1.4 TRANSDUCERS:

Instrument Society of America defines a sensor or transducer as a device which provides a usable output in response to a specified measurand. Here the measurand is a physical quantity to be measured and the output may be an electrical, mechanical or optical quantity. The words ‘sensor’ and ‘transducer’ are often used interchangeably although they are different devices with different characteristics.

- Transducer contains two parts.
- The sensing element
- Transduction element

The sensing element

Sensor senses the difference or change in the environment they are exposed to and gives an output in the same format. Sensor is defined as a device which measures a physical quality (light, sound, space etc.) and converts them into an easily readable format. If calibrated correctly, sensors are highly accurate devices. Not all transducers are sensors but most sensors are transducers.

For example, a thermistor is a type of sensor; it will respond to the change in temperature but does not convert the energy into a different format to what it was originally sensed in.

Transduction element

Transducer converts a specified measurand into usable output using transduction principle.

For example, a properly cut piezoelectric crystal can be called a sensor where as it becomes a to it. So, the sensor is the primary element of a transducer. transducer with appropriate electrodes and input/output mechanisms attached

1.9 Classification of transducers

The transducers may be classified based on:

- The physical effect employed .
- The physical quantity measured.
- The source of energy.
- The method of energy conversion.
- The nature of output.
- Transducer and Inverse Transducer.

Classification based on physical effect (Transduction Principle)

The physical quantity applied as measurand (quantity to be measured) to the transducer causes some physical changes in its element. By this physical effect the transducer converts the physical quantity into electrical quantity.

For example, a change in temperature to be measured causes variation of resistance (physical change) in a copper wire and this effect could, be used to convert temperature into an electrical output. The physical effects commonly employed are:

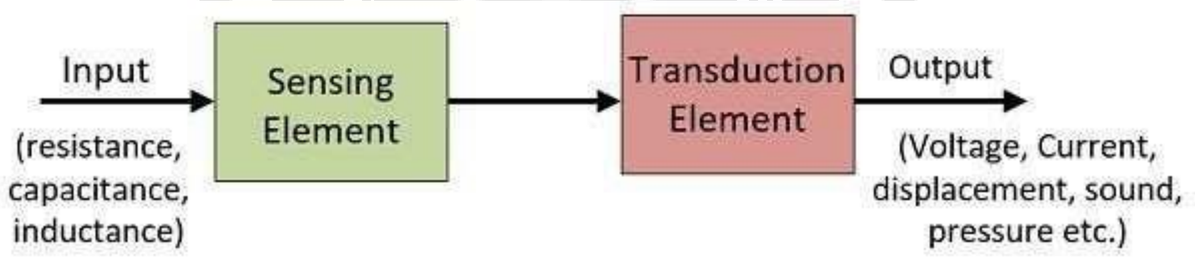

Fig 1.4.1 Transducer

- Variation of resistance
- Variation of inductance
- Variation of capacitance
- Piezo electric effect
- Magnetostrictive effect

- Elastic effect
- Hall effect
- Electromagnetic effect
- Optical effect

Variation of resistance

The transducer whose resistance varies because of the environmental effects is known as the resistive transducer

The resistance of a length of metallic wire is given by

- The resistance of the transducers can vary because of the change in environmental conditions as well as the physical properties of the conductor. Some of the transducers based on this principle are potentiometer, strain gauge, resistance thermometer, carbon microphone, and photoconductive cell.
- The resistance thermometer is based upon thermo resistive effect which is the change in electrical resistivity of a metal or semiconductor due to change in temperature co-efficient of resistivity.
- Carbon microphone works on the principle of change in contact resistance due to applied pressure.
- Photoconductive cell is based on photoconductive effect which is the change in electrical conductivity due to incident light.
- Potentiometer works on the principle of change in resistance due to linear or rotational motion.
- Strain gauge works on the principle of change in resistance due to applied pressure.

Variation of inductance

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

Where, R- Resistance in ohm.

P – Resistivity (or specific resistance) of the material in ohmmeter

L – Length of the wire in meter

A – Area of cross section of the wire in m^2

The inductive transducers work on the principle of the electromagnetic induction. The inductance of the magnetic material depends on a number of variables like the number of turns of the coil on the material, the size of the magnetic material, and the permeability of the flux path. In the inductive transducers the magnetic materials are used in the flux path and there are one or more air gaps. The change in the air gap also results in change in the inductance of the circuit and in most of the inductive transducers it is used for the working of the instrument.

The inductance of a coil is given by

$$L = N \frac{d\emptyset}{dt}$$

$$L = \frac{N^2 \mu_o \, \mu_r A}{l}$$

Where,

L - Inductance in henrys

N -No. of turns

μ_o = Absolute permeability

μ_r = relative permeability

A – Area of cross section of the core

l - Length of the magnetic path

As L is a function, of N,, A and I, when anyone of these quantities changes, the inductance changes. This leads to the design of a variable inductance transducer. Some of the transducers based on variation of inductance are induction potentiometer, linear variable differential transformer (LVDT) and synchros.

Variation of capacitance

The capacitance between two conductor plates is given by

$$C = \frac{\varepsilon_o \varepsilon_r A}{d}$$

Where,

ε_o = Absolute Permittivity

ε_r = Relative permittivity of the separating medium

A - Area of cross-section of the plates

C - Capacitance in farad

As 'C' is a function of A and d, when anyone of these quantities changes, the capacitance varies. This leads to the design of a variable capacitance transducer. The capacitive transducer is used in the measurement of the linear and angular displacement, force, pressure and humidity in gases.

Piezoelectric effect

When a piezoelectric crystal like quartz or Rochelle salt is subjected to mechanical stress, the mechanical energy is converted into charge or voltage. This is known as piezoelectric effect. The transducer based on this effect is piezoelectric transducer.

Magneto strictive effect

Magneto striction can be explained as the change in length of a magnetic material produced as a result of magnetization. The material should be Magneto strictive in nature. This phenomenon is known as

Magneto strictive Effect. The same effect can be reversed in the sense that, if an external force is applied on a magnetostrictive material, there will be a proportional change in the magnetic state of the material. This property was first discovered by James Prescott Joule by noticing the change in length of the material according to the change in magnetization. He called the phenomenon as

Joule effect. The reverse process is called Villari Effect or Magneto strictive effect. This effect explains the change in magnetization of a material due to the force applied.

Joule effect is commonly applied in magneto strictive actuators and Villari effect is applied in magneto strictive sensors.

Elastic effect

When an elastic member is subjected to mechanical stress it is deformed. The transducer based on this effect is called elastic transducer. Most pressure measuring devices use elastic members for sensing pressure at the primary stage. These elastic members convert the pressure into mechanical displacement which is later converted into an electrical form using a secondary transducer.

Hall effect

The Hall-effect element is a type of transducer used for measuring the magnetic field by converting it into an E.M.F. The direct measurement of the magnetic field is not possible. When a magnetic field is applied to a current carrying conductor at right angles to the direction of current, a transverse electric potential gradient is developed in the conductor. This effect is called as Hall Effect and the transducer based on this effect is called as Hall effect transducer. The Hall effect element is mainly used for magnetic measurement and for sensing the current.

Electromagnetic effect

In this type, the measurand is converted to the voltage induced in a conductor by a change in the magnetic flux in the absence of excitation. These transducers are active transducers and change in flux is done by the motion between a piece of magnet and electromagnet.

Optical effect

The optical transducer converts light into electrical quantity. They are also called as photoelectric transducers.

The optical transducer can be classified as photo emissive, photoconductive and photovoltaic transducers.

- The photo emissive devices operate on the principle that radiation falling on a cathode causes electrons to be emitted from the cathode surface.
- The photoconductive devices operate on the principle that whenever a material is illuminated, its resistance changes.
- The photovoltaic cells generate an output voltage that is proportional to the radiation intensity. The radiation that is incident may be x-rays, gamma rays, ultraviolet, infrared or visible light.

Classification based on physical quantity measured

The transducers may be classified based on the quantity they measure as follows:

- Temperature transducers
- Pressure transducers
- Flow transducers
- Liquid level transducers
- Force/Torque transducers
- Velocity/Speed transducers
- Humidity transducers
- Acceleration/vibration transducers
- Displacement transducers
- Ultraviolet, infrared or visible light.

Classification based on source of energy

Transducers may be, classified based on source of energy into two types.

- Passive transducer
- Active transducer

Passive transducer

Passive transducer converts a form of energy into another (electrical) by making use of an external source of power. Passive transducer is a device which converts the given non-electrical energy into electrical energy by external force. The capacitive, resistive and inductive transducers are the example of the passive transducer.

Active transducer

The transducer which does not require the external power source is known as the active transducer. Such type of transducer develops theirs owns voltage or current, hence known as a self-generating transducer. The output signal is obtained from the physical input quantity.

The physical quantity like velocity, temperature, force and the intensity of light is induced with the help of the transducer. The piezoelectric crystal, tacho-generator, thermocouples, photovoltaic cell and electromagnetic transducer are the examples of the active transducers.

Classification based on method of energy conversion

- Primary Transducers
- Secondary Transducers

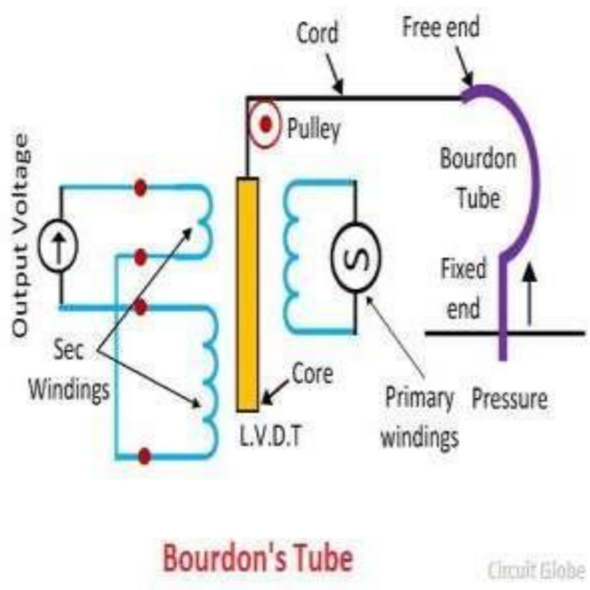

Fig 1.4.2 Bourdon's Tube

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 289]

Primary Transducers

Some transducers contain the mechanical as well as electrical device. The mechanical device converts the physical quantity to be measured into a mechanical signal. Such mechanical device are called as the primary transducers, because they deal with the physical quantity to be measured

Secondary Transducers

The secondary transducer converts the mechanical signal into an electrical signal. The magnitude of the output signal depends on the input mechanical signal.

Bourdon's Tube shown in the figure below. The tube act as a primary transducer. It detects the pressure and converts it into a displacement from its free end. The displacement of the free ends moves the core of the linear variable displacement transformer. The movement of the core induces the output voltage which is directly proportional to the displacement of the tube free end.

Nature of Output

- Analog Transducer
- Digital Transducer

The transducer can also be classified by their output signals. The output signal of the transducer may be continuous or discrete.

Analog Transducer

The Analog transducer changes the input quantity into a continuous function. The strain gauge, L.V.D.T, thermocouple and thermistor are the examples of the analogue transducer.

Digital Transducer

These transducers convert an input quantity into a digital signal or in the form of the pulse. The digital signals work on high or low power. Example: Shaft Encoders.

Transducer and Inverse Transducer

Transducer: The device which converts the non-electrical quantity into an electric quantity is known as the transducer.

Inverse Transducer: The transducer which converts the electric quantity into a physical quantity, such type of transducers is known as the inverse transducer. The transducer has high electrical input and low nonelectrical output. The piezoelectric ultrasonic transducer is an example of the inverse transducer.

Selection criteria for transducers

Transducers are the instruments which converts non-electric signals into an electric signal.

So while selecting any type of transducers for any special purpose, we should think about its specifications or characteristics. Any transducer is based on a simple concept that physical property of a sensor must be altered by an external stimulus to cause that property either to produce an electric signal or to modulate an external electric signal. Selection criteria of a transducer are based on different factors, such as availability, cost, power consumption, environmental conditions, etc. After considering all these factors we can select a best one for our use.

Selection of the transducer among the many available mainly depends upon:

- Input characteristics.
- Transfer characteristics.
- Output characteristics.
- Life span: It determines how long the selected transducer will work.
- Availability: While selecting a transducer we should think about its availability.
- Cost.
- Stability and reliability.
- Purpose: indication, recording or control.

Input characteristics

This is one of the most important characteristic, while selecting a transducer. By considering input characteristics we can determine, what type of input is needed for that transducer? What is the operating range for that transducer? What is the loading effect on that transducer?

- Type of input
- Operating range
- Loading effect

Transfer Characteristics

Transfer characteristics also plays very important role in selection of transducer. Transfer characteristics means, the effects on the signal when it is being processed. Errors and hysteresis also occurs when the signal is being processed. Following are some major transfer characteristics which we should keep in mind while selecting a transducer for any special purpose:

- Transfer function (input
- Accuracy and precision output relation)
- Error and hysteresis
- Response of transducer

Output Characteristics

As we all know, while we are doing some work, we always set some goal or aimed for output.

Similarly for our use we should first think about what type of output we required? So here output characteristics play a vital role while selecting a special type of transducer. Some of the output characteristics are summarized below:

- Type of output
- Output impedance
- Useful Range