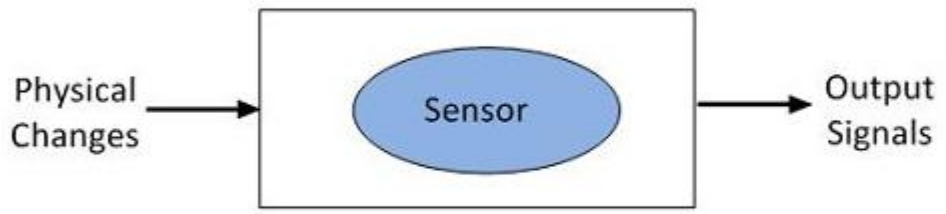
# UNIT-I

**Sensor**

A sensor is a device, module, machine, or subsystem whose purpose is to detect events or changes in its environment and send the information to other electronics circuit. The sensor is a device that measures the physical quantity (i.e. Heat, light, sound, etc.) into an easily readable signal (voltage, current etc.). It gives accurate readings after calibration. A sensor is always used with other electronics. A Sensor converts the physical parameter (for example: temperature, blood pressure, humidity, speed, etc.) into a signal which can be measured electrically.




Sensor

**Examples** – The mercury used in the thermometer converts the measure and temperature into an expansion and contraction of the liquid which is easily measured with the help of a calibrated glass tube. The thermocouple also converts the temperature to an output voltage which is measured by the thermometer.

**The sensors have many applications in the electronics equipment. The few of them are explained below.**

i. The motion sensors are used in the home security system and the automation door system.
ii. The photo sensor senses the infrared or ultraviolet light.
iii. The accelerometer sensor is used in the mobile for detecting the screen rotations.

One of the significant differences between the sensor and the transducer is that the sensor senses the physical changes occur in the surrounding whereas the transducer converts the physical quantity or nonelectrical into another signal or electrical signal.

**Classification of sensor:**

All types of sensors can be basically classified into analog sensors and digital sensors. But there are a few types of sensors such as temperature sensors, IR sensors, ultrasonic sensors, pressure sensors, proximity sensors, and touch sensors are frequently used in most electronics applications.

**1. Temperature Sensor:** A temperature sensor is an electronic device that measures the temperature of its environment and converts the input data into electronic data.

**2. IR Sensor:** An infrared (IR) sensor is an electronic device that measures and detects infrared radiation in its surrounding environment. IR sensors are now widely used in motion detectors, which are used in building services to switch on lamps or in alarm systems to detect unwelcome guests. In a defined angle range, the sensor elements detect the heat radiation (infrared radiation) that changes over time and space due to the movement of people.

**3. Ultrasonic Sensor:** An ultrasonic sensor is an electronic device that measures the distance of a target object by emitting ultrasonic sound waves, and converts the reflected sound into an electrical signal.

**4. Touch Sensor:** A touch sensor is a type of device that captures and records physical touch or embrace on a device and/or object. It enables a device or object to detect touch or near proximity, typically by a human user or operator.

**5. Proximity Sensors**: A proximity sensor is a sensor able to detect the presence of nearby objects without any physical contact.

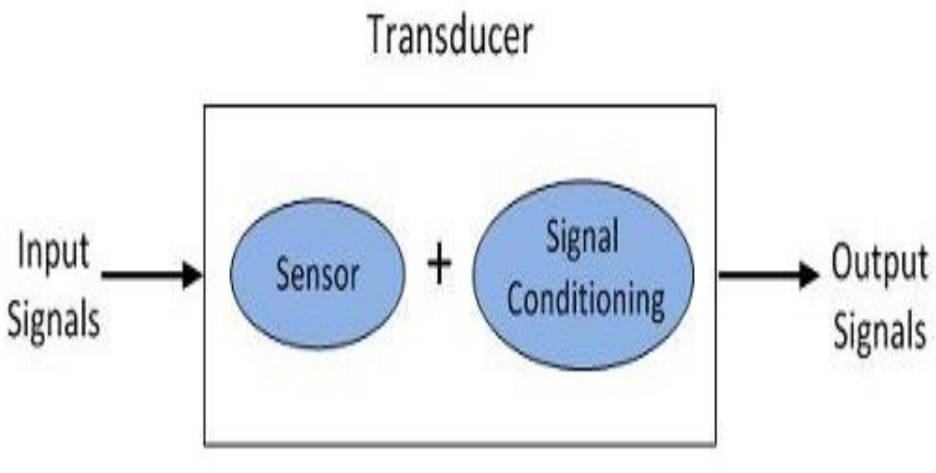
**6. Pressure Sensor**: A pressure sensor is a device for pressure measurement of gases or liquids. Pressure is an expression of the force required to stop a fluid from expanding, and is usually stated in terms of force per unit area

**7. Level Sensor:** Level sensors are useful devices that are used to detect the level of substances such as liquids, powders and granular materials

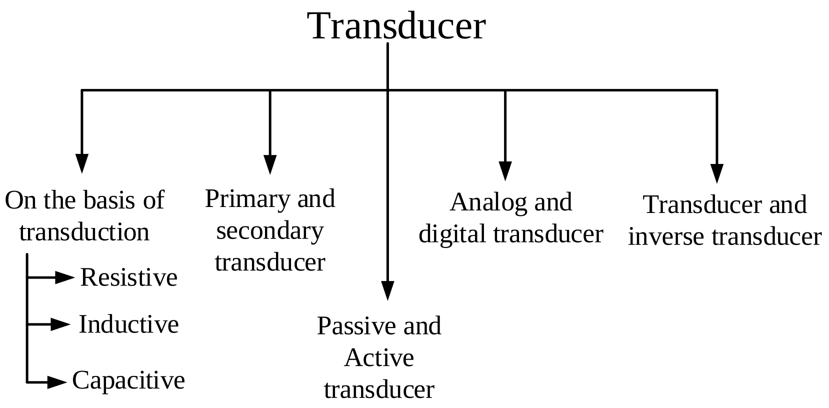
**8. Smoke and Gas Sensor:** The sensor detects these and turns the electricity supply on. It can be used to detect the presence of carbon monoxide gas (CO). Smoke alarms or gas alarms work on the same principle. In a fire many gas particles are created and trigger the gas sensor so the fire alarm sounds.

**Transducer:**

A device that converts energy from one form to another form. The transducer changes the physical quantity into an electrical signal. It is an electronic device which has two main functions, i.e., sensing and transduction. It senses the physical quantity and then converts it into mechanical works or electrical signals. The transducer receives the measure and gives a proportional amount of output signal.



**Types of Transducers**




**1. Classification based on the Principle of Transduction**

The transducer is classified by the transduction medium. The transduction medium may be resistive, inductive or capacitive depends on the conversion process that how input transducer converts the input signal into resistance, inductance and capacitance respectively.

**2. Primary and Secondary Transducer**

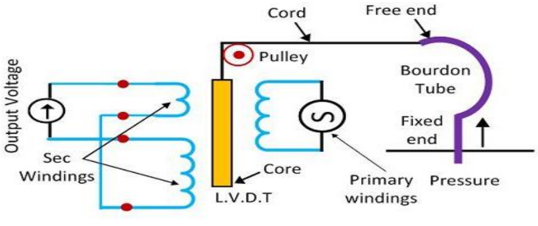
**Primary Transducer**: The transducer consists the mechanical as well as the electrical devices. The mechanical devices of the transducer change the physical input quantities into a mechanical signal. This mechanical device is known as the primary transducers.

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

**Example of Primary and Secondary Transducer**

Consider the 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.

Thus, two type of transduction occurs in the Bourdon's tube. First, the pressure is converted into a displacement and then it is converted into the voltage by the help of the L.V.D.T (Linear Variable Differential Transformer).




Bourdon's Tube

The Bourdon's Tube is the primary transducer, and L.V.D.T is called the secondary transducer.

**3. Passive and Active Transducer**

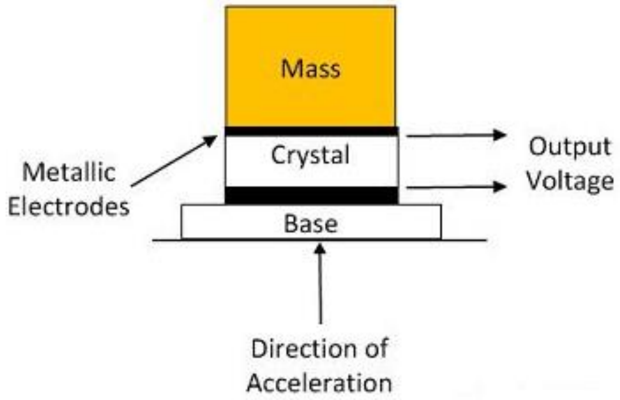
The transducer is classified as the active and passive transducer.

**Passive Transducer** – The transducer which requires the power from an external supply source is known as the passive transducer. They are also known as the external power transducer. 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, photo-voltaic cell, tacho generator, thermocouples, photovoltaic cell are the examples of the active transducers.

**Examples** – Consider the examples of a piezoelectric crystal. The crystal is sandwiched between the two metallic electrodes, and the entire sandwiched is fastened to the base. The mass is placed on the top of the sandwiched.
The piezo crystal has the special property because of which when the force is applied to the crystal, they induce the voltage. The base provides the acceleration due to which the voltage is generated. The mass applies on the crystals induces an output voltage. The output voltage is proportional to the acceleration.




The above mention transducer is known as the accelerometer which converts the acceleration into an electric voltage. This transducer does not require any auxiliary power source for the conversion of physical quantity into an electrical signal.

**4. Analog and 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, 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.

**5. 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 non-electrical output.

**Selection Criteria of Sensor**

There are certain features which have to be considered when we choose a sensor. They are as given below: -

1) **Accuracy:** - It is the difference between measured value and true value. Accuracy of the sensor should be as high as possible.

2) **Precision:** - It is the ability to reproduce repeatedly with a given accuracy. It should be Very high.

3) **Sensitivity:** - It is the ratio of change in output to a unit change of the input. It should be chosen to allow sufficient output.

4) **Operating range:** - It is the difference between maximum and minimum value of the sensed parameter. Sensors should have wide operating range and good accuracy over the range.

5) **Resolution: -** It is the smallest change in the sensor which can differentiate. Sensors should have high resolution

6) Speed of Response: - Time taken by the sensor to respond should be minimum. Response time should be very less.

7) **Reliability:** - Reliability of the sensor should be high. Mean time to failure (MTTF) should be high. It results the increased life.

8) **Maintenance:** - It should be less and frequency of maintenance required should be less over the period.

9) **Calibration:** - Sensors need frequent calibration for many reasons. Hence, it should be easy to calibrate. Drift should be as minimum as possible.

10) **Cost:** - Cost of the sensor should be low.

11) **Linearity:** - Sensor's curve should linear. The percentage of deviation from the best-fit linear calibration curve should be less.

12) **Environmental condition:** - Sensors should operate over wide environmental conditions such as temperature, corrosion, pressure, shocks etc

13) **Interfacing:** - Sensors should be compatible with different instruments for interfacing.

14) **Size and Weight:** - Sensors should have small size and less weight.

15) **Output:** - The nature of output required from the sensor whether the digital or analog has to be considered while selecting a sensor.

**Selection Criteria of Transducer**

1) **Operating Principle-** The transducers are many times selected on the basis of operating principle used by them. The operating principles used may be resistive, inductive, capacitive, optoelectronic, piezoelectric etc.

2) **Sensitivity-** The transducer must be sensitive enough to produce detectable output.

3) Operating Range. The transducer should maintain the range requirements and have a good resolution over its entire range. The rating of the transducer should be sufficient so that it does not breakdown while working in its specified operating range.

4) **Accuracy-** High degree of accuracy is assured if the transducer does not require frequent calibration and has a small value for repeatability. It may be emphasized that in most industrial applications, repeatability is of considerably more importance than absolute accuracy.

5) **Transient and Frequency Response-** The transducer should meet the desired time domain specifications like peak overshoot, rise time, settling time and small dynamic error. It should ideally have a flat frequency response curve. In practice, however, there will be cut-off frequencies and higher cut off frequency should be high in order to have a wide bandwidth.

6) **Loading Effects.-** The transducer should have a high input impedance and a low output impedance to avoid loading effects.

7) **Environmental Compatibility-** It should be assured that the transducer selected to work under specified environmental conditions maintains its input-output relationship and does not break down. For example, the transducer should remain operable under its temperature range.

8) **Reliability:** Reliability of the sensor should be high. Mean time to failure (MTTF) should be high. It results the increased life.

**Advantages:**

- The electrical output of the transducer can be easily used, transmitted and processed for the purpose of measurement.
- The electrical systems can be controlled with a very small level of power.
- The reduce effects of friction and other mechanical non-linearities.
- Due to the integrated circuit technology, the electrical and electronic systems are compact, having less weight and portable.
- The data transmission through mechanical means is eliminated. Thus no mechanical wear and tear and no possibility of mechanical failures exist.
- The reduce effects of mass inertia problems.

**Disadvantages:**

- The electrical transducer has costly.
- While designing the circuit the effects of ageing and drifts of parameters of active components must be considered. This makes the design complicated.

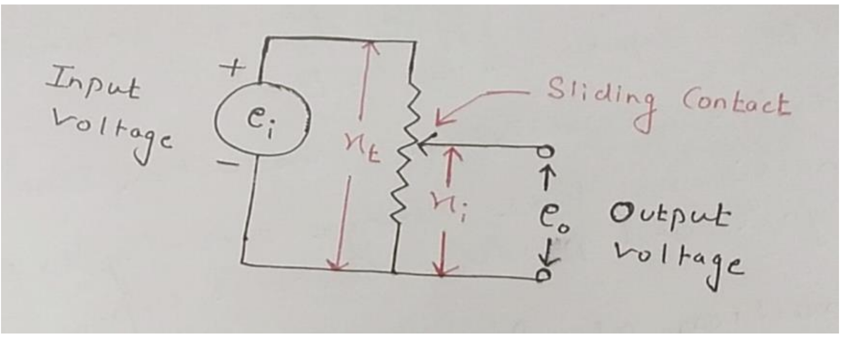
**Measurement of Displacement using Potentiometer (POT):**

- Potentiometer is a type of transducer because it converts displacement (linear or angular) into voltage (electrical signal).
- It is a passive transducer because it needs external supply.
- It is also an analog transducer because it is giving continuous output.
- I t has a resistive transduction element.
- Resistive element is made up of CERMET, Carbon Film, etc.

**Construction of potentiometer**

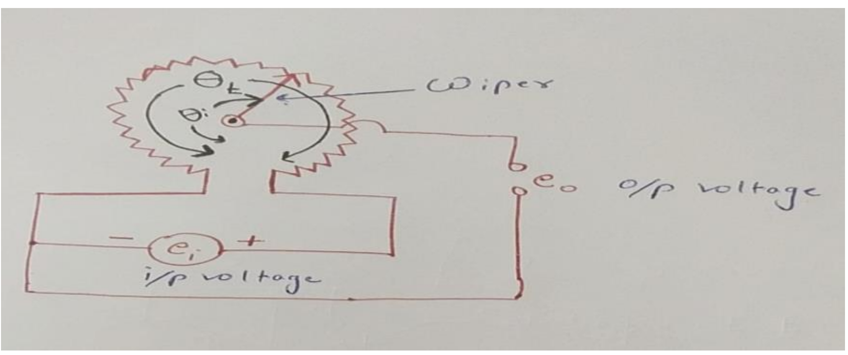
- The construction of potentiometer is categorized into two parts, sliding or movable part i.e., called wiper and non-sliding part i.e., resistive element.
- Wiper is moving on the resistive element and because of that resistance is varying.
- Now, movement of wiper is categorized in three parts,
    - Linear or Translational
    - Rotational
    - Helipot

**Linear or translational movement**




- There is one resistive element and one movable element which is called wiper.
- Wiper is linearly moving; input voltage is given to resistive element and output voltage is generated according to the movement of wiper.
- The movement i.e., displacement is converted into electrical signal.

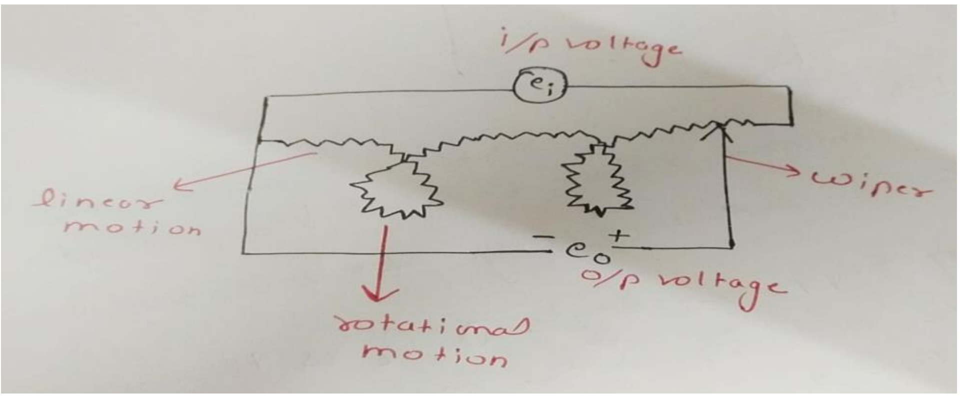
**Rotational Movement**




- In rotational motion, resistive element is in the circular form and wiper is a sliding contact.

- Suppose, $\theta_t$ is the complete angle of resistance and $\theta_i$ is the angle of wiper or sliding contact.
- The motion of wiper is rotational is rotational or in the form of angle.
- Input voltage is connected with its fixed terminals and output voltage is connected with one fixed terminal and sliding contact.
- The output voltage is depended upon the $\theta_i$ and measure the rotational motion of wiper.

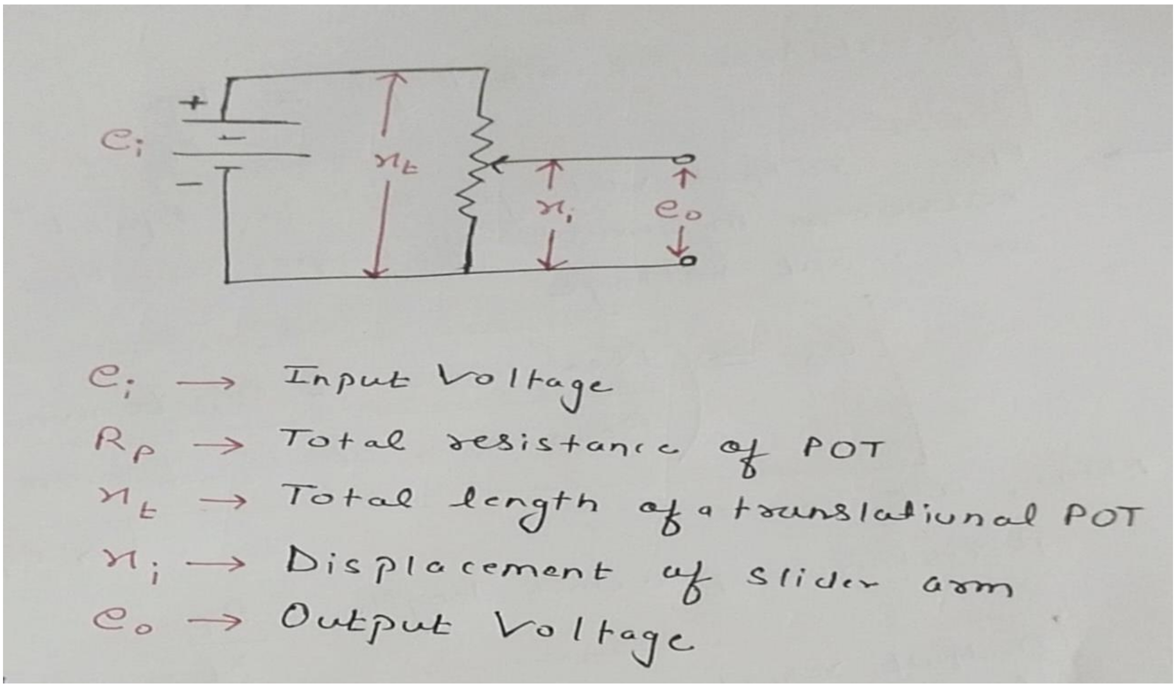
**Helipot**




- Helipots are the combination of linear and translational motion.
- The resistive element used in heliport are called helix.
- In this POT, input voltage is connected with fixed terminals and output voltage connected with one fixed terminal and movable.

**Working Principle of Potentiometer**

Suppose, wiper motion is translation,



→ When sliding contact is start moving then its displacement is $x_i$ meter

→ And total length ($x_t$) has total resistance $R_p$

$$\text{Resistance per unit length} = \frac{R_p}{x_t}$$

→ Here, Output voltage will be depend on movement of wiper on the resistance and input voltage.

$$e_o = \left( \frac{\text{Resistance at o/p terminals}}{\text{Resistance at i/p terminals}} \right) \times e_i$$

↳ eq. (1)

Now, we know,

$$\text{Resistance per unit length} = \frac{R_p}{x_t}$$

$$\text{Output resistance for } x_i \text{ length} = \frac{R_p}{x_t} \times x_i$$

$$\text{Total i/p resistance for length } x_t = R_p$$

Now put all the values of resistances at o/p and i/p terminals in eq. (1)

$$e_o = \left( \frac{\text{Resistance at o/p terminals}}{\text{Resistance at i/p terminals}} \right) \times e_i$$

$$e_o = \left( \frac{\frac{R_p}{x_t} \times x_i}{R_p} \right) \times e_i$$

$$e_o = \frac{R_p}{x_t} \times x_i \times \frac{1}{R_p} \times e_i$$

O/p voltage

$$e_o = \frac{x_i}{x_t} \cdot e_i \quad \text{--- (2)}$$

→ $e_o \propto x_i$

→ Sensitivity = $\frac{O/p}{I/p}$

$= \frac{e_o}{x_i}$

(O/p is voltage and i/p is displacement of sliding arm $x_i$)

Now from eq. (2)

Sensitivity = $\frac{e_i}{x_t}$

Now, for rotational motion same derivation is applicable but,

$$x_i = \theta_i$$

$$x_t = \theta_t$$

$$e_o = \left( \frac{\theta_i}{\theta_t} \right) \cdot e_i$$

**LVDT (Linear Variable Differential Transformer):**

- The most widely used inductive transducer to translate the linear motion into electrical signals is the *linear variable differential transformer* (LVDT)
- The transformer consists of a single primary winding *P* and two secondary windings $S_1$ and $S_2$ wound on a cylindrical former.
- The secondary windings have equal number of turns and are identically placed on either side of the primary winding.
- The primary winding is connected to an alternating current source.
- A movable soft iron core is placed inside the former.
- The displacement to be measured is applied to the arm attached to the soft iron core.
- In practice the core is made of high permeability, nickel iron which is hydrogen annealed. This gives low harmonics, low null voltage and a high sensitivity.
- This is slotted longitudinally to reduce eddy current losses.
- The assembly is placed in a stainless-steel housing and the end lids provide electrostatic and electromagnetic shielding. The frequency of a.c. applied to primary windings may be between 50 Hz to 20 kHz.

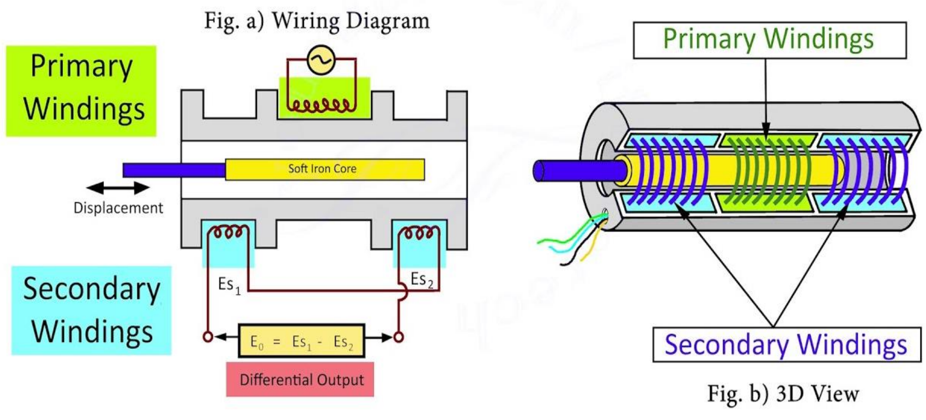
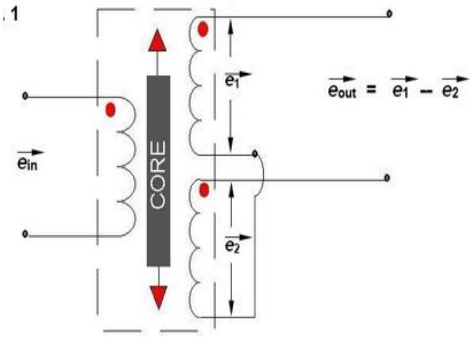



Fig. 5: Linear variable differential transformer (LVDT).

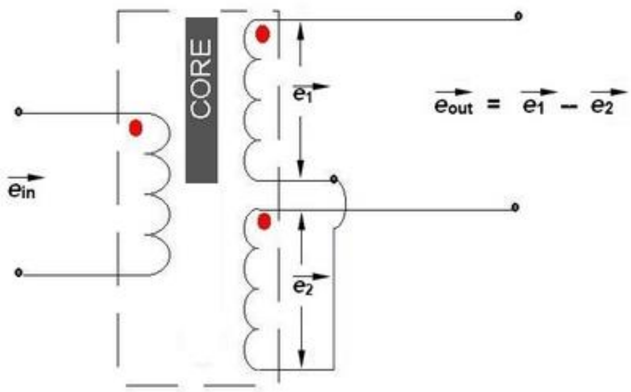
- Since the primary winding is excited by an alternating current source, it produces an alternating magnetic field which in turn induces alternating current voltages in the two secondary windings.
- The output voltage of secondary $S_1$' is $E_{s1}$ and that of secondary, $S_2$' is $E_{s2}$.
- In order to convert the outputs from $S_1$ and $S_2$ into a single voltage signal, the two secondaries $S_1$ and $S_2$ are connected in series opposition. Thus, the output voltage of the transducer is the difference of the two voltages.
- Differential output voltage is $\mathbf{E_0 = E_{S1} - E_{S2}}$

- When the core is at its normal (NULL) position, the flux linking with both the secondary windings is equal and hence equal emfs are induced in them. Thus, at null position: $E_{s1}$-$E_{s2}$.




When core is at null position.

- Since the output voltage of the transducer is the difference of the two voltages, the output voltage $E_0$ is zero at null position.
- Now if the core is moved to the left of the NULL position, more flux links with winding $S_1$ and less with winding $S_2$. Accordingly output voltage $E_{sl}$, of the secondary winding $E_{s1}$ is more than $E_{s2}$, the output voltage of secondary winding $S_2$. The magnitude of output voltage is, thus, $E_o = E_{sl} - E_{s2} > 0$ and the output voltage are in phase with say the primary voltage.




When core is moved upward.

- Similarly, if the core is moved to the right of the null position, the flux linking with winding $S_2$ becomes larger than that linking with winding $S_1$ This results in $E_{s2}$ becoming larger than $E_{sl}$. The output voltage in this case is $E_o = E_{s1} – E_{s2}$ and is 180° out of phase with the primary voltage. Therefore, the two differential voltages are 180° out of phase with each other.

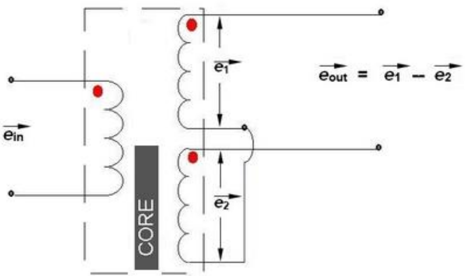



Fig. 8: When core is moved downward.

- The amount of voltage changes in either secondary winding is proportional to the amount of movement of the core. Hence, we have an indication of amount of linear motion.
- By noting which output voltage is increasing or decreasing, we can determine the direction of motion. In other words, any physical displacement of the core causes the voltage of one secondary winding to increase while simultaneously reducing the voltage in the other secondary winding. The difference of the two voltages appears across the output terminals of the transducer and gives a measure of the physical position of core and hence the displacement.
- As the core is moved in one direction from the null position, the differential voltage *i.e.*, the difference of the two secondary voltages, will increase while maintaining an in-phase relationship with the voltage from the input source. In the other direction from the null position, the differential voltage will also increase, but will be 180° out of phase with the voltage from the source. By comparing the magnitude and phase of the output (differential) voltage with that of the source, the amount and direction of the movement of the core and hence of displacement may be determined.

## Advantages of LVDT

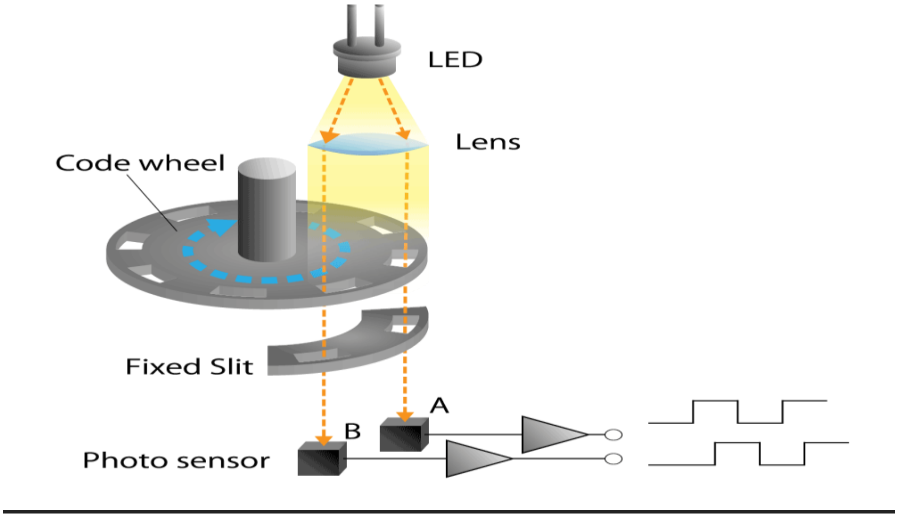
- **High Range** – The LVDTs have a very high range for measurement of displacement. They can used for measurement of displacements ranging from 1.25 mm to 250 mm
- **No Frictional Losses** – As the core moves inside a hollow former so there is no loss of displacement input as frictional loss so it makes LVDT as very accurate device.
- **High Input and High Sensitivity** – The output of LVDT is so high that it doesn't need any amplification. The transducer possesses a high sensitivity which is typically about 40V/mm.
- **Low Hysteresis** – LVDTs show a low hysteresis and hence repeatability is excellent under all conditions
- **Low Power Consumption –** The power is about 1W which is very as compared to other transducers.
- **Direct Conversion to Electrical Signals** – They convert the linear displacement to electrical voltage which are easy to process.

## Disadvantages of LVDT

- LVDT is sensitive to stray magnetic fields so it always requires a setup to protect them from stray magnetic fields.
- LVDT gets affected by vibrations and temperature.

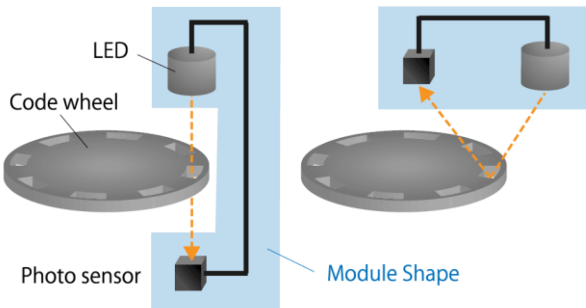
**Optical encoder-**

**Structure**




- It is composed of LED, photo sensors and a disc called a code wheel with slits (holes) in the radial direction and detects rotational position information as an optical pulse signal.
- When a code wheel attached to a rotating shaft such as a motor rotates, an optical pulse is generated depending on whether light emitting element passes through a slit of code wheel.
- Photo sensor detect the optical pulse and convert it into electrical signal.
- LED is a semiconductor device that emits lights when an electric current flows through it.
- Code wheel is also called disc which has slits for passing or blocking light emitted from the led which is made up of metal or glass and resin.
- Light emitted from LED is diffused light so that it is made parallel by using convex lens.
- The resolution of an optical encoder is basically determined by the number of slits in the code wheel. Therefore, it is necessary to increase no. of slits in the code wheel in order to achieve high resolution but it is necessary to reduce area of each slit in order to be compatible with the miniaturizes of the encoder.

**Classification of optical encoder by structure**




**(a) Transmission** **(b) Reflection**

**Transmission Type-**

- In this led and photosensor sandwich the code wheel. Photo sensor detects whether the light emitted from the led passes through the slit of code wheel or not.
- This type of structure is used to improve signal accuracy.

**Reflection Type-**

- In this the photo sensor detects where the light emitted from the led is reflected by the code wheel or not.
- It is easy to miniaturize.

**Classification by output electrical signal format**

Optical encoders are classified in to two types depending on the format of the output electrical signal,

- **Incremental method-**
  - It detects the amount of movement or angle change of disc from one position to the next.
  - It has one row of slit
  - Its cost is low
- **Absolute method-**
  - It gives absolute angle of rotating disc
  - It has multiple slits so, its cost is high

**Advantages**

- It is easy to improve accuracy and resolution by devising the shape of the slit because it has a mechanism that detect whether light passes through the slit or not.
- It is not affected by the surrounding magnetic fields.
- Highly reliable and accurate.
- Compact in size

**Disadvantage**

- They are fragility, susceptibility to foreign substances and high temperatures, the possibility of sudden breakdown.
- They are not designed for adverse operating conditions. It is almost impossible to detect an impending failure in advance.

**Applications**

- Electronics
- Medical and healthcare
- Aerospace

**Measurement of force using strain gauge**

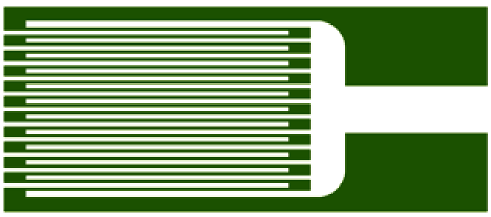
## Strain gauge

- A Strain gauge (sometimes referred to as a Strain gage) is a sensor whose resistance varies with applied force.
- It converts force, pressure, tension, weight, etc., into a change in electrical resistance which can then be measured.
- When external forces are applied to a stationary object, stress and strain are the result.
- Stress is defined as the object's internal resisting forces.
- Strain is defined as the displacement and deformation that occur.
- The strain gauge is one of the most important sensor of the electrical measurement technique applied to the measurement of mechanical quantities
- The resistance of their semiconductor material changes when the strain occurs on it.
- This property of metals is used for the measurement of the pressure, force-displacement etc..
- When an external force is applied on an object, due to which there is a deformation occurs in the shape of the object. This deformation in the shape is both compressive or tensile is called strain, and it is measured by the strain gauge.
- When an object deforms within the limit of elasticity, either it becomes narrower and longer or it become shorter and broadens. As a result of it, there is a change in resistance end-to-end.
- The strain gauge is sensitive to that small changes occur in the geometry of an object. By measuring the change in resistance of an object, the amount of induced stress can be calculated.

## Construction of Strain gauge

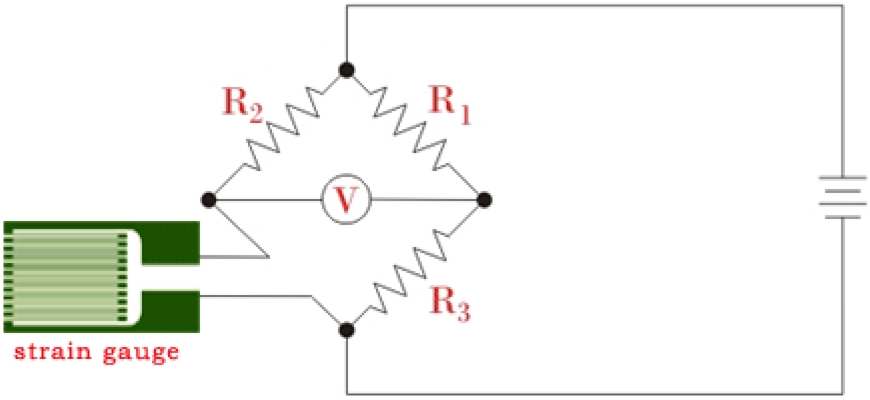
- The change in resistance normally has very small value, and to sense that small change, strain gauge has a long thin metallic strip arrange in a zigzag pattern on a non-conducting material called the carrier, as shown below, so that it can enlarge the small amount of stress in the group of parallel lines and could be measured with high accuracy. The gauge is literally glued onto the device by an adhesive.

- When an object shows physical deformation, its electrical resistance gets change and that change is then measured by gauge.



**Strain Gauge Bridge Circuit**

- **Strain gauge bridge circuit** shows the measured stress by the degree of discrepancy, and uses a voltmeter in the center of the bridge to provide an accurate measurement of that imbalance:




Quarter-bridge strain gauge circuit

- In this circuit, $R_1$ and $R_3$are the ratio arms equal to each other, and $R_2$ is the rheostat arm has a value equal to the strain gage resistance.
- When the gauge is unstrained, the bridge is balanced, and voltmeter shows zero value.
- As there is a change in resistance of strain gauge, the bridge gets unbalanced and producing an indication at the voltmeter. The output voltage from the bridge can be amplified further by a differential amplifier.

**Variation of Temperature of Strain Gauge**

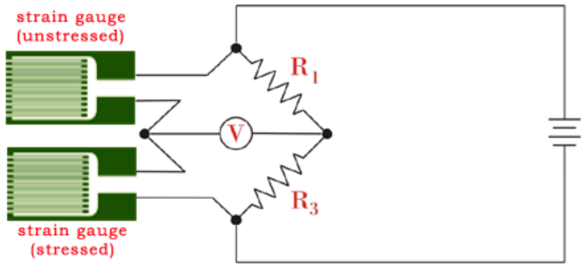
- One more factor that affects the resistance of the gauge is temperature.

- If the temperature is more resistance will be more and if the temperature is less the resistance will be less. This is a common property of all the conductors.

- We can overcome this problem by using strain gauges that are self- temperature-compensated or by a dummy strain gauge technique.

- Most of the strain gauges are made of constantan alloy which cancel out the effect of temperature on the resistance. But some strain gauges are not of an isoelastic alloy. In such cases, dummy gauge is used in the place of $R_2$ in the quarter bridge strain gauge circuit which acts as a temperature compensation device.

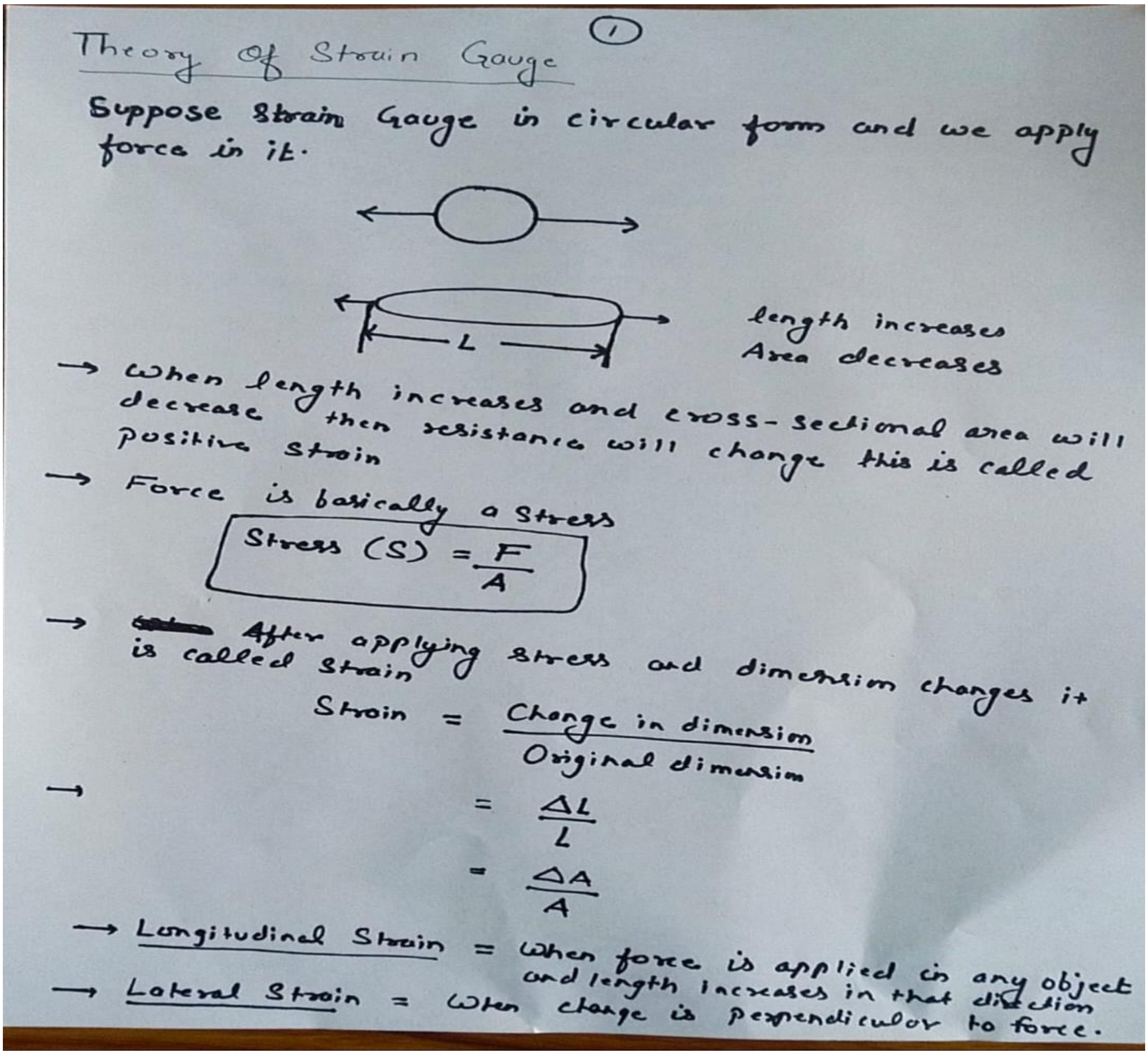
- Whenever temperature changes, the resistance will change in the same proportion in the both arms of the rheostat, and the bridge remains in the state of balance. Effect of temperature get nullifies. It is good to keep voltage low so that the self-heating of **strain gauge** could be evaded. Self-heating of gauge depends upon its mechanical behavior.




Quarter-bridge strain gauge circuit
with temperature compensation

**Application of Strain Gauge**

- In the field of mechanical engineering development.
- To measure the stress generated by machinery.
- In the field of component testing of aircraft like; linkages, structural damage etc.



Theory of Strain Gauge (1)

Suppose Strain Gauge in circular form and we apply force in it.

length increases
Area decreases

→ When length increases and cross-sectional area will decrease then resistance will change this is called positive strain

→ Force is basically a Stress

$$\text{Stress } (S) = \frac{F}{A}$$

→ After applying stress and dimension changes it is called strain

$$\text{Strain} = \frac{\text{Change in dimension}}{\text{Original dimension}}$$

→ $= \frac{\Delta L}{L}$

$= \frac{\Delta A}{A}$

→ Longitudinal Strain = When force is applied in any object and length increases in that direction

→ Lateral Strain = When change is perpendicular to force.

As we know resistance change after applying stress

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

Differentiate R w.r.t to S (Stress)

$$\frac{dR}{dS} = \frac{d}{dS}\left(\frac{\rho L}{A}\right) \quad \text{— (1)}$$

$$\frac{d(A^{-1})}{dS} = -1 A^{-1-1} = -\frac{1}{A^2}$$

$$= \frac{\rho}{A}\frac{\partial L}{\partial S} - \frac{\rho L}{A^2}\frac{\partial A}{\partial S} + \frac{L}{A}\frac{\partial \rho}{\partial S}$$

Divide both sides by R

$$\frac{1}{R}\frac{dR}{dS} = \frac{\rho}{AR}\frac{\partial L}{\partial S} - \frac{\rho L}{RA^2}\frac{\partial A}{\partial S} + \frac{L}{AR}\frac{\partial \rho}{\partial S}$$

Now put $R = \frac{\rho L}{A}$ in R.H.S

$$\frac{1}{R}\frac{dR}{dS} = \frac{\rho}{A \cdot \frac{\rho L}{A}} \cdot \frac{\partial L}{\partial S} - \frac{\rho L}{\frac{\rho L}{A} \cdot A^2}\frac{\partial A}{\partial S} + \frac{L}{A \cdot \frac{\rho L}{A}}\frac{\partial \rho}{\partial S}$$

$$\frac{1}{R}\frac{dR}{dS} = \frac{1}{L}\frac{\partial L}{\partial S} - \frac{1}{A}\frac{\partial A}{\partial S} + \frac{1}{\rho}\frac{\partial \rho}{\partial S} \quad \text{— (2)}$$

As we know,

$$\text{Area of Circle} = \pi r^2 \quad \text{— (3)}$$

$$r = \frac{\text{Diameter}}{2}$$

put $r = \frac{\text{Diameter}}{2}$ in eq. (3)

$$\text{Area of circle} = \pi \frac{D^2}{4} \quad \text{— (4)}$$

Now differentiate eq. (4) w.r.t to S

$$\frac{\partial A}{\partial S} = \frac{\pi}{4} \times 2D \frac{\partial D}{\partial S} \quad \text{— (5)}$$

Now put value of $\frac{\partial A}{\partial S}$ in eq. (2)

$$\frac{1}{R}\frac{dR}{dS} = \frac{1}{L}\frac{\partial L}{\partial S} - \frac{1}{A}\frac{\pi}{4} \times 2D \frac{\partial D}{\partial S} + \frac{1}{\rho}\frac{\partial \rho}{\partial S} \quad \text{— (6)}$$

Put $A = \pi \frac{D^2}{4}$ in eq. (6)

$$\frac{1}{R}\frac{dR}{dS} = \frac{1}{L}\frac{\partial L}{\partial S} - \frac{1}{\frac{\pi D^2}{4}} \times \frac{\pi}{4} \times 2D \frac{\partial D}{\partial S} + \frac{1}{\rho}\frac{\partial \rho}{\partial S}$$

$$\frac{1}{R}\frac{dR}{dS} = \frac{1}{L}\frac{\partial L}{\partial S} - \frac{2}{D}\frac{\partial D}{\partial S} + \frac{1}{\rho}\frac{\partial \rho}{\partial S} \quad \text{— (7)}$$

As we know,

$$\text{Poisson Ratio} = -\frac{\text{Lateral Strain}}{\text{Longitudinal Strain}}$$

(Poisson Ratio) $\gamma = -\frac{\partial A / A}{\partial L / L}$

Put $A = D$ (because change in diameter means change in area)

$$\gamma = -\frac{\partial D / D}{\partial L / L}$$

$$\frac{\partial D}{D} = -\gamma \frac{\partial L}{L} \quad \text{— (8)}$$

Now put $\frac{\partial D}{D}$ in eq. (7)

$$\frac{1}{R}\frac{dR}{ds} = \frac{1}{L}\frac{\partial L}{\partial s} + \frac{2\nu}{L}\frac{\partial L}{\partial s} + \frac{1}{\rho}\frac{\partial \rho}{\partial s} \quad (9)$$

Take common $\left(\frac{1}{L}\frac{\partial L}{\partial s}\right)$ on R.H.S

$$\frac{1}{R}\frac{dR}{ds} = \frac{1}{L}\frac{\partial L}{\partial s}\left[1+2\nu\right] + \frac{1}{\rho}\frac{\partial \rho}{\partial s} \quad (10)$$

Gouge factor will measure strain

Gouge factor = Change in resistance / Original resistance over Change in Length / Original Length

$$\text{Gouge factor } (G_F) = \frac{\Delta R/R}{\Delta L/R}$$

$$\frac{\Delta R}{R} = G_F \cdot \frac{\Delta L}{R}$$

if we remove ds from R.H.S and L.H.S from eq. (10)

$$\frac{dR}{R} = \frac{\partial L}{L}\left[1+2\nu\right] + \frac{\partial \rho}{\rho} \quad (11)$$

There is small variation in dimension so we can write

Δ

$$\frac{\Delta R}{R} = \frac{\Delta L}{L} + 2\nu\frac{\Delta L}{L} + \text{[redacted]}\,\frac{\partial \rho}{\rho}$$

Now Divide $\frac{\Delta L}{L}$ on both sides

$$\frac{\frac{\Delta R}{R}}{\frac{\Delta L}{L}} = \frac{\Delta L/L}{\Delta L/L} + 2\nu\frac{\Delta L/L}{\Delta L/L} + \frac{\Delta \rho/\rho}{\Delta L/L}$$

↓ $G_F$

$$G_F = 1 + 2\nu + \frac{\Delta \rho/\rho}{\Delta L/L}$$

$$\varepsilon = \text{strain} = \frac{\Delta L}{L}$$

$$G_F = 1 + 2\nu + \frac{\Delta \rho/\rho}{\varepsilon}$$

→ This is very small

$$G_F = 1 + 2\nu$$

**Example 25.17** *A compressive force is applied to a structural member. The strain is 5 micro-strain. Two separate strain gauges are attached to the structural member, one is a nickel wire strain gauge having a gauge factor of − 12.1 and the other is nichrome wire strain gauge having a gauge factor of 2. Calculate the value of resistance of the gauges after they are strained. The resistance of strain gauges before being strained is 120 Ω.*

**Solution.** According to our convention, the tensile strain taken as positive while the compressive strain is taken as negative.

Therefore, strain $\varepsilon = -5 \times 10^{-6}$

(1 micro strain = 1 μm / m)

Now $\Delta R / R = G_f \varepsilon$ (See Eqn. 25.68)

∴ Change in value of resistance of nickel wire strain gauge :

$$\Delta R = G_f \varepsilon \times R$$
$$= (-12.1) \times (-5 \times 10^{-6}) \times 120$$
$$= 7.26 \times 10^{-3} \Omega = 7.26 \text{ m}\Omega$$

Thus there is an increase of 7.26 mΩ in the value of resistance.

For nichrome, the change in the value of resistance is :

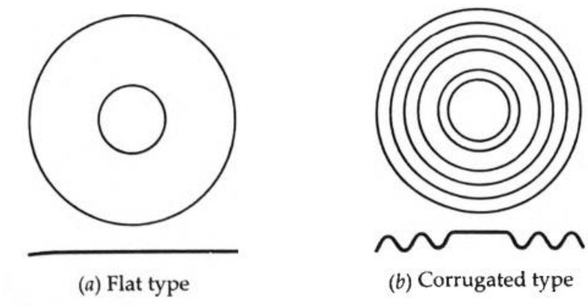
$$\Delta R = (2) \times (-5 \times 10^{-6}) \times 120$$
$$= 1.2 \times 10^{-3} \Omega = -1.2 \text{ m}\Omega$$

Thus, with compressive strain, the value of resistance gauge shows a decrease of 1.2 mΩ in the value of resistance.

**Measurement of pressure using LVDT based Diaphragm:**

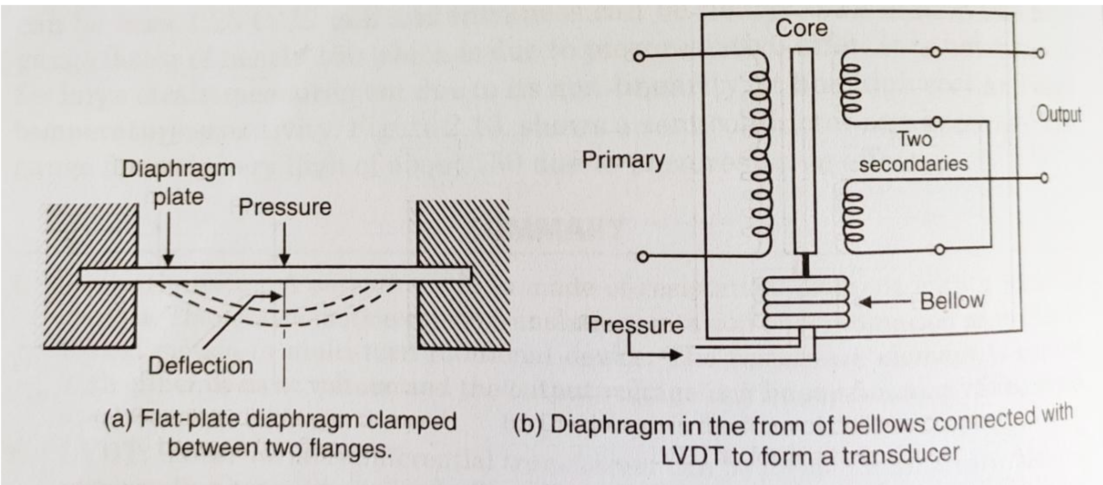
- The diaphragms are pressure-sensitive and are primarily available in the form of a flat-plate.
- The pressure to be measured is applied to the diaphragm, causing it to deflect, the deflection being proportional to the applied pressure.
- The movement of the diaphragm depends on its thickness and diameter. The movement is small and hence a diaphragm element does not require any springs as is the case in bellows.
- The movement of a diaphragm is a convenient way of sensing a pressure.
- The unknown pressure is applied to one side of a diaphragm. The edge of the diaphragm is rigidly fixed and causes a deflection on account of the applied pressure.
- The displacement of the diaphragm may be measured to determine the value of applied pressure, *P*.
- The diaphragm, which is a very thin membrane under pressure and therefore under radial tension, may use capacitive or inductive transducers, to produce an electrical output which is proportional to the output of the transducers.

- The use of diaphragms using thin membranes is limited to measurement of low-level pressure fluctuations. Since membranes can withstand only limited values of force (produced by pressure), diaphragms using thin membranes.
- For greater displacements than are produced by membrane type of diaphragms. In place of membranes, it is usual to employ thin circular plates which are either clamped, around their circumference between two solid rings, or are machined from a solid piece of metal.
- The diaphragm are two types (i) Flat type and (ii) Corrugated type.




Single diaphragm elements

- In LVDT based diaphragm transducer, bellow made of diaphragm is connected with core of LVDT. The movement of bellow due to pressure moves the core of LVDT which give electrical signal proportional to the pressure.

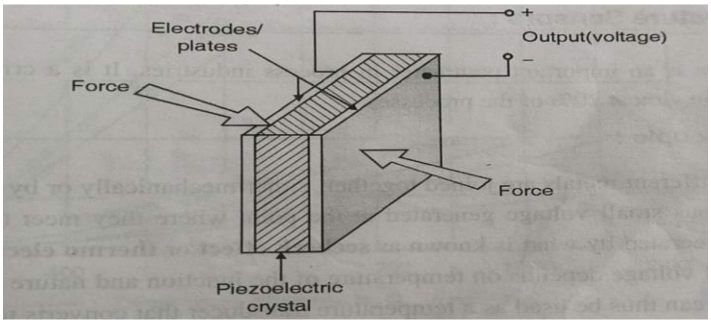



LVDT based diaphragm transducer

**Piezoelectric Transducer:**

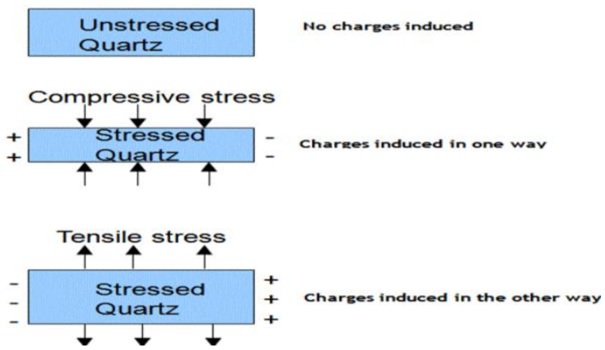
- A **piezoelectric transducer** (also known as a piezoelectric sensor) is a device that uses the piezoelectric effect to measure changes in acceleration, pressure, strain, temperature or force by converting this energy into an electrical charge.
- A piezoelectric transducer is based on the principle of the piezoelectric effect. The word piezoelectric is derived from the Greek word piezen, which means to squeeze or press.

- The piezoelectric effect states that when mechanical stress or forces are applied on quartz crystal, produce electrical charges on the quartz crystal surface.
- The piezoelectric effect is discovered by Pierre and Jacques Curie.
- The rate of charge produced will be proportional to the rate of change of mechanical stress applied to it.
- Higher will be stress higher will be voltage.
- A transducer can be anything that converts one form of energy to another. The piezoelectric material is one kind of transducers.




- A piezoelectric transducer consists of quartz crystal which is made from silicon and oxygen arranged in crystalline structure ($SiO_2$).
- Generally, unit cell (basic repeating unit) of all crystal is symmetrical but in piezoelectric quartz crystal, it is not.
- Piezoelectric crystals are electrically neutral.
- The atoms inside them may not be symmetrically arranged but their electrical charges are balanced means positive charges cancel out negative charge.
- The quartz crystal has the unique property of generating electrical polarity when mechanical stress applied to it along a certain plane.
- When we squeeze this piezoelectric material or apply any force or pressure, the transducer converts this energy into voltage. This voltage is a function of the force or pressure applied to it. The electric voltage produced by a piezoelectric transducer can be easily measured by the voltage measuring instruments. Since this voltage will be a function of the force or pressure applied to it, we can infer what the force/pressure was by the voltage reading. In this way, physical quantities like mechanical stress or force can be measured directly by using a piezoelectric transducer.

- Basically, there are two types of stress. One is compressive stress and the other is tensile stress.




Piezoelectric effect of Quartz material

- When there is unstressed quartz, no charges induce on it.
- In the case of compressive stress, positive charges are induced on one side and negative charges are induced in the opposite side. The crystal size gets thinner and longer due to compressive stress.
- In the case of tensile stress, charges are induced in reverse as compare to compressive stress and quartz crystal gets shorter and fatter.

**Applications**

1. In microphones, the sound pressure is converted into an electric signal and this signal is ultimately amplified to produce a louder sound.
2. Automobile seat belts lock in response to a rapid deceleration is also done using a piezoelectric material.
3. It is also used in medical diagnostics.
4. It is used in electric lighter used in kitchens. The pressure made on piezoelectric sensor creates an electric signal which ultimately causes the flash to fire up.
5. They are used for studying high-speed shock waves and blast waves.
6. Used infertility treatment.
7. Used in Inkjet printers
8. It is also used in restaurants or airports where when a person steps near the door and the door opens automatically. In this, the concept used is when a person is near the door pressure is exerted person weight on the sensors due to which the electric effect is produced and the door opens automatically.

**Advantages**

1. No need for an external source
2. Easy to handle and use as it has small dimensions
3. High-frequency response it means the parameters change very rapidly

**Disadvantages**

1. It is not suitable for measurement in static condition
2. It is affected by temperatures
3. The output is low so some external circuit is attached to it
4. It is very difficult to give the desired shape to this material and also desired strength