CHAPTER 6

Unit - V

Sensors and Transducers

Syllabus :

Working of sensors and transducers, Selection criteria for transducers, Active and passive transducers, Inductive, Capacitive, Resistive pressure and piezoelectric transducers, Thermocouple and proximity sensors, Photodiode and phototransistor transducer.

6.1 Introduction :

- Instrumentation has become the heart of the industrial applications because instrumentation facilitates system automation.
- Instrumentation is being used in industry on a large scale since 1930.
- With the introduction of electronics, availability of reliable electrical equipments, sophisticated monitoring systems etc., the use of instrumentation increased to a great extent in the last three or four decades.

6.1.1 Basic Instrumentation System :

The block diagram of a generalized instrumentation system is shown in Fig. 6.1.1. It consists of the following blocks :

1. A transducer
2. A signal conditioner
3. The display or read out devices
4. An electrical power supply
5. Data transmission and data presentation element.

Measurand :

The input to the instrumentation system is the physical quantity which is to be measured, such as pressure, temperature, displacement, force, acceleration etc. Such a quantity is called as the input measurand.

Transducer :

A transducer converts the measurand into an equivalent electrical signal. The transducer is a device which is capable of converting the physical quantity into a proportional electrical quantity such as voltage or current.

Signal conditioner :

The signal conditioner operates on the transducer output signal and makes it suitable (compatible) for control, recording and display operations.

The signal conditioner performs one or more of the following functions :

1. Amplification to increase the amplitude
2. Modulation
3. Filtering
4. Analog to digital conversion

Data transmission element :

The data transmission element provides the transmission path or transmission channel overwhich we can send the signal from signal conditioner to the rest of the instrumentation system. Examples of data transmission elements are as follows :

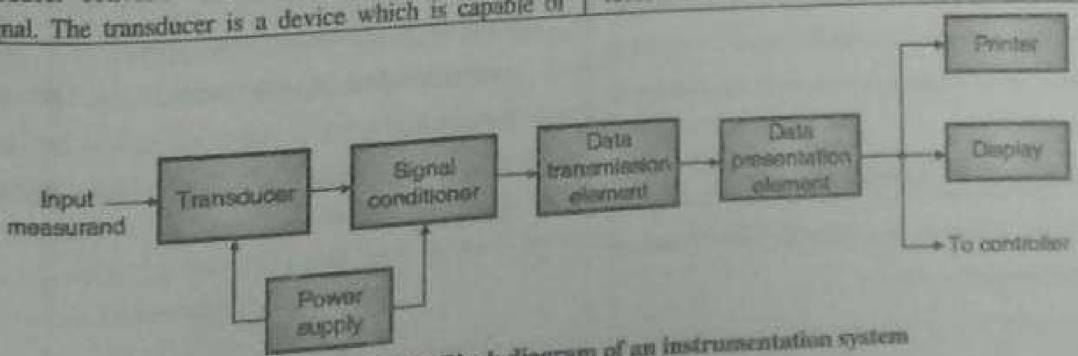
1. Electric cables 2. Pneumatic pipes 3. Radio links

Data presentation element :

This stage comes after the data transmission unit. It carries out the functions such as amplification/attenuation, demodulation, filtering, analog to digital conversion. Output of data presentation element is applied to the printer and display units and it is also used by the controller to control certain parameters.

Printer, display units :

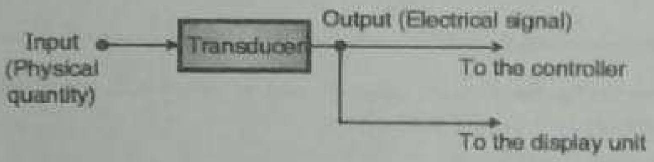
These units are also called as the read out devices. The display unit will display the value of measurand with the help of analog meters or digital display. The printer can be used to print the displayed quantity in order to preserve data, or maintain the records.



(B-625) Fig. 6.1.1 : Block diagram of an instrumentation system

6.1.2 Transducer : I-Scheme : W-18, S-19

- Transducer is a device which converts a physical quantity to be measured into an equivalent electrical signal (voltage or current).
- The physical quantity to be measured can be temperature, pressure, displacement, flow, vibration etc.
- The electrical signal obtained from the transducer can be used to control the physical quantity automatically and/or to display the same, as shown in Fig. 6.1.2.



(B-626) Fig. 6.1.2 : Transducer

6.1.3 Sensors :

- A sensor is defined as a device that detects and responds to some type of input from the physical environment e.g. temperature, pressure etc.
- The output is generally a signal that is converted to human readable display at the sensor location.

Difference between transducer and sensor :

- A sensor is almost always a transducer but a transducer is not necessarily a sensor.
- In today's world these two terms are used in various contexts interchangeably. But they are not the same.
- A sensor is a body which reacts to a physical, chemical or biological condition. It senses. It can be considered as detector.
- A classic example of sensor is a thermocouple.
- But a transducer is more than a sensor. It consists of a sensor / actuator alongwith a signal conditioning circuit.
- Thus the output from a sensor may or may not be meaningful. i.e. most of the times it needs to be conditioned and converted into various other forms, whereas the output of a transducer is always meaningful.

6.2 Classification of Transducers :

Transducers can be classified into different types based on various criteria. The criteria are as follows :

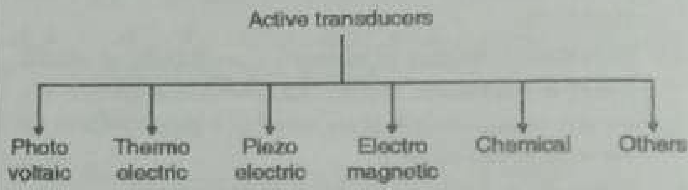
1. Depending on the quantity to be measured.
2. Depending on the principle of operation.
3. Depending on the application area and
4. Depending on whether an external source of excitation is required or not.

- The last criteria of classification gives rise to the terms called "Active transducers" and "Passive transducers".

6.2.1 Active Transducers :

I-Scheme : S-19

- These transducers do not need any external source of power for their operation. Therefore they are also called as self generating type transducers. The active transducers can be further classified as shown in Fig. 6.2.1.
- The active transducers are self generating devices which operate under the energy conversion principle.

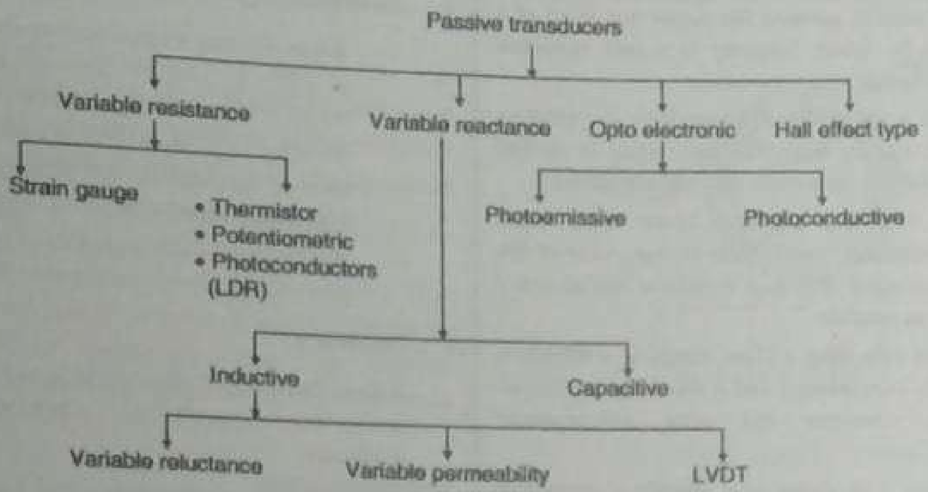


(B-627)Fig. 6.2.1 : Classification of active transducers

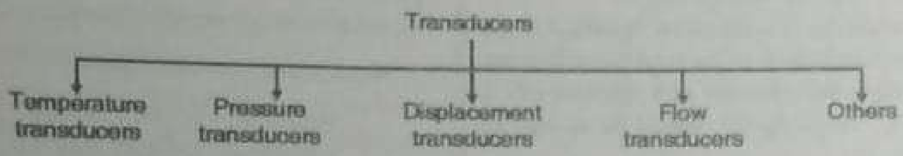
- At the output of active transducers we get an electrical output signal which is proportional to the input quantity of transducer e.g. temperature to electric potential, without any external source of energy being used.

6.2.2 Passive Transducers : I-Scheme : W-18

- These transducers need external power supply for their operation. So they are not "self generating type" transducers.
- A DC power supply or an audio frequency generator is used as an external power source to the passive transducers.
- These transducers produce the output signal in the form of variation in resistance, capacitance or some other electrical parameter which is proportional to the input quantity to be measured.
- Passive transducers are further subdivided as shown in Fig. 6.2.2.



(B-628)Fig. 6.2.2 : Classification of passive transducers



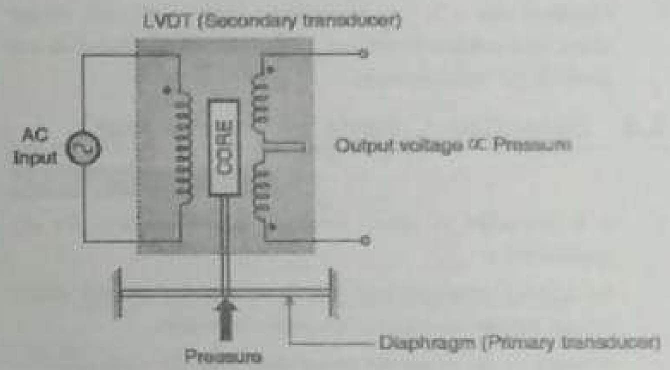
(B-629)Fig. 6.2.3 : Classification based on quantity to be measured

Comparison of active and passive transducers :

Sr. No.	Active transducers	Passive transducers
1.	Do not need the external power supply for operation.	They need external power supply for their operation.
2.	These are self generating transducers. They produce voltage or current proportional to the physical quantity to be measured.	These transducers produce variation in resistance, capacitance or inductance in response to the physical quantity being measured.
3.	Examples : Thermocouple, photo voltaic sensors such as photocell, piezoelectric transducers.	Examples : Thermistors, LDR, LVDT, Phototransistor.

6.2.3 Primary or Secondary Transducers :

- Some transducers contain the mechanical as well as electrical devices. The mechanical device converts the physical quantity to be measured into a mechanical signal. Such mechanical devices are called as the **primary transducers,** because they deal with the physical quantity to be measured.
- The electrical device then converts this mechanical signal into a corresponding electrical signal. Such electrical devices are known as the **secondary transducers.**



(B-630) Fig. 6.2.4 : Primary and secondary transducers

- Refer Fig. 6.2.4 in which the diaphragm acts as a primary transducer. It converts pressure (the quantity to be measured) into displacement (the mechanical signal).
- This displacement signal is then converted into electrical signal using LVDT. Hence LVDT acts as the secondary transducer.

6.3 Characteristics (Parameters) of a Transducer :

Some of the important characteristics of a transducer are as follows :

1. **Ruggedness :** It is the ability of a transducer to withstand overloads. A good transducer must have a high value of ruggedness.

2. **Linearity :** The relation between the output and input of a transducer should be linear. Linearity is a very important characteristics while selecting a transducer.
3. **Repeatability :** It is the ability of a transducer to reproduce the output signal exactly when the same input is applied multiple times under the same environmental conditions.
4. **Accuracy :** It is defined as closeness of the actual output produced by a transducer, to the ideal or true value of the quantity being measured. For any transducer the accuracy should be as high as possible.
5. **High stability and reliability :** There should be a minimum amount of error in measurement and it should be unaffected by temperature, vibrations and other environmental variations.
6. **Speed of response :** It shows how quickly a transducer responds to the changes in the quantity being measured. The speed of response should be as high as possible.
7. **Sensitivity :** The sensitivity of a transducer is defined as the output produced per unit change in the input quantity being measured. For example the sensitivity of a thermocouple is expressed in mV/°C. The sensitivity should be as high as possible.
8. **Dynamic range :** The operating range of the transducer should be wide so that we can use it over a wide range of measuring conditions.
9. **Physical size :** A transducer must have small size, proper shape and minimum volume so that it can be placed at any location for measurements.

6.4 Selection Criteria of Transducer :

I-Scheme : S-18, W-18

- It is important to select the right type transducer for any application.
- As a design engineer you will have to make the best choice among various transducers available in market.
- In order to do so certain parameters must be considered for comparison of the transducers.
- All the characteristics mentioned in the previous section must be considered while selecting a transducer.

1. Operating range :

The operating range of the selected transducer should be as per the requirements of the application. It should also provide a good resolution.

2. Sensitivity :

The sensitivity should be high in order to produce a sufficient output for even a small change in the quantity to be measured.

3. Frequency response :

The frequency response should be flat over the entire frequency of operation, so that all the frequency components are processed equally.

4. Environmental considerations :

- While selecting a transducer we should make sure that it is "fit" to survive and operate reliably in the environment in which it is supposed to work.
- We must know the effects of environmental parameters such as temperature, vibration, pressure, etc. on the transducer characteristics.
- A transducer which is capable of working reliably in the given working environment should only be selected.

5. Accuracy :

It should have a high accuracy so as to minimize all the errors arising due to repeatability, calibration problems, and low sensitivity.

6. Usage and Ruggedness :

The transducer should be rugged and work without any wear and tear over its expected life span.

7. Measurand characteristics :

- Measurand is the quantity being measured i.e. temperature, pressure, flow etc. A transducer must be selected based on which quantity is to be measured.
- The transducer selected to measure temperature should be sensitive to only temperature changes.
- It should not be insensitive to any other quantity such as pressure, vibration, displacement etc.

8. Electrical characteristics :

- Once the measurand is known, the next important factor in selecting a transducer is its expected electrical characteristics such as : type of excitation (AC or DC), type of output (analog or digital) impedance, whether amplification is needed or not etc.
- The transducer should not "load" the source physical quantity being measured. That means it should not draw high currents from the source i.e. input.
- That means there should not be any change in the value of quantity being measured, due to the introduction of a transducer.

9. Mechanical characteristics :

The next factor for transducer selection is its mechanical characteristics such as : shape of the transducer, its size and dimensions, mounting, provisions to make the internal and external connections and mechanical strength of the transducer.

10. Time span :

This factor indicates the expected time span over which a transducer should work reliably. The period over which a transducer gives output as per specifications is called as its "time span".

11. Cost and availability :

The other important deciding factor is the cost and availability of the transducer in market. It should be cost effective and readily available in market so that whenever required we can replace it. The transducer selected should not need frequent repairs and maintenance.

12. Compatibility :

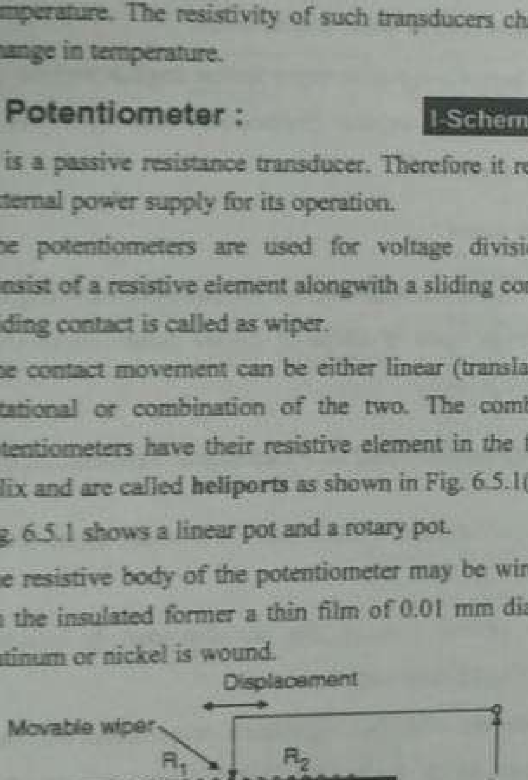
The transducer selected to measure a quantity should be compatible with the measuring system. The electrical characteristics of a transducer should match with those of the measuring system.

6.5 Resistive Transducer : I-Scheme : S-19

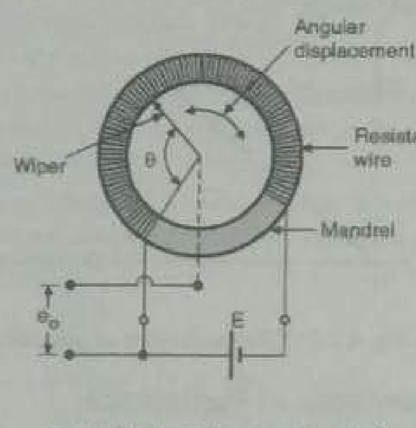
- We define a resistive transducer as the one the resistance of which changes due to change in the quantity to be measured. (such as displacement, pressure etc.).
- A strain gauge operates on this principle. Its resistance changes when strained. It is used for measuring displacement, force and pressure.
- Resistive transducers can also be used to measure temperature. The resistivity of such transducers change with change in temperature.

6.5.1 Potentiometer : I-Scheme : S-19

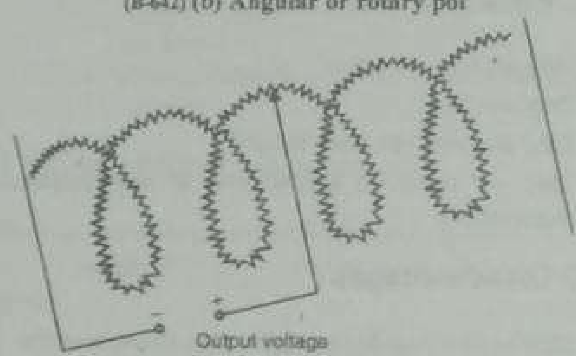
- It is a passive resistance transducer. Therefore it requires an external power supply for its operation.
- The potentiometers are used for voltage division. They consist of a resistive element alongwith a sliding contact. The sliding contact is called as wiper.
- The contact movement can be either linear (translational) or rotational or combination of the two. The combinational potentiometers have their resistive element in the form of a helix and are called **heliports** as shown in Fig. 6.5.1(c).
- Fig. 6.5.1 shows a linear pot and a rotary pot.
- The resistive body of the potentiometer may be wire wound. On the insulated former a thin film of 0.01 mm diameter of platinum or nickel is wound.



(a) Linear pot



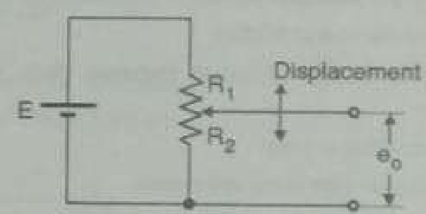
(B-642) (b) Angular or rotary pot



(B-2179) (c) Helipot (Rotational)

Fig. 6.5.1

Fig. 6.5.1(a) shows a linear potentiometer.



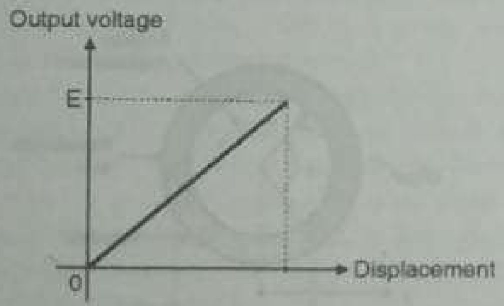
(B-2180) Fig. 6.5.2 : Translational potentiometer

Operation :

- Refer to Fig. 6.5.1(a) and Fig. 6.5.1(c). Here the movable wiper of the potentiometer is connected to the moving object.
- As the attached object moves, the wiper will change its position. The output voltage e_o is given by,

$$e_o = \frac{R_2}{R_1 + R_2} \times E \quad ...(6.5.1)$$

- Thus with change in the position of the object, the wiper position changes. This will change the value of R_2.
- The total resistance ($R_1 + R_2$) remains constant. Thus output voltage "e_o" is proportional to the displacement of the object.
- The output voltage varies linearly with displacement as shown in Fig. 6.5.3. The sensitivity is constant under ideal conditions, and the output is faithfully reproduced. Fig. 6.5.3 shows the characteristics of potentiometers.



(B-2181) Fig. 6.5.3 : Characteristics of potentiometers

6.5.2 Advantages of Resistance Potentiometers :

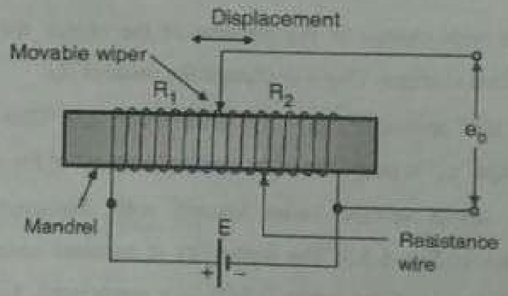
1. They are easy to operate.
2. They are cheap.
3. Their electrical efficiency is high.
4. They are useful for measurement of large amplitudes of displacement.

6.5.3 Disadvantages :

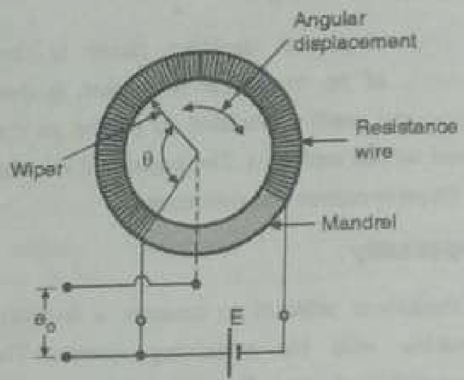
1. They require large force to move their sliding contacts.
2. There are some problems with the sliding contacts such are they wear out, generate noise and become misaligned. This reduces the life of the transducer. However the use of roller contact wiper increases the life of transducer by 40 times.
3. Wear and tear due to friction
4. They have a poor dynamic response (they are slow to respond)
5. Their resolution is poor.
6. Susceptible to vibrations and shocks
7. They produce noise alongwith the desired signal.

6.5.4 Variable Resistance Transducers for Displacement Measurement :

- The sensing element used for this type of transducer is basically a resistance potentiometer, as shown in Fig. 6.5.4.
- The shaft of the potentiometer is linked to the point under measurement. The contact motion can be rotary or linear or combination of the two.



(a) Linear motion



(b) Angular motion

(B-642) Fig. 6.5.4

- As discussed earlier, the output voltage will be directly proportional to the displacement of the wiper.

6.5.5 Measurement of Angular Displacement :

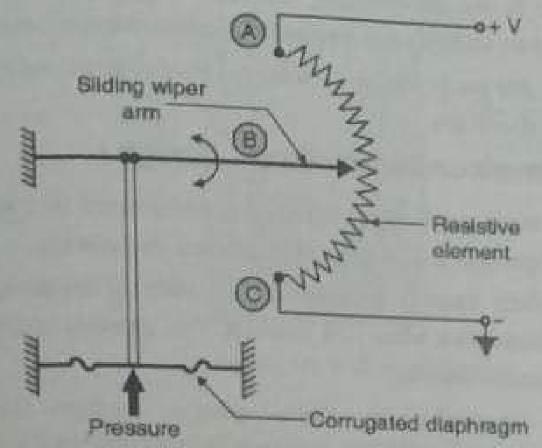
- The use of a potentiometric transducer for the measurement of angular displacement is as shown in Fig. 6.5.1(b). The principle of operation is same as that of the transducer for measurement of linear displacement.
- But here the movable wiper has an angular motion. Angle θ represents the angular displacement and "e_o" is the voltage proportional to it.

Materials used :

The resistance wire used for the potentiometric displacement transducers is made of alloys of copper nickel, nickle-chromium and silver-platinum.

6.5.6 Potentiometric Pressure Transducer :

- The potentiometric transducer for pressure measurement is as shown in Fig. 6.5.5.
- The sliding arm of the potentiometer is coupled to a corrugated diaphragm.
- Therefore, with the application of pressure, the diaphragm moves which forces the sliding wiper arm to change its angular position.
- This will change the voltage between points B and C as shown in Fig. 6.5.5.
- Thus the transducer produces a voltage which is proportional to the pressure.



(B-655)Fig. 6.5.5 : Potentiometric pressure transducer

6.6 Strain Gauge Transducer :

Principle of operation of a strain gauge :

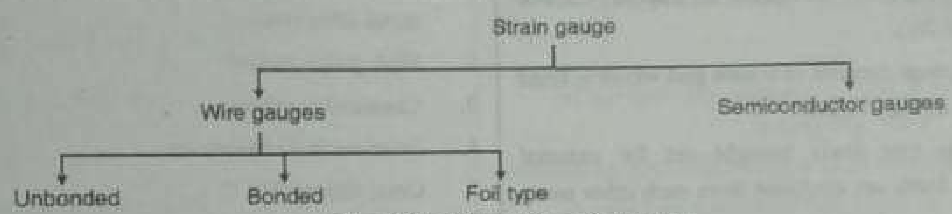
- Strain gauge is a passive, resistive transducer which converts the mechanical elongation and compression into a proportional resistance change.
- This change in resistance takes place due to variation in length and cross sectional area of the gauge wire, when an external force acts on it.
- The characteristics of a strain gauge are described in terms of its sensitivity which is also called as gauge factor, of the strain gauge.
- The Gauge Factor (G.F.) is defined as the unit change in resistance per unit change in length of the strain gauge wire.
- Mathematically,

$$G.F. = \frac{dR / R}{dl / l} \quad ...(6.6.1)$$

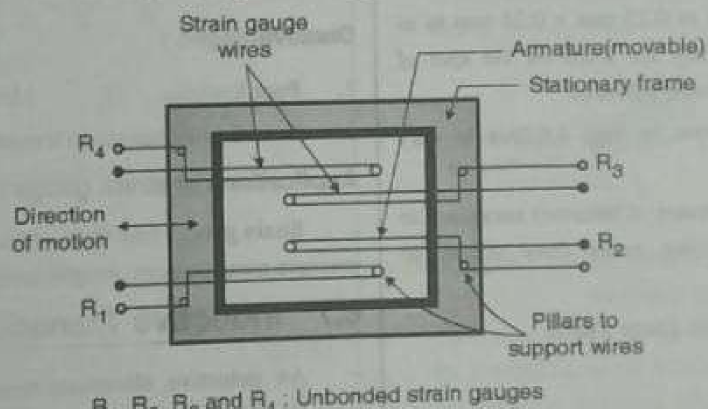
Where, R = Resistance of the gauge wire (Ω),
dR = Change in resistance of wire (Ω),
l = Length of gauge wire in unstressed condition (in meter).
dl = Change in length of the wire when stressed (in meter).

6.6.1 Types of Strain Gauges :

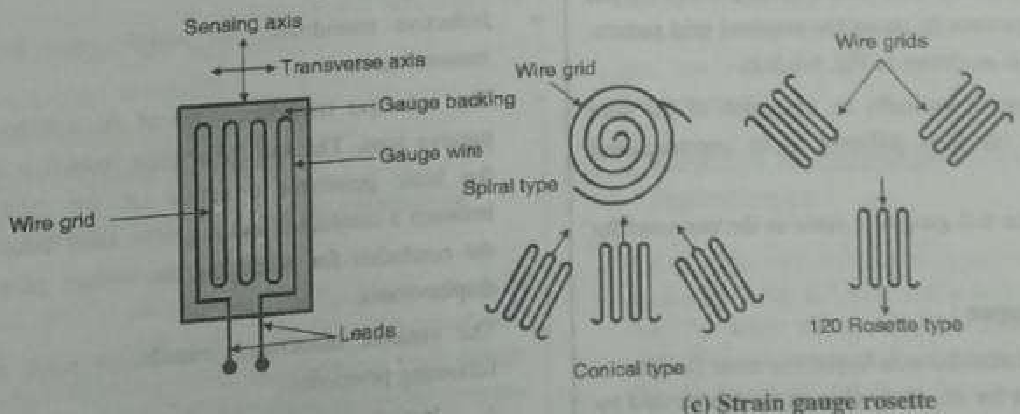
The types of strain gauges are as listed in Fig. 6.6.1.



(B-658)Fig. 6.6.1 : Types of strain gauges



(B-659)Fig. 6.6.2(a) : Unbonded strain gauge



(b) Bonded strain gauge (c) Strain gauge rosette

(B-660)Fig. 6.6.2 : Various types of strain gauges

6.6.2 Unbonded Strain Gauge :

- The gauge wire is stretched between two terminals and fitted on a stationary frame. The construction of an unbounded strain gauge is as shown in Fig. 6.6.2(a).
- The stationary frame consists of a movable armature which is supported in its centre.
- Due to the movement of armature in one direction, the gauge wire is stretched and as a result of this there is a change in its resistance.
- However the unbonded strain gauges are not very commonly used. Usually four such gauges are used in four arms of a Wheatstone bridge for measuring the resistance change.

6.6.3 Bonded Strain Gauges :

- Bonded strain gauges are of different types as shown in Fig. 6.6.2(b). These gauges are bonded using a cement to the surface.
- These gauges find wide applications in many fields such as mechanical, biomedical, structural and industrial fields.
- The shape of the wire grid can be square, rectangular, circular as shown in Fig. 6.6.2(c).
- The bonded strain gauge consists of a wire grid which is fixed on a base as shown in Fig. 6.6.2(b).
- The wire grid has two leads brought out for external connections. These leads are insulated from each other using sleeves.
- These gauges may be as small as 0.25 mm × 0.25 mm to as large as 2.5 cm × 1.5 cm. They are fixed on the spot of measurement with the help of some adhesive.
- The strain gauge rosette shown in Fig. 6.6.2(c) is very important.
- While measuring the biaxial stresses, it becomes necessary to measure two strains or in some cases three strains to determine the stress.
- This can be achieved by the strain gauge rosette.

6.6.4 Foil Gauges :

- The modern strain gauges are formed by rolling out a thin foil of the resistive material and then cutting away parts of the foil by a photoetching process to create the required grid pattern. The foil strain gain is as shown in Fig. 6.6.3(a).
- The foil strain gauge is basically an extension of the wire gauge in principle but it is different in its constructional features.
- The material used for foil gauges is same as the one used for the wire gauges.

Advantages of foil gauges :

1. The foil is more thin than the wire hence it is more flexible.
2. It gives a larger area for the dissipation of heat generated by current flowing through the gauge.
3. Due to the photoetching technique used, it is possible to produce multiple foil gauges of identical characteristics.
4. The foil gauge has much smaller dimensions as compared to the other types.

6.6.5 Semiconductor Strain Gauge :

- If a metal conductor is stretched or compressed, its resistance changes due to change in its length and its diameter.
- Similarly there is a change in the value of resistivity of a semiconductor when it is strained. This property is called as the piezoresistivity.
- The semiconductor strain gauges operate on the **piezoresistive property** of doped silicon and germanium.
- They are fabricated from single crystals of silicon and germanium. The resistance of the semiconductor gauge changes mainly due to the changes in the resistivity of the semiconductor material, itself.

Advantages of semiconductor gauge :

1. Change in resistance is much higher than that of conventional metal alloy types.
2. High gauge factor.
3. Chemical inertness.
4. Freedom from hysteresis.
5. Good fatigue life.
6. Small size.

Disadvantages :

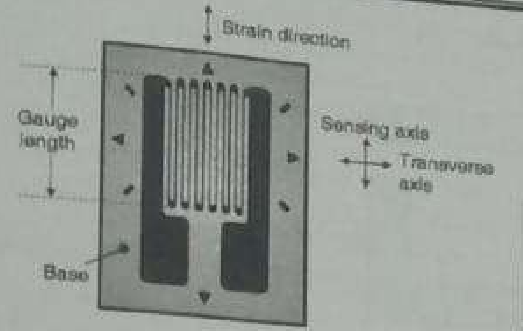
1. Poor linearity. 2. More expensive.
3. Sensitive to changes in temperature.

Applications of strain gauge :

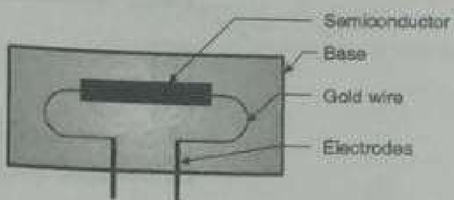
Strain gauges find their application in the applications such as pressure measurement, weight measurement etc.

6.7 Inductive Transducers :

- An inductive electromechanical transducer is a transducer which converts the physical movement into a proportional change in inductance.
- Inductive transducers are mainly used for displacement measurement.
- The inductive transducers are of the self generating or the passive type. The self generating inductive transducers use the basic generator principle i.e. the relative movement between a conductor and magnetic field induces a voltage in the conductor for producing the voltage proportional to the displacement.
- The variable inductance transducers work on one of the following principles :
  1. Variation of self inductance.
  2. Variation of mutual inductance.



(B-661) (a) Foil strain gauge



(B-661(a))(b) Semiconductor strain gauge

Fig. 6.6.3

6.7.1 Transducers Working on the Principle of Variation of Self Inductance :

Let us consider an inductive transducer having N turns and reluctance R. When current i is passed through the transducer, it produces a flux given by the following expression :

$$\phi = \frac{N \times i}{R}$$

- Differentiating both sides with respect to t,

$$\frac{d\phi}{dt} = \frac{N}{R} \times \frac{di}{dt} + Ni\left(\frac{-1}{R}\right)^2 \times \frac{dR}{dt}$$

- If the current changes rapidly then,

$$\frac{d\phi}{dt} = \frac{N}{R} \times \frac{di}{dt}$$

- The emf induced in a coil is given by,

$$e = N \times \frac{d\phi}{dt} = N \times \frac{N}{R}\frac{di}{dt} = \frac{N^2}{R} \times \frac{di}{dt}$$

- The self inductance is given by,

$$L = \frac{e}{di/dt} = \frac{N^2}{R}$$

The reluctance of the magnetic circuit is $R = \frac{l}{\mu A}$

where, l : Length of coil in m.

μ : Effective permeability in H/m.

A : Cross section area in m^2.

$$\therefore L = \frac{N^2}{l/\mu A} = \frac{N^2 \mu A}{l} = N^2 \mu G \quad ...(6.7.1)$$

where, $G = \frac{A}{l}$ is called as geometric form factor.

- From Equation (6.7.1) we can see that the self inductance of the inductive transducer may vary due to :

1. Change in the number of turns N.
2. Change in the geometric configuration.
3. Change in the permeability of magnetic circuits.

Change in self inductance with change in number of turns N :

- From Equation (6.7.1) we can see the output may vary with the variation in the number of turns. As inductive transducers are mainly used for displacement measurement, with change in the number of turns the self inductance of the coil changes inturn changing the displacement.

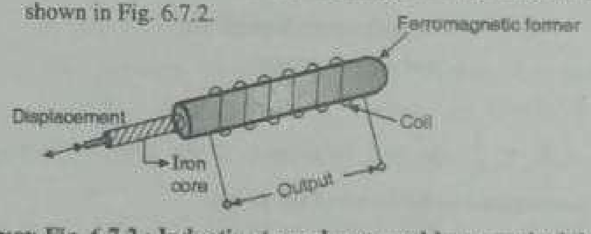
- Fig. 6.7.1 shows transducers used for linear and angular displacement. Fig. 6.7.1(a) shows an air cored transducer for the measurement of linear displacement and Fig. 6.7.1(b) shows an iron cored transducer used for angular displacement measurement.

(a) Air core transducer (b) Iron core transducer

(B-2182) Fig. 6.7.1

Change in self inductance with change in permeability :

- An inductive transducer that works on the principle of change in self inductance of coil due to change in the permeability is shown in Fig. 6.7.2.

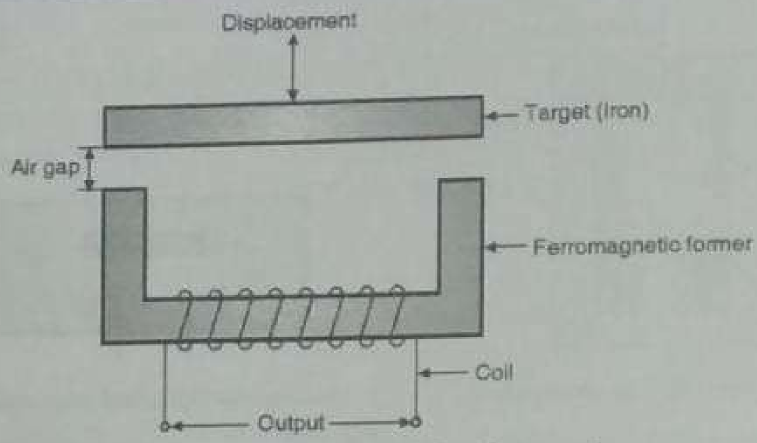


(B-2183) Fig. 6.7.2 : Inductive transducer working on principle of variation in permeability

- As shown in Fig. 6.7.2 the movable iron core is surrounded by a winding. If the iron core is inside the winding then the permeability increases otherwise permeability decreases. This causes the self inductance of the coil to increase or decrease depending on the permeability. The displacement to be measured using this transducer will change the position of iron core and therefore we get an output proportional to the displacement.

6.7.2 Variable Reluctance Inductive Transducer :

- Fig. 6.7.3 shows a variable reluctance inductive transducer.
- As shown in Fig. 6.7.3 the coil is wound on the ferromagnetic iron. The target and core are not in direct contact with each other. They are separated by an air gap.
- The displacement that is to be measured is applied to the ferromagnetic core.



(B-2184) **Fig. 6.7.3 : Variable reluctance inductive transducer**

- The reluctance of the magnetic path is on dependent the size of the air gap.
- The self inductance of a coil is given by.

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

Where, N : Number of turns,

R : Reluctance of the coil.

R_i : Reluctance of iron parts,

R_a : Reluctance of air gap.

- The reluctance of iron parts is negligible.

$$\therefore L = \frac{N^2}{R_a}, \quad \text{But } R_a = \frac{l_a}{\mu_0 A_a}$$

l_a : Length of air gap.

μ_0 : Permeability

A_a : Area of flux path through air.

μ_0 and A_a are constant.

$\therefore R_a \propto l_a$

$\therefore L \propto \frac{1}{l_a}$ i.e. self inductance of the coil is inversely proportional to the length of the air gap.

- When the target is close to the core, the air gap is small. Hence the self inductance is large. But when the target is away from the core, the air gap is large. So reluctance is also large. This results in decrease in self inductance. i.e. small self inductance.
- Thus, the inductance of this transducer is a function of the distance of the target from the core. Displacement changes with the length of the air gap, the self inductance is a function of the displacement.

6.7.3 Transducers Operating on the Principle of Change in Mutual Inductance :

- Multiple coils are required for inductive transducers that operate on the principle of change in mutual inductance.
- The mutual inductance between two coils is given by,

$$M = K\sqrt{L_1 L_2}$$

Where, M : Mutual inductance,

K : Coefficient of coupling.

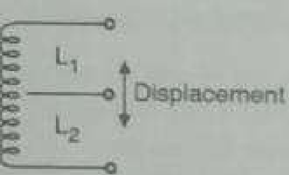
L_1 : Self inductance of coil 1,

L_2 : Self inductance of coil 2.

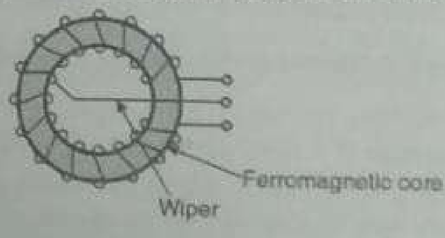
- By varying the self inductance or the coefficient of coupling the mutual inductance can be varied.
- The mutual inductance can be converted to self inductance by connecting the coils in series. The self inductance then varies from $L_1 + L_2 - 2M$ to $L_1 + L_2 + 2M$. One coil is stationary while the other coil is movable.
- Depending on the displacement of the movable coil the mutual inductance changes. The self inductance is constant.

6.7.4 Differential Output Transducers :

- Usually the change in self inductance ΔL for inductive transducers is not sufficient for the detection of stages of an instrumentation system. But if the instrumentation responds to ΔL or ΔM and not to $L + \Delta L$ or $M + \Delta M$ then the accuracy and sensitivity will be high. The transducer can be designed inorder to produce two outputs. One output corresponds to the increase in self or mutual inductance and the other output corresponds to the decrease in self or mutual inductance.
- The preceding stages of the system will measure the difference between the two outputs i.e. $2\Delta L$ or $2\Delta M$. Such an output is called as **differential output.**
- The differential arrangement makes use of a coil that is divided in two parts as shown in Figs. 6.7.4(a) and (b).



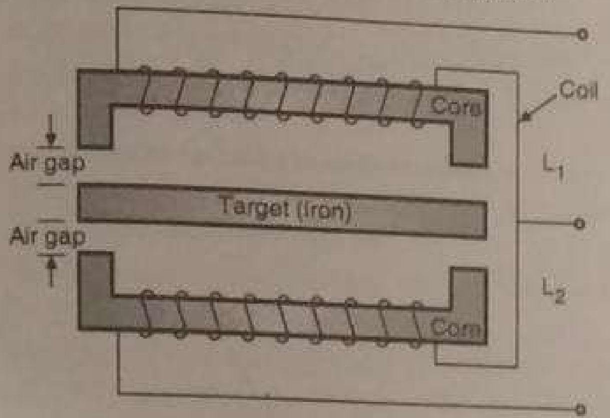
(a) Linear differential output transducer



(b) Angular differential output transducer

(B-2185) **Fig. 6.7.4**

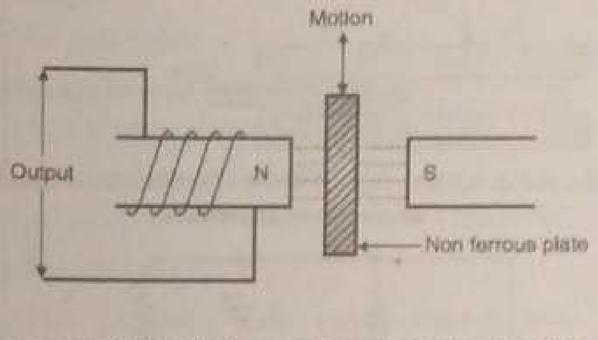
- In response to displacement, the inductance of one part increases from L to L + ΔL while the inductance of the other part decreases from L to L – ΔL. The difference of two is measured so to get output 2 ΔL. This will increase the sensitivity and minimize error.
- Fig. 6.7.5 shows an inductive transducer that provides differential output. Due to variation in the reluctance, the self inductance of the coil changes. This is the principle of operation of differential output inductive transducer.



(B-2186) **Fig. 6.7.5 : Differential output**

6.7.5 Eddy Current type Inductive Transducers :

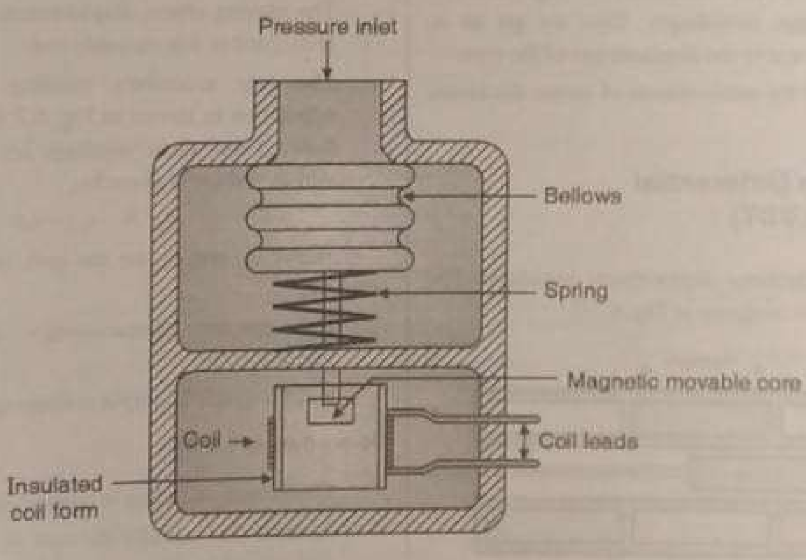
- It is a self generating type of transducer as shown in Fig. 6.7.6.
- A non-ferrous plate moves in a direction perpendicular to the lines of flux of a magnet.
- The generated eddy currents are proportional to the velocity of the plate. The eddy currents will set up the magnetic field in a direction which is opposite to the magnetic field which produces these currents.
- The output is proportional to the change in eddy current of the plate. As the air gap between the magnet and plate is constant the characteristics of transducer are linear.



(B-2212) **Fig. 6.7.6 : Eddy current type inductive transducer**

6.7.6 Pressure Inductive Transducer :

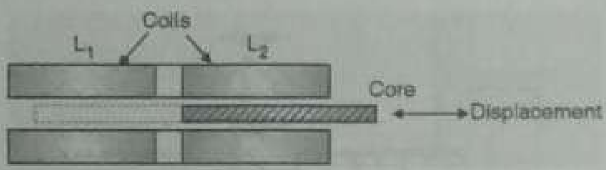
- Fig. 6.7.7 shows a pressure inductive transducer.
- In such a transducer the pressure change causes change in the inductance of the sensing element.
- As the pressure passes through the inlet, it is acting on the movable magnetic core. It causes an increase in the inductance of the coil. As the pressure applied changes, the inductance of the coil also changes proportionally.
- The change in inductance can be used further with the help of an electrical signal using an ac bridge.
- The transducer is called as variable reluctance sensor or magnetic pick up transducer if there is a change in the induced voltage.



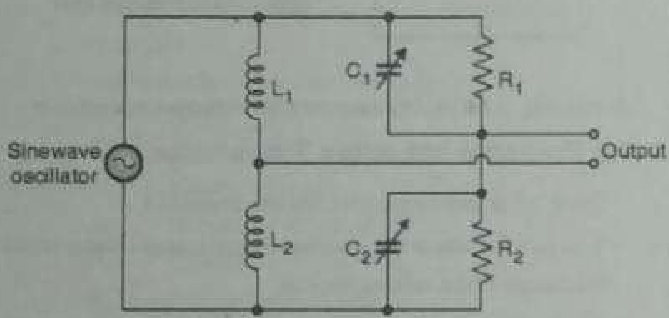
(B-2187) **Fig. 6.7.7 : Pressure inductive transducer**

6.7.7 Variable Reluctance (Inductive) Transducer for Displacement Measurement :

- The construction of a variable reluctance transducer is as shown in Fig. 6.7.8(a).



(B-2188)**Fig. 6.7.8(a) : Construction of a variable reluctance displacement transducer**



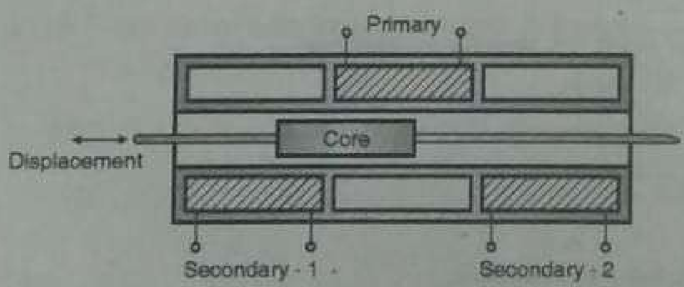
(B-2189)**Fig. 6.7.8(b) : Detector circuit of variable reluctance displacement transducer**

Principle of operation :

- Two coils L_1 and L_2 are wound continuously over a cylindrical bobbin. A core of ferromagnetic material can move within the bobbin.
- As the core moves due to the displacement of the object attached to it, the self inductance of the coils i.e. L_1 and L_2 will change.
- The output voltage "e_o" of the Wheatstone's bridge shown in Fig. 6.7.8(b) will change accordingly. Thus we get an ac output voltage proportional to the displacement of the core.
- This transducer is used for measurement of stress, thickness, vibration and shock.

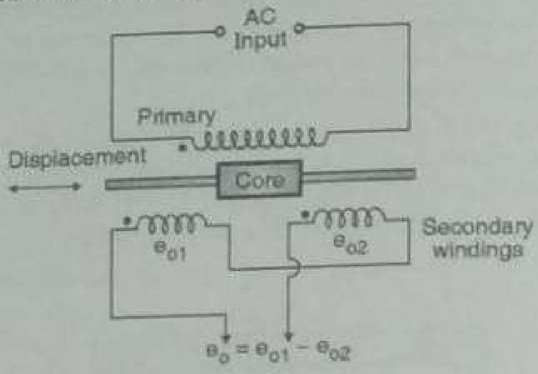
6.7.8 Linear Variable Differential Transformer (LVDT) :

- LVDT is a variable inductance displacement transducer. The construction of LVDT is as shown in Fig. 6.7.9.

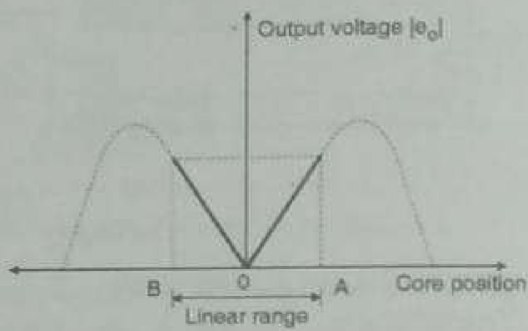


(B-2190)**Fig. 6.7.9 : Construction of LVDT**

Construction of LVDT :



(a) Connections of LVDT windings



(b) Transfer characteristics of LVDT

(B-2191)**Fig. 6.7.10**

- Refer to Fig. 6.7.10(a), which shows that the LVDT consists of a primary winding and two identical secondary windings. These windings are axially placed and wound on a cylindrical coil former.
- A rod shaped magnetic core is positioned centrally inside the coil assembly. This rod provides a low reluctance path for the magnetic flux which links the coils (windings).
- The moving object, displacement of which is to be measured, is coupled to this movable rod.
- The two secondary winding are connected in series opposition as shown in Fig. 6.7.10(a). Therefore the voltages induced into these windings are of opposite polarities. The output voltage is given by,

$$e_o = e_{o1} - e_{o2} \quad ...(6.7.2)$$

Where e_{o1} and e_{o2} are the emfs induced in the two secondary windings.

- The transfer characteristics of LVDT is shown in Fig. 6.7.10(b).
- It is the graph of output voltage against the core position.

Operation of LVDT :

- The primary winding is connected to the ac source.
- Assume that initially the core is exactly at the center of the coil assembly. Then equal amount of flux gets linked to both the secondary windings.

- Due to equal flux linkage, the induced voltages in both secondary windings are equal but they have opposite polarities.
- The output voltage of LVDT i.e. "e_o" is therefore zero corresponding to the central position of the core. This position of the core is called as the "null position".
- Now if the core is displaced from its null position towards secondary-1 then the flux linked to secondary-1 increases and flux linked to secondary-2 decreases.
- Therefore the induced voltage "e_{o1}" is now higher than "e_{o2}" and the output voltage of LVDT i.e. "e_o" will be positive as shown in Fig. 6.7.10(b).
- Similarly if the core is displaced downwards i.e. towards the secondary-2 then "e_{o2}" will be higher than "e_{o1}" and the output voltage "e_o" will be negative.
- Thus the magnitude of output signal will vary "linearly" with the mechanical displacement of the core.
- Therefore the word "Linear," is used in LVDT. The output is obtained "differentially" between the two secondary windings. Hence the word "differential" is used in LVDT.

Performance characteristics of LVDT :

Some of the important characteristics of LVDT are,

1. Null voltage
2. Linearity
3. Excitation voltage and excitation frequency
4. Resolution
5. Sensitivity
6. Dynamic response.

Advantages of LVDT :

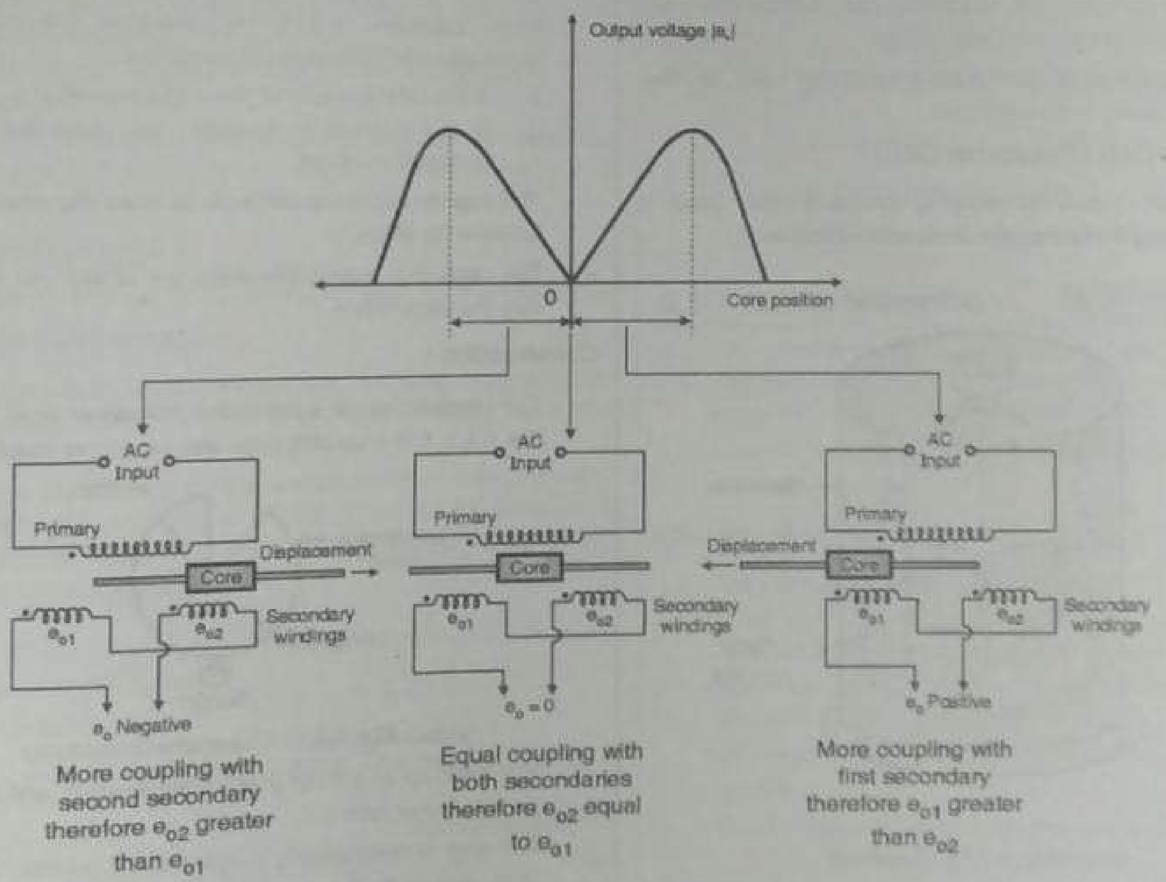
1. Very fine resolution
2. High accuracy
3. Very good stability
4. The transfer characteristic (is linear)
5. LVDT is easy to fabricate and installation.
6. LVDT can operate at high temperature
7. High sensitivity (2mV/Volt/10 microns at 4 kHz excitation).

Disadvantages of LVDT :

1. LVDT is sensitive to the external magnetic fields. To minimize this effect magnetic shielding is necessary.
2. Complicated circuitry is needed.
3. Due to mass of the core, LVDT is not suitable for measurement of fast displacements.
4. Larger displacements are needed to get a substantial differential output.

Applications of LVDT :

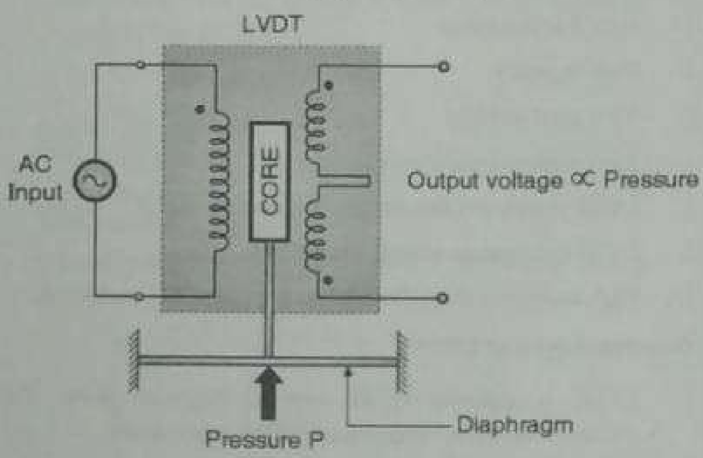
In addition to displacement measurement the LVDT is used in measurement of pressure, load, acceleration, force, weight etc.



(B-2192)**Fig. 6.7.11 : Operation of LVDT**

LVDT Type Pressure Transducer :

- The construction of an LVDT type pressure transducer is as shown in Fig. 6.7.12.
- This is one of the most popular types of pressure transducers.

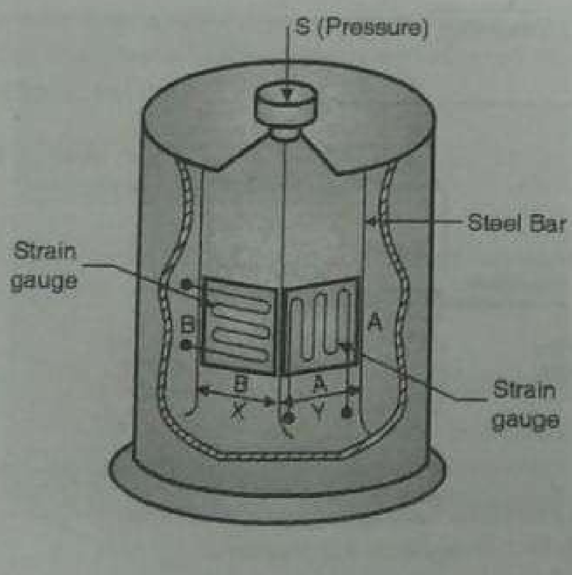


(B-2193)**Fig. 6.7.12 : LVDT type pressure transducer**

- LVDT stands for Linear Variable Differential Transformer, and its output voltage is proportional to the displacement of its movable core.
- The elastic element which is a diaphragm or bourdon tube is coupled to the movable core of LVDT.
- As we apply pressure the diaphragm will be displaced.
- Due to this the core of LVDT is displaced and the output voltage of LVDT will change accordingly.
- Thus pressure is first converted into displacement and displacement is converted into voltage.
- The deflection of the diaphragm must be kept small, in order to ensure linearity of conversion.

6.7.9 Load Cell (Pressure Cell) :

- A load cell is used for weighing extremely heavy loads. It uses the length of a steel bar as an active element.



(B-2194)**Fig. 6.7.13 : Load cell**

- The load cell is as shown in Fig. 6.7.13. It uses strain gauges for measuring weight.
- The weight is applied along the direction shown by the arrow in Fig. 6.7.13. Due to this stress, the steel bar gets compressed along axis S and expands along the X-Y axes.
- Due to this the resistance of strain gauge A will decrease and that of strain gauge B will increase.
- These two strain gauges and those on the two remaining sides of the steel are connected to form a bridge. This increases its sensitivity four times as compared to a single gauge.
- This arrangement will make the load cell very very sensitive to very small values of the applied stress and it can measure very heavy loads as well.

6.8 Capacitive Transducers (Pressure) :

- We can use a capacitive transducer to convert the change in the physical position of a moving element into a linear change in capacitance.
- Thus a capacitive transducer converts the physical change in position into a proportional change in capacitance.
- Capacitance is given by,

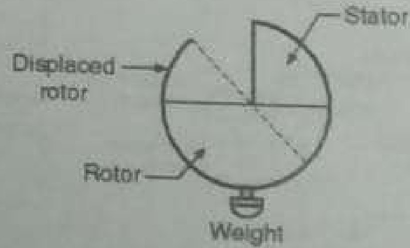
$$C = \frac{kA}{d} \quad \ldots(6.8.1)$$

Where
- k = Dielectric constant
- A = Total area of the capacitor surfaces
- d = Distance between two capacitive surfaces
- C = Resultant capacitance

- From Equation (6.8.1), we conclude that capacitance increases under following circumstances :
  1. If the effective area of plates (A) increases.
  2. If the material in between the plates has a higher dielectric constant.
- The capacitance decreases with increase the separation (d) between the plates.
- The capacitive transducers make use of any one method to vary the capacitance.

Construction :

- The construction of a capacitive transducer is as shown in Fig. 6.8.1. It is a variable plate area capacitive transducer.



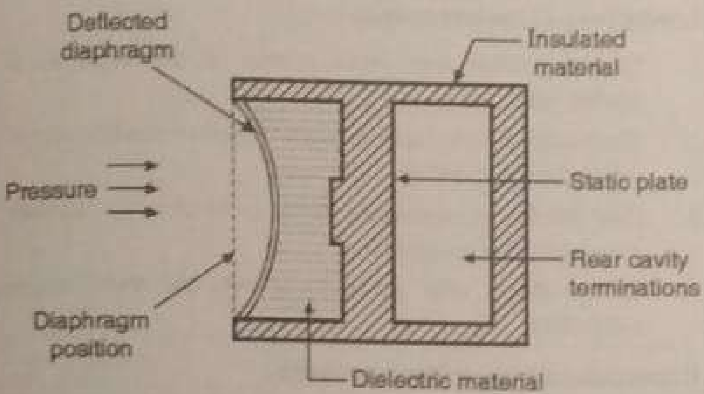
(B-2862) **Fig. 6.8.1 : Capacitive transducer**

- It is made up of a fixed plate called as stator and a movable plate called as rotor.
- The rotor is mechanically coupled to the member under test. With change in the member's position, the position of the rotor changes.

- This will change the effective overlapping area of the plates which ultimately changes the value of capacitance.
- Thus the amount of angular movement is converted into a proportional change in capacitance.
- This type of transducer is used to detect the amount of roll in an aircraft. As the aircraft rolls to the left and the capacitance decreases proportionally. Similar operation takes place when the aircraft rolls to the right.

6.8.1 Capacitive Pressure Transducer :

- A capacitive pressure transducer is as shown in Fig. 6.8.2.



(B-2863) **Fig. 6.8.2 : Capacitive pressure transducer**

- This transducer has been designed to measure pressure in vaccum.
- As seen from Fig. 6.8.2, a movable metallic diaphragm is enclosed in an airtight container.
- The metallic diaphragm moves to the left when pressure is applied to the chamber and it moves to the right when vaccum is applied.
- This metallic diaphragm acts as the moving plate of the capacitive transducer.
- The distance between the diaphragm and the stationary plate changes with change in the applied pressure, which changes the capacitance in proportion with the pressure.

6.8.2 Advantage :

They provide a high degree of accuracy if calibrated properly.

6.8.3 Disadvantages :

1. Errors may be introduced due to stray magnetic and capacitive effects. To avoid this proper shielding needs to be done.
2. Some capacitive dielectrics are temperature sensitive which makes the capacitance of the transducer a function of temperature. So temperature variations should be minimized.

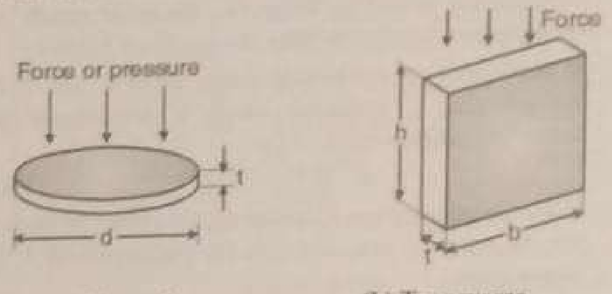
6.8.4 Applications :

1. A typical application of a capacitive transducer is in the capacitive microphone.
2. In the ac bridges.

6.9 Piezoelectric Pressure Transducers :

I-Scheme : S-18

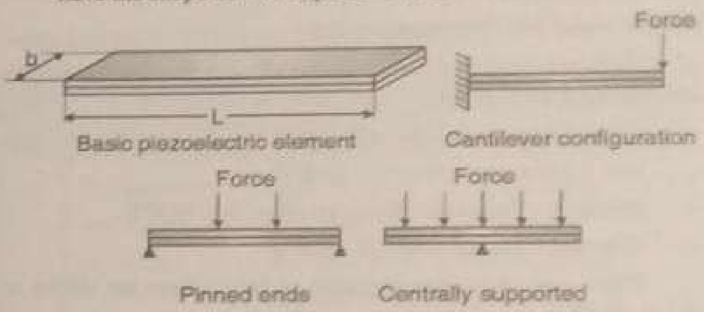
- Some materials possess a special property called "piezoelectricity".
- These materials will generate an electrostatic charge or voltage when mechanical stresses are applied across them. Materials exhibiting this property are called as piezoelectric materials.
- Examples of piezoelectric materials are quartz, Rochelle salt and different synthetic ceramic materials.
- Natural quartz is the most suitable device as it has a higher resistivity and less sensitivity to temperature.
- It exhibits good linearity over a wide range of stress level. Different arrangements of using the piezoelectric transducer for pressure measurement is as shown in Fig. 6.9.1.



(a) Normal (b) Transverse

(B-456)**Fig. 6.9.1 : Different modes of piezoelectric transducer**

- The different loading arrangement of piezoelectric element to measure pressure are as shown in Fig. 6.9.2. The element can have the shape of a disc, plate or tube.



(B-457)**Fig. 6.9.2 : Different loading configurations of piezoelectric transducers in pressure measurement**

6.10 Thermocouples : I-Scheme : W-18, S-19

- The resistance type temperature sensors (PRT and thermistors) are passive type transducers because they need an external dc power supply for their operation.
- Now let us see an active temperature sensor which does not require external dc source.

Principle of operation (Seebeck Effect) :

- The operation of thermocouples is based on a phenomenon called as **seebeck effect.** It states that a current flows in a closed circuit made of two dissimilar metals if the junctions of the two metals are kept at different temperatures. Due to this current flow, an emf proportional to the temperature difference is produced. This is as shown in Figs. 6.10.1(a) and (b).
- The sensitivity of the thermal element is given by,

$$s = e/t = a + bt + ct^2 \quad ...(6.10.1)$$

- Where "e" is the emf generated corresponding to a temperature change of "t". a, b and c are constants determined by measuring the value of "e" at three standard reference temperatures.
- The thermocouples are classified into various types namely type E, type K, type R, type S, type T etc.
- Thermocouple elements are enclosed in a housing assembly for their protection. The assembly is then called as a thermocouple probe.

Construction of thermocouple :

Thermocouple circuits :

- Consider Fig. 6.10.1(a), where two dissimilar metals 'x' and 'y' are joined together to form two junctions J_1 and J_2.
- If these junctions are kept at temperatures T_1 and T_2 then a thermal emf is produced which is proportional to the temperature difference $T_1 - T_2$.

$$e = K(T_1 - T_2) \quad ...(6.10.2)$$

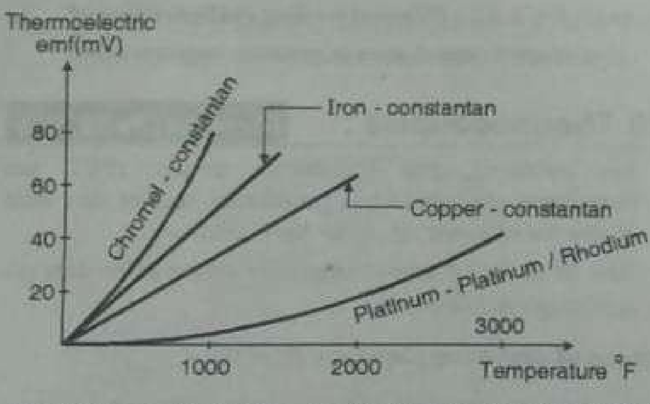
- In the temperature measurement system, using thermocouples one of the two junctions can be maintained at a known temperature.
- Then that junction is called as a reference junction or "cold" junction. The reference temperature generally used is 273°K or 0°C.
- A millivoltmeter is used to measure the thermally generated emf as shown in Fig. 6.10.1(b).

Metals used for Thermocouples :

Different metals used for manufacturing the thermocouples and their temperature ranges are as follows :

- Copper-constantan alloy : 0 – 2000°F
- Iron - constantan alloy : 0 – 1200°F
- Platinum - Platinum / Rhodium alloy : 0 – 3000°F
- Chromel - Alumel alloy : 0 – 900°F

The temperature characteristics of these alloys are shown in Fig. 6.10.1(c).



(B-638)**Fig. 6.10.1(c) : Emf versus temperature characteristics for commonly used thermocouple alloys**

Advantages of thermocouple :

1. Wide temperature range (– 200°C to 1100°C).
2. External dc source is not required.
3. Good sensitivity i.e. small changes in temperature can be sensed.
4. Fast dynamic response i.e. it responds quickly to any temperature changes.
5. Moderate accuracy of measurement.
6. Less expensive and small in size.

Limitations of thermocouple :

1. The temperature emf characteristics of thermocouples is slightly nonlinear.
2. Thermally generated emf is small. Therefore amplification is required to be provided.
3. Cold junction compensation needs to be done for accurate measurement of temperature.
4. Stray voltages may get induced into the thermocouple conductors.

Expectations from a thermocouple :

A high quality thermocouple should satisfy the following expectations, to overcome the limitations discussed earlier :

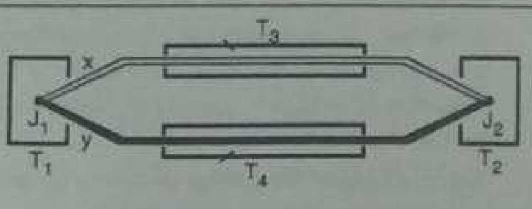
1. It should have a linear thermo-emf characteristics.
2. The magnitude of thermally generated emf should be as large as possible to avoid the use of amplifiers.
3. The thermocouple materials should be tough enough to withstand high temperatures and environmental effects.
4. Thermocouples should be cost effective.

6.10.1 Thermocouple Materials :

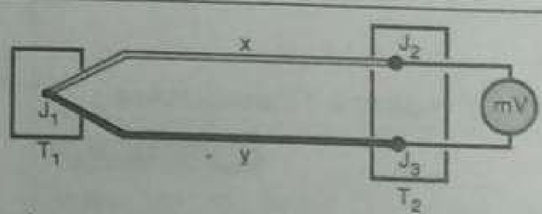
Some of the important thermocouple materials and the corresponding temperature ranges are copper constantan, platinum-platinum/Rhodium, Iron constantan, chromel-constantan, Chromel-Alumel.

Applications of thermocouples :

- Thermocouples are used for the applications for which a wide temperature range operation is required. For example temperature measurement of industrial furnaces.
- Thermocouples are also used in those applications where temperatures at remote places are to be measured.



(a) Basic thermocouple circuit



(b) Circuit arrangement for thermocouple measurement

(B-637) **Fig. 6.10.1**

6.10.2 Comparison of Temperature Transducers :

Comparison of various temperature transducers is as given below :

Comparison of RTD and thermocouple :

Sr. No.	Parameter	RTD	Thermocouple
1.	Principle of operation	"R" changes with temperature	A voltage proportional to temperature is developed.
2.	Type of transducer	Passive. So dc source is needed for operation.	Active. So external source is not needed for operation.
3.	Temperature range	– 200°C to 650°C	– 200°C to 1100°C
4.	Sensitivity	Excellent	Good
5.	Response time	Good	Excellent
6.	Cost	High	Moderate
7.	Accuracy	Very good	Moderate
8.	Size	Large	Small
9.	Material used	Platinum, Nickel, Copper, Semiconductors	Iron-constantan, Copper-constantan etc.
10.	Linearity of characteristics	Non-linear	Non-linear
11.	Compensation	Not required	Cold junction compensation is necessary
12.	Applications	For shorter temperature range applications.	For the applications which need wide temperature range.

Comparison of thermocouple and thermistor :

Sr. No.	Parameter	Thermocouple	Thermistor
1.	Principle of operation	A voltage proportional to temperature is developed.	"R" changes with changes in temperature.
2.	Type of the transducer	Active. So no external dc source is needed for operation.	Passive. So external source of dc source is needed.
3.	Temperature range	– 200°C to 1100°C	– 100°C to 320°C
4.	Sensitivity	Good.	Excellent.
5.	– Precautions	– Amplification needed. – Cold junction compensation needed. – Located away from the flame.	– Shielded cables needed – Limited temperature range. – Low excitation current.
6.	Applications	For the applications for which a wide temperature range operation is needed.	In process instrumentation.

Comparison of NTC and PTC thermistors :

Sr. No.	Parameter	PTC Thermistor	NTC Thermistor
1.	Temperature coefficient of resistivity.	Positive i.e. resistance increases with increase in temperature.	Negative i.e. resistance decrease with increase in temperature.
2.	Temperature range.	– 400°C to 1000°C	– 100°C to 320°C
3.	Sensitivity.	Excellent.	Good.
4.	Slope of R versus T curve.	Positive.	Negative.
5.	Stability.	Very good.	Moderate.
6.	Applications.	Thermostat, resistance thermometers.	Process instrumentation and biomedical applications.

6.11 Proximity Sensors : I-Scheme : S-18

Definition :

A proximity sensor is a sensor which can detect the presence of nearby objects without any physical contact.

Principle of operation :

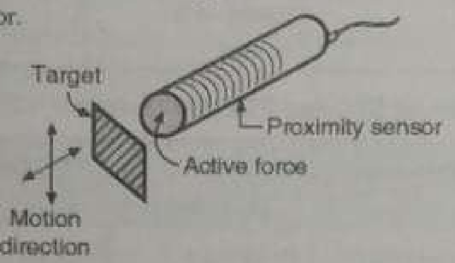
- A proximity sensor often emits an **electromagnetic field** or a beam of E.M. radiation e.g. infrared and looks for any changes in the field or return signal.
- The object being sensed is called as the target of the proximity sensor.
- Different types of proximity sensors are suitable for different target materials.
- For example, a capacitive or photoelectric sensor is suitable for plastic targets or inductive proximity sensors are suitable for metal targets.

Nominal range :

- The maximum distance that can be detected by this sensor is called as the **nominal range** of a proximity sensor.
- Proximity sensors can have high reliability and long functional life because no mechanical parts are used and there is no physical contact between the sensor and the target.

Typical construction :

- Fig. 6.11.1 shows the typical construction of a proximity detector.



(B-2950) **Fig. 6.11.1 : Construction of a proximity detector**

Types of proximity sensors :

Following are the types of proximity sensors :

1. **Capacitive :** For resins, liquids, powders.
2. **Inductive :** For iron, aluminium, brass, copper objects.
3. Doppler effect.
4. **Magnetic :** For mobile phone, tablets, security application.
5. Optical.
6. Laser.
7. Radar.
8. Ultrasonic sensor.
9. Hall effect sensor.
10. Fiber optics sensor.

Applications :

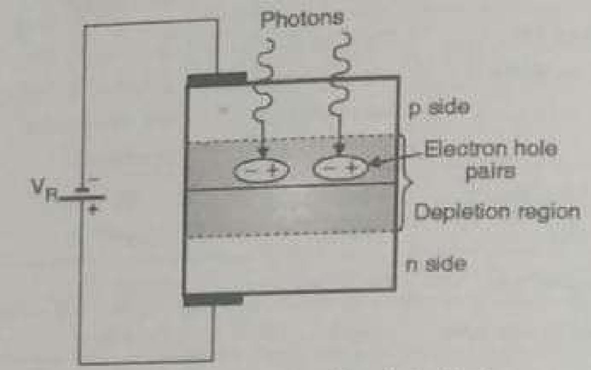
Some of the important applications of proximity sensors are as follows :

1. In mobile phones to detect if someone is in the nominal range.
2. In machine vibration monitoring.
3. In large steam turbines.
4. In compressors.
5. In motors.
6. A proximity sensor adjusted to a very short range is used as a touch switch.
7. As parking sensors for cars.
8. Ground proximity warning system for aviation safety.
9. In the conveyor systems.

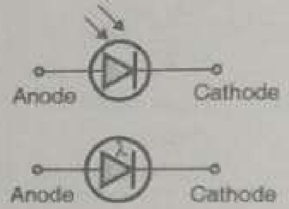
6.12 Photodiode :

I-Scheme : S-18, S-19

- The photodiode is a p-n junction semiconductor diode which is always operated in the reverse biased condition.
- The construction of a photodiode and its circuit symbols are as shown in Figs. 6.12.1(a) and (b) respectively.



(a) Construction of a photodiode



(b) Symbols of a photodiode

(B-2080) **Fig. 6.12.1**

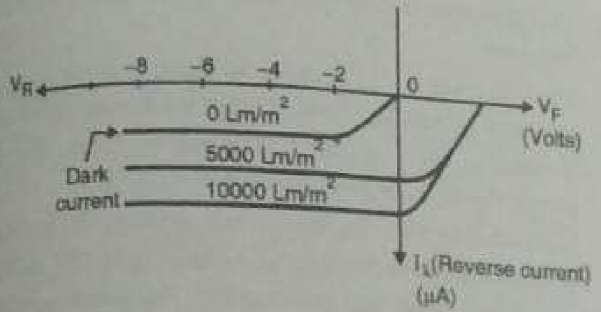
6.12.1 Construction and Operation :

I-Scheme : S-19

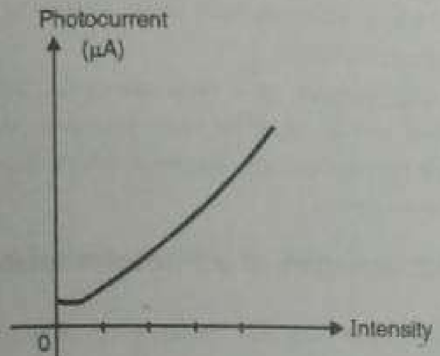
- The light is always focussed through a glass lens on the junction of the photodiode.
- As the photodiode is reverse biased, the depletion region is quite wide, penetrated on both side of the junction, as shown in Fig. 6.12.1(a).
- The photons incident on the depletion region will impart their energy to the ions present there and generate electron hole pairs.
- The number of electron hole pairs will be dependent on the intensity of light (number of photons). These electrons and holes will be attracted towards the positive and negative terminals respectively of the external source, to constitute the photo current.
- With increase in the light intensity, more number of electron hole pairs are generated and the photocurrent increases. Thus the photocurrent is proportional to the light intensity.

6.12.2 Photodiode Characteristics :

- The photodiode V-I characteristics are as shown in Fig. 6.12.2(a) and the variation of photocurrent with light intensity is as shown in Fig. 6.12.2(b).



(a) V-I characteristics of a photodiode



(b) Variation of photocurrent with intensity of light

(B-2081)**Fig. 6.12.2**

- **Dark current :** It is the current flowing through a photodiode when there is no incident light on the device. (See Fig. 6.12.2(a)). Dark current flows due to the thermally generated minority carriers, and hence increases with increase in temperature.
- The reverse current I_λ (photocurrent) depends only on the intensity of light incident on the junction. It is almost independent of the reverse voltage as shown in Fig. 6.12.2(a).

6.12.3 Advantages of Photodiode :

1. **High sensitivity :** This means, a large change in the photocurrent will take place for a small change in light intensity.
2. High speed of operation as compared to LDR. (Light Dependent Resistor).

6.12.4 Disadvantages of Photodiode :

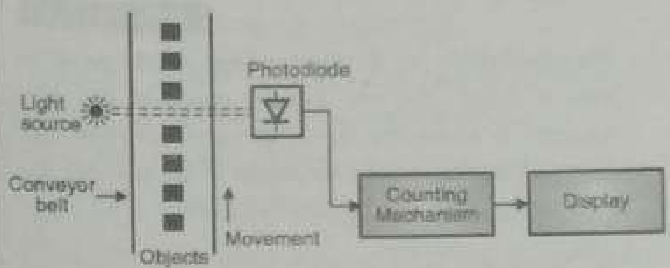
1. Dark current increases with temperature.
2. Poor temperature stability.
3. External bias voltage is essential for operation.
4. Amplification is required, as the output current is of small magnitude.

Why is the photodiode operated in reverse biased condition ?

In the reverse biased condition the only current flowing through the diode in the absence of light is the reverse saturation current which is very small in magnitude. Hence the change in diode current due to the light incident on it is significant (photocurrent is in μA). If the diode was forward biased then the forward current in the absence of light would be in mA and the change in forward current due to light will not be even noticeable. Hence the photodiode is operated in the reverse biased condition.

6.12.5 Applications of Photodiode :

- A popular application of the photodiode is an object counting system shown in Fig. 6.12.3. This system is used for counting the number of objects that are passing on a conveyor belt. A light beam is focused continuously on the photodiode and the reverse photocurrent is flowing through it.



(B-778) **Fig. 6.12.3 : Object counting system using photodiode**

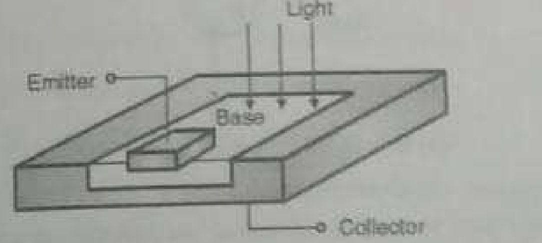
- As soon as an object passes and interrupts the beam of light, the photocurrent flowing through the photodiode will reduce to zero. This will be counted by a counting mechanism to count the number of objects. In general the applications of photodiode are same as those of an LDR. In addition they can be used in optical measurement system and fibre optic communication.

6.12.6 Other Applications :

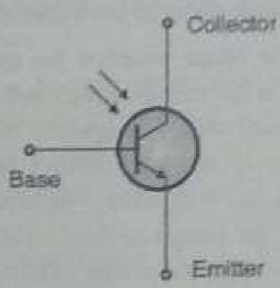
1. In the cameras for sensing the light intensity.
2. In the fiber optic receiver.
3. In light intensity meters.

6.13 Phototransistor :

- A photodiode cannot provide any amplification action. A phototransistor can provide the internal current multiplication and can generate a larger output signal.



(B-2195)**Fig. 6.13.1(a) : Construction of a phototransistor**



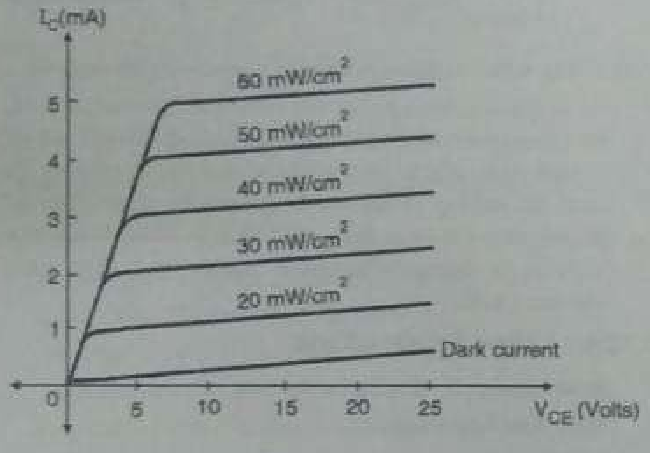
(B-2195)Fig. 6.13.1(b) : Symbol of a phototransistor

- The light is allowed to fall on the reverse biased collector base junction of the transistor.
- The photocurrent produced there, acts as the base current for the transistor and gets multiplied by β of the phototransistor. The construction and circuit symbol of a phototransistor are as shown in Figs. 6.13.1(a) and (b) respectively.

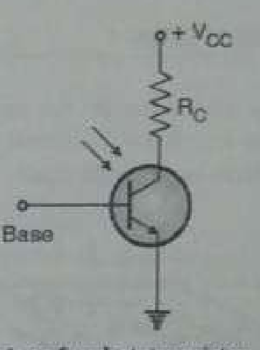
6.13.1 Construction and Biasing :

I-Scheme : S-19

- The construction of a phototransistor is as shown in Figs. 6.13.1(a). The base collector region of the photo transistor is responsible for the generation of photo base current. Therefore in the construction of the transistor, the base collector area is kept as large as possible.



(a) Output characteristics of a phototransistor



(b) Biasing of a phototransistor

(B-2196)Fig. 6.13.2

- The base terminal is sometimes not brought out and the phototransistor acts as a two terminal device. But if the base terminal is brought out, then it acts as a conventional transistor.
- The base terminal is either left open or connected to ground through a large value resistor. The biasing of the phototransistor is otherwise same as that of a conventional transistor.
- **Dark current :** In absence of light, a small thermally generated current I_{CEO} flows through the device. This current is called as dark current. It is in the nA range. The dark current should be as small as possible.
- In presence of light, the base current produced (I_L) is directly proportional to the intensity of incident light. The collector current is β times this base current. The phototransistor is biased as shown in Fig. 6.13.2(b).
- The output characteristics of a phototransistor are as shown in Fig. 6.13.2(a). They are very much similar to those of a conventional transistor.
- These characteristics have been drawn for different light intensities. As the light intensity increases, the optically produced base current also increases which inturn increases the collector current.

6.13.2 Advantages of a Phototransistor :

1. Photocurrent gets internally multiplied by β, so no additional amplifier is required.
2. High sensitivity of the order of 100 times that of a photodiode.
3. High switching speed.
4. No memory effect.

6.13.3 Disadvantages of a Phototransistor :

1. Phototransistor is not as fast as a conventional transistor due to sluggishness of the photoconducting material.
2. It has a poor linearity.
3. Phototransistor are temperature sensitive devices. That means the phototransistor current is proportional not only to the intensity of light but also to the temperature.
4. Signal to dark current ratio is poor. This is because the dark current also gets multiplied by β of the transistor.
5. External voltage source is needed for operation.

6.13.4 Applications of Phototransistor :

1. **Light sensitive relay :**
   - The light sensitive relay is as shown in Fig. 6.13.3(a). The phototransistor turns on when a sufficient light is incident on it.