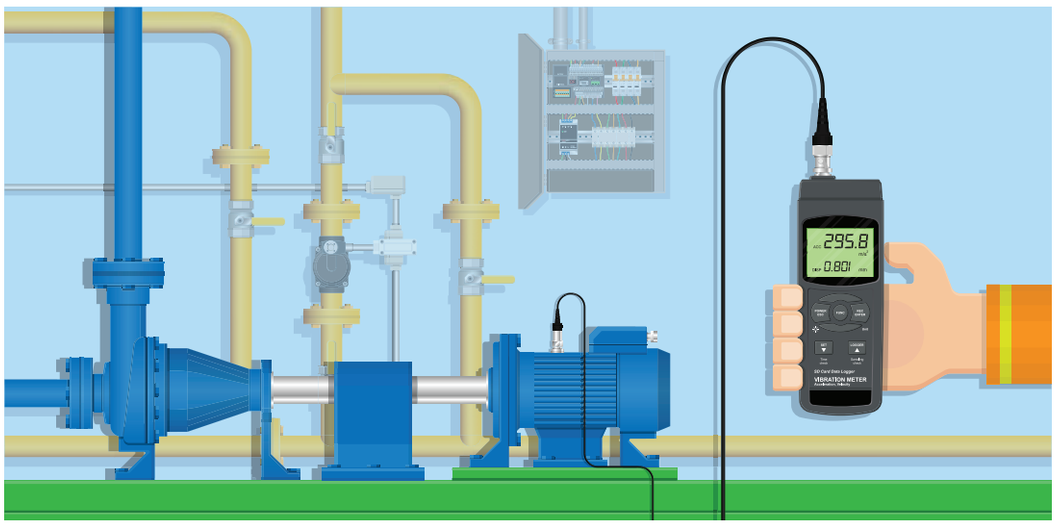
Chapter 7

Transducers

JCKVKE



Peace begins with a smile

— **Mother Theresa**

Learning Objectives

The main objectives of this lesson is how to change non-electrical Parameters into electrical parameters according to law of conservation of energy. We have to learn how to convert mechanical parameters into electrical parameters in detail.

Table of Content

7.1 Introduction

Instrumentation is the heart of an industry for the measurement of the parameters like pressure, temperature, force, displacement and rotation etc. A basic instrumentation system consists of major devices for its operation. One of these categories is transducers and it acts as major role in the measurement and instrumentation systems.

Transducers are energy conversion devices which transforms non-electrical quantity into electrical quantity. The transducers are very important in our day to life to measure the electrical parameters such as current, voltage etc., and physical parameters are pressure, load, torque etc.

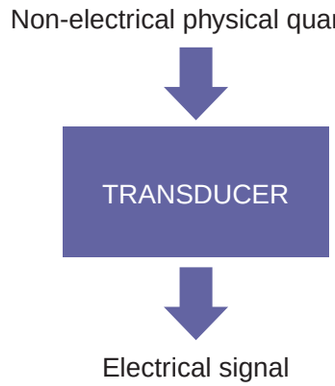


Fig. 7.1 Transducer

7.2 Principle of operation of transducers

All electrical instrumentation system consists of operating elements to perform a measurement and to display its results. The major elements of an instrumentation system is

i. Input devices
ii. Processing devices and
iii. Output devices

The input devices receive the quantity under measurement. The processing devices transmit the signal from the input devices to the output devices. The output device gives the value of output sensed by the transducers. So, in a broad category the transducers convert the non-electrical quantity such as temperature, pressure, sound etc into electrical quantity like voltage, current and capacitance etc.

7.3 Classification of transducers

The transducer can be classified as,

i. On the basis of transduction form used
ii. Primary and secondary transducers
iii. Passive and active transducers
iv. Analog and digital transducers
v. Transducers and inverse transducers

i. The transducers are classified based on the method of transduction such as resistive, inductive and capacitive

For resistive transducers, variation of input causes the resistance to change.

For inductive transducers, variation of input causes the inductance to change.

For capacitive transducers, variation of input causes the capacitance to change.

ii. Primary and Secondary transducers

The transducer connected on the detector stage is called Primary transducer and the output of primary transducer is

converted into a usable output is called secondary transducers.

iii. Passive and active transducers

The transducers which are externally powered are called passive transducers and self-generating types are called as active transducers.

iv. Analog and digital transducers

The transducer which gives output in analog form is called analog transducers and transducer which gives output in digital form is called digital transducers.

v. Transducers and inverse transducers

The transducers which converts non-electrical quantity into electrical quantity is called transducers and the transducers which converts electrical quantity into non-electrical quantity is called inverse transducers.

7.4 Factors to be considered for the selection of transducers

The selection of transducers is based on the applications where it is used. The following important factors are to be considered for the selection of transducers.

i. It should have high input impedance and low output impedance, to avoid loading effect.
ii. It should have good resolution over is entire selected range.
iii. It must be highly sensitive to desired signal and insensitive to unwanted signal.
iv. Preferably small in size.
v. It should be able to work in corrosive environment.
vi. It should be able to withstand pressure, shocks, vibrations etc...
vii. It must have high degree of accuracy and repeatability.
viii. Selected transducer must be free from errors.

Do you Know?

A **biometric device** is a security identification and authentication device. Such devices use automated methods of verifying or recognizing the identity of a living person based on a physiological or behavioral characteristic. These characteristics include finger prints, facial images, iris and voice recognition. Biometrics are being used to establish better and accessible records of the hours employee's work

7.4.1 Advantages of electrical transducers

The advantages of electrical transducers compared with other types of transducers are numerous. As to say some of the points

i. Electrical amplification is simple and easy.
ii. Frictional effects are minimized.
iii. Mass-inertia effects are minimized.
iv. Small power is used to control.
v. Transmission of electrical signal is easy.

The physical quantity is under measurement is first connected to primary transducers. This primary transducer changes the positions due to the external applied quantity. This variation is then connected to one of the arms of a Wheatstone bridge. Before applying the pressure, the bridge is brought to a balanced condition. The change in the resistance causes the bridge to unbalance. This deviation in the unbalance is measured in terms applied force. This is the basic principle of operation of transducers using wheatstone bridge method.

In a wheatstone bridge method, the four arms are connected as shown in figure 7.2 then one of the arm is connected to the unknown parameter to be find.

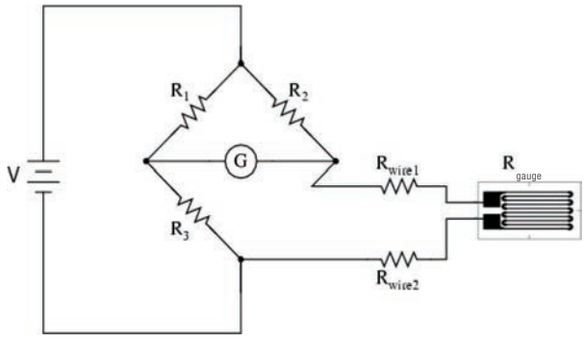


Fig. 7.2 Wheatstone bridge for strain gauge

7.5 Resistive, inductive and capacitive transducers

7.5.1 Resistive transducers

The types of transducers which work by changing its resistance are called resistive transducers. This type of transducer works both in AC and DC supply.

The resistance of metal conductor is given by $R = \frac{\rho l}{A} \Omega$

Where R = resistance

l = length of conductor

A = cross-sectional area of conductor

ρ = Resistivity of conductor material

Any method of varying the above said parameters by applying external force in the relationship is the very basic principle of operation for an electrical resistive transducer.

The Applications of resistive transducers are discussed below.

7.5.2 Measurement of displacement, pressure and force using resistive transducers

a. Potentiometers type transducers for linear displacement

A potentiometer is a three-terminal resistor with a sliding or rotating contact that forms an adjustable voltage divider. A resistive potentiometer or simply POT, consists of a resistive element provided with a sliding contact. Potentiometer transducers used to measure translational and rotational.

For example, let us consider the measurement of linear displacement

through POT. The linear displacement is connected to the sliding contact. The sliding contact is called as wiper. First, the wheatstone bridge is brought to balanced condition. At that time the galvanometer in the bridge shows null deflection.

Now the displacement is connected to the wiper. This linear displacement makes bridge to unbalance. The unbalance causes deflection in the galvanometer. This deflection is calibrated in terms of the applied displacement.

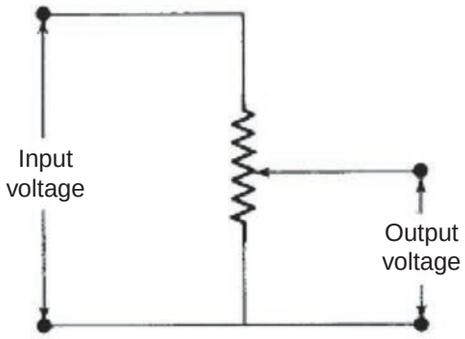


Fig. 7.3 Linear displacement

b. Potentiometers for rotary displacement

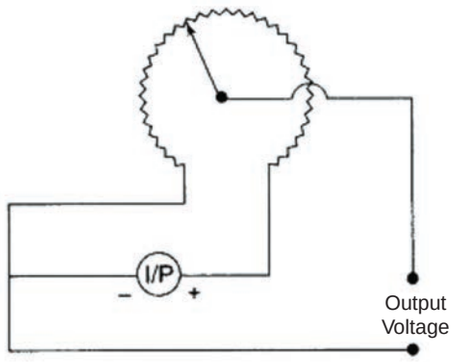


Fig. 7.4 Potentiometer for rotary pot

The input voltage is given to the two terminals of the potentiometer. The output voltage is taken from the output terminals as shown in figure 7.4. The slider arm is connected to the rotating quantity which we want measure. The rotating arm causes output voltage to change. This change in output is measured in terms of the applied rotary motion.

c. Strain gauge

The strain gauges are used to measurement of strain and associates stress. It works on the principle of piezo-resistivity. If a metal conductor is stretched or compressed, is resistance changes on account of the reason length and diameter changes.

d. Unbonded strain gauge

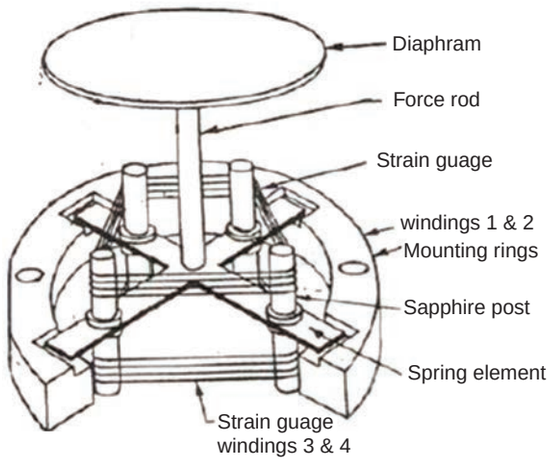


Fig. 7.5 Unbonded strain gauge

This gauge consists of a wire stretched between two points in an insulating medium such as air. The unbonded wires may be made up of various copper nickel, chrome nickel or nickel ion alloys.

The unbonded strain gauge wire acts as the four arms of a wheatstone bridge. Before applying pressure, the bridge is brought under balanced condition. Pressure is applied on the top of the diaphram as shown in figure 7.5. This makes unbonded wire to stretch along

its length and corresponding change in diameter. Therefore, the resistance of the wire is changed. This change in resistance is measured in terms of applied pressure.

e. Bonded strain gauge

These gauges are directly bonded (that is pasted) on the surface of the structure under study. Hence, they are termed as bonded strain gauges. Bonded strain gauges offer a rugged assembly and good accuracy that is not degraded by shock and vibration. However, bonded strain gauges are limited in their pressure and temperature ranges. The three types of bonded strain gauges are

i. Fine wire strain gauge
ii. Metal foil strain gauge
iii. Semi-conductor gauge

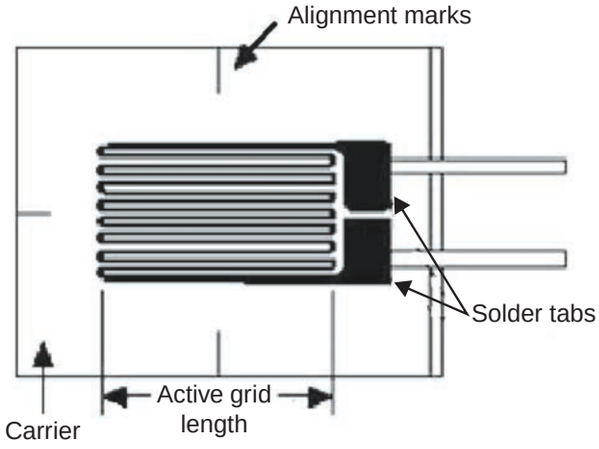


Fig. 7.6 Bonded strain gauge

f. Resistance thermometers

The resistance of a conductor changes when its temperature is changed. This property is utilized for measurement of temperature. The resistance thermometer detector (RTD) uses the change in electrical resistance of conductor to determine the temperature. Platinum and nickel are used for the measurement of temperature being it can withstand high temperature. These types of temperature detector are having positive temperature coefficient.

The platinum element is placed inside the RTD and connecting wires are pulled out from the RTD to the external circuit. The external circuit may be wheatstone bridge. The temperature variation causes the deflection in the bridge which is the measure of temperature. The mounting threads are used to mount this detector to the equipment of temperature measurement.

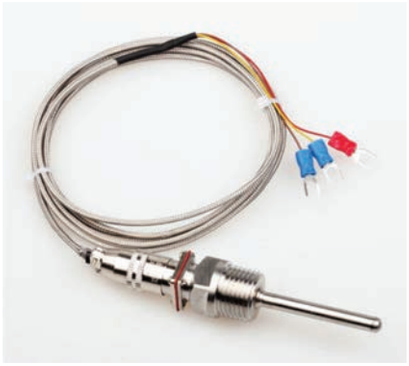


Fig. 7.7 Industrial platinum RTD

g. Thermistor

Fig. 7.8 Thermistor

Another type of resistive transducer is thermistor whose resistance depends on temperature. Thermistors are available in the form of beads, rods and discs.

Thermistors are rugged in construction, cheaper in cost and highly sensitive devices.

h. Advantages of resistance transducers

i. Simple in construction
ii. High output
iii. Less expensive
iv. Available in different shapes and ranges
v. High electrical efficiency

7.5.3 Inductive transducers

Inductive transducers are passive transducers which operate generally one of the following parameters.

i. Variation of self-inductance of the coil
ii. Variation of mutual-inductance of the coil
iii. Production of eddy currents

a. Working principle

The self inductance of a coil is given by,

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

where L = self inductance

N = Number of turns

μ = permeability of magnetic materials

A = Area of cross-section of magnetic path

l = lengnth of mean turn

From the above expression it is clear that, the self-inductance of the coil can be varied by varying the number of turns on the coil (N), permeability μ , Area of cross-section (A) and length of mean turn (l). These transducers are usually used for the measurement of linear and rotary displacement. The following figures shows the schematic diagram of linear and rotary type inductive transducers.

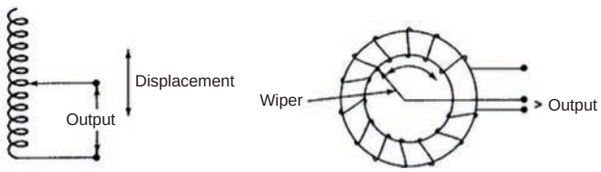


Fig. 7.9 Inductive transducers

b. Linear variable differential transformer (LVDT)

This is most widely used inductive transducer for translating linear movement into electrical signal. The basic construction of LVDT is shown below.

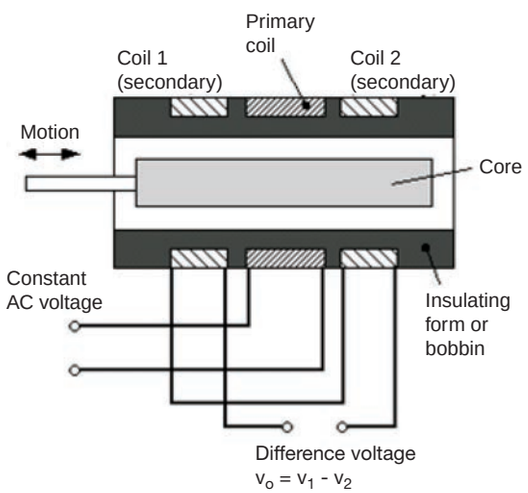


Fig. 7.10 LVD transformer

LVDT is working on the principle of a Transformer only. Like a transformer LVDT has both primary and secondary. Primary winding is connected to an AC supply. The secondary has two identical windings which are connected in series opposition. A soft iron core is attached

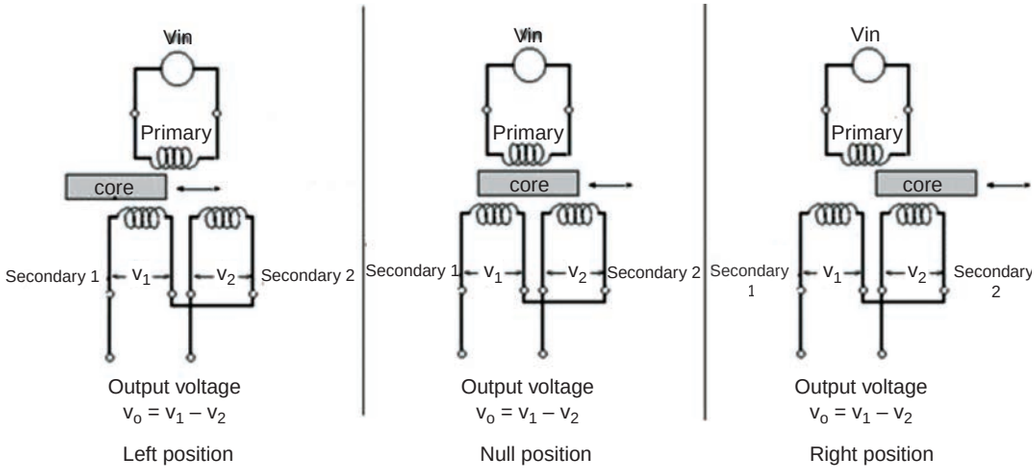


Fig. 7.11 LVD Transformer

to the sensing element of displacement is to be measured. This core is movable with respect to the applied displacement.

When there is no force, the central core occupies null position as shown in figure 7.11. At this time the magnetic coupling of primary to secondary are equal. Hence the two output voltages of secondary windings V_1 and V_2 are equal.

As the core is moved towards the left from its null position, the secondary winding voltage V_1 increases over V_2. This is shown in figure 7.11.

As the core is moved towards the right from its null position, the secondary winding voltage V_2 increases over V_1. This is shown in figure 7.11.

In this way the displacement is measured by LVDT.

c. Advantages of LVDT

i. LVDT has high sensitivity.
ii. Consumes very less power.
iii. Good frequency response.
iv. LVDT is more reliable device.
v. It is very rugged device.

d. Disadvantages

i. Relatively large displacement is needed to make output.
ii. Affected by vibrations.
iii. Temperature affects the performance of LVDT.

7.5.4 Capacitive transducers

The capacitance of a parallel plate is given by,

$$C = \frac{\epsilon_0 \epsilon_r A}{d}$$

Where,

ϵ_0 = permittivity of free space.
ϵ_r = the relative permittivity of free space
A = Area of plates
d = Distance between the plates.

As the capacitance of a capacitor depends on the above parameters, such transducers can be used to measure the non-electrical quantity such as displacement, force, pressure etc.

7.5.5 Types of capacitive transducers

a. Capacitive transducers - By variation overlapping area

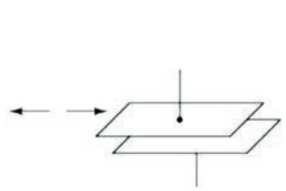
This type of transducers operates on the fact that capacitance of the capacitor is proportional to the overlapping area of plates. As shown in the figure 7.12, one plate is fixed and the other is movable. If the displacement is taken place, one of the plates connected to displacement moves over the fixed plate, thereby changing the overlapping area.

b. Capacitive transducers - By variation of distance between the plates

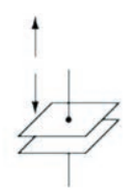
This type of transducers operates on the fact that capacitance of the capacitor is inversely proportional to the distance between the plates. Such type of transducers are used to measure the linear displacement as shown in figure 7.12.

c. Capacitive transducers - By variation of permittivity of the di-electric material

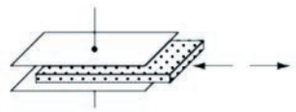
This type of transducers operates on the fact that capacitance of the capacitor is varied by varying the permittivity of the dielectric material. In this arrangement, a dielectric material of permittivity 'e' moves between the two fixed plates as shown in figure 7.12.



Capacitance changes with changes in plate overlap



Capacitance changes with changes in distance



Capacitance changes with changes in dielectric

Fig. 7.12 Capacitive transducers

d. Advantages of capacitive transducers

i. Good frequency response.
ii. These are not affected by stray magnetic fields.
iii. These are extremely very sensitive.
iv. Operates at a very little force.

e. Disadvantages

i. The output changes with temperature.
ii. Adequate design is needed for accurate measurements.
iii. Electrostatic screening is needed.

7.6 Piezo electric transducers

The piezo electric sensors are based on the principles of electro mechanical energy conversion. The mechanical input is converted to the electrical output and that is the basis of this transducers and this transducer shows piezo electric effect.

In some crystalline materials, a potential is developed across the opposite faces of the material when a mechanical force is applied on it. This is called piezo electric effect and the materials which exhibit this behavior is called as piezo electric materials. This effect is used to measure the dynamic pressure, force, shock and vibratory motion. Common piezo-electric materials are rochelle salt, ammonium de-hydrogen phosphate, lithium sulphate and quartz ceramic.

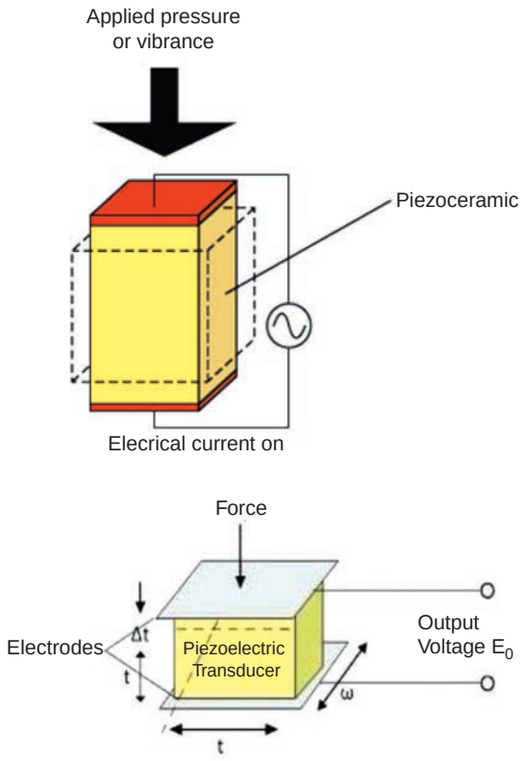


Fig. 7.13 Piezo transducer

a. Advantages

i. Piezo electric transducers are small in size, light in weight.
ii. It is rugged in construction.
iii. They are self-generating type of transducers.
iv. Good frequency response.
v. Measurable output.

b. Disadvantages

i. Output voltage is being affected by temperature.
ii. Leakage resistance affects its performance.

7.7 Thermocouples

In 1821, According to Thomas Seebeck, "When two dissimilar metals are in contact, a voltage is generated where the voltage is a function of temperature". This is the basic working principle of thermocouples.

This principle is used to convert heat energy into electrical energy at the junction of two conductors. This thermocouple works on principle of thermo-electric effect and this thermo-electric emf depends on the difference in temperature between the hot junction and reference junction. The thermocouples are placed inside protective wells without interruption of the working environment.

As an example, joining copper and constantan produces a voltage in the order of milli volts with the positive terminal as copper. An increase in temperature causes an increase in voltage.

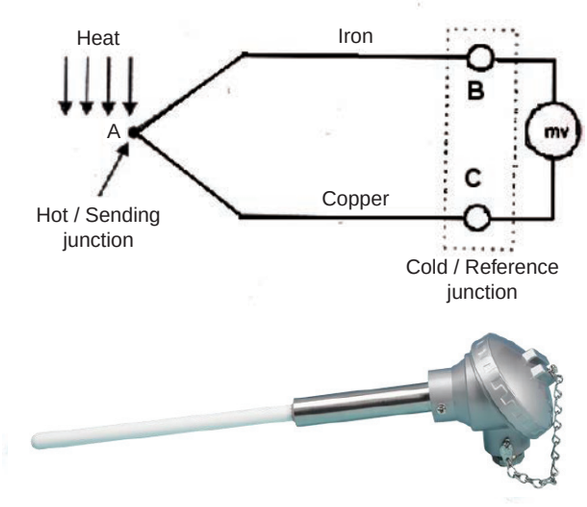


Fig. 7.14 Thermocouples

a. Advantages

i. Self-powered transducers.
ii. Simple and rugged in construction.
iii. Wide range of temperatures measurements.
iv. Inexpensive.

b. Disadvantages

i. Non-linear characteristics.
ii. Low-voltage only generated.
iii. Least – sensitivity to temperature changes.

7.8 Photo voltaic Cells (Solar cells)

Photo voltaic cells may be used in a number of applications. The silicon solar cell converts the radiant energy of the sun into electrical power. The solar cell consists of a thin slice of single crystal p-type silicon, up to 2cm square, into which a very thin layer of n-type material is diffused. The conversion efficiency depends on the spectral content and intensity of the illumination.

a. Advantages

i. Simple and green environment.
ii. Pollution free.
iii. Renewable electric power generation.

Fig. 7.15 **Photo voltaic Cell**

iv. Use batteries to store extra power for use at night.
v. Solar can be used to heat water, power homes and building, even power cars.
vi. Safer than traditional electric current.

b. Disadvantages

i. High initial costs for material and installation.
ii. Needs a lot of space.
iii. No solar power at night. Hence there is a need for a large battery bank.
iv. Cloudy days do not produce much energy.

Glossary

Piezo resistivity	-	தகவுத்தடை
Potentiometer	-	மின்னழுத்தமானி
Signal	-	சிக்னல்
Strain gauge	-	திரிபளவுமானி
Thermistor	-	வெப்பத்தடையகம்
Permeability	-	ஊடுருவும் தன்மை
Linear variable differential transformer	-	நேரியல் மாறி மாறுபட்டமின்மாற்றி
Thermocouple	-	வெப்பமின்னிரட்டை

Evaluation

PVDFW1

PART-A

Choose the correct answer **(1 Marks)**

1. Which type of devices are used to estimate the parameters to be measured
   a. Input devices
   b. Processing devices
   c. Non processing devices
   d. Output devices

2. Which device converts non-electrical quantity into electrical quantity
   a. Generator
   b. Transducer
   c. Motor
   d. Transformer

3. The display of quantity to be measured is in these types of devices
   a. Input devices
   b. Processing devices
   c. Non processing devices
   d. Output devices

4. Transducers are classified according to
   a. resistance only
   b. inductance only
   c. capacitance only
   d. resistance, inductance and capacitance

5. hich one of the following is not advantage in electrical transducers
   a. Electrical amplification is easy
   b. Less frictional effects
   c. Less mass-inertia effects
   d. Transmission of electrical signal is not easy

6. At starting time, wheatstone bridge is in which position
   a. deflection
   b. null deflection
   c. balanced
   d. unbalanced

7. Resistive transducers are used to measure
   a. displacement only
   b. pressure only
   c. displacement, pressure, force
   d. force only

8. Which parameter is measured from strain gauge meter
   a. resistance
   b. Strain
   c. stress
   d. strain and stress

9. Which one of the following is not correct in thermistor transducers
   a. rust in construction
   b. low cost
   c. high sensible
   d. Simple in construction

10. The advantage of photo voltaic cell is
    a. rust in construction
    b. not safety
    c. Pollution free
    d. more polluted

PART-B

Answer the questions in brief **(3 Marks)**

1. Define primary and secondary transducers.
2. Write short notes on analog and digital transducers.
3. Write about Strain gauge transducer.
4. What are the advantages of resistive transducers?
5. What are the advantages of linear variable differential transformers?
6. What are the disadvantages of linear variable differential transformers?
7. What are the various types of capacitive transducers?
8. What are the advantages of capacitive transducers?

PART-C

Answer the questions in one page **(5 Marks)**

1. What are the advantages of electrical transducers?
2. Write short notes on piezo electric transducers?
3. What are the advantages of piezo electric transducers?
4. What are the advantages of photo voltaic cell?

PART-D

Answer the questions in two page **(10 Marks)**

1. What are the factors to be considered for the selection of transducers?
2. Explain about thermocouple.
3. Explain with neat diagram of linear variable differential transformer.

Reference Book

1. A text book of 'Electrical Technology' Volume-III B.L.Theraja and A.K.Theraja, S.Chand & Company Ltd.

Reference Internet Source

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