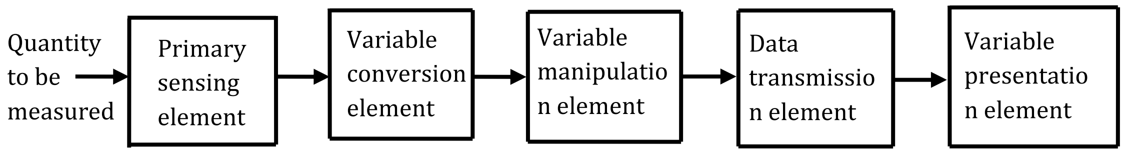
Part – 10: Transducers

10.1: Classification of Transducers

An instrument may be defined as a device or a system which is designed to maintain a functional relationship between prescribed properties of physical variables and must include ways and means of communication to a human observer.

Generalized Measurement System

Primary sensing element	The quantity under measurement makes its first contact with the primary sensing element of a measurement system
	
Variable conversion element	The output of the primary sensing element is converted to some other suitable form for the instrument to perform desired function
Variable manipulation element	The function of this element is to manipulate the signal presented to it preserving the original nature of the signal.
Data preserving element	This element conveys the information about the quantity under measurement to the personnel handling the instrument or the system for monitoring, control & analysis purposes.

We can define Transducer as a device which, accurately transforms energy from one form to another.

Another name for Transducer is 'PICK – UP'.

Classification of Transducers

The transducers can be classified as:

(i) Based upon transduction principle
(ii) Primary and secondary transducers
(iii) Passive and active transducers
(iv) Analog and digital transducers
(v) Transducers and inverse transducers

(i) Based upon Transduction Principle

The transducers can be classified on the basis of principle of transduction as resistive, inductive, capacitive etc., depending upon how they convert the input quantity into resistance, inductance or capacitance respectively.

(ii) Primary and Secondary Transducers

The first transducer which converts physical phenomenon into displacement, pressure, velocity etc. which is to be accepted by next stage is known as "**Primary Transducer**".

The output of the primary transducer is converted subsequently into a usable output by a device called "**Secondary Transducer**"

(iii) Passive and Active Transducers

Passive transducers: They derive the power required for transduction from an auxillary power source.

Eg: Resistive, inductive and capacitive transducers.

Active transducers: They do not require an auxillary power source to produce their output. They are also known as self – generating type since they develop their own voltage or current output.

Eg: piezoelectric, photovoltaic etc

(iv)Analog and digital Transducers

Analog transducers: These Transducers convert the input quantity into an analog output which is a continuous function of time.

Eg: LVDT, thermocouple etc.

Digital Transducers: These transducers convert the input quantity into an electrical output which is in the form of pulses.

(v) Transducers & Inverse Transducers

Transducer: A transducer can be broadly defined as a device which converts a non – electrical quantity into an electrical quantity.

Example: L.V.D.T, Resistive and Capacitive Transducers as well.

Inverse transducer: An inverse transducer is defined as a device which converts an electrical quantity into a non – electrical quantity.

NOTE: Generally a Inverse Transducer is a output transducer.

Example: Indicating Instruments, Pen Recorders, Oscilloscope.

1. Input Characteristics

1.A Type of Input and operating Range

1. The type of input, which can be any physical quantity, is generally determined in advanced a physical quantity may be measured through use of a number of transducers.
2. However the choice of a particular transducer that is selected for the purpose, depends upon the useful range of selected quantity over which the transducer can be used.

1.B Loading Effects

1. The transducer, that is selected for a particular application should ideally extract no force, power or energy from the quantity under measurement in order that the latter is measured accurately.
2. Ideally a transducer should have no loading effect on the input quantity being measured.

2. Transfer Characteristics

2.A Transfer Function

1. The transfer function of a transducer defines a relationship between the input quantity and the output.
2. The **Sensitivity** of a transducer is defined as the differential Quotient,
   $S = \frac{dq_o}{dq_i}$
3. The **Scale Factor** is defined as the inverse of Sensitivity,
   $= \frac{1}{S} = \frac{dq_i}{dq_o}$

2.B Error

The errors in transducers occur because they do not follow, in many situations the input – output relationship given by $q_o = f(q_i)$. Any deviation from above mentioned relationship results in errors.

3. Output Characteristics

3.A Type of Electrical Output

The types of outputs which may be available from the transducers may be a voltage, current, impedance or a time function of these amplitudes.

3.B Output Impedance

The output impedance $\mathbf{Z_o}$ of a transducer determines to the extent the subsequent stages of instrumentation is loaded.

Constant Voltage Source

If the output Impedance is low compared to the forward Impedance of the System, then the transducer has the characteristics of a constant voltage Source. Provided the output of the transducer is a voltage.

Constant Current Source

If the forward Impedance is High as compared with the output impedance of the transducer, it then behaves as a Constant Current Source.

10.2: Resistive Transducers

Introduction

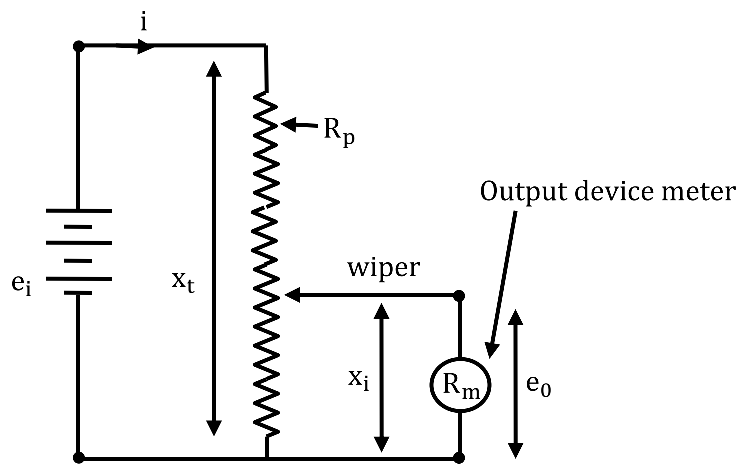
- It is generally seen that methods which involve the measurement of change in resistance are preferred to those employing other principles.
- This is because both alternating as well as direct currents and voltage are suitable for resistance measurements.

Effect	As a primary transducer	
1. Change in length	Linear and angular displacements, thickness	Temperature, pressure, weight, force, fluid flow rate, viscosity, velocity, acceleration and altitude of vehicles in space
2. Change in length and area of cross section	High pressure strain	All the above quantities except velocity and altitude
3. Change in resistivity	Temperature	Thermal conductivity, gas composition, fluid flow rate, wind velocity and direction, low pressure and vacuum and infrared radiation

Potentiometer

1. A resistance potentiometer, or simply a POT (a resistive potentiometer used for the purpose of voltage division is called a POT) consists of a resistive element provided with a sliding contact. This sliding contact is called a wiper.
2. The resistive element of the POT may be excited by either d.c. or a.c. voltage. The POT is a **Passive Transducer** since it requires an external power source for its operation.

Analysis



Let e_i and e_0= input and output voltages respectively

x_t= total length of translational pot

x_i= displacement of wiper from its zero position

R_p= total resistance of potentiometer

R_m= resistance of a meter or a recording monitoring the output be R_m

R_L=left over resistance

Resistance per unit length= $\frac{R_p}{X_t}$

The total resistance seen by the source is:

$$R= R_p\ (1\text{-}K)+\frac{K\,R_p\,R_m}{K\ R_p+R_m}$$

$$=\frac{KR_p^{\ 2}(1-K)+R_p\,R_m}{KR_p+R_m}$$

Current, $i = e_i/R$

$$=\frac{e_i(KR_{p+}R_{m)}}{k\,R_p^{\ 2}(1-K)+R_p\,R_m}$$

The output voltage under load condition is:

$$e_0 = i\left(\frac{KR_p\,R_m}{KR_p+R_m}\right)$$

$$=\frac{e_i(KR_{p+}R_{m)}}{k\,R_p^{\ 2}(1-K)+R_p\,R_m}\ X\ \frac{KR_p\,R_m}{KR_p+R_m}$$

$$=\frac{e_i\ K}{K(1-K)(R_p|R_m)+1}$$

Error = output voltage under load –output voltage under no load

$$=\frac{e_i\ K}{[K(1-K)(R_p|R_m)+1]}-e_i\,K$$

$$= \text{-}e_i\left[\frac{K^{\,2}\,(K-1)}{K(K-1)+R_{m/R_p}}\right]$$

$$\%\ \text{error} = \text{-}e_i\left[\frac{K^{\,2}\,(K-1)}{K(1-k)+R_{m/R_p}}\right]$$

Power Rating of Potentiometers

1. The potentiometers, are designed with a definite power rating which is related directly to their heat dissipating capacity.
2. Since, Power $= ei^2/R_p$, the maximum input excitation voltage that can be used is,

   $$e_{i(max)} = \sqrt{PR_P}\ \text{volts}$$

Linearity and Sensitivity of POTs

1. In order to achieve a good linearity, the resistance of potentiometer R_P, should be as low as possible when using a meter for reading the output voltage which has a fixed value of input resistance R_m.
2. In order to get a high sensitivity the output voltage e_0, Should be high which in turn requires a high input voltage e_i.
3. The resistance of the potentiometer R_P, cannot be made low because if we do so the power dissipation goes up with the result that we have to make the input voltage small to keep the power dissipation to the acceptable level. This results in lower sensitivity.
4. Thus linearity and sensitivity are therefore two conflicting requirements. If R_P is made small, the linearity improves, but a lower value R_P requires a lower input voltage e_i in order to keep down the power dissipation and a lower value of e_i results in a lower value of output voltage e_0 resulting in lower sensitivity.

Materials used for Potentiometers

1. The materials used for POTs may be classified as wire wound and Non wire wound.
   a. Wire wound POTs → Platinum, Nickel, Chromium, Copper and some other precious resistance elements.
   b. Non wire wound POTs → These are also called as continuous POTs and have improved resolution and life. Cermet, Hot Moulded Carbon, Carbon film, Thin metal films are used.

Strain Gauge

If a metal conductor is stretched or compressed its resistance changes on account of the fact that both length and diameter of conductor changes.

Also there is a change in the value of resistivity of the conductor when it is strained and this property is called piezo resistive effect. Therefore, resistance strain gauges are also known as piezo resistive gauges.

Theory of Strain Gauges

Let us consider a strain gauge made of circular wire.

The wire has the dimensions,

Length $=L$

Area $= A$

Diameter $= D$ before being strained.

The material of the wire has a resistivityρ.

$\therefore$Resistance of unstrained gauge, $R=\rho L/A$.