12

Transducers

TOPICS DISCUSSED

- Use of transducers in measurement system
- Classification of transducers
- Characteristics of transducers
- Linear variable differential transducer
- Capacitive transducer
- Inductive transducer
- Potentiometric transducer
- Strain gauge transducer
- Thermistor
- Thermocouples
- Hall effect transducer
- Photoelectric transducer
- Selection of transducers

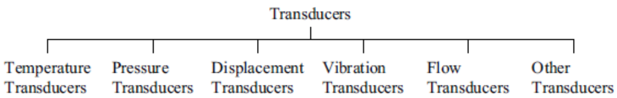
voltage or current. This is done with the help of devices called transducers. Therefore, we can state that **a transducer is a device which converts a non-electrical quantity to be measured into a proportional electrical signal.** Such a transducer is also called an electric transducer.

The advantage of creating a proportional electrical signal is that it is easy to process and transmit electrical signals. The electrical signal obtained from the transducer is used in the measurement system to measure, and if required to control the quantity being measured.

12.2 CLASSIFICATION OF TRANSDUCERS

Transducers are classified on the basis of quantity to be measured or depending upon whether external power supply is required for their operation or not.

The classification of transducers on the basis of quantity to be measured is shown below:



The classification of transducers on the basis of power supply requirement are made into two categories, namely *active transducers* and *passive transducers.*

Active transducers do not require any external source of supply for their operation. That is why they are also called self-generating transducers. Examples of active transducers are piezoelectric transducers, electromagnetic-type transducers, photovoltaic-type transducers, thermo-electric-type transducers, etc.

Passive transducers require power supply for their operation and they are not self generating.

To understand the difference between active and passive transducers, let us take a simple example. In Fig. 12.1 has been shown a transformer with a movable core. The movement of the core is the measure of displacement. The output voltage, e_o will depend upon the position of the core. Thus, $e_o \propto d$, where d is the measure of displacement. Thus, this passive transducer requires input power supply and its output voltage can be made proportional to the displacement of the core material. Here, voltage generated is proportional to displacement. Deflection of a millivoltmeter connected across the output terminal A and B can be calibrated in terms of displacement of the core. Now, suppose we want to use this transducer to measure pressure. To convert pressure to displacement, we will need an input transducer, in this case, a bourdon tube, which we call sensor. A sensor senses the desired physical quantity and converts it into another energy form. In this case, pressure is converted into displacement by an input transducer, called a sensor, and the displacement is converted to voltage by an output transducer. These are also called *primary transducers* and *secondary transducers*. Here, the primary transducer converts the physical quantity, i.e., the pres-

Transducers may also be classified on the basis of the type of their output. If the output is a continuous function of time, such transducers are called *analog transducers*. If the output is in discrete steps, such transducers are called *digital transducers*. The output of transducers like a thermocouple, a tachogenerator, a potentiometer, etc. are voltages which vary with time and is a continuous function of time. These are examples of analog transducers.

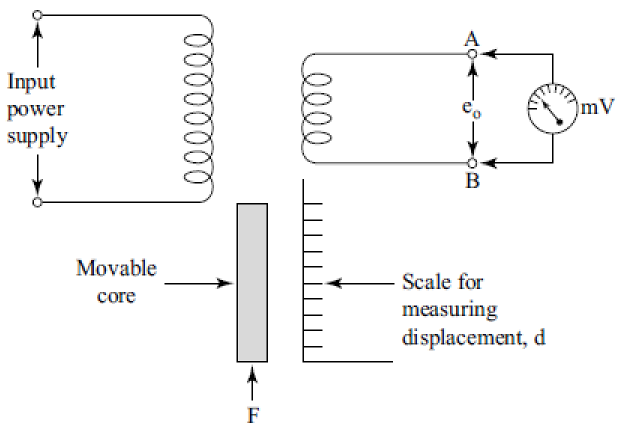


Figure 12.1 Illustration of the principle of a passive transducer

Digital transducers convert the input physical phenomenon into an electrical output in the form of a train of digital pulses using a binary system of notation. Since transducers are often required to communicate with computers, transducers with digital output are required. In the case of analog transducers, conversion of analog signals to digital signals will be required to be interfaced with a computer system.

Since digital transducers are few, we therefore mostly use analog transducers to produce a voltage signal and an electronic A to D (Analog to Digital) converter to get the digital data in the binary form, i.e., 0 and 1.

12.3 CHARACTERISTICS OF A TRANSDUCER

Transducers are used in the measurement of system parameters as an input-sensing element. The received signal requires processing. The signal processing involves amplification of the signal, its conversion from analog to digital form, its transmission, its display, its recording, etc.

Since transducers generate the basic measurement signal, they must possess certain desirable characteristics which are mentioned below:

1. **Sensitivity:** It is defined as the output per unit input of the quantity being measured. For example, the output of a thermocouple used as a transducer is expressed as EMF induced per degree centigrade. Sensitivity of a transducer

3. **Linearity:** The output signal produced by the transducer should vary linearly with the variation of the input. For a thermocouple, for example, the EMF induced should maintain a linear relation with the variation of input, i.e., the temperature.
4. **Ruggedness:** The transducer should require no maintenance and should be able to withstand any over-load conditions.
5. **Speed of response:** The transducer should be such that it quickly responds, i.e., provides output to the changing input, i.e., the changes in the quantity being measured.
6. **Repeatability:** Repeatability means that the transducer should produce the same output signal for the same input every time, provided that the environmental conditions remain the same.

Various types of transducers and their applications are described as follows.

12.4 LINEAR VARIABLE DIFFERENTIAL TRANSFORMER

A linear variable differential transformer (LVDT) is an electromagnetic induction-type displacement transducer. It is a reliable and accurate sensing device that can be used to convert linear motion (displacement) to a proportional electrical output. The basic construction of a LVDT is shown in Fig. 12.2. It consists of three elements, viz one primary winding, two identical secondary windings, and a movable magnetic core.

As shown in Fig. 12.2 (a), the position of the core is at null position. In this position the induced EMF in the two secondary windings, E_1 and E_2 are equal and opposite. The transducer output voltage is zero. When the core is displaced by a force towards the left as shown in Fig. 12.2 (b), E_1 will be greater than E_2 due to the difference in flux linkage created by the primary winding ampere turns. When the core is moved towords the right as shown in Fig. 12.2 (c), the induced EMF E_2 will be greater than E_1. The magnitude of the differential output voltage E_0 will vary with the change in core position. The output voltage, E_0 at null position is ideally zero and will increase when the core is made to move either towords the left or towords the right as shown in Fig. 12.3. It is observed that the output voltage changes linearly with the displacement of the core. The output voltage is a function of the displacement of the core.

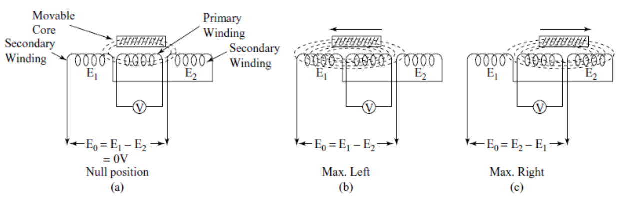


Figure 12.2 Basic constructional details of an LVDT transducer

Although the output voltage, E_0 at null position should be zero, it is observed from Fig. 12.3 that a small amount of voltage appears output voltage curve is linear upto a certain range of displacement beyond which the characteristic start deviating from linearity.

Advantages and disadvantages of LVDT transducers

The advantages and disadvantages of a LVDT is expressed in terms of certain performance characteristics like range, sensitivity, resolution, ruggedness, dynamic response, linearity, etc. Some of these are mentioned as follows:

1. **Range of measurement:** LVDT can be used for the measurement of high range of displacement ranging from 1mm to 250 mm.
2. **Frictionless and electrical isolation:** There is no physical contact between the windings and the core. This provides the LVDT a very long life as there is no wear and tear due to friction.
3. **Resolution:** A very small movement of the core produces a proportional voltage output. This makes the resolution of LVDT very high.

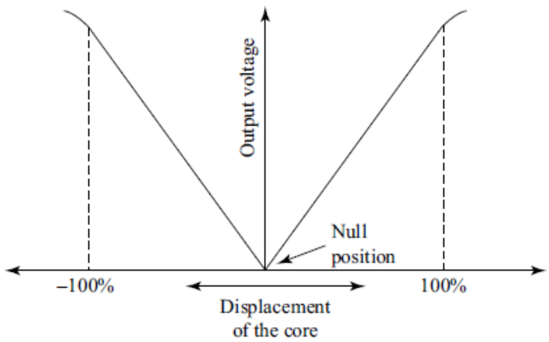


Figure 12.3 The output characteristics of an LVDT

4. **Sensitivity:** It is the amount of voltage induced per mm of displacement of the core. The LVDT gives high output voltage per mm of displacement of the core making it a high-sensitive transducer. Sensitivity is expressed as Volts/mm.
5. **Ruggedness:** LVDT transducers are rugged in construction, and therefore can tolerate high degree of vibrations and mechanical shock, especially when the core is loaded with a spring.
6. **Power consumption:** LVDT transducers consume very low power, maybe in the range of 1 Watt or so.
7. **Temperature effect:** Variation in temperature affects the performance of the transducer. The resistance of the copper wires used for the windings change with change in temperature.
8. The transducer is **sensitive to stray magnetic field** for which magnetic shielding may be necessary.
9. The output voltage of a LVDT is almost linear upto a certain limit.

like the measurement of displacement, force, weight, and pressure are mentioned below.

LVDT converts displacement directly to an electrical output for which it is called primary transducer. The output voltage can be read in digital form through conversion of analog signal to digital signal Since displacement is produced by force, weight, and pressure, etc., an LVDT can be used as a secondary transducer to measure these quantities. For example, the pressure is first converted into displacement with the help of a primary transducer, say a diaphram or a Bourdon tube, and then the displacement is converted into an electrical signal by the LVDT (a Bourdon tube converts pressure into displacement).

Use of LVDT can be seen in weight-measuring machines used in many department stores and shops. The object to be weighed is kept on a tray which is placed on a LVDT shaft. A spring is attached to the shaft which allows the tray to return to its original position once the object from the tray is removed. The object on the tray whose weight is to be measured creates a downward displacement of LVDT shaft (core) and develops a differential voltage. The differential voltage is proportional to displacement, which in turn is proportional to the weight of the object being measured. The generated differential voltage is converted into seven segment digital display to indicate the weight of the object.

There are many other applications of LVDT like in the measurement of thickness of metal sheets being rolled out in industry, in the measurement of tension of a wire in a wire-drawing machine, automatic opening and closing of gates at railway crossings, etc.

12.5 CAPACITIVE TRANSDUCERS

The Capacitance of a parallel plate capacitor is expressed as

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

where, $\in$ is the permitivity of the dielectric material placed between the two plates,

A is the overlapping area of the plates, and

d is the distance between the two plates.

Change in the capacitance of a capacitor due to the variation in A, d, or $\in$ can be utilized for the measurement of physical variables like displacement, force, pressure, etc. The liquid level in a container can also be measured by measuring the change in capacitance due to change in dielectric constant of the liquid poured into the container having two plates inserted inside.

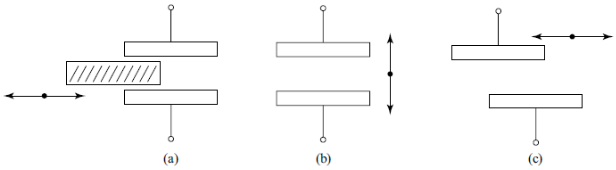


Figure 12.4 Capacitive transducer. (a) Variation in dielectric between the plates;(b) variation in gap between the plates; (c) variation in overlapping area

Fig. 12.4 shows a capacitive displacement transducer with variation in (a) dielectric placed between the plates, (b) gap between the plates, and (c) the area of overlap of the capacitor plates.

The change in capacitance is measured using a bridge circuit which is then calibrated in terms of force or pressure to be measured.

In transducers using change in area of the plates, the capacitance changes lenearly with change in overlapping area of the plates. Hence, this type of transducer can be used to measure displacement upto say, 1mm to a few centimeters.

This principle of the change in the capacitance due to the change in area can be used for the measurement of angular displacement using a fixed semicircular plate and a movable semicircular plate as shown in Fig. 12.5 (a). Fig. 12.5 (b) shows the linear variation of C with the variation of angular displacement, θ of the movable plate.

In a parallel-plate capacitor, the variation of distance between the plates creates a change in capacitance. The value of C is inversely proportional to the distance, d. Therefore, the relationship between displacement and the value of capacitance is hyperbolic. Their relationship can be considered linear only for a very small range of displacement.

By making one of the plates in the form of a flexible diaphragm, a capacitive transducer can be used to measure pressure due to the flow of liquid or gas as in Fig. 12.6. As shown in the figure, the flexible diaphragm, A acts as one of the capacitor plates. The pressure to be measured is applied to the flexible diaphragm, which bends, changing the effective distance, d between the two plates A and B. This will increase the capacitance, C of the capacitor, which can be measured and used to know the value of the pressure applied by the liquid or the gas.

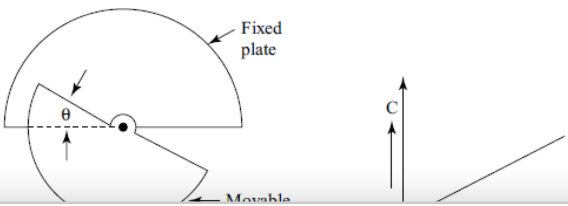


Figure 12.5 Measurement of angular displacement by a capacitive transducer.(a) Fixed and moveable semicircular plates; (b) linear variation of capacitance with angular displacement of the plate

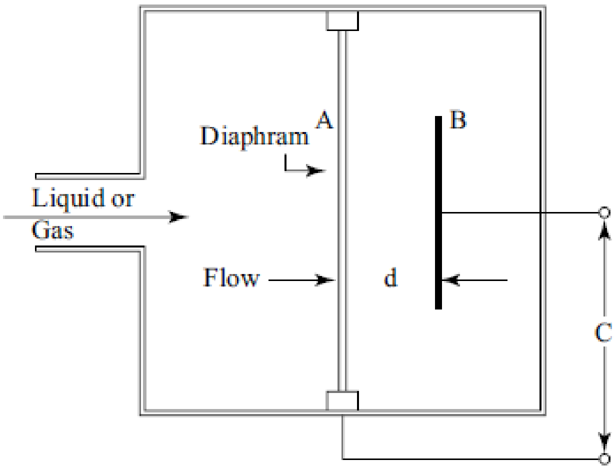


Figure 12.6 Capacitive transducer with a flexible diaphram as one of the plates

Variation of position of the dielectric material between the plates can be made to create change in capacitance. Linear distance can be measured by measuring the change in capacitance due to the movement of a piece of dielectric material between the two plates.

The advantages of capacitive transducers are that they

1. require small force to change their capacitance, and hence can be used in small systems;
2. are extremely sensitive;
3. have high resolution;
4. are very little affected by stray magnetic fields;
5. can be used for measurement of linear and angular displacement, force, pressure, liquid level, etc.

12.6 INDUCTIVE TRANSDUCERS

Inductive transducers operate on the principle of variation of self inductance of a coil or on the principle of variation of mutual inductance.

Inductance of a coil, L is defined as

$$L = N\frac{d\varphi}{di}$$

Assuming linear relationship between flux, ϕ current, i producing

$$L = N\frac{\varphi}{I} = N\frac{BA}{I} = N\frac{\mu HA}{I} \qquad [\text{as } \phi = B.A \text{ and } B = \mu H]$$

or,

$$L = N\frac{\mu NI}{l}\cdot\frac{A}{I} \qquad \left[\text{as } H = \frac{NI}{\ell}\right]$$

or,

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

where μ is the permeability of the core material around which the coil is wound,

N is the number of turns of the coil,

A is the area of cross-section of magnetic flux path,

l is the length of the flux path.

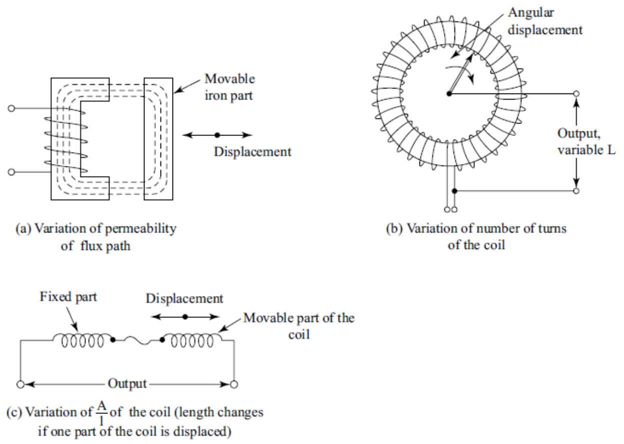


Figure 12.7 Transducers operating on the basis of variable inductance

Thus, the inductance of a coil can be varied by (i) changing the permeability of the core material, i.e., by changing the position of the core inside the coil; (ii) changing the number of turns through which current will flow in the coil, and (iii) changing the ratio of A/*l* of the coil. These methods are shown in Fig. 12.7. These are passive transducers requiring power supply and the output is analog in nature.

Two coils having inductance L_1 and L_2 will have mutual inductance M as

$$M = K\sqrt{L_1 L_2}\text{, where K is the coefficient of coupling}$$

The variation of magnetic coupling between two coils can be utilized to change M. Displacement of the core or a part of the core can cause change in M. The change in M will be measured by a bridge circuit and a proportional signal created for the measurement of

A potentiometric transducer is basically an electrical resistive transducer. A potentiometer is an electromechanical device having a resistance element with a sliding facility which enables changes in the resistance value at the output. The sliding contact is known as wiper, which may be translatory or rotary, according to the design. Fig. 12.8 shows potentiometric transducers of translational and rotational design. Some potentiometers, also called 'pots', are designed combining these two types of motions. The output voltage is

$$e_o = e_i \frac{x_o}{x_T}$$ and $$e_o = e_i \frac{\theta_i}{\theta_T} Z$$ in the case of translational and rotational potentiometer, respectively, as shown in Fig. 12.8. The resistance element of a potentiometer is excited either by ac or dc voltage. The motion of the wiper or slider makes a resistance change that may be linear, logarithmic, or exponential. In Fig. 12.9 are shown applications of potentiometric transducers in the measurement of linear and angular displacement.

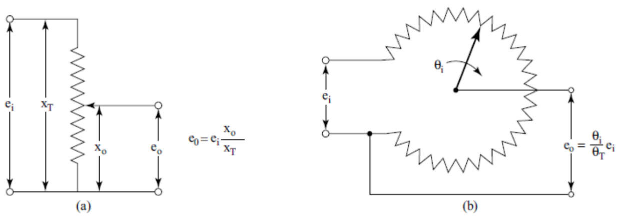


Figure 12.8 Potentiometric transducers. (a) Translational design; (b) rotational design

The output voltage, V_0 appearing across the terminals A and B is directly proportional to the displacement of the moving object as has been shown in Fig. 12.9 (a). A typical potentiometric transducer used in a feedback control system used as error sensor has been shown in Fig. Fig. 12.9 (b). Any derivation of the output, i.e., θ_0 from the input reference angular displacement, θ_r will produce an error signal, e which will be amplied by the amplifier having gain K. The amplifier will supply additional input to the armature terminals AA of the motor, M to produce additional torque to change θ_0, and hence reduce the error.

Potentiometric transducers are widely used in control applications because they provide sufficient output for control operation, in many cases not requiring any amplifier.

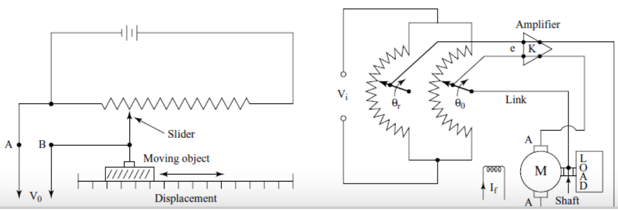


Figure 12.9 Applications of potentiometric transducers. (a) Measurement of displacement of a moving object; (b) error detection in a feedback control system

Example 12.1 A linear resistance potentiometer as shown in Fig. 12.9 (a) has a displacement range of 50 cm. The potentiometer is uniformely wound having a resistance of 200 kΩ. Under normal condition the slider is set at the centre of the potentiometer. Calculate the displacement of the object when the output resistance is measured as 80 kΩ.

Solution:

Output resistance of the potentiometer under set condition $= \dfrac{200\ \text{k}\Omega}{2} = 100\ \text{k}\Omega$

Resistance of the potentiometer per unit length

$$= \frac{200\ \text{k}\Omega}{50\ \text{cm}} = 4\ \text{k}\Omega/\text{cm}$$

Change in resistance due to displacement

$$= 100\ \text{k}\Omega - 80\ \text{k}\Omega$$

$$= 20\ \text{k}\Omega$$

Displacement of the object $= \dfrac{20\ \text{k}\Omega}{4\ \text{k}\Omega} = 5\ \text{cm}$

12.8 STRAIN GAUGE TRANSDUCER

We have known that the resistance of a metallic wire is dependent upon its length and cross-sectional area. If a long resistance wire is stressed and strained, i.e., its dimensions are changed, its resistance value will change. A strain gauge converts strain into change in resistance of the wire under strain.

The basic principle of a strain gauge is that when a resistance wire is stressed within its elastic limit, its dimensions change, and hence its resistance change. This change in resistance can be used as a measure of the stress and strain of the object on which the strain gauge is attached or embedded. In civil engineering and mechanical engineering, field strain gauges are used extensively to measure stress on structures.

A strain gauge transducer is made of thin wires of diameter varying from 0.02 to 0.04 mm cemented (permanently fixed) in a zig-zag pattern on a thin flat paper. The zig-zag pattern of winding reduces the inductance and capacitance of the wire to a very low value, which is desirable. The end connecting leads are twisted to minimize any inductive effect.

ivity of a strain gauge is expressed as **gauge factor**. Gauge factor is the change in resistance per unit change in length of the strain wire. To make the transducer more sensitive, the material for the wire should be so chosen that the gauge factor is high, i.e., there is considerable change in resistance due to strain. Flexible silicon strain gauge has a gauge factor much higher than a metallic gauge.

Two types of strain gauges are in use. They are bonded type and semiconductor type. Bonded strain gauges are available in different shapes. These are bonded with elastic cement to the surface whose stress is to be measured. The bonded strain gauge consists of a wire grid whose shape may be square, rectangular, or circular. The wire grid is on a base paper as shown in Fig. 12.10 (a) and Fig. 12.10 (b)

A semiconductor strain gauge is made from a single piece of semiconductor material. There is change in resistivity when the material is strained. Many adhesives have been developed for pasting strain gauges to specimen structures and surfaces. A semiconductor strain gauge has been shown in Fig. 12.10 (c).

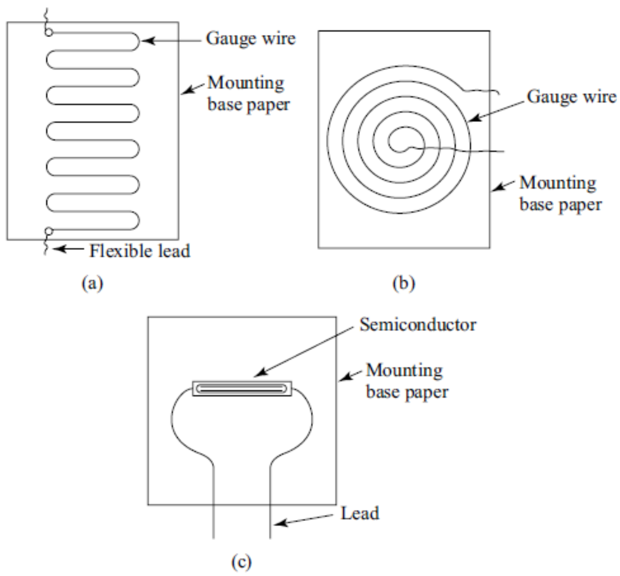


Figure 12.10 Strain gauges of different types and shapes

Strain gauges are extensively used for the measurement of strain and associated stress in experimental stress analysis. Strain gauges are pasted on the surface of the structures or bodies to sense strain under applied load. An electrical output signal proportional to the strain can be obtained from the transducer when an input voltage is provided. Measurement of stress occurring under varied environmental conditions can be measured using strain gauge. For example, the strain in an aircraft body structure can be measured by using the electrical signal generated by the strain gauges and by transmitting the signal to ground instruments.

their resistance decreases with increase in temperature. They are manufactured, generally from the sintered mixure of metallic oxides like manganese, nickel, iron, copper, and uranium. They are made in a variety of sizes and shapes. They may be in the form of rods, discs, beads, etc., as shown in Fig. 12.11. They are enclosed in glass containers or encapsulated in plastics or encased in a variety of enclosures to provide support and to protect from any damage. A thermistor, when placed in an environment whose temperature is to be measured, will show a change in its resistance with change in the temperature of the environment.

A shown in Fig. 12.11 (d), there will be change in thermistor resistance, R_{th} due to change in the temperature of the environment where it is placed. This change can be converted into a proportional voltage change, V_0 using a standard wheatstone bridge. An amplifier is used to amplify the signal generated. Usually the wheatstone bridge is balanced with the thermistor as one of its arms. The wheatstone bridge becomes unbalance a when resistance of the thermistor changes due to variation of temperature being measured.

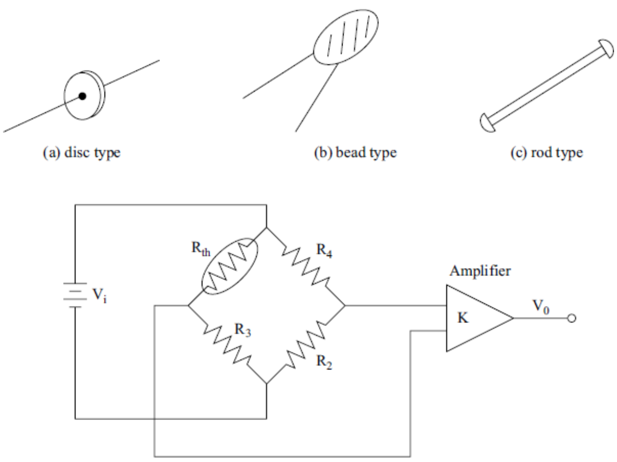


Figure 12.11 (a), (b), (c) show three types of thermistors; (d) shows use of a thermistor in a wheatstone bridge for measurement of temperature

The voltage generated can be used to make digital output or analog deflection depending upon the arrangement. If calibrated, the output will be a measure of the variation in temperature.

The sensitivity of a thermistor is expressed in terms of variation of resistance per degree change in temperature. High sensitivity of thermistors together with their initial high value of resistance make them suitable for measurement of temperature accurately. They are, therefore, suitable for precision temperature measurement and its control. Thermistors can be used to measure minute change of temperature variation, as low as 0.005°C.

Since the resistance versus temperature characteristic of thermis-

Thermistor-based measurement system using digital readouts which read the temperature directly are widely available.

12.10 THERMOCOUPLES

Thermocouples are active transducers requiring no power supply. A thermocouple is a junction of two dissimilar materials used for measurement of temperature. It consists of a pair of dissimilar conducting wires joined at two junctions. One junction is maintained at a reference temperature while the other junction is placed at the unknown temperature as shown in Fig. 12.12. The temperature difference between the two junctions produces a thermal EMF which is measured by a milli voltmeter or a digital voltmeter. The use of this thermo EMF as a measure of temperature is known as thermocouple thermometry. The magnitude of induced EMF is generally small and depends on the material used as wires and the temperature difference between the junctions. Sensitivity of a thermocouple transducer is expressed as EMF induced in mV per degree Kelvin. Table 12.1 shows the various combinations of thermocouple materials with their sensitivity and temperature range.

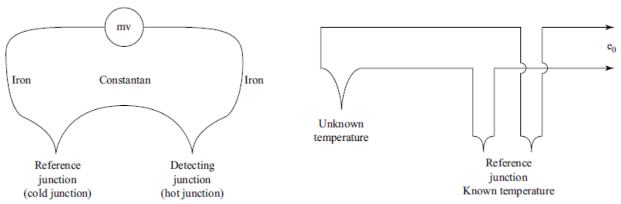


Figure 12.12 Simple thermocouple circuits

For measurement of temperature at remote places, extension wires are to be used. The connecting wires from the thermocouple lead to the place of measurement are long and are usually not at the same temperature throughout their length. This causes error in the measurement. To avoid such error, the connecting wires are made of the same material as the thermocouple wires. Thermocouple junctions are made by welding or soldering without using any flux. Industrial thermocouples generally have the hot junction placed at the sensing place and the cold junction or the reference junction in the measuring instrument itself. The reference junction is maintained at room temperature. Extension wires are used for connections. For achieving high sensitivity, a number of thermocouples may be connected in series so that the total EMF is the sum of EMF induced in each of the thermocouples. Such arrangement is known as *thermopile*.

Thermocouples are very cheap and handy devices used for temperature measurement in remote and inaccessible places. They are also conveniently used in measuring temperature at one particular point in a piece of equipment. For example, if we want to measure the temperature of the windings of an electrical machine, we can embed a thermocouple there and bring out the connecting leads for connection to the measuring instrument placed in the control room. The ac-

Table 12.1 Characteristics of Thermocouple Materials

Thermocouple material	Sensitivity (EMF in mV per °K)	Temperature range in °K
Copper–constantan	0.05	3–673
Iron–constantan	0.05	63–1473
Chromel–aclumel	0.04	3–1643
Chromel–constantan	0.08	3–1273
Platinum–platinum rhodium	0.01	223–2033

Example 12.2 A temperature transducer circuit uses an iron–constantan thermocouple which gives at output a voltage of 20 mV when measuring a temperature difference of 750°C. The resistance of the measuring instrument, R_m is 100 Ω and gives a full-scale deflection for a current of 0.1 mA. The resistance of junctions and connecting wires is 10 Ω, Calculate the value of a series resistance that should be connected so that a temperature of 750°C will give a full–scale deflection of the instrument. If the junction resistance is increased by 2 Ω due to temperature rise, what would be the measurement error? The cold junction is maintained at 0°C.

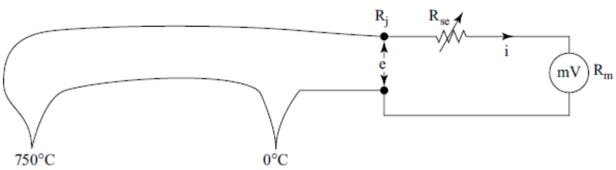


Figure 12.13

Solution:

Current, i for full-scale deflection A=0.1×10^{-3}

$$i = \frac{e}{R_m + R_j + R_{se}} = \frac{20\times10^{-3}}{100+10+R_{se}}$$

or, $$0.1\times10^{-3} = \frac{20\times10^{-3}}{110+R_{se}}$$

or, $$R_{se} = 90\ \Omega$$

$$i = \frac{20\times10^{-3}}{100+10+2+R_{se}} = \frac{20\times10^{-3}}{112+90}$$

$$= 0.099\times10^{-3}A$$

$$= 0.099 \text{ mA}$$

When current flowing is 0.1 mA, the temperature read is 750°C.

When current is 0.099 mA, the temperature reading will be

$$= \frac{750\times0.099}{0.1} = 742.5°C$$

Therefore, the error will be equal to 750°C - 742.5°C = 7.5°C

The error is negative as the reading will be less than the previous reading.

12.11 HALL EFFECT TRANSDUCERS

The principle of working of a Hall effect transducer is that when a strip of conducting material carries current in the presence of the transverse magnetic field, as shown in Fig. 12.14, an EMF will be induced between the opposite edges of the conducting strip. The magnitude of-the voltage induced too will depend upon the material of the strip, the current, and the magnetic field strength. Thus, we can state that **Hall effect refers to the potential difference (Hall voltage) on the opposite sides of an electrical conductor through which an electric current is flowing, created by a magnetic field perpendicular to the current.**

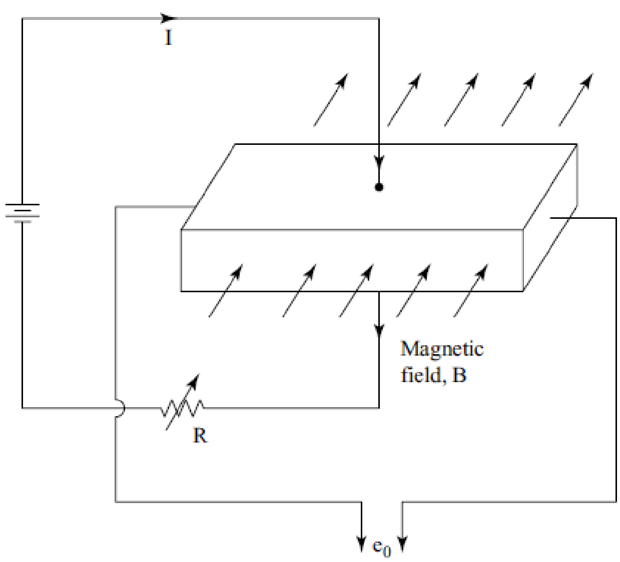


Figure 12.14 Hall effect transducer

$$\text{Hall coefficient} = \frac{e_o}{I \times B \times t}$$

Hall coefficient is the characteristic of the material, i.e., it depends on the material from which the conductor is made. To understand how a potential gets developed due to Hall effect, let us consider the following explanation.

When current flows through the conductor, it consists of the movement of charge carriers. In the presence of a perpendicular magnetic field, the moving charges experience a force, called the Lorenz force. This makes the path of the moving charge somewhat curved (and not a straight line flow) so that charges accumulate on one face of the conductor material. Equal and opposite charges start appearing on the other face of the conductor material where there is a shortage of mobile charges. This results in unequal and asymmetric distribution of charges across the conducting element both perpendicular to the direction of a straight line flow of charge (in the absence of a magnetic field) and in the direction of the applied magnetic field. This separation of charge establish an electric field that would oppose the migration of further charge, and therefore an electrical potential gets build up.

Hall effect transducers are non-contact devices, have small size, and high resolution. Such transducers can be used in the measurement of velocity, revolutions per second, magnetic field, charge carrier density, measurement of displacement, etc. Hall effect transducers can be used to measure current in a conductor without actually connecting a meter in the conducting circuit.

12.12 PIEZOELECTRIC TRANSDUCER

In certain materials called piezoelectric materials a potential difference appears across their opposite faces as a result of dimensional changes due to application of pressure created by mechanical force. This potential is produced as a result of displacement of charges in the body of the material. The effect is reversible, i.e., the reverse happens when a varying potential is applied to the proper axis of the crystal; a change in the dimensions of the crystal occurs. This effect is known as the piezoelectric effect. Commonly used piezoelectric materials are quartz, barium, titanite, lithium sulphate, etc. Fig. 12.15 shows a piezoelectric material used for the measurement of force. Since these transducers are self-generating, i.e., active transducers, the EMF induced due to force applied is directly proportional to the force. As shown in Fig. 12.15, an external force, which is to be measured, exerts a pressure on the top of the crystal and as a result EMF is produced across the crystal.

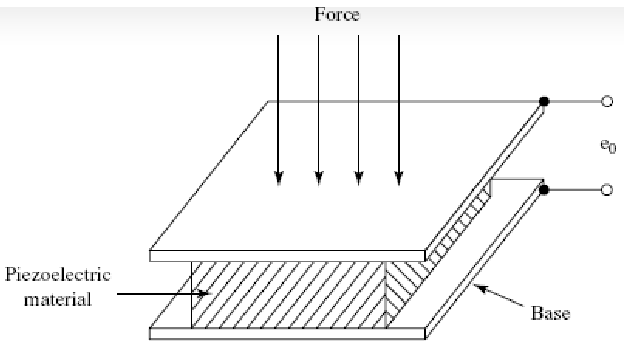


Figure 12.15 Piezoelectric material is used to measure force

A piezoelectric material should not be sensitive to temperature and humidity variations. They should lend themselves to forming different shapes. Quatz is the most suitable piezoelectric material on this account. However, the voltage induced is quite small. Rochelle salt provides higher values of induced EMF, but it is affected by temperature variations.

Fig. 12.6 shows a pressure transducer which utilizes the property of piezoelectric crystals. The transducer consists of a diaphragm by which pressure is transmitted to the piezoelectric crystal. The crystal generates an EMF across its two surfaces which is proportional to the magnitude of the applied pressure.

Piezoelectric pressure transducers are used to measure high pressure that changes rapidly like the pressure inside a cylinder of a petrol or diesel engine, or a compressor. The main drawback of this transducer is that the output voltage in affected by temperature variations of the crystal.

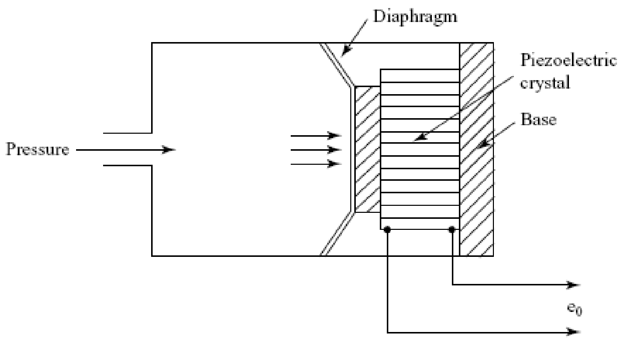


Figure 12.16 Piezoelectric pressure transducer

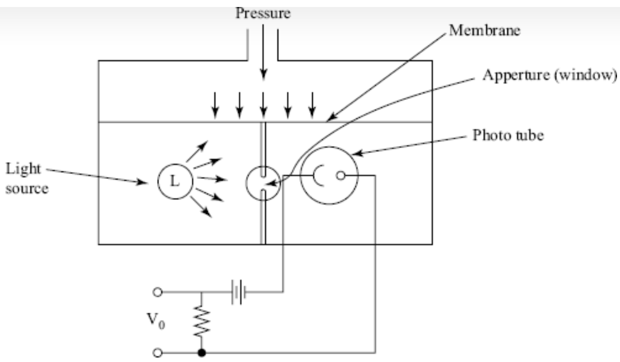


Figure 12.17 Measurement of pressure by a photoelectric transducer

12.13 PHOTOELECTRIC TRANSDUCER

This is an optical transducer which uses a photo tube and a light source. The amount of light falling on the photosensitive cathode of the photo tube is varied so that the anode current is changed. Fig. 12.17 shows a light source and a photo tube used for the measurement of pressure. The output voltage depends upon the amount of light falling on the tube through the window. The opening of the window is controlled by the pressure of the gas falling on a membrane.

The output voltage approximately varies linearly with the displacement of the aperture, and hence the pressure.

Photo cells, or solar cells are another opto-electric transducer in which light intensity controls the value of electrical potential as output. There are three general types of photo cells, viz photo-emissive, photo-conductive, and photovoltaic type.

A photovoltaic transducer may be considered as a voltage source whose value depends upon the amount of light striking its surface. The materials used are selenium, germanium, and silicon. Photovoltaic transducers are also called solar cells. A large number of solar cells interconnected together form a *solar battery*. Photovoltaic cells, in addition to their use as transducers, are used for illumination in remote areas as a non-conventional source of energy.

12.14 SELECTION OF TRANSDUCERS

The commonly used transducers, their basic principle of operation, and typical applications are shown in a tabular form in table 12.2. Passive transducers, i.e., those requiring external power supply and active transducers, which are self-generating have been shown separately in the table.

The factors which decide the selection of a particular transducer for an application are the following:

(i) Sensitivity; (ii) accuracy; (iii) operating range; (iv) ruggedness; (v) environmental effects; (vi) stability and reliability; (vii) linearity, repeatability, and high resolution; (viii) size and shape; and (ix) cost and availability.

(A) Passive transducers	Conversion principle	Typical applications
1. Potentiometric	Position of the slider is changed by the force or pressure, resistance, and hence output voltage gets changed.	Measurement of force, pressure, displacement
2. Strain gauge	Resistance of a wire or a semiconductor gets changed due to stress developed on the surface on which the gauge is pasted/fixed.	Stress, pressure, force, torque, displacement
3. Thermistor	Temperature rise changes the resistance. Resistance of certain materials decrease with increase in temperature. Resistance change is a measure of temperature.	Temperature, thermal conductivity
4. Hall effect transducer or pick-up	Potential difference is attained across a material carrying current in a transverse magnetic field.	Magnetic flux, current, velocity
5. Linear variable differential transformer (LVDT)	When the position of the magnetic core is changed, the differential voltage of two secondary windings of a transformer is changed. Output voltage is proportional to the position of the core, i.e., its displacement.	Measurement of displacement, force, pressure, position
6. Capacitive transducer	Variation of distance between the two plates, area of overlap, changing, the position of the dielectric material between the plates changes the capacitance. Change in capacitance is converted into an	Displacement, force, pressure,

	coil its self-inductance is changed. Mutual inductance between two coils is changed by varying the magnetic circuit.	

(B) Active transducers requiring no power supply	Conversion principle	Typical applications
1. Thermocouple transducer	EMF is induced when junctions of certain dissimilar materials are heated at different temperatures. One junction is taken as reference junction of known temperature.	Temperature, heat flow
2. Piezoelectric transducer	When force is applied on certain material such as quatz, EMF is induced between the two sides.	Pressure, force, vibrations
3. Photovoltaic transducer	Solar energy or light energy causes voltage to be generated in certain semi-conducting materials.	Lumen, pressure, solar cell

It is important that we select the right type of transducer for any application in the area of measurement, instrumentation, and control.

12.15 REVIEW QUESTIONS

1. Define a transducer and give a classification of transducers on the basis of various factors.
2. Name some important characteristics of transducers and explain their significance.
3. Distinguish between a passive transducer and an active transducer giving one example in each case.
4. Explain the working of a LVDT and mention its applications.
5. Explain the working principle of a piezoelectric transducer and show how this can be used for pressure measurement.
6. Explain the basic principle of Hall effect and how this effect can be used to make a transducer.
7. Explain the principle of working of a strain gauge and

10. Write short notes on the following:
    1. photoelectric transducer;
    2. thermistor;
    3. LVDT;
    (c) pressure transducer.
11. What kind of transducers would you select for the measurement of the following:
    1. vibrations;
    2. pressure;
    3. displacement;
    4. temperature;
    5. liquid level.
12. Prepare a table mentioning the principle of operation and typical applications of the following transducers:
    1. LVDT;
    2. strain gauge;
    3. potentiometer;
    4. thermistor;
    5. piezoelectric crystal.
13. Explain how displacement can be measured using an inductive transducer.
14. State the difference between a sensor and a transducer. Distinguish between an analog transducer and a digital transducer.
15. Show how a potentiometric transducer can be used in a measurement system. Mention advantages and disadvantages.
16. Explain different types of transducers for the measurement of displacement.

Multiple Choice Questions

1. A transducers is a device which
    1. transfers a signal from one circuit to the other
    2. converts a physical quantity to be measured into an equivalent electrical signal
    3. amplifies a signal for the purpose of measuremxent
    4. converts an ac signal into a dc signal.
2. Transducers which require external power supply for their operation are called
    1. passive transducers
    2. active transducers
    3. separately excited transducers
    4. self-excited transducers.
3. Which of the following is an active transducers?
    1. Thermistor
    2. LVDT
    3. Photo transistor
    4. Thermocouple.
4. Sensitivity of a Transducers is
    1. the quality of output produced by the transducers
    2. the variation of output produced under any disturbed condition
    3. the output produced per unit change in the input quantity being measured
    4. the correctness of the output produced as a proportion to the input variations.

    2. temperature-dependent resister mode of semiconducting of resistance
    3. temperature-dependent resistor mode of conducting material having positive temperature coefficient of resistance
    4. temperature-dependent resistor mode of semiconducting material having positive temperature coefficient of resistance.
6. Linear variable differential transformer is a
    1. temperature-sensitive transducer
    2. pressure transducer
    3. displacement transducer
    4. vibration measuring transducer.
7. For the measurement of weight-type weighing machine we can use
    1. LVDT-type transducer
    2. thermistor transducers
    3. thermocouple-type transducer
    4. none of these.
8. Which of the following is not a pressure measurement transducer?
    1. Piezoelectric transducers
    2. Strain gange
    3. LVDT
    4. Thermocouple.

Answers to Multiple Choice Questions

1. (b)
2. (a)
3. (d)
4. (c)
5. (b)
6. (e)
7. (a)
8. (d)