Transducers

Transducers are devices that are used to convert one form of energy into another form. They convert physical quantities such as pressure, force, temperature into quantities suitable for measuring. The transducer, which converts non-electrical form of energy into electrical form of energy, is known as electrical transducer. The output of electrical transducer is equivalent to the input, which has non-electrical energy.

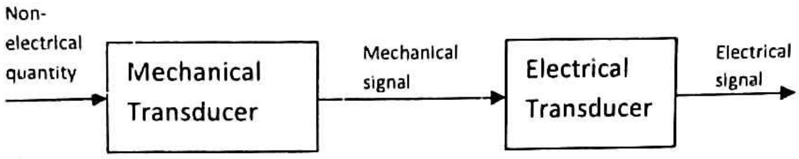

Fig 1: cascading of mechanical and electrical transducers

Transducer is a device which responds to the physical conditions or chemical state of a substance and converts to an output signal. If the output is a mechanical signal then it is called as Mechanical Transducer and if the output signal is electrical in nature then it is termed as Electrical transducer. The Electrical transducers are the devices that convert energy in the form of sound, light, heat, etc., into an equivalent electrical signal, or vice versa. The output electrical signal may be voltage, current, or frequency. Production of these electrical signals is based upon resistive, inductive, capacitive effects. For measuring non electrical quantities, a detector is used which usually converts the physical quantity into a displacement, that activates the electrical transducers. Transducer is a device that can convert energy from one form to another, whereas a sensor is a device that can detect a physical quantity and convert the data into an electrical signal.

Based on the role of transducers, it can be classified into input and output type. An input transducer is used to measure and hence is known as instrument transducer. The power transducers are nothing but output transducers which provide output signals like force, torque etc when electrical signal is given as input.

Based on operation it is classified as active and passive transducers. When the physical quantity is measured active transducers produce voltage and current as output signals. But in case of passive transducer external energy is required to create electrical signals.

Need for transducers

1. Physical parameters like temperature need to measured and controlled in the industry
2. To measure heart rate, blood pressure, to obtain EEG and ECG waveforms in the medical field
3. Converting variations in sound into variations in voltage or current in communication system
4. To measure and indicate the speed, to indicate the fuel level and so on in automobile industry

Passive Transducers:

It is also called as externally powered transducers. They derive the power required for energy conversion from an external power source. The passive transducers are further classified into Resistive type, Inductive type and capacitive type.

I) Resistance: Thermistor, Photoconductive cell, Resistance strain gauge
II) Inductance: LVDT- Linear Variable Differential Transformer
III) Capacitance: Photoemissive cell, Hall effect based devices.

I) Resistive transducer:

A passive transducer is said to be a resistive transducer, when it produces the variation in resistance value.

$R=\rho*l/A$
Where,

ρ is the resistivity of conductor
l is the length of conductor
A is the cross sectional area of the conductor

The resistance value depends on the three parameters ρ,l & A. We can make the resistive transducers based on the variation in one of the three parameters ρ,l & A. The variation in any one of those three parameters changes the resistance value. When the resistive element is subjected to pressure, force or torque, changes in the dimensions occur. Which will in turn change the conductive properties of the material. They can be used to measure displacement, force and pressure. Resistance, R is directly proportional to the resistivity of conductor, ρ. So, as resistivity of conductor, ρ increases the value of resistance, R also increases. Similarly, as resistivity of conductor, ρ decreases the value of resistance, R also decreases. Resistivity of a material changes with temperature and composition of the material. Resistance thermometer make use of these properties.

1) Resistance thermometer

The change in temperature is measured in terms of the change in resistance. The resistive element is usually made from metal, metal alloy or semiconductor. The only difference is that the resistivity decreases in semiconductor and insulator materials where as in metals it increases as the temperature increases. In metals there is change in resistance due to change in length also.

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

R_o= resistance at 0^0C

T= temperature in ^0C

α = temperature co-efficient in ^0C

$=\frac{1}{\Delta T}\frac{\Delta R}{R_0}$

Where ΔT = change in temperature

ΔR = change in resistance

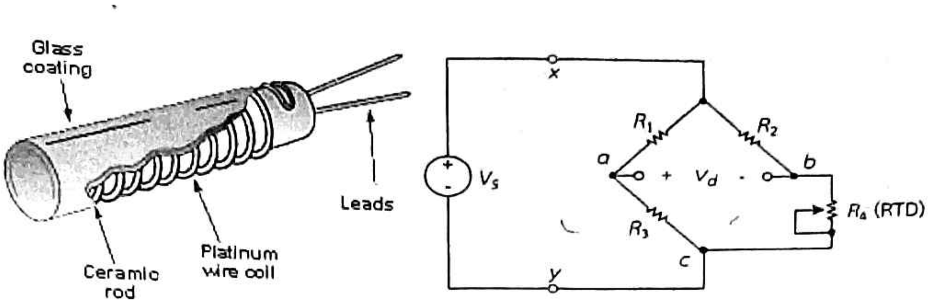

Fig 2a: Wire resistance thermometer construction 2b: RTD with wheat stone bridge

Wire resistance thermometer consists of fine wire wrapped around a ceramic, mica or glass bar. Since the element is very fragile and hence it is enclosed in protective glass, porcelain, quartz or nickel. Thermometer is built using platinum, copper etc (fig 2a). Temperature measurement is carried on by placing resistance thermometer as one of the arm in wheat stone bridge as in the (fig 2b). Whenever resistance of RTD changes due to change in temperature the bridge is imbalanced generating difference voltage V_d.

Advantages:
Accurate temperature sensor
Provides excellent stability and precision
High linear temperature-resistance characteristics
Faster response
Disadvantage:
Bigger in size
Higher cost
Possibility of self heating

2) Thermistor

Thermistor is a temperature sensing device made from semiconductor material that acts like an electrical resistor but is temperature sensitive. Thermistors can be used to produce an analogue output voltage with changes in temperature and hence is referred to as transducer. It is a two terminal device whose resistance decreases with increase in temperature i.e. negative temperature coefficient.

$$R = R_0 e^{-\alpha T}$$

R_0=maximum resistance corresponding to minimum temperature
α =a constant dependent on the thermistor type
It is made up of oxides of metals such as manganese, nickel etc

Advantages:
Small size
Fast response
Good sensitivity
Disadvantages:
The temp-resis characteristics is non-linear
Not suitable for wide range of temperature measurement

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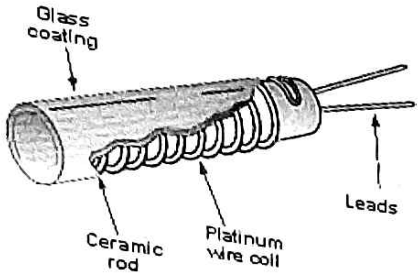

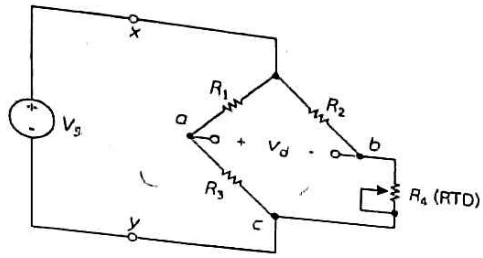

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Fig 3: Thermistor

Applications: measurement of temperature, flow and pressure, liquid level, voltage and power

Active Transducers:

It is also known as self-generating type transducers. They develop their own voltage or current as the output signal. The energy required for production of this output signal is obtained from the physical phenomenon being measured.
Examples: Thermocouple, Piezoelectric transducers, Photovoltaic cell, Moving coil generator, Photoelectric cell.

I) Piezoelectric transducers

The ability of materials to produce charges when subjected to mechanical stress is called piezoelectric effect. The EMF develops because of this displacement of the charges. The effect is changeable, i.e. if the varying potential applies to a piezoelectric transducer, it will change the dimension of the material or deform it. This effect is known as the piezoelectric effect. The piezo-electric effect is direction sensitive (fig.4)

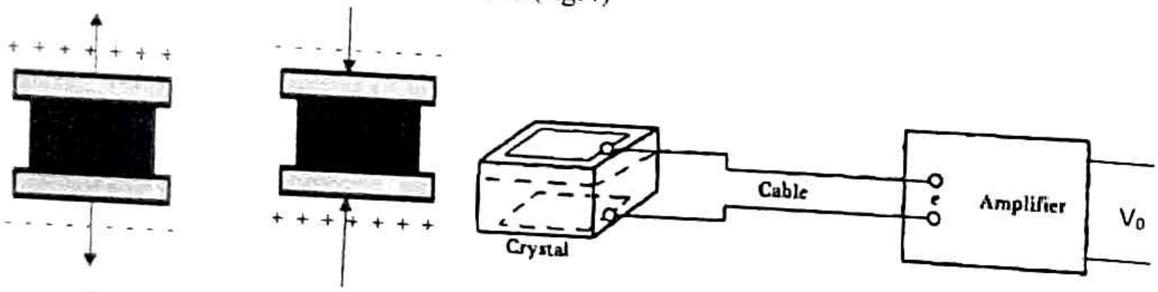

Fig 4 (a): direction sensitivity of Piezo-electric material (b): Piezoelectric Transducer

The Quartz is the examples of the natural piezoelectric crystals, whereas the Rochelle salts, ammonium dehydration, phosphate, lithium sulphate, dipotassium tartrate are the examples of the man-made crystals.
These materials operate in four different modes: (i) thickness expander mode (ii) length expander mode (iii) thickness shear mode (iv) face shear mode
When the mechanical deformation occurs in the crystals, it generates charges. And this charge develops the voltages across the electrodes. The Piezoelectric crystal is direction sensitive. The polarity of the voltage depends on the direction of the force which is either tensile or ompressive. The magnitude and the polarity of the charges depend on the magnitude and the direction of the applied force. The whole setup of parallel plates and piezoelectric material between them forms a capacitor structure. $V = Q/C$

Advantages:

1) High frequency response 2) High transient response
3) High output 4) The piezoelectric transducers are small in size and have rugged construction

Disadvantages:

1) High impedance: The piezoelectric crystals offer high impedance hence they have to be connected to the amplifier and the auxiliary circuit. These external circuits have the potential to cause errors in measurement. To reduce these errors amplifiers high input impedance and long cables should be used.

2) Forming into shape: It is very difficult to give the desired shape to the crystals with sufficient strength.

Applications:

Used to measure force, pressure, acceleration, torque, strain etc

II) Photoelectric transducer

Low-work function materials like cesium emit electrons when light falls on it. This property of materials is called as photo electricity. When the light falls on such materials photons interact with the electrons on the surface of such materials, converting quantum energy into kinetic energy. Acceleration of electrons in the flow of current.

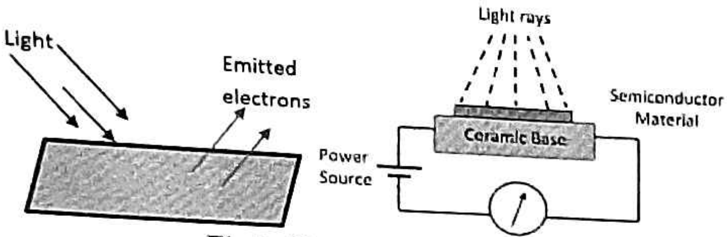

Fig 5: Photoconductive Cell

Different types of Photo-electric transducers:

Photo-emissive Cell: it consists of semi cylindrical cathode coated with photo-emmisive material and anode is made from thick metallic wire, both of these enclosed in glass tube. When the light is made to fall on the emmisive material electrons are emitted. If positive voltage is applied the anode draws all these electrons. The current generated is proportional to the light incident on the material.

Photoconductive Cell: The photoconductive cell converts the light energy into an electric current. It uses the semiconductor material like cadmium selenide, Ge, Se, as a photo sensing element. When the beam of light falls on the semiconductor material, their conductivity increases and the material works like a closed switch. The current starts flowing into the material and deflects the pointer of the meter.

Photo-voltaic cell: it generates potential when light falls on it. Photodiode and Phototransistor work in both photo-voltaic and photo-emmisive modes

Applications:

- Power stations for generating electrical power
- Solar vehicle
- Space craft
- Rural electrification

References:

1) Basic electronics (Book), U B Mahadevaswamy
2) Basic electronics (Book), D P Kothari, I J Nagrath
3) Tutorials Point,
https://www.tutorialspoint.com/electronic_measuring_instruments/electronic_measuring_instruments_transducers.htm