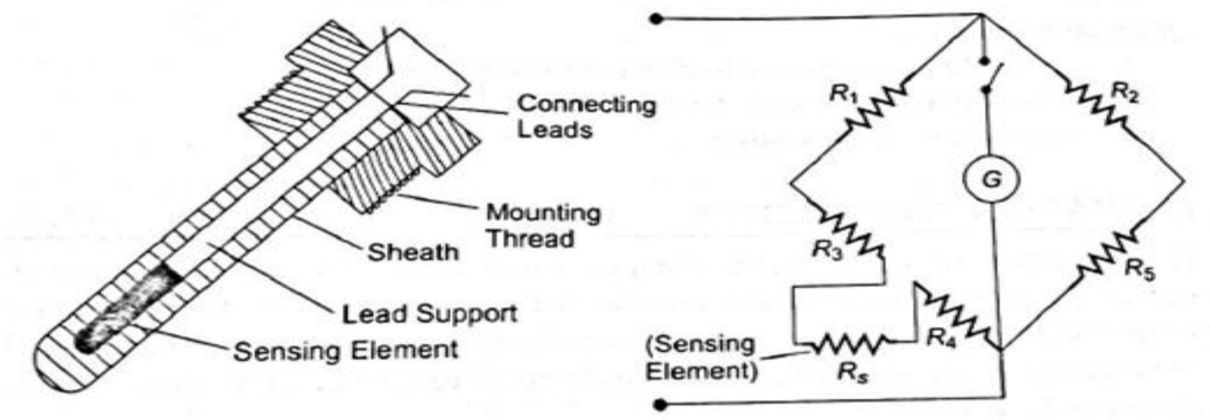


Fig : a) Industrial platinum resistance thermometer
b) Bridge circuit.

4.2.THERMISTOR:

Thermistor (THERMally sensitive resiSTOR) are non-metallic resistors (semiconductor material), made by sintering mixture of metallic oxides such as manganese, nickel, cobalt, copper and uranium.

Thermistors have a negative temperature coefficient (NTC), i.e. resistance decreases as temperature rises.

The smallest thermistors are made in the form of beads. Some are as small as 0.15mm (0.006 in) in diameter. These may come in a glass coating or sealed in the tip of solid glass probes. Glass probes have a diameter of about 2.5mm and a length which varies from 6- 50mm. The probes are used for measuring the temperature of liquids. The resistance ranges from 300ohms to 100Mohms.

Thermistors of disc, washer or rod forms are used when greater power dissipations are required.

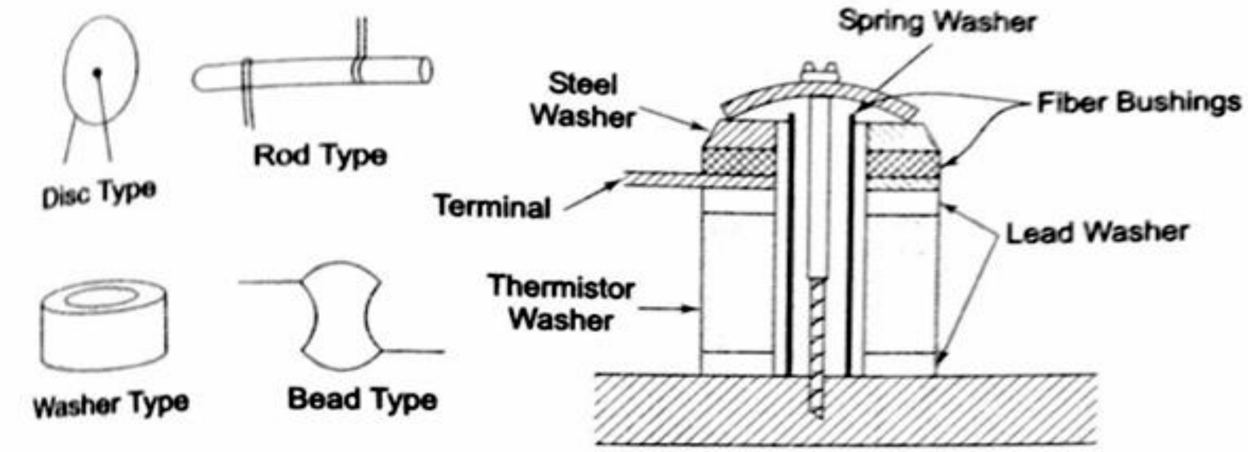


Fig : a) various configurations of thermistor. b) Bush – type thermistor.

Disc thermistor about 10mm in diameter, either self supporting or mounted on a small plate, are mainly used for temperature control. These thermistors are made by pressing thermistor material under several tons of pressure in a round die to produce flat pieces 1.25-25mm in diameter and 0.25 to 0.75 mm thick, having resistance values 1ohm to 1Mohm.

Washer thermistors are made like disc thermistors, except that a hole is formed in the centre in order to make suitable for mounting on a bolt.

Rod thermistors are extruded through dies to make long cylindrical units of 1.25, 2.75 and 4.25 mm in diameter and 12.5 -50 mm long. leads are attached to the end of rods. The resistance usually varies from 1 – 50kohms.The advantage of rod thermistors over other configurations is the ability to produce high resistance units with moderately high power handling capability.

Advantages of thermistor :

1. Small size and low cost.
2. Fast response over narrow temperature range.
3. Good sensitivity in the NTC region.
4. Cold junction compensation not required due to dependent of resistance on absolute temperature.
5. Constant and lead resistance problems not encountered to large R_{th}.

Limitations of thermistor:

1. Non – linearity in resistance vs temperature characteristics.
2. Unsuitable for wide temperature range.
3. Very low excitation current to avoid self – heating.
4. Need of shielded power lines, filters, etc. due to high resistance.

4.3. THERMOCOUPLE:

Principle: Thermocouples are temperature sensors that are made from two metal alloys. When the two metals are brought together to form a junction, a voltage is generated when there are temperature differences between them. This is known as the Seebeck effect.

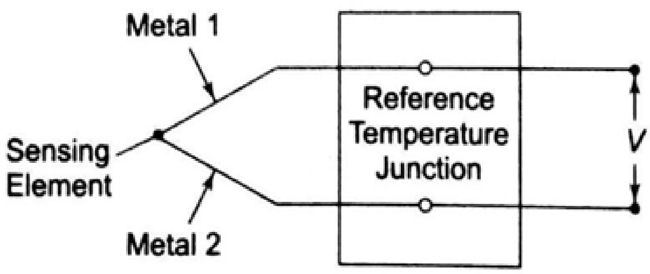


Fig.1 Basic Thermocouple Connection

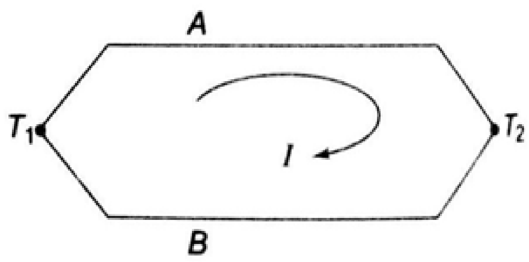


Fig.2 Current through two dissimilar Metals

Temperature measurement with thermocouple is based on the **seebeck effect.** A current will circulate around a loop made up of two dissimilar metal when the two junctions are at different temperatures.

Construction:

Two metal alloys are brought together to form a junction. One portion of the junction is placed on a source whose temperature is to be measured, while the other end is maintained at a constant reference via a temperature source. The temperature source is usually a solid-state temperature sensor.

One factor in temperature sensitivity is the kind of metal combinations used. A nickel-nickel combination has a temperature range of -50 to 1,410 degrees Celsisus, while a rhenium-rhenium can measure from 0 to 2,315 degrees Celsisus. Chromel-alumel, copper-constantan, and iron-constantan are the most common.

Advantages of Thermocouple:

1. Fast reaction time.
2. Small size.
3. They have the ability to accurately measure extreme temperatures, with ranges from 270 to 2,500 degrees Celsius.
4. Errors within 0.5 to 2 degrees Celsius.

Disadvantages of Thermocouple:

1. The signals produced in Thermocouple may be non-linear, and thus they need to be calibrated carefully.

Applications of Thermocouple:

1. They are used as hospital thermometers,
2. In diagnostics testing for vehicle engines.
3. Some gas appliances such as boilers, water heaters, and ovens use them as safety features; if the pilot light is out, the thermocouple stops the gas valve from operating.
4. They are also used as an aid in milk pasteurization, and as food thermometers.
5. In industry, they are valuable as probes and sensors.

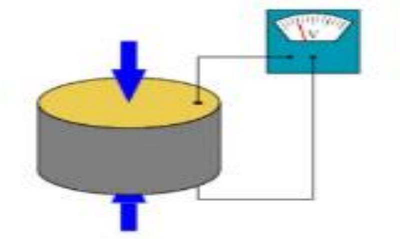
5. MEASUREMENT OF PRESSURE:

PIEZOELECTRIC TRANSDUCER:

Principle: The piezoelectric transducers work on the principle of PIEZOELECTRIC EFFECT.

When mechanical stress or force are applied to some materials along certain planes, they produce electric voltage.

This electric voltage can be measured easily by the voltage measuring instruments, which can be used to measure the stress or force.



A piezoelectric disk generates a voltage when deformed (change in shape is greatly exaggerated)

The voltage output obtained from the materials due to piezoelectric effect is very small and it has high impedance. To measure the output some amplifiers, auxiliary circuits and the connecting cables are required.

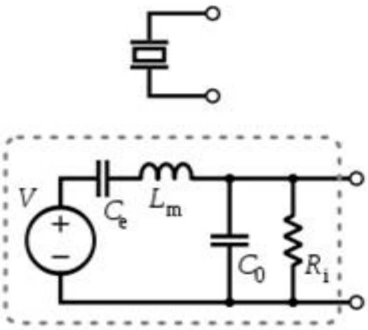
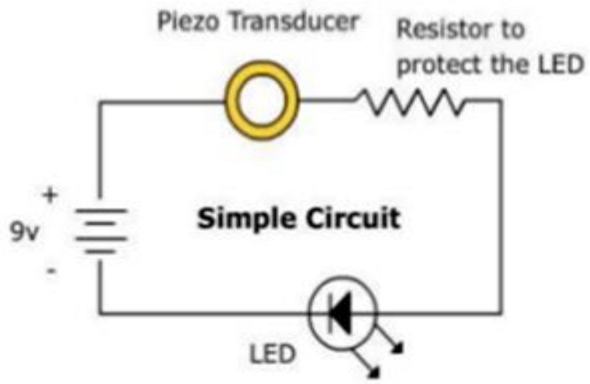


Fig. Piezoelectic sensor symbol

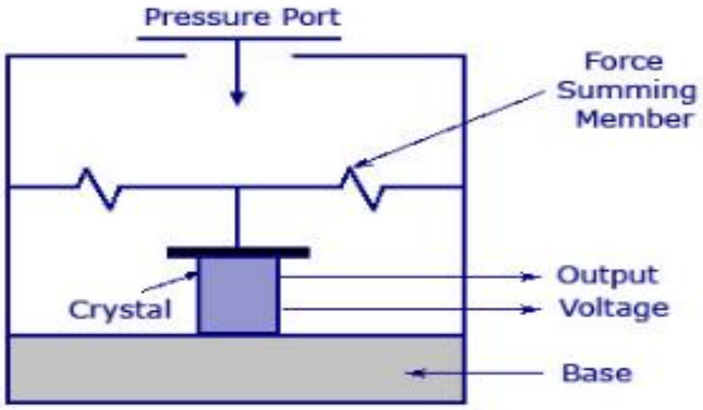


Materials used for the Piezoelectric Transducers:

There are various materials that exhibit piezoelectric effect. The materials used for the measurement purpose should posses desirable properties like

- Stability.
- High output.
- Insensitive to the extreme temperature and humidity.
- Ability to be formed or machined into any shape.
- But none of the materials exhibiting piezoelectric effect posses all the properties.
- The materials are Barium Titanate, Lead zircode titanium (PZT), Rochelle salt, Quartz.

Construction and Working:



Piezo-Electric Transducer

The figure shows a conventional piezoelectric transducer with a piezoelectric crystal inserted between a solid base and the force summing member.

If a force is applied on the pressure port, the same force will fall on the force summing member. Thus a potential difference will be generated on the crystal due to its property. The voltage produced will be proportional to the magnitude of the applied force.

Piezoelectric Transducer can measure pressure in the same way a force or an acceleration can be measured. For low pressure measurement, possible vibration of the amount should be compensated. For the pressure measuring quartz disc stack faces the pressure through a diaphragm and on the other side of this stack, the compensating mass followed by a compensating quartz.

Advantages:

- Very high frequency response.
- Self generating, so no need of external source.
- Simple to use as they have small dimensions and large measuring range.
- Barium titanate and quartz can be made in any desired shape and form. It also has a large dielectric constant. The crystal axis is selectable by orienting the direction of orientation.

Disadvantages:

- It is not suitable for measurement in static condition.
- Since the device operates with the small electric charge, they need high impedance cable for electrical interface.
- The output may vary according to the temperature variation of the crystal.
- The relative humidity rises above 85% or falls below 35%, its output will be affected. If so, it has to be coated with wax or polymer material.

Applications:

- Due to its excellent frequency response, it is normally used as an accelerometer, where the output is in the order of (1-30) mV per gravity of acceleration.
- The device is usually designed for use as a pre-tensional bolt so that both tensional and compression force measurements can be made.
- Can be used for measuring force, pressure and **displacement** in terms of voltage.

6. MEASUREMENT OF VELOCITY, ACCELERATION, VIBRATION

6.1 VELOCITY TRASDUCER

MEASUREMENT OF LINEAR VELOCITY:

- Velocity is the first derivative of displacement.
- Linear velocity is defined as the rate of change of the position vector with time at an instant in time.

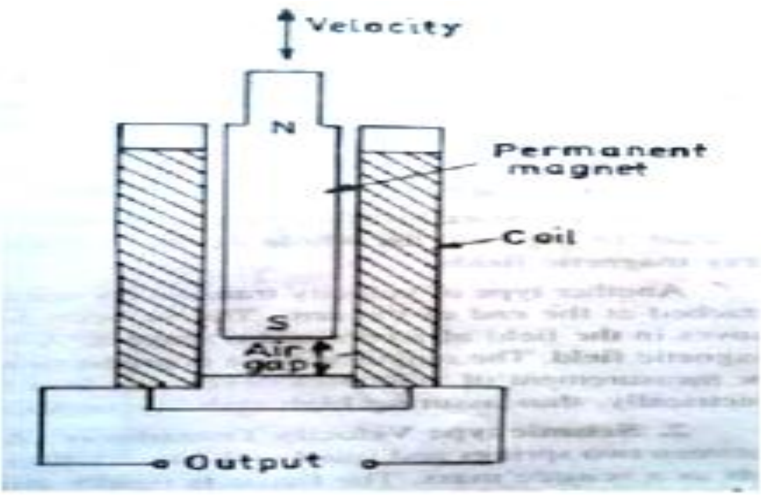
The methods used for measurement of linear velocity.

- Electro-magnetic transducers: This transducer utilizes the voltage produced in a coil on account of change in flux linkages resulting from change in reluctance.

- Moving magnet type
- Moving Coil Type

6.1.1 MOVING MAGNET TYPE TRANSDUCER:

- The sensing element is a rod type permanent magnet that is rigidly coupled to the device whose velocity is being measured.
- There is a coil surrounding the permanent magnet. The motion of the magnet induces a voltage in the coil and the amplitude of the voltage is directly proportional to the velocity.



- The polarity of the output voltage determines the direction of motion.
- For a coil placed in magnetic field the voltage generated is:

$$e_0 = B.A.N.v$$

where B=flux density ; Wb/m^2 ,

A= area of coil,

N= Number of turns of coil,

v= relative velocity of magnet with respect to coil.

Now, $e_0 = Kv$ where K=BAN= a constant

ADVANTAGES:

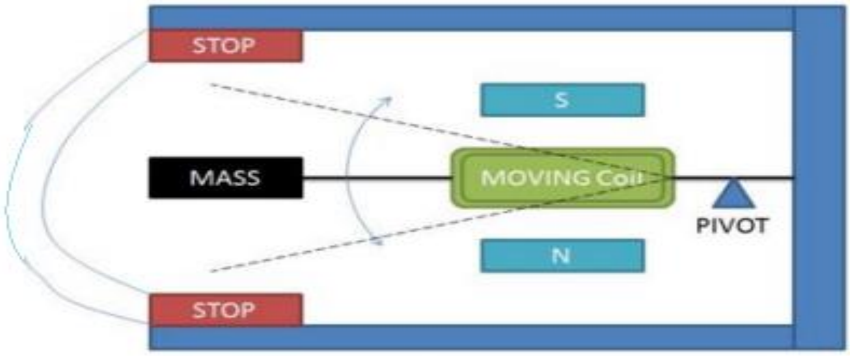
1. The maintenance requirements of these transducers are negligible, because there are no mechanical surfaces or contacts.
2. The output voltage is linearly proportional to velocity.

DISADVANTAGES:

1. The performance of these transducers is adversely affected by stray magnetic fields. These fields can cause noise.
2. The frequency response is usually limited and is stated.
3. These transducers are not very useful for measurement of vibrations because their calibration deteriorates as contact with steel tools etc. leads to progressive demagnetization.

6.1.2 MOVING COIL TYPE VELOCITY TRANSDUCER:

- It operates essentially through the action of a coil moving in a magnetic field. A voltage is generated in the coil which is proportional to the velocity of the coil.
- The velocity to be measured is applied to the arm and therefore the coil moves in the field of permanent magnet. A voltage is generated on account of motion of the coil in the magnetic field. The output voltage is proportional to the velocity.



ADVANTAGES:

1. This is a more satisfactory arrangement as the system now forms a closed magnetic circuit with a constant air gap, and the whole device is contained in an antimagnetic case which reduces the effects of stray magnetic fields.

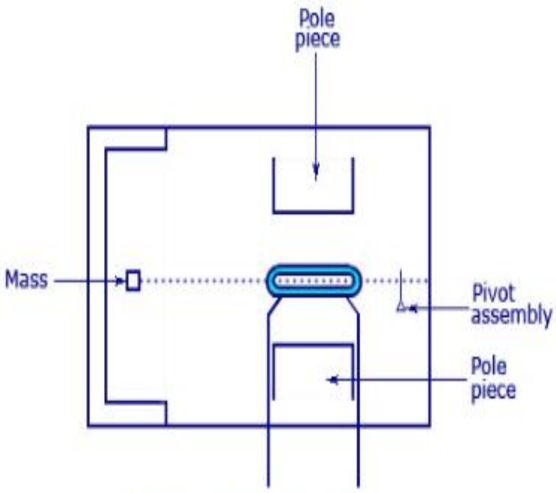
2. The instrument has permanent pole pieces which generate the magnetic field.

3. There is a pivoted arm on which a coil is mounted. There is a mass attached to the end of the coil. The whole device is contained in an antimagnetic case.

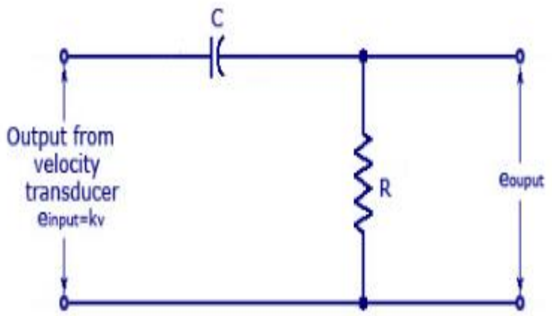
6.2 ACCELERATION TRANSDUCER

In **velocity transducer,** it is observed that velocity is a time derivation of displacement and displacement is the time integral of velocity. Similarly, we can also observe that acceleration is the time derivative of velocity.

Thus, a velocity transducer/sensor is enough to measure acceleration. For Acceleration Transducer, a differentiator circuit is added to the velocity transducer. The figure of an acceleration transducer is shown below.



Velocity Transducer Structure



Simple Differentitator for measurement of accilaration using a velocity transducer

Acceleration Transducer

The figure shows a velocity transducer with a moving coil placed in between two magnetic poles. In order to obtain a linear motion, a pivot is placed on the surface that supports the coil.

This device can be used to find both linear as well as non-linear acceleration. The output voltage is obtained according to the motion of the coil inside the magnetic field.

This output voltage is given as the input of a differentiator circuit. The output voltage of a differentiator can be written as

$$e_{\mathbf{output}} = e_{input} \ (R/(R+(1/jwc))$$

Over the frequency range where the value of resistance R is very small in comparison with reactance 1/wc of the capacitor, the equation can be written as

$$e_{\mathbf{output}} = e_{\mathbf{input}} \ R/(R+(1/jwc))$$

$$= kv \text{ Sin } (wt).jwCR$$

$$e_{\mathbf{output}} = kvw \text{ CR Cos } (wt)$$

The equation shows that the output voltage is the time derivative of the input and leads the input by 90 degrees. Accordingly, the output voltage is a measure of the displacement.

6.3 VIBRATION TRANSDUCER

Vibration measurement is an effective, reliable and non-intrusive technique to monitor the condition of the machine during startups, shutdowns and normal operations. Vibration sensors are considered as the heart of modern computerized SHM (Structure Health Monitoring) systems. The International Standards Organization (ISO) establishes universally acceptable metric units for machinery vibration.

Figure1shows the basic features of the vibration measurement scheme.

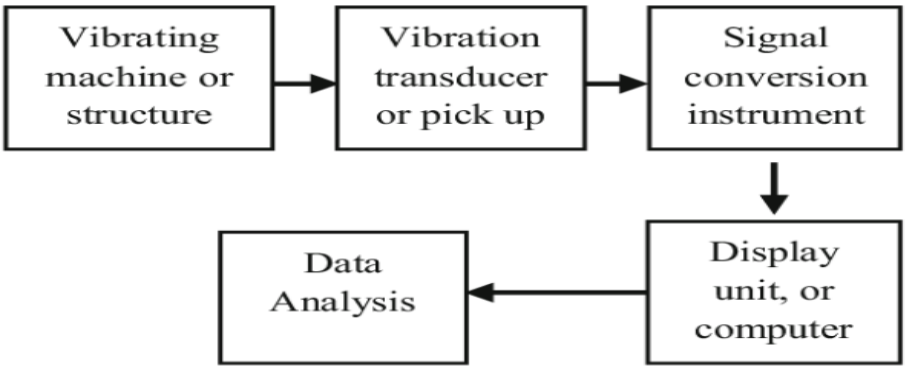


Fig.1 Basic principle of vibration measurement

A vibration sensor detects the vibration parameter from a vibrating body through its mechanical structure and converts these vibration signals to equivalent electrical signal.

This output signal is then analyzed by various signal processing and feature extraction techniques to measure the various characteristics of vibration such as amplitude, frequency, displacement, velocity, acceleration, phase and period.

Vibration pickup: The integration of the contact type transducer and another device to measure vibrations is called a vibration pickup.

A seismic instrument, commonly used vibration pickup, consists of a mass–spring–damper system mounted on the vibration.

The various vibration transducers used are:

1. Displacement transducers (Vibrometer/proximity probes)
2. Velocity transducers (Velometer)
3. Accelerometers
4. Laser Doppler Vibrometers

Applications of Vibration Transducer:

1. Vibration transducers or vibration sensors are used in the manufacturing of machinery.

2. Machines which have an important oscillation can be quickly identified to avoid major damages.

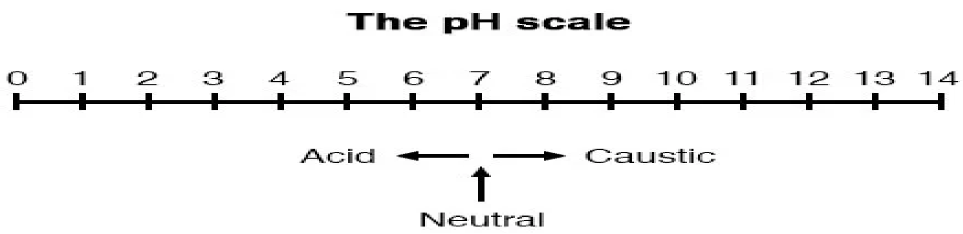
3. Vibration transducers can be connected to an easy-to-read display which allows the user to control the current vibration level, to check the production process.

4. Vibration transducers combined with a control system can automate completely a machine, accelerating production and preventing damages caused by strong vibrations and their expensive repair costs.

7. pH MEASUREMENT SIGNAL CONIDITIONING CIRCUITS

A very important measurement in many liquid chemical processes (industrial, pharmaceutical, manufacturing, food production, etc.) is that of pH: the measurement of hydrogen ion concentration in a liquid solution.

A solution with a low pH value is called an “acid,” while one with a high pH is called a “caustic.” The common pH scale extends from 0 (strong acid) to 14 (strong caustic), with 7 in the middle representing pure water (neutral).



pH is defined as follows: the lower-case letter “p” in pH stands for the negative common (base ten) logarithm, while the upper-case letter “H” stands for the element hydrogen. Thus, pH is a logarithmic measurement of the number of moles of hydrogen ions (H+) per liter of solution.

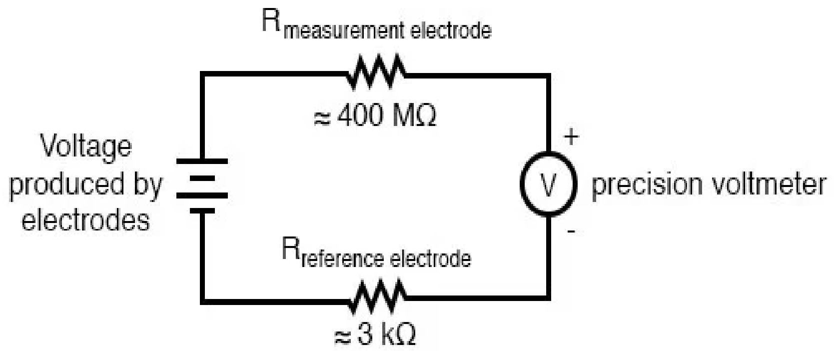


Fig.1 Equivalent circuit diagram of a typical pH probe

pH can be **measured** by **measuring** the voltage produced between two special electrodes immersed in the liquid solution. This provides a point of continuity for a complete **circuit** so that the voltage produced across the thickness of the glass in the **measurement** electrode can be **measured** by an external voltmeter.

This voltage appears across the thickness of the glass, placing the silver wire on one side of the voltage and the liquid solution on the other.

The reference electrode’s purpose is to provide the stable, zero-voltage connection to the liquid solution so that a complete circuit can be made to measure the glass electrode’s voltage. While the reference electrode’s connection to the test liquid may only be a few kilo-ohms, the glass electrode’s resistance may range from ten to nine hundred mega-ohms, depending on electrode design.