Transducers

Syllabus: *Transducers: Introduction, Passive Electrical Transducers, Resistive Transducers, Resistance Thermometers, Thermistor. Linear Variable Differential Transformer (LVDT). Active Electrical Transducers, Piezoelectric Transducer, Photoelectric Transducer.* ***(4 Hours)***

Introduction

A transducer is a device that converts a signal in one form of energy to another form of energy. It is a device or combination of elements, which responds to the physical condition or chemical state of a substance and converts it into an output signal.

Transducers should have satisfactory static and dynamic characteristics. Some of the steady-state (static) characteristics are accuracy, precision, repeatability, reproducibility, stability, sensitivity and linearity. Dynamic performance characteristics are dynamic error, fidelity, bandwidth and speed.

Classification of Transducers

Classification Based on Nature of Output

Based on the nature of output, transducers are classified into mechanical and electrical transducers.

1. Mechanical Transducer

If a transducer produces mechanical-nature signal as its output, then it is called mechanical transducer. Examples: Diaphragm, cantilever, gyroscope, thermocouple, capillary tube, etc.

2. Electrical Transducer

If a transducer produces electrical signals as output, then it is called an electrical transducer. Examples: Thermistor, LVDT, photovoltaic cell, resistance thermistor, etc.

Classification Based on Role of Transducer

Based on the role, transducers are classified into input and output transducers.

1. Input Transducer

It can be used as a measurement device and is known as an instrument transducer.

2. Output Transducer

It delivers output signals like force, torque, pressure, or displacement when the electrical signal is applied as an input. It is known as power transducer.

Classification Based on Operation

Based on the operation, transducers are classified into active and passive transducers.

1. Active Transducer

It develops a voltage or current as the output signal from the physical parameter being measured. It does not require any external source of power for its operation. Examples: Thermocouple, piezoelectric transducer, photovoltaic cell, photoelectric cell, etc.

2. Passive Transducer

It requires an external source of power. It produces a change in the electrical parameters such as resistance, inductance or capacitance in response to the physical parameter being measured. Examples: Resistance strain gauge, thermistor, LVDT, resistance thermometer, etc.

Table 1 Comparison between active and passive transducers

Active Transducers	Passive Transducers
They do not require any external source of power for their operation	They require an external source of power for their operation
They are self-generating type of transducers	They are not self-generating type of transducers
They produce electrical parameter such as voltage or current proportional to the physical parameter being measured	They produce a change in the electrical parameters such as resistance, inductance or capacitance in response to the physical parameter being measured
Examples: Thermocouple, piezoelectric transducer, photovoltaic cell, photoelectric cell, etc.	Examples: Resistance strain gauge, thermistor, LVDT, resistance thermometer, etc.

Table 1 gives the comparison between active and passive transducers.

Sensors and Transducers

A transducer is a device that converts a signal in one form of energy to the other, whereas a sensor converts any type of energy into electrical.

Sensor is the primary sensing element which is not directly coupled to the system under examination. A transducer does the task of measurement by drawing a little amount of power and energy from the system, whereas a sensor does it by standing away without getting into physical with the system under examination.

For example, intensity and luminance of a source may be measured by sensors, whereas temperature is measured by transducers.

Passive Electrical Transducers

The transducers that are based on the variation of the parameters due to application of an external stimulus are called passive transducers.

The passive elements in an electric circuit are resistor, inductor and capacitor. Passive electrical transducers can be further classified into:

i) Resistive Transducers (where resistance is varied)

ii) Inductive Transducers (where inductance is varied)

iii) Capacitive Transducers (where capacitance is varied)

Resistive Transducers

The resistance of a conductor is given by

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

where ρ = resistivity in Ωm
L = length of conductor in m
A = area of cross-section in m^2

Thus resistance might change if there is a change in the dimensions or resistivity. Dimensions can be changed by applying pressure, force or torque. The resistivity varies with temperature and composition of the medium.

Resistance Thermometer (RTD)

A resistive transducer that is used to measure temperature is called resistance thermometer or Resistance Temperature Device (RTD).

Principle of Operation

The resistance of a conductor changes with temperature. The temperature coefficient is given by

$$\alpha = \frac{1}{\Delta T} \cdot \frac{\Delta R}{R_o}$$

where ΔT = change in temperature in °C
ΔR = change in resistance in Ω
R_o = resistance at 0°C

Resistance at any other temperature is

$$R_T = R_o(1 + \alpha T)$$

The change in the resistance can be measured using a Wheatstone bridge as shown in Fig. 1, the output of which is directly calibrated to indicate the temperature.

Initially, the bridge is balanced and hence the output is zero.

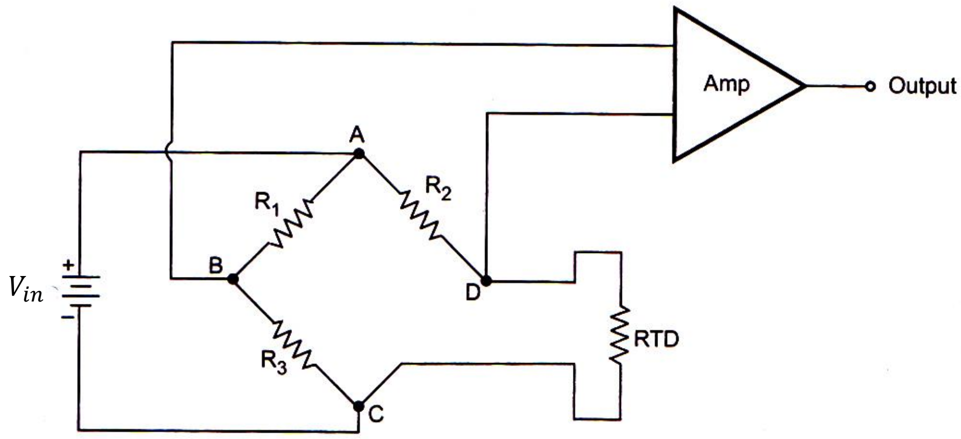


Fig. 1 RTD Operation

If there is a change in temperature, the resistance of RTD will change and as a result, there is a change in output voltage which is proportional to change in resistance and hence to change in temperature.

Construction

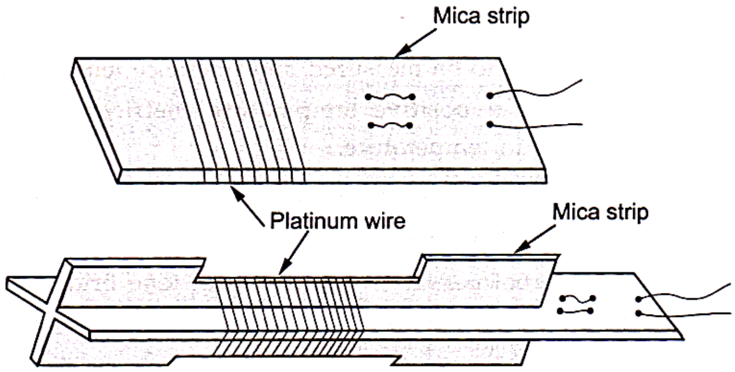


Fig. 2 Resistance thermometer

It consists of a coil of platinum wound on a mica or ceramic strip as shown in Fig. 2. This element is enclosed in a protective tube of pyrex glass, porcelain, quartz or nickel to avoid corrosion.

The element is brought in contact with the fluid whose temperature is to be measured. The two ends of the platinum wire are connected to the Wheatstone bridge.

Advantages

1. High accuracy
2. Wide temperature range
3. Does not require temperature compensation
4. Fast response
5. Good stability
6. Good sensitivity

Disadvantages

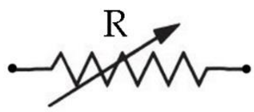
1. Requires bridge circuit and external power source for measurement
2. Chances of self-heating due to current through RTD and thus the change in resistance
3. Large size
4. High cost

Thermistor

A thermistor is a ***thermally sensitive resistor***. It is a two-terminal semiconductor device whose resistance decreases with increase in temperature.

It is said to have high negative temperature coefficient of 3-5% per ℃. Thermistors are made of oxides of cobalt, nickel, copper, iron, uranium and manganese.

The circuit symbol of a thermistor is shown below



Principle of Operation

The resistance of a thermistor is given by

$$R = R_o \exp\left[\beta\left(\frac{1}{T} - \frac{1}{T_o}\right)\right]$$

where R_o = resistance at T_o K
R = resistance at T K
β = material constant

For large values of T,

$$R \cong R_o \exp\left(\frac{\beta}{T}\right)$$

Fig. 3 shows the resistance versus temperature characteristics of a thermistor.

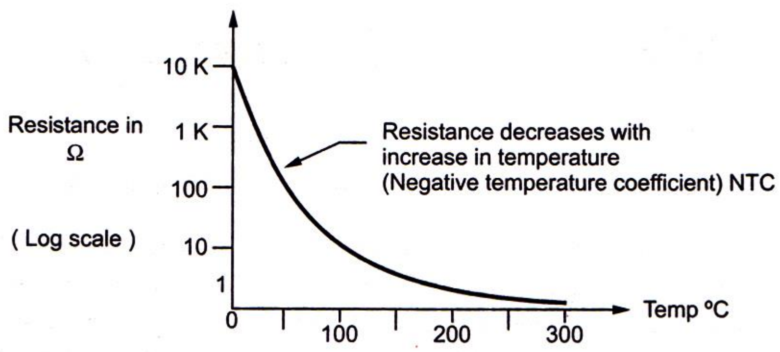


Fig. 3 Resistance vs. Temperature characteristics of thermistor

Construction

Thermistors are composed of a sintered mixture of metallic oxides such as manganese, nickel, cobalt, copper, iron and uranium. Their resistances varies from 10Ω to $100k\Omega$.

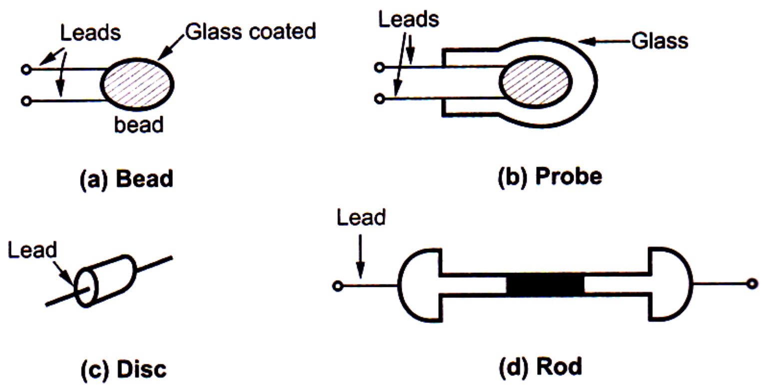


Fig. 4 Different forms of thermistors

Fig. 4 shows different shapes and sizes in which thermistors are available. Smallest in size are the beads with a diameter of 0.15 mm to 1.25 mm. Beads are sealed in the tips of solid glass rods to form probes. Discs and washers are made by pressing thermistor material under high pressure into flat cylindrical shapes.

Advantages

1. Small size
2. Large change in resistance for a small change in temperature
3. Fast response
4. Low cost

Disadvantages

1. Resistance vs. Temperature characteristic is highly nonlinear
2. Not suitable for a wide temperature range
3. Shielded cables have to be used to minimize interference

Applications

1. It is used primarily used to measure temperature.
2. It is also used in the measurement of flow and pressure, liquid level, voltage and power, vacuum and thermal conductivity.

Inductive Transducers

In inductive transducers, the self-inductance or mutual inductance of a pair of coils is varied due to variation in the parameters under measurement. They are used to measure displacement and thickness.

Linear Variable Differential Transformer (LVDT)

The LVDT is a variable inductance displacement transducer in which the inductance is varied according to the displacement.

Construction

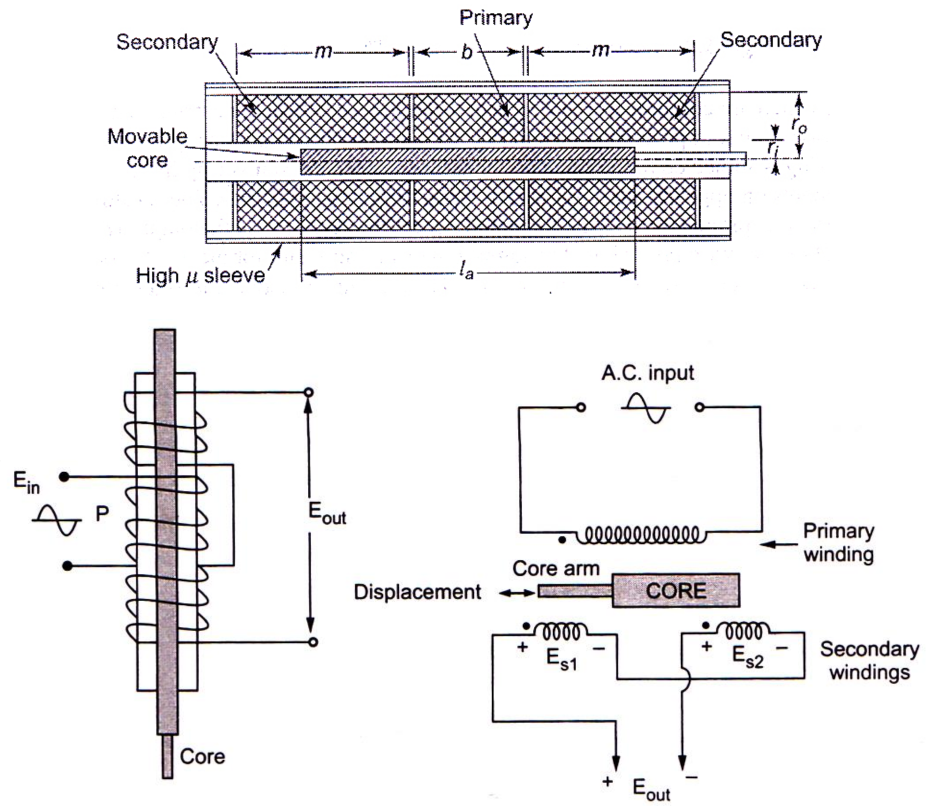


Fig. 5 Linear variable differential transformer

It consists of a primary coil, uniformly wound over a range of the transducer and two identical secondary coils symmetrically wound on either side of the primary as shown in Fig. 5. The iron core is free to move inside the coil in either direction from the centre.

Principle of Operation

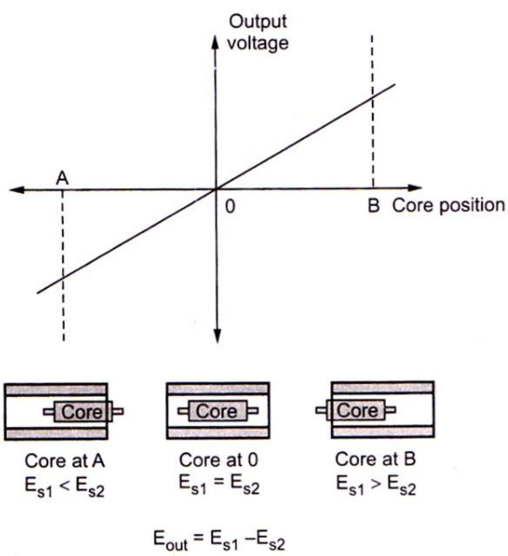


Fig. 6 Operation of LVDT

The LVDT is based on mutual inductance with variable coupling between the primary and the two secondary coils.

As shown in Fig. 6, when the iron core is at the centre, the secondary emfs are equal to each other. i.e. $E_{s1} = E_{s2}$. The secondary coils are connected in series, but in phase opposition so that net voltage is zero.

If the core is moved in any direction, it results in an output voltage that is proportional to displacement.

When the core is moved to the right (Position A), more flux links the right-hand coil than the left -hand coil. i.e. $E_{s1} < E_{s2}$. Therefore E_{out} is negative.

When the core is moved to the left (Position B), more flux links the left-hand coil than the right-hand coil. i.e. $E_{s1} > E_{s2}$. Therefore E_{out} is positive.

Advantages

1. Wide range of displacement
2. Frictionless operation as there is no physical contact
3. Ruggedness
4. Insensitive to temperature change
5. High sensitivity
6. Linearity of output

Disadvantages

1. Sensitive to stray magnetic fields
2. Large displacements are necessary for differential output

Applications

1. LVDT is used to measure displacement ranging from millimeters to centimeters.
2. As secondary transducer, it can also be used to measure force, weight, pressure, etc. Force or pressure is first converted into a displacement using a primary transducer. This displacement is applied to an LVDT that acts as a secondary transducer.

Capacitive Transducers

They are also called proximity transducers and are used to measure the nearness of an object without any mechanical coupling between them.

Active Electrical Transducers

They are self-generating transducers which generate their own voltage based on the change in parameter that is being measured.

Thermoelectric Transducers

They convert thermal energy (heat) into electric energy. This is governed by three principles:

Seebeck Effect

If two wires of different metals are joined together to form two junctions and if the two junctions are held at different temperatures, an electric current will flow round the circuit. The current flows across the hot junction from the former to the latter metal of the following series:

Bi – Ni – Co – Pd – Pt –
U – Cu – Mn – Ti – Hg – Pb –
Sn – Cr – Mo – Ph – Ir – Au – Ag –
Zn – W – Cd – Fe – As – Sb – Te

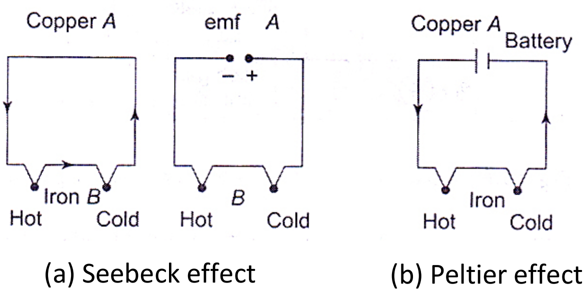


Fig. 7 Seebeck and Peltier effect

If metal A is copper and B is iron, then the current flows from copper to iron at the hot junction and from iron to copper at the cold junction as shown in Fig. 7 (a). The Seebeck emf depends on the difference in the temperature of the two junctions.

Peltier Effect

It is the reverse phenomenon of Seebeck effect. An external emf is connected as shown in Fig. 7 (b) and a current is forced through the junctions.

It is observed that heat is absorbed when the current flows across iron-copper if the flow of current is reversed.

The amount of heat liberated or absorbed is proportional to the quantity of electricity that crosses the junction. The amount of heat liberated or absorbed when one ampere current passes for a second is called the Peltier coefficient.

Thompson Effect

If a temperature difference exists in a wire of the same metal, then the contribution of Seebeck effect in that circuit is called Thompson effect.

When a current flows through a copper conductor having a thermal gradient (temperature difference) along its length, heat is liberated at any point where the current flows in the direction of heat flow, while heat is absorbed at any point where the current flows in the direction opposite to that of heat flow.

In iron, heat is absorbed at any point where the current flows in the direction of heat flow, while heat is liberated at any point where the current flows in the direction opposite to that of heat flow.

Piezoelectric Transducers

They convert mechanical energy into electrical energy and are based on piezoelectric effect.

Principle of Operation

When the surface of crystals are under mechanical strain due to application of stress, electrical charge is developed. This is called ***piezoelectric effect***. The basic piezoelectric phenomenon is the effect of force applied in longitudinal and transverse directions. The three modes of operation are thickness expander mode, length expander mode and volume expander mode. These modes are based on the direction of force applied which is to be measured.

The materials exhibiting piezoelectric effect are quartz, Rochelle salt, tourmaline, Ammonium Dihydrogen Phosphate (ADP), Lithium Sulphate (LS), Di Potassium Tartrate (DKT), etc.

Fig. 8 shows a piezoelectric crystal used as a transducer.

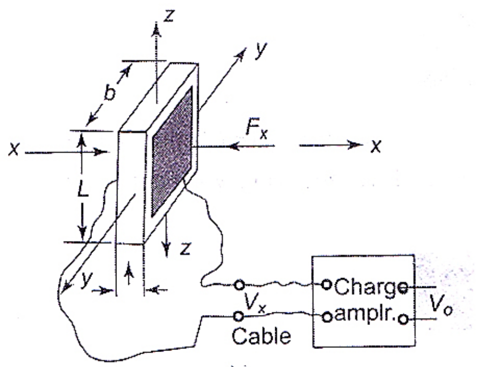


Fig. 8 Piezoelectric transducer

Advantages

1. Smaller in size
2. High natural frequency
3. Linearity
4. High sensitivity
5. Wide measuring angle
6. Polar sensitivity
7. High mechanical rigidity

Applications

Piezoelectric transducers are used to measure force, pressure, acceleration, torque, strain.

Photoelectric Transducers

They convert light energy into electrical energy. If light energy interacts with an electron bound in a metal surface, the entire quantum energy is converted into kinetic energy. This kinetic energy helps the electrons to move and contribute current in the metal. This is called ***photoelectric effect***. There are three different forms of photoelectric effect:

1. Photo-emissive

They consist of a metallic cathode and an anode in an evacuated tube. The electrons emitted from the cathode are attracted towards the anode, which causes the current flow proportional to the amount of light fallen.

2. Photovoltaic

Photovoltaic cells are self-generating and are used in exposure meters.

3. Photoresistive

In photoresistive cells, the change in the resistance value according to illumination of light is to be measured. It is also known as Light Dependent Resistor (LDR). The photoresistive or photoconductive cells are passive in nature.

Hall Effect Transducers

Hall Effect is the production of a potential difference across an electrical conductor when a magnetic field is applied in a direction perpendicular to that of the flow of current.

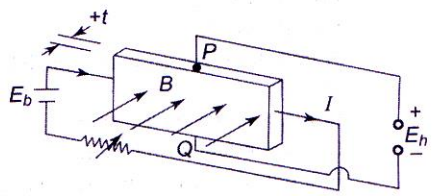


Fig. 9 Hall-effect transducer

It is one of the galvanomagnetic phenomena in which the interaction between the magnetic field and moving electrical charges results in the development of forces that alter the motion of the charge. This is observed in semiconductor materials.

A thin strip of bismuth or N-type germanium is subjected magnetic field B normal to its surface as shown in Fig. 9. It carries a current I along the length of the strip, but normal to B. Because of the force from magnetic field, the electrons move towards the edges of the strip with a velocity v. So the edge surfaces act like charged electrodes and potential difference between two edges is known as Hall potential E_h.

Hall-effect transducers are used for measurement of magnetic fields. It is also used to measure dc and ac currents without making physical contact with the conductor.

Questions

1. What is a transducer? Mention any four characteristics a transducer should possess. ***(Dec '17, Jun '17, Jun '16 – 2M, Dec '15 – 2M, Dec '14, MQP '14)***
2. Write a note on classification of transducers.
3. Distinguish between active and passive transducers. ***(Dec '17 – 6M, Jun '17 – 4M, Dec '16 – 5M, Dec '15 – 5M, Dec '14 – 6M, MQP '14 – 5M)***
4. What is a transducer? Mention four important parameters of an electrical transducer. ***(Dec '17 – 4M)***
5. Explain the construction and principle of operation of resistive thermometer (RTD). ***(Dec '17 – 5M, Dec '16 – 5M)***
6. Write a note on thermistor. Explain its advantages and limitations. Mention its applications. ***(Dec '17 – 5M, Dec '15 – 6M, Dec '14 – 5M)***
7. Explain the construction and the principle of operation of LVDT. Mention its applications. ***(Dec '17 – 6M, Jun '17 – 6M, Dec '16 – 5M, Jun '16 – 6M, Dec '15 – 8M, Jun '15 – 6M, Dec '14 – 6M, MQP '15 – 5M, MQP '14 – 6M)***
8. Explain (i) Seebeck effect (ii) Peltier effect (iii) Thompson effect (iv) Hall effect ***(Jun '17 – 6M, Jun '15 – 6M, MQP '14 – 6M)***
9. Explain the principle of operation of piezoelectric transducers. ***(Dec '17 – 4M, Jun '17, Jun '16 – 8M)***
10. Write a note on photoelectric transducers. ***(Dec '17, Jun '17 – 6M)***
11. Explain the working of photovoltaic transducer. ***(Dec '15 – 8M)***

References

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