Subject - Basic Electronics Engg. (104010)

FE - 2019 course

UNIT-V: Sensors

Syllabus

- Classification of sensors.
- Active /Passive Sensors
- Analog/Digital Sensors
- Motion Sensors (LVDT, Accelerometer)
- Temperature Sensors (Thermocouple, Thermistor, RTD)
- Semiconductor Sensors (Gas Sensors), Optical Sensors (LDR)
- Mechanical Sensors (Strain Gauge, Load Cell, Pressure sensors)
- Biosensors. (Working Principle and one application).

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UNIT-V: Sensors

Q.1)What is sensor? Give the classification of sensors.

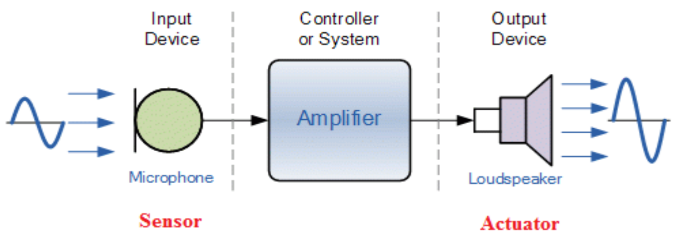
Answer:

Sensor: A sensor is a device which detects one form of energy and produces corresponding electrical signal.

Transduces: A transducer is a device that converts one form of energy into another form of energy.

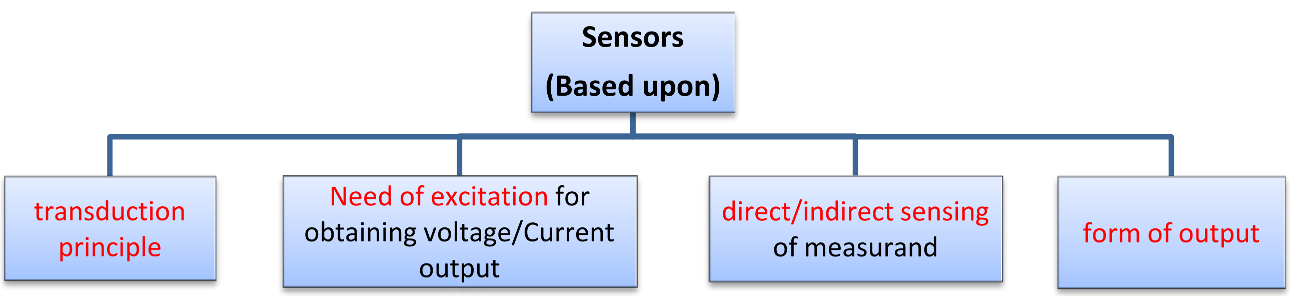
Thus sensor is type of transducer.

Devices which perform an "**Input**" function are commonly called **Sensors** because they "sense" a physical change in some characteristic that changes in response to some excitation, for example heat or force and covert that into an electrical signal.
Devices which perform an "**Output**" function are generally called **Actuators** and are used to control some external device, for example movement or sound.



#Classification of sensors:

The sensors are classified based upon various aspects as follows



A) Based upon - Transduction principle used:

1. **Resistive Sensor:** The output of resistive sensor is the change in their resistance (R) corresponding to change in measurand.
   Example: Resistance Temperature Detector (RTD), Strain gauge, Thermistor.
2. **Capacitive Sensor:** The output of capacitive sensor is the change in their capacitance (C) corresponding to change in measurand.
   Example: Gang capacitor, Parallel plate capacitor
3. **Inductive Sensor:** The output of inductive sensor is the change in their inductance (L) corresponding to change in measurand.
   Example: Linear Variable Differential Transformer (LVDT).
4. **Piezoelectric Sensor:** (Pressure → Electrical) It converts pressure signal into electrical signal.
   Example: Quartz crystal
5. **Thermoelectric Sensor:** (Thermal energy → Voltage) It converts thermal energy into voltage signal.
   Example: Thermocouple.
6. **Photoelectric/Photovoltaic (Optical) Sensor:** It has change in electrical properties due to incident light.
   Example: LDR, Photodiode, Photo transistor, Solar cell.

B) Based upon - Need of excitation for obtaining voltage/current output:

1. **Active sensor:** Active sensor is sensor which does not require any external energy to generate voltage/current output upon applying input measurand.
   Example: Thermocouple, Piezoelectric Sensor, Solar cell
2. **Passive sensor:** Passive sensor is sensor which requires external energy to generate voltage/current output upon applying input measurand.
   Example: (R,L,C) Sensor, RTD, LVDT, LDR, Strain gauge.

C) Based upon – Direct/Indirect sensing of measurand:

1. **Primary sensor:** Primary sensor is a sensor which accepts measurand as input and converts it into another quantity corresponding to input.
   Example: LVDT for displacement measurement, Strain gauge for pressure measurement**.**
2. **Secondary sensor:** Secondary sensor is sensor which accepts output of primary sensor as input and converts it into another quantity
   Example: LVDT for pressure measurement, LVDT for accelerometer**.**

D) Based upon – form of output:

1. **Analog sensor:** Analog sensor is a sensor whose output is in analog form (graph or waveform).
   Example: LVDT, Strain gauge, Thermocouple**.**
2. **Digital sensor:** Digital sensor is a sensor whose output is in digital form (digital code).
   Example: Rotary and absolute encoders, Stroboscope.

Q.2)Compare active & passive sensors.
Answer:

#Comparison between active & passive sensors:

Active sensor	Passive sensor
They don't require any external power or energy.	They require external power or energy.
They produce V or I signal which is proportional to the physical quantity to be measured.	They produce variations in R, L, C w.r.t. the physical quantity to be measured
They are simple	They are complex
Size is small	Size is bulky
Less expensive	More expensive
Examples: Thermocouple, Piezoelectric devices, Photovoltaic cells etc.	Examples: Variable (R,L,C), LDR, RTD, LVDT etc.

Q.3)Compare analog and digital sensors

Answer:

#Comparison between analog and digital sensors:

Analog Sensor	Digital Sensor
Output is in analog form	Output is in digital form
Can be directly measured	One line can transmit multiple sensors
No compatibility issues	Need to interpret the 1's and 0's
More prone to noise	Need to make sure clocks a synced up
Ex. LVDT, Strain gauge, Thermocouple	Rotary and absolute encoders, Stroboscope

Q.4)What is motion sensor? Explain the working principle of LVDT with suitable diagram. Write its advantages, disadvantages and applications.

Answer:

Motion Sensor: The motion sensor is used to sense the motion related parameters like displacement velocity, acceleration.

The sensors are available for linear as well as rotary motion.

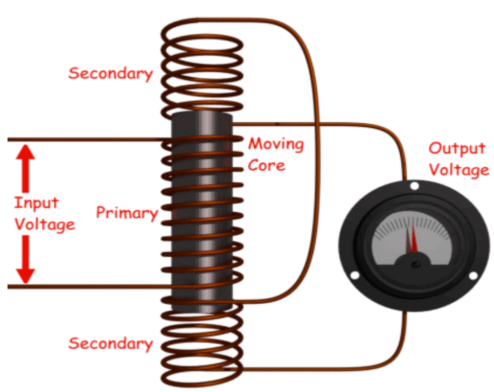
Examples: LVDT, Accelerometer

#Linear variable differential transformers (LVDT)

The term **LVDT** stands for the **Linear Variable Differential Transformer**. It is the most widely used inductive transducer that converts the linear motion into the electrical signal. LVDTs are used to measure displacement. The output across secondary of this transformer is the differential.

LVDT consists of a coil assembly and a core. Magnetic flux produced by the primary is coupled to the two secondary coils, inducing an AC voltage in each coil.

Construction:



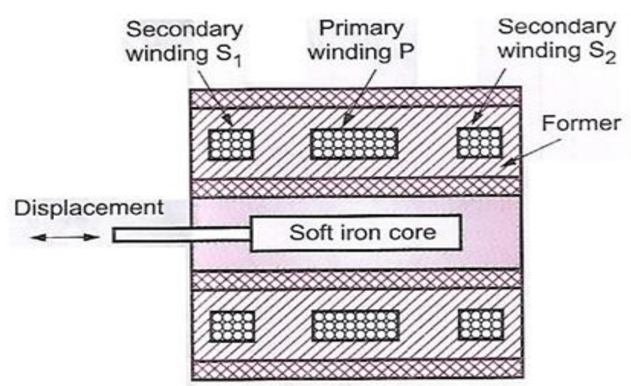
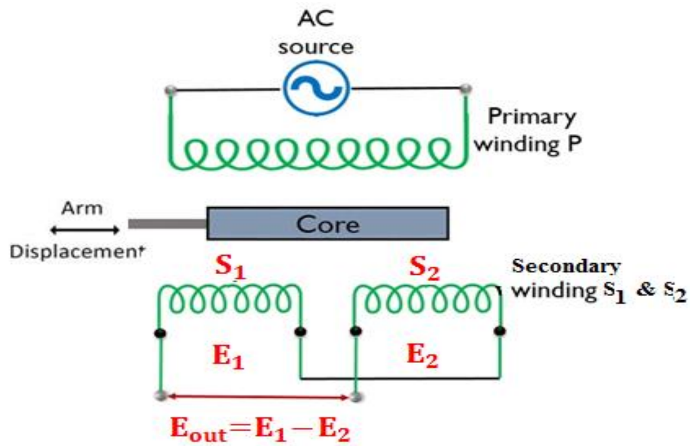


Fig. Construction of LVDT



Circuit of LVDT

Main Features of Construction:

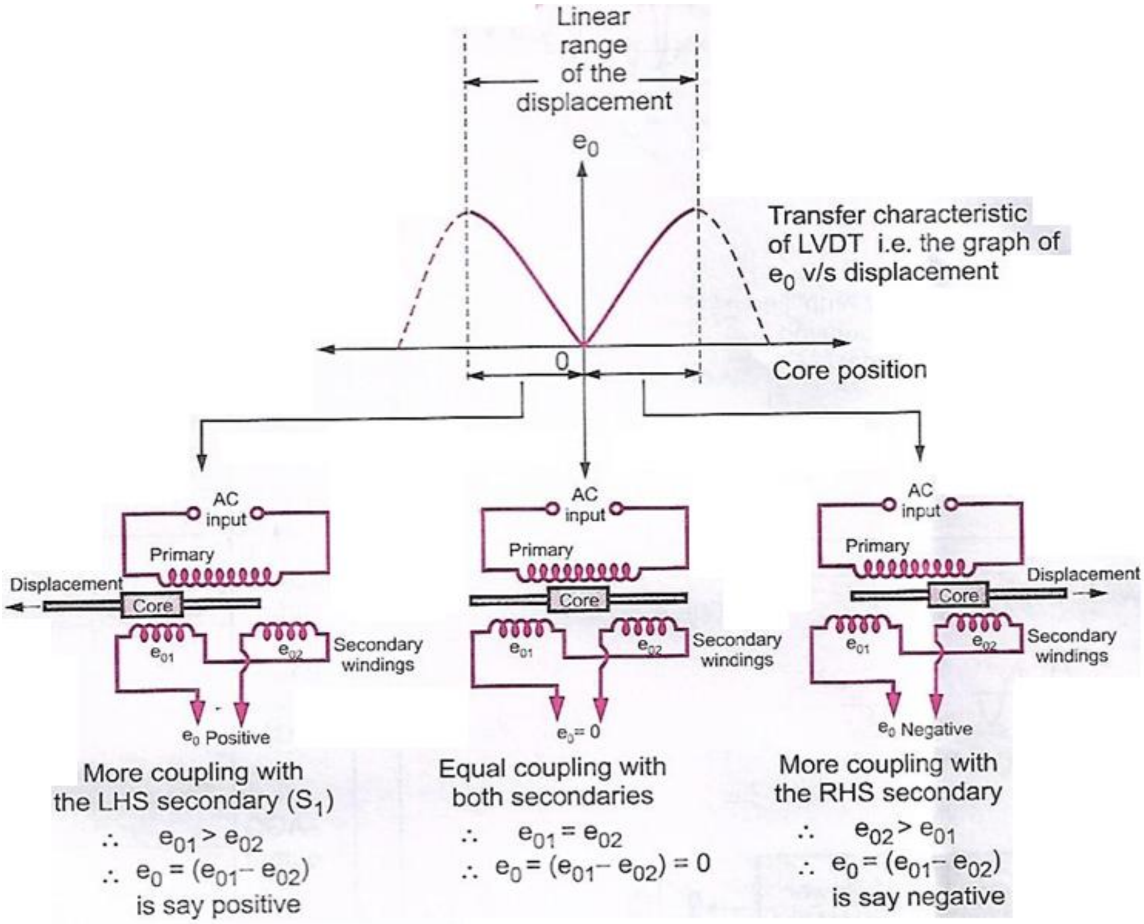
- The LVDT consists of a primary winding P and two secondary windings S_1 and S_2 wound on a cylindrical former (which is hollow in nature and contains the core).
- Both the secondary windings have an equal number of turns, and we place them on either side of primary winding
- The primary winding is connected to an AC source which produces a flux in the air gap and voltages are induced in secondary windings.
- A movable soft iron core is placed inside the former and displacement to be measured is connected to the iron core.
- The iron core is generally of high permeability which helps in reducing harmonics and high sensitivity of LVDT.
- The LVDT is placed inside stainless steel housing because it will provide electrostatic and electromagnetic shielding.
- The both the secondary windings are connected in such a way that resulted output is the difference between the voltages of two windings.

Principle of Operation and Working

As the primary is connected to an AC source so alternating current and voltages are produced in the secondary of the LVDT. The output in secondary S_1 is E_1 and in the secondary S_2 is E_2.
So the differential output is,

$$\mathbf{E_{out} = E_1 - E_2} \quad \textbf{or} \quad e_{out} = e_1 - e_2$$

This equation explains the **principle of Operation of LVDT**.



Now three cases arise according to the locations of core which explains the working of LVDT are discussed below as,

- **CASE I : (E_{out} = 0) -** When the core is at null position (for no displacement)
  When the core is at null position then the flux linking with both the secondary windings is equal so the induced emf is equal in both the windings. So for no displacement, $E_{out} = 0$ as $E_1 = E_2$. So it shows that no displacement took place.
- **CASE II : (E_{out} = Positive) -** When the core is moved to left of null position (For displacement to the upward of reference point)
  In the this case the flux linking with secondary winding S_1 is more as compared to flux linking with S_2. Due to this $E_1 > E_2$ => E_{out} is positive.
- **CASE III : (E_{out} = Negative) -** When the core is moved to right of null position (For displacement to the upward of reference point)
  In the this case the flux linking with secondary winding S_2 is more as compared to flux linking with S_1. Due to this $E_1 < E_2$ => E_{out} is negative.

  Output V_S Core Displacement A linear curve shows that output voltage varies linearly with displacement of core.

Some important points about magnitude and sign of voltage induced in LVDT:

- The amount of change in voltage either negative or positive is proportional to the amount of movement of core and indicates amount of linear motion.
- By noting the output voltage increasing or decreasing the direction of motion can be determined
- The output voltage of an LVDT is linear function of core displacement.

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 possess 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.

Applications of LVDT:

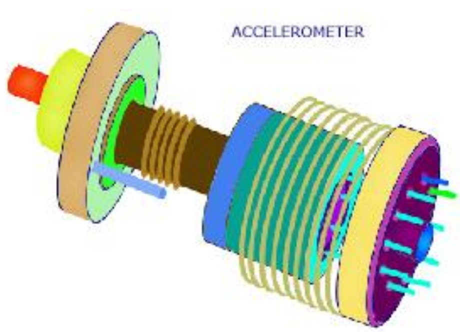
1. We use LVDT in the applications where displacements to be measured are ranging from a fraction of mm to few cms. The **LVDT** acting as a primary transducer converts the displacement to electrical signal directly.
2. The LVDT can also act as a secondary transducer. E.g. the Bourbon tube which acts as a primary transducer and it converts pressure into linear displacement and then LVDT coverts this displacement into an electrical signal which after calibration gives the readings of the pressure of fluid.

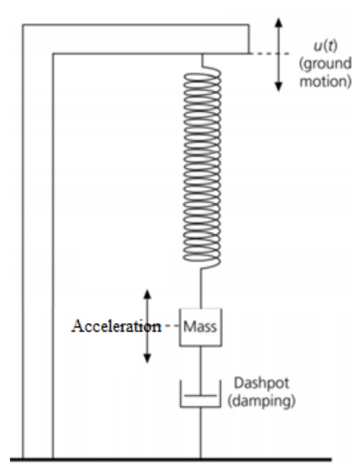
Q.5) What is Accelerometers? Draw its construction diagram and explain its operation. Write its advantages, disadvantages and applications.

Answer:

Accelerometers:

An **accelerometer** is a sensor which measures acceleration, which is the change in an object's velocity per second. It is also used for measurement of vibration, shock. An **accelerometer** measures proper acceleration, which is not the same as coordinate acceleration. This means that the **accelerometer** can be used to detect the direction of gravity.





The basic **accelerometer** is mechanical system with mass, damper and spring. Such arrangement is known as Seismic instrument.

Construction:

The **accelerometer** consists of a mass, damper and spring as shown in figure. The mass is suspended freely and is connected to casing through damper and spring. The mass-damper-spring assembly is enclosed by casing.

Working:

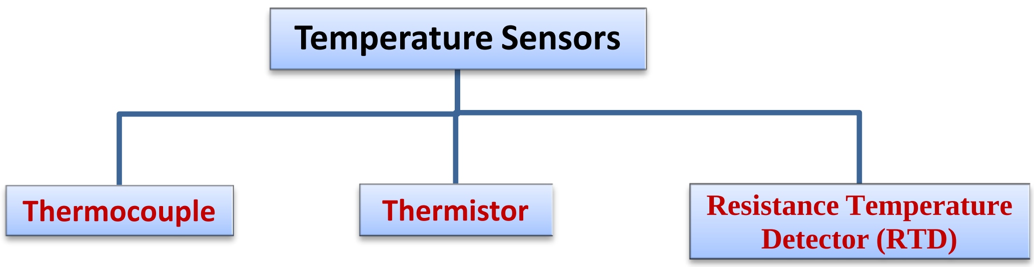
Due to application of force the acceleration takes place. Hence mass-damper-spring experiences displacement x and the casing experiences displacement y. Then the relative displacement is x-y. The acceleration is directly proportional to the displacement. Thus by measuring x with displacement sensor attached to mass and knowing all constants (k, m, B) the acceleration can be measured.

Where,
k - Spring constant
m - Seismometer mass
B - Damper constant

Q.6)What are the different types of temperature sensors? Explain the working principle of thermocouple. Also give its advantages, disadvantages & applications.

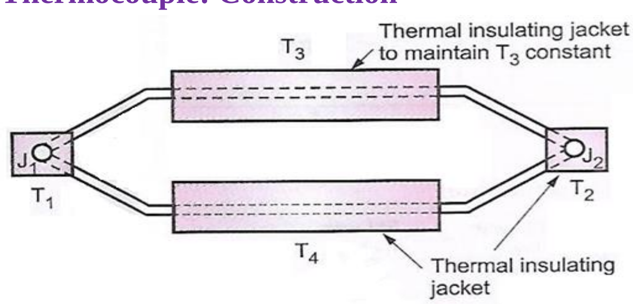
Answer:

Temperature Sensor: Types

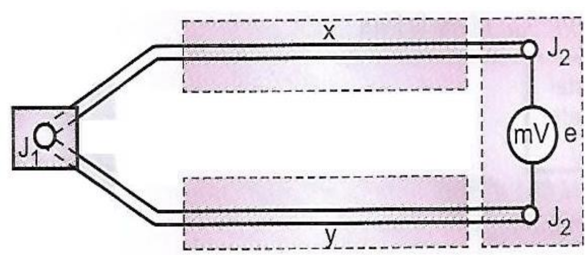


Temperature sensor: The sensor that change their output with change in temperature.
Example: Thermocouple, Thermistor, Resistance Temperature Detector (RTD)
Thermocouple: It is an active temperature sensor which generates voltage proportional to applied temperature

Thermocouple: Construction



Thermocouple: Principle



Principle: (work on Seeback effect)

If two dissimilar metals are joined together at each end to form a loop with two junctions and a temperature difference exists between two junctions then a thermo emf (voltage) proportional to temperature difference is generated.

$$V_0 \propto (T_2 - T_1)$$

$$V_0 = C.(T_2 - T_1)$$

Where C is sensitivity of thermocouple in mV/ ^{0}C.

The above principle is known as seeback effect.
Thus by measuring the output voltage across the junction the temperature can be determined.

Construction:

If two dissimilar metals are joined together to form two junctions. The thermocouple junctions are placed in protective casing of stainless steel and output terminals are made available for voltage measurement.

Working:

One of the thermocouple junction is kept as reference junction (J_1) and other is considered as measuring junction (J_2). The reference junction is kept at ambient temperature (T_1) and the measuring junction is exposed to chamber whose temperature is to be measured. Then due to temperature difference the thermo emf (V_0) is generated.

We have,

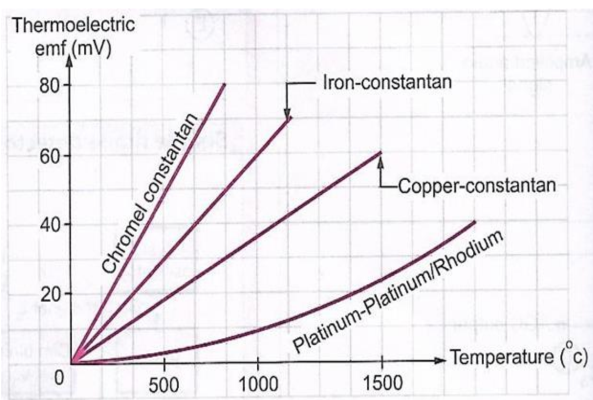
$$V_0 = C.(T_2 - T_1)$$

$$T_2 = \frac{V_0}{C} + T_1$$

For better accuracy, the reference junction is kept in ice bath to have T_1=0, then $T_2 = \frac{V_0}{C}$

This eliminates error due to fluctuations in ambient temperature

Thermocouple: Temperature Characteristics



Advantages:

1. External source not required.
2. Less expensive and compact in size.
3. Responds quickly to temperature changes.
4. High working range

Disadvantages:

1. Their performance is affected by stray magnetic fields.
2. The generated output voltage is very small therefore it needs amplification.
3. Maintaining the junction temperature stable is difficult.
4. Characteristics V_0 *Vs* Temp. is non-linear.
5. The thermocouple system requires periodic maintenance.

Application:

1. Cement manufacturing plants.
2. Tube mills.

3. Food industries, bakeries.
4. Heat treatment plants.
5. Semiconductor manufacturing plants.
6. Seamless pipes manufacturing plants.

Q.7)Explain the working principle of thermistor with suitable diagram. Also give its advantages, disadvantages and applications.

Answer:

Thermistor:

- A thermistor is a type of resistor whose resistance is dependent on temperature. The word is a combination of thermal and resistor.
- Thermistor is temperature sensing resistor.
- It is manufactured using semiconductor materials having negative temperature coefficient.

Principle:

- The resistance of thermistor changes with change in temperature.
- The relation between the resistance of thermistor and temperature is,

$$\mathbf{R_T = R_0 \cdot e^{\beta \cdot \left(\frac{1}{T} - \frac{1}{T_0}\right)}}$$

Where,

R_T – Resistance of thermistor at T ^{0}C
R_0 – Resistance of thermistor at T_0 ^{0}C
β - Material constant

Thermistors are available in two types,

1. Negative temperature coefficients (NTC) thermistor – Resistance decreases due to increase in temperature
2. Positive temperature coefficients (PTC) thermistor – Resistance increases due to increase in temperature

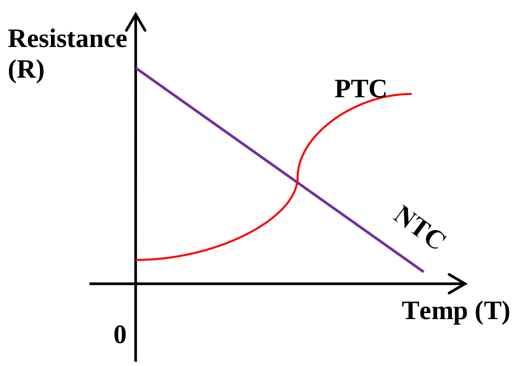
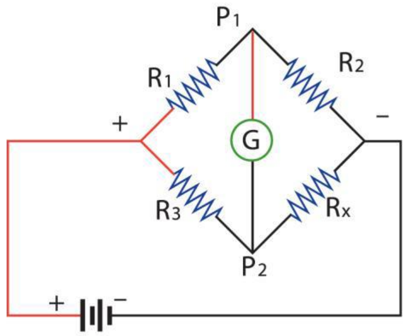


Fig. Input-Output Characteristics curve of NTC & PTC thermistors

Due to non-linear characteristics, PTC thermistors are less preferred over NTC thermistors.

Working: Measurement system-Circuit diagram



Thermistor is inserted in the system of which temperature is to be measured. The resistance of thermistor changes with change in temperature. The bridge circuit is used to convert the change in resistance into corresponding voltage. In this circuit R_1, R_2 & R_3 are fixed resistors and R_X (Thermistor) is the variable resistor.

As the temperature of the system changes the resistance of thermistor changes and corresponding voltage is produced at output terminals.

Advantages:

1. Compact size and cheaper in cost.
2. Their resolution is high

Disadvantages:

1. They are passive transducer and need external power supply.
2. The generated output voltage is very small therefore it needs amplification.
3. Characteristics R *Vs* Temp. is non-linear.
4. Their range of operation is small.

Application:

1. For precision temperature measurement.
2. Biomedical instrumentation.
3. Measuring temp. distribution around the object.

Q.8)Explain the working principle of RTD. Also give its advantages, disadvantages & applications.

Answer:

Resistor Temperature Detector (RTD):

Principle:

- RTD works on the principle that "the electric resistance of a metal changes with change in its temperature". (increases with increase in temperature)
- The relation is given by,

$$\mathbf{R_T = R_0 \cdot (1 + \alpha_0 \cdot T)}$$

Where,

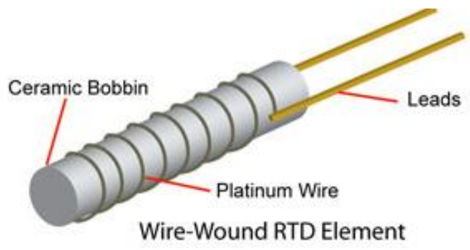
R_T – Resistance of RTD at T ^{0}C

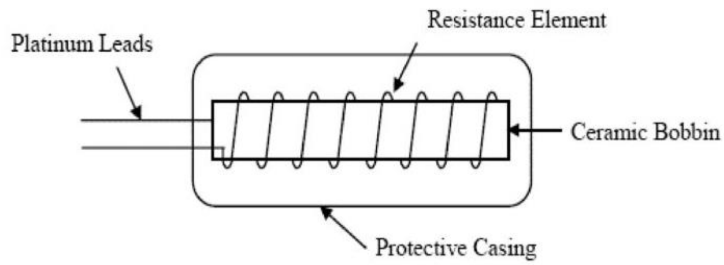
R_0 – Resistance of RTD at 0 ^{0}C

α_0 – Resistance Temperature Coefficient at 0 ^{0}C

Construction:

The construction diagram of RTD is shown in fig.

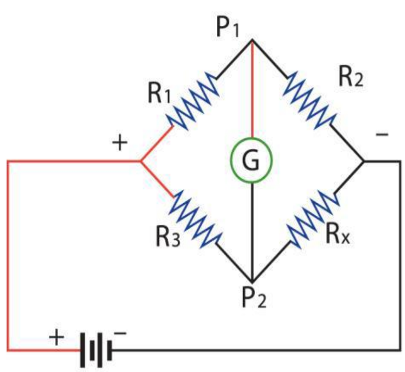




The sensitive portion of an RTD, called an element is a coil of small-diameter, high purity wire, usually constructed of platinum, copper or nickel.

This type of RTD is called a wire wound RTD. With thin-film elements, a thin film of platinum is deposited onto a ceramic substrate.

Working: Measurement system-Circuit diagram



RTD is inserted in the system of which temperature is to be measured. The resistance of RTD changes with change in temperature. The bridge circuit is used to convert the change in resistance into corresponding voltage. In this circuit R_1, R_2 & R_3 are fixed resistors and R_X (RTD) is the variable resistor.

As the temperature of the system changes the resistance of RTD changes and corresponding voltage is produced at output terminals.

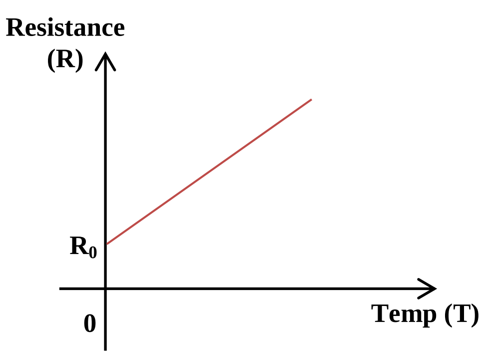


Fig. Input-Output Characteristics curve of RTD

Advantages:

- Due to no fluid present absolute temperature is recorded
- It is highly sensitive and gives accurate results.
- It has good range of temperature measurement.
- High accuracy
- Don't need reference temperature.
- Due to electrical output it can be used with PLCs and complete can be achieved

Disadvantages:

- It needs external power supply.
- Its size is not compact.
- It has low resolution
- Cost is high

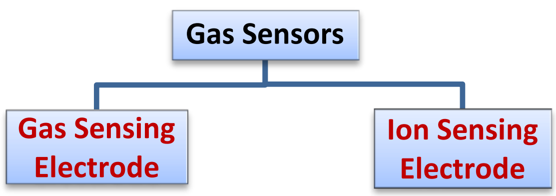
Applications:

- Air conditioning and refrigeration servicing
- Food Processing
- Textile processing
- Plastics processing
- Petrochemical processing
- Air, gas and liquid temperature measurement in pipes and tanks
- Exhaust gas temperature measurement

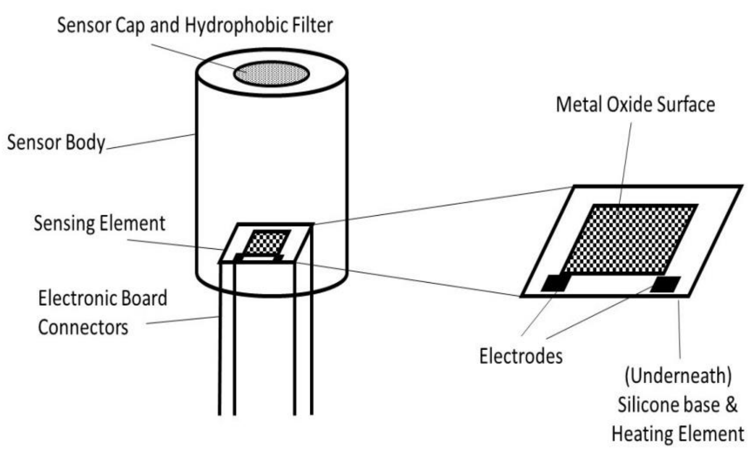
Q.9) Enlist the different types of gas sensors. Explain working principle of gas sensor. Also give its advantages, disadvantages & applications.

Answer:

Gas Sensor Types:



Gas Sensing Electrode: Gas sensor



Principle:

- Semiconductor gas sensors relay on the gas coming into metal oxide surface and then undergoing either oxidation or reduction.

Construction:

- The construction diagram of Semiconductor gas sensor is shown in fig.
- It consists of metal oxide film as a sensing element. The exact metal depends upon the gas to be detected. The film is connected to electrodes and from electrodes the connecting wire are taken out for measurement of resistance. This sensing element is covered with a sensor body having sensor cap and a filter.

Working:

- When the gas is allowed to enter the sensor body, it is observed by the sensing element which changes its resistance. The change in resistance is proportional to gas concentration. Thus a linear equation between resistance and gas concentration can be established. Also the change in resistance can be converted into voltage using electric circuit.
- The gas sensors are generally used for detection of carbon monoxide (CO), carbon dioxide (CO_2). Accordingly the material of sensing element is selected.

Advantages:

- High accuracy
- High sensitivity
- Good dynamic response
- Compact size

Disadvantages:

- It needs external power supply.
- It needs careful and periodic maintenance

Applications:

- To detect the presence of CO_2, SO_2, NH_3 gases in residential complex & industrial plants.
- To measure the percentage CO2, SO_2, NH_3 gases.
- To control pollution

Q.10) Explain working principle of Optical sensor. Also give its advantages, disadvantages & applications.
Answer:

Optical sensor:

The optical sensors are sensitive to light. The electrical properties of these sensors change with the intensity of light incident on them.
Example: Photodiode, Photo transistor, Photovoltaic cell - Solar cell. LDR,

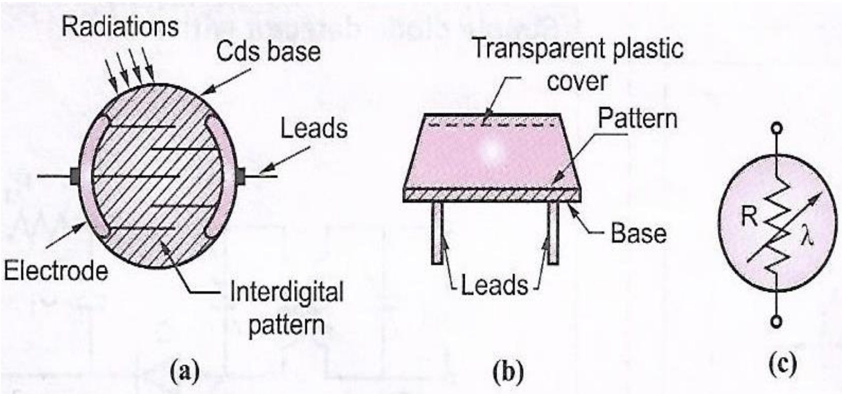
Light Dependent Resistor (LDR):

Principle:

The resistivity of LDR decreases with increase in intensity of light.

Construction:

Figure (a) & (b) – Construction of LDR.
Figure (c) - Symbol of LDR.



LDR has lightly doped active semiconductor region deposited on the semi-insulating material. The material contact is placed on the active layer. To have relatively large area that is exposed to the light, the pattern is cut in the metallization on the surface of the active area which allows light to pass through.

Working:

LDR is made up of semiconductor material with high resistance. It has high resistance because there are very less electrons and majority of electrons are locked into the crystal lattice structure. When the light falls on the LDR, the protons are absorbed by the active layer region. The energy of absorbed protons is transferred is transferred to electrons locked into the crystal lattice. This energy makes the electrons free to move which allows conduction of electricity. Due to this action, the resistivity of LDR falls. The typical characteristics of LDR are shown in fig.

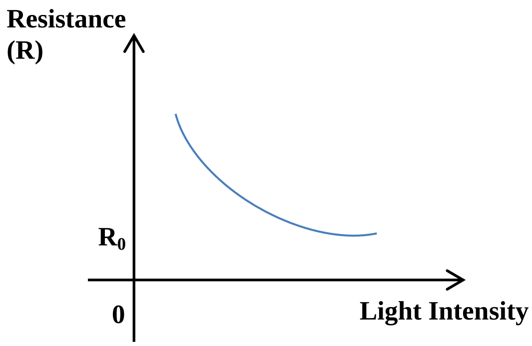


Fig. Input-Output Characteristics curve of LDR

The resistance of LDR when no light falls on it is called as dark resistance. The typical value of dark resistance is in MΩ. In day light the resistance of LDR is in KΩ.

Advantages:

- High sensitivity
- Compact size & low cost
- High dark to light resistance approximately 100:1

Disadvantages:

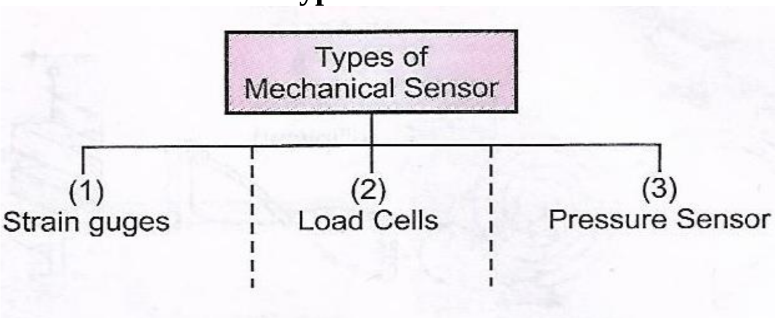
- Response time – very large
- It needs external power supply

Applications:

- Counting circuits.
- CdS cells are used as On-Off switch.

- They are used to check the intensity of light.
- In security alarm system.

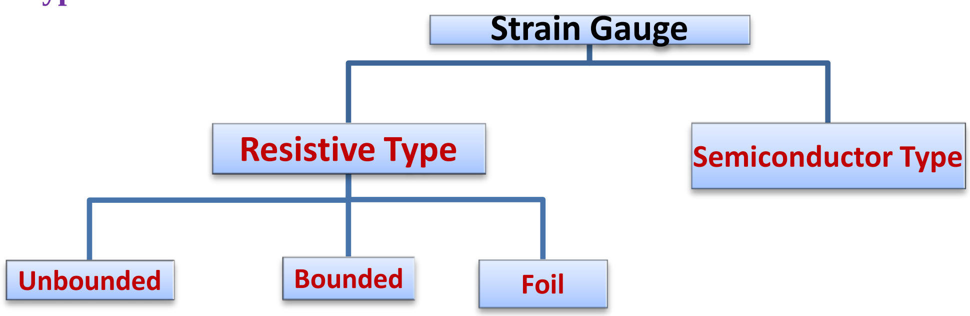
Mechanical Sensor: Types



Q.11) What are the different types of strain gauges? Explain working principle of any one strain gauge.

Answer:

Strain gauges: Types

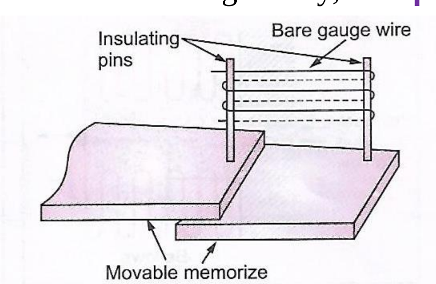


Strain gauge is an elastic resistive transducer which converts mechanical elongation and compression (strain) into change in resistance. Strain gauge is widely used for measurement of strain, pressure, force and weight.

Principle

Resistance of any conductor depends on its resistivity, length and cross sectional area. Hence if there is change in length or cross sectional area due to compression or elongation, resistance gets changed. Also in elastic material, upon application of stress, proportionate strain takes place in material and resistance gets changed.

The resistance is given by, $\mathbf{R = \rho \frac{l}{A}}$



$$\frac{dR}{R} = (1 + 2v)\varepsilon_a = \text{G.F.}\,x\,\varepsilon_a = \text{G.F.}\,x\,\frac{dl}{l}$$

Where,

dR – change in Resistance

R – Resistance when no stress is applied

ε_a – Axial strain = $\frac{dl}{l}$

v – Possion's ratio

G.F. = Gauge factor = $(\mathbf{1 + 2}v)$

Q.12) What are the different types of load cell? Explain working principle of Load cell

Answer:

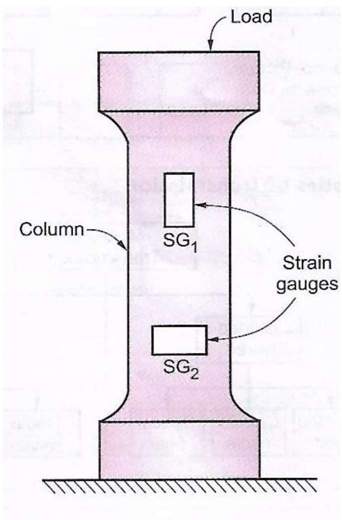
Load cell:

Load cell is a sensor used for force and weight measurement. It uses strain gauge as sensing element. Strain gauge produces change in resistance proportional to applied pressure. The relation between force and pressure is,

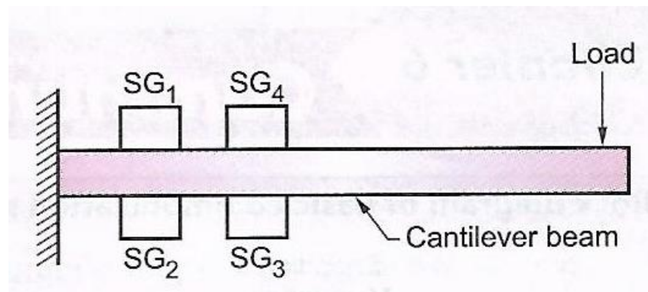
$P = \frac{F}{A} \Rightarrow P \propto F.$

The load cell is used in two configurations,
Column type load cell
Cantilever beam cell

Column type Load cell



Cantilever Beam cell:



Q.13) What are different types of pressure sensors? Explain working principal of any one.

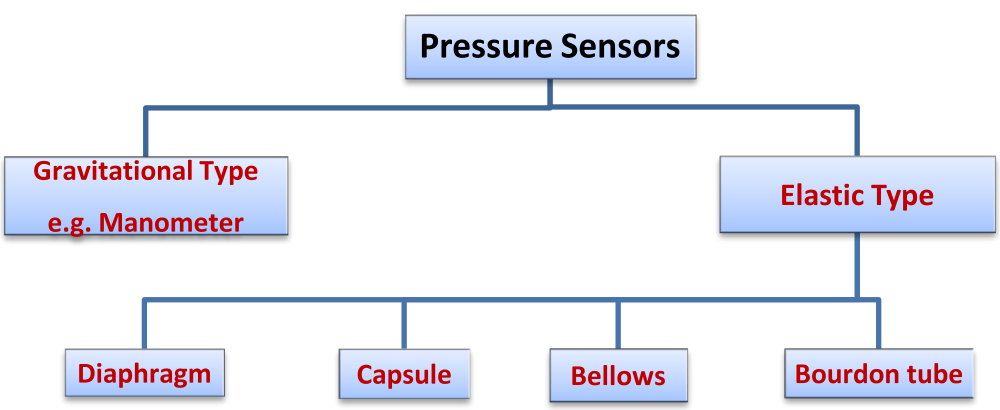
Answer:

Pressure Sensor:

The mechanical pressure sensors are form of elastic elements.

Pressure Sensor: Types

1. Burdon tube
2. Bellows
3. Diaphragm

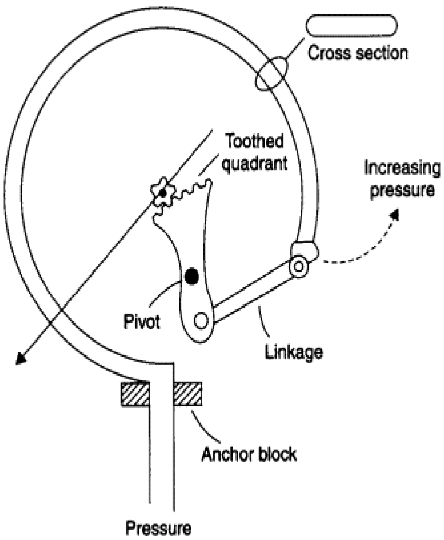


Burdon Tube:

Principle:

The **Bourdon** pressure **gauge** operates on the **principle** that, when pressurized, a flattened **tube** tends to straighten or regain its circular form in cross-section.
When a **gauge** is pressurized, the **Bourdon** creates the dial tip travel to enable pressure measurement

Construction:



Bourdon tube is the most commonly used elastic pressure sensor in mechanical dial gauges. The bourdon tubes are available in C-shape, spiral shape, twisted tube & helical shape.
C-shape tube is used in dial gauges. The C-shape Bourdon tubes are made out of an elliptically flattened tube bent in such a way that produces C shape. One end of tube is sealed and the other end is exposed to pressure.

Working:

When the pressure is applied at open end of Bourdon tube, the tube bends to straighten. This cause the movement of sealed end of tube. This movement is connected to pointer through the mechanical linkage. Thus pointer moves and shows pressure on the calibrated scale.

Advantages:

- Low cost
- Simple construction
- High pressure range
- High accuracy

Disadvantages:

- Susceptible to shock & vibration
- Elasticity of spring reduces gradually due to ageing effect.

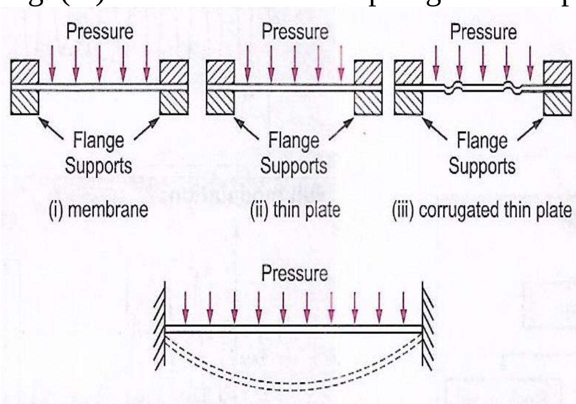
Applications:

- Low as well as high pressure measurement.

Other Pressure Sensors:

#Diaphragm: Construction: Fig. (i), (ii), (iii)

Fig. (iv)Deflection in the diaphragm due to pressure

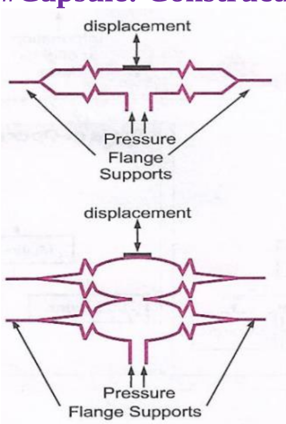


Diaphragms are flexible circular disks either flat or corrugated.

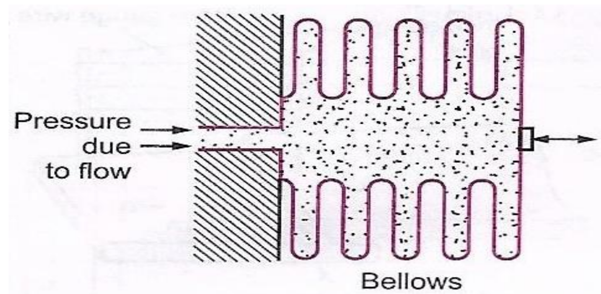
Working:

When pressure is applied the flat diaphragm bends and causes deflection at center. This deflection at centre can be converted into movement of pointer on calibrated scale by using mechanical linkage

#Capsule: Construction:



#Bellows: Construction



Q.14) Explain operation of Biosensor with block diagram.

Answer:

Biosensor:

It is a device which uses living organism or biological molecule (bioreceptor) to detect the presence of chemicals.

Principle:

A specific enzyme (type of bireceptor) or preferred biological molecule is deactivated. The change in properties of biomaterial is related to chemical under detection.

Block diagram of Biosensor:

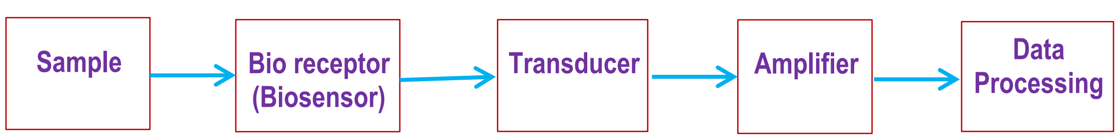


Fig. Block diagram of Biosensor

The block diagram of biosensor consists of,

1. Bioreceptor
2. Transducer
3. Amplifier
4. Data Processing

Explanation:

1. **Bioreceptor:** The bioreceptor is in the vicinity of sample. Depending on the sample and its concentration the properties of bioreceptor changes. The bioreceptor can be enzymes, tissues, microorganisms or chemoreceptors.
2. **Transducer:** The transducer converts one form of signal into another form. In this case the change in properties of bioreceptor is converted into electrical signal.
3. **Amplifier:** The electrical signals produced by the transducer are very weak. Hence the output of transducer is amplified by using amplifier.
4. **Data Processing:** The amplified electrical signal is calibrated against composition and concentration of sample.

Formulae & Problems:

#L.V.D.T.:

$$\mathbf{V_0} = \frac{\mathbf{V_{in}} \cdot \mathbf{d}}{\textbf{Total Travel}}$$

Where,

V_0 – Output voltage

V_{in} – Input supply voltage

d – displacement of core from Centre

Total travel – maximum possible from Centre

Assumption : $V_{in} = V_{secondary}$
that is turns in primary and each secondary are equal

Problem 1: An LVDT has secondary voltage of 6V is having travel span of ± 25mm. Find the output voltage if
(i) Core is 10 mm from center toward S1.
(ii) Core is 15 mm from center toward S2.
(iii) Also find core movement if output voltage is 1 V.

Solution:

Given data:

$V_{in} = V_S = 6\ V$

Total travel span $= \pm 25mm$

(i) $d = 10mm$ towards S_1

(ii) $d = -15mm$ towards S_2

(iii) $V_0 = 1\ V$

(i) $d = 10mm$, **Find V_0 = ?**

$$\mathbf{V_0} = \frac{\mathbf{V_{in}} \cdot \mathbf{d}}{\textbf{Total Travel}} = \frac{6 \cdot (10)}{25}$$

$$\mathbf{V_0} = \mathbf{2.4\ V}$$

(ii) $d = -15mm$, **Find V_0 = ?**

$$\mathbf{V_0} = \frac{\mathbf{V_{in}} \cdot \mathbf{d}}{\textbf{Total Travel}} = \frac{6 \cdot (-15)}{25}$$

$$\mathbf{V_0} = \mathbf{-3.6\ V}$$

(iii) $V_0 = 1\ V$, **Find d =? mm**

$$\mathbf{V_0} = \frac{\mathbf{V_{in}} \cdot \mathbf{d}}{\textbf{Total Travel}}$$

$$1 = \frac{6 \cdot d}{25}$$

$$\mathbf{d = 4.166\ mm\ \ towards\ S_1}$$

#Thermocouple:

$$\mathbf{V_0} = \mathbf{C} \cdot (\mathbf{T_2} - \mathbf{T_1})$$

Where,

V_0 – Output voltage

T_2 – Temperatute of hot junction

T_1 – Temperatute of cold junction

C – Sensitivity

Problem 2: A thermocouple with sensitivity 45 µV/ 0C is inserted in an oven. Its cold junction is at ambient temperature of 25 0C. The output voltage of thermocouple is 45mV. Then what is the temperature of oven.

Solution:

Given data:

$C = 45\mu V / {}^0C$

$T_1 = 25\ {}^0C$

$V_0 = 45mV$

Find $T_2 = ?\ {}^0C$

$$\mathbf{V_0 = C \cdot (T_2 - T_1)}$$

$$45 \text{ x } 10^{-3} = 45 \text{ x } 10^{-6} \cdot (T_2 - 25)$$

$$(T_2 - 25) = \frac{45 \text{ x } 10^{-3}}{45 \text{ x } 10^{-6}} = 1000$$

$$\mathbf{T_2 = 1000 + 25 = 1025\ {}^0C}$$

#RTD:

$$\mathbf{R_T = R_0 \cdot (1 + \alpha_0 \cdot T)}$$

Where,

R_T − Resistance of RTD at T ${}^0C$

R_0 − Resistance of RTD at 0 ${}^0C$

α_0 − Resistance Temperature Coefficient at 0 ${}^0C$

Problem 3: RTD inserted in an oven has resistance 160 Ω. Its resistance at 0 ${}^0C$ is 100 Ω and its Resistance Temperature Coefficient is 0.00392Ω/${}^0C$. Determine temperature T ${}^0C$.

Solution:

Given data:

$R_T = 160\Omega$ at T ${}^0C$

$R_0 = 100\ \Omega$ at 0 ${}^0C$

$\alpha_0 = 0.00392\Omega/{}^0C$

Find T = ? ${}^0C$

$$\mathbf{R_T = R_0 \cdot (1 + \alpha_0 \cdot T)}$$

$$160 = 100 \cdot (1 + 0.00392\ .T)$$

$$0.00392\ T = \left(\frac{160}{100} - 1\right) = 0.6$$

$$\mathbf{T = 153.0612\ {}^0C}$$

#Thermistor:

$$\mathbf{R_T = R_0 \cdot e^{\beta \cdot \left(\frac{1}{T} - \frac{1}{T_0}\right)}}$$

Where,

R_T − Resistance of thermistor at T ${}^0C$

R_0 − Resistance of thermistor at T_0 ${}^0C$

β - Material constant

Problem 4: Thermistor with material constant 100 is placed in an oven, has a resistance 5 kΩ. Its resistance at 25${}^0C$ is 1000 Ω. Determine temperature of oven.

Solution:

Given data:

$R_T = 5k\Omega = 5000\Omega$ at T ^{0}C

$R_0 = 1000\ \Omega$ at $T_0 = 25\ ^0C$

$\beta = 100$

Find T =? ^{0}C

$$R_T = R_0 \cdot e^{\beta \cdot \left(\frac{1}{T} - \frac{1}{T_0}\right)}$$

$$5000 = 1000 \cdot e^{100 \cdot \left(\frac{1}{T} - \frac{1}{25}\right)}$$

$$e^{100 \cdot \left(\frac{1}{T} - \frac{1}{25}\right)} = \frac{5000}{1000} = 0.5$$

$$100 \cdot \left(\frac{1}{T} - \frac{1}{25}\right) = ln\,(0.5)$$

$$\left(\frac{100}{T} - 4\right) = ln\,(0.5) = -0.693$$

$$\frac{100}{T} = 4 - 0.693 = 3.307$$

$$T = \frac{100}{3.307} = 30.24\ ^0C$$

$$\mathbf{T = 30.24\ ^0C}$$

#Strain Gauge:

$$\frac{dR}{R} = (1 + 2\nu)\varepsilon_a = G.F.\,x\,\varepsilon_a = G.F.\,x\,\frac{dl}{l}$$

Where,

dR – change in Resistance

R – Resistance when no stress is applied

ε_a – Axial strain $= \frac{dl}{l}$

v – Possion's ratio

G. F. = Gauge factor = $(1 + 2v)$

Problem 5: A strain gauge with gauge factor of 4 has a resistance 120 Ω when unstrained. If strain gauge undergoes change in length from 0.25 mm to 0.255 mm. Determine new resistance.

Solution:

Given data:

R = 120Ω

G.F. = 4

l = 0.25 mm

dl = 0.255 – 0.25 =0.005 mm

Find R_{new} = R + dR =?

$$\frac{dR}{R} = G.F.\,x\,\frac{dl}{l}$$

$$\frac{dR}{120} = 4\ x\ \frac{0.005}{0.25}$$

$$dR = 120\ x\ 4\ x\ \frac{0.005}{0.25}$$

$$dR = 9.6\Omega$$

$$R_{new} = \mathbf{R + dR} = \mathbf{120 + 9.6}$$

$$R_{new} = \mathbf{129.6\ \Omega}$$