Unit 6: PHYSICS OF SENSORS

Q6.1. Define transducer.

It is defined as a device which receives energy in one form and transmits it in some other form. (for example, electrical, mechanical, etc.)

Q6.2. Define resistive sensors.

Resistive sensors are transducers (receives energy as physical quantity and converts it to change in its resistance) whose resistance varies with various physical quantities like temperature, pressure, displacement etc. The physical quantity can be measured by measuring the resistance change of the resistive transducer.

Q6.3. What is a Resistance Thermometer?

Temperature is one of the most measured quantities. Thermometer is a device that measures temperature. When the temperature of a conductor is changed, it's resistance changes. This Property of a conductor is used for measurement of temperature in a device that is called the resistance thermometer. The properties that a conductor material should possess to be used in such thermometers are:

1. The change in resistance of conductor material per unit change in temperature must be as large as possible.
2. The conductor material must have linear change in resistance with change in temperature.
3. For a smaller size of a given conductor material used, less heat is required to raise its temperature and a faster response can be obtained.

The main component of a resistance thermometer is its sensing element or the conductor material and its characteristics is what determines the sensitivity and operating temperature range of the instrument. Metals like Platinum, Nickel and Copper are most commonly used to measure temperature. The resistivity of platinum tends to increase less rapidly at higher temperatures than for other materials; hence it is a commonly used material for resistance thermometers.

Q6.4. Define Platinum Thin Film Sensor (PT-100) with its construction, working and calibration.

A Resistance thermometer where Platinum is used as a sensing element and has a resistance of 100 Ohms at 0^0C is called PT100 as shown in *Figure 6.4.1*.

Platinum has a high range of stability i.e., 260^0C -1100^0C. An industrial Platinum resistance thermometer is as shown in *Figure 6.4.1*

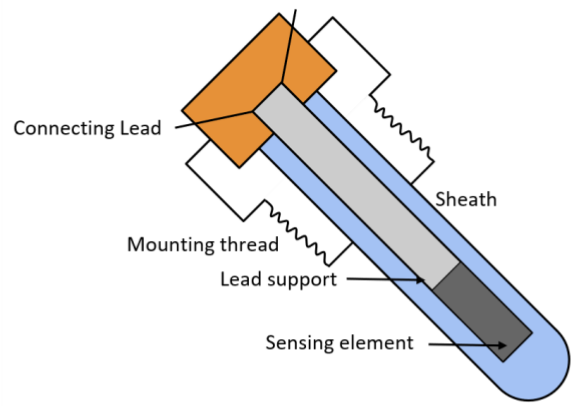

Figure 6.4.1: Construction of PT100

Construction:

1. The external body of the Pt100 sensor is made of a ceramic base also called the sheath.
2. The sensing element is enclosed in this sheath lined by a layer of lead to help sustain mechanical jerks or any chemical reactions.
3. It is placed on a mounting thread which supports the tube.
4. The rear end of the tube has connecting leads which help in connecting the sensor with the Wheatstone circuit.

Working:

1. The Probe or the sensing element (Platinum contained in a bulb) senses the temperature and its resistance (R_s) changes in correspondence to the temperature.
2. When resistance R_s, changes, the Wheatstone's Bridge balance is upset and the galvanometer shows a deflection.
3. This can be calibrated to give a suitable temperature scale.

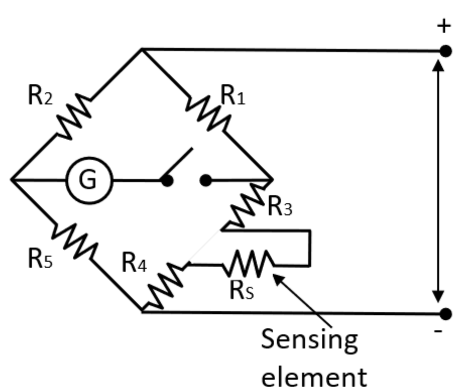

Figure 6.4.2: Working of PT100

4. Thus, change in temperature is detected by a Wheatstone's Bridge as shown in Figure.
5. When the sensing element is very near the bridge as shown in *Figure 6.4.2*, and under balanced conditions, the following relationship holds good.

$$\frac{R_1}{R_2} = \frac{R_s}{R_5}$$

6. In normal practice, the sensing element is away from the bridge and its leads have a resistance, then the relationship can be given as:

$$\frac{R_1}{R_2} = \frac{R_s + R_3 + R_4}{R_5}$$

Q6.5. What are the advantages of thin film resistance thermometers?

Advantages of thin film Resistance Thermometers are

1. The measurement is very accurate.
2. They are cheaper to manufacture
3. The temperature resistance element can be easily installed and replaced.
4. Resistive elements have a wide working range and can be used for temperature ranges (-200°C-650°C) without loss of accuracy.
5. The time of response of the resistive element is short around 2-10 s
6. The size of the resistive element is small and may be about 6-12 mm in diameter.

Q6.6. Explain the principle of resistive Humidity sensors.

- Humidity is the measure of extent of water vapour present in the sensing area.
- The device used to measure humidity is called a hygrometer.

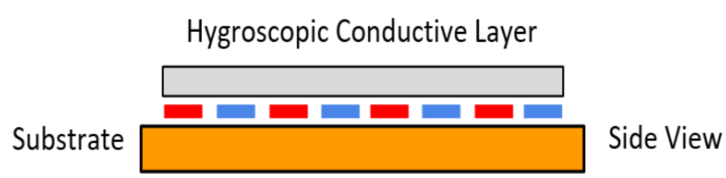

Figure 6.6.1: Hygrometric sensor side view

- A conductive hygrometric sensor is shown in *Figure 6.6.1*. The sensor is made on a ceramic (alumina) base.
- The humidity sensing material is deposited on the top of two electrodes to provide a large contact area. When the relative humidity increases, the resistivity of this material decreases.
- When water molecules are absorbed by this upper layer, resistivity between the electrode's changes, and is measured with the help of an electric circuit.

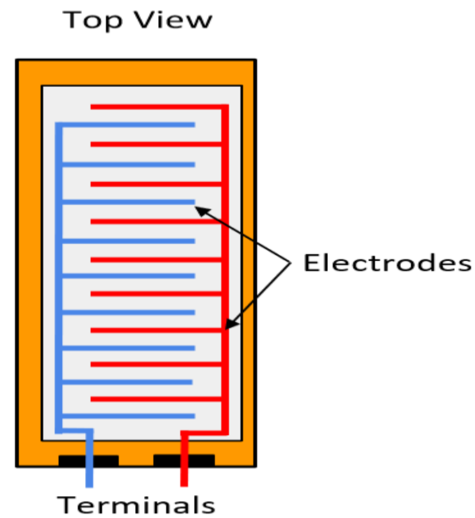

Figure 6.6.2: Hygrometric sensor top view

Q6.7. What is a pressure sensor? Explain the concept of pressure sensing using capacitive method and inductive method.

The sensor or a transducer that can convert applied pressure to a measurable electrical signal is called a pressure transducer or pressure sensor.

Capacitive pressure sensor

Principle: The capacitive pressure sensor is based on the simple formula of capacitance of a parallel plate capacitor. The capacitance of a parallel plate capacitor is directly proportional to the plate area and inversely proportional to the distance between them. Applied pressure changes the distance between two plates of a capacitor and the resultant change in capacitance would be the measure of pressure.

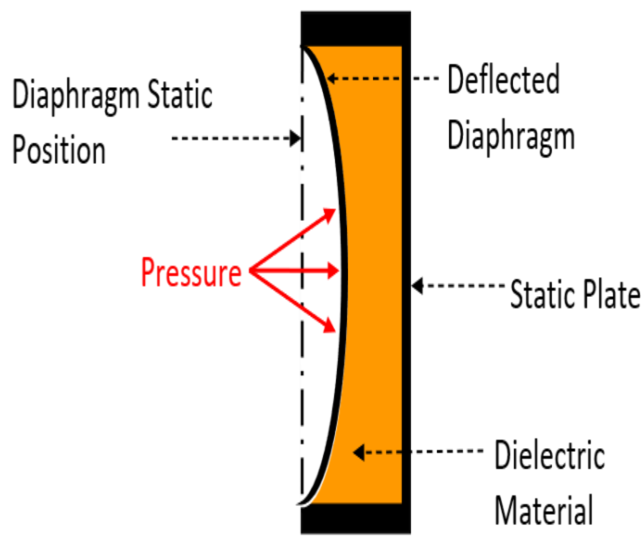

Figure 6.7.1: Capacitive Pressure Sensor

The capacitance formula for a parallel plate capacitor is given as:

$$C = k\frac{A \in_0}{d}$$

Where, 'C' is the capacitance, 'k' is the dielectric constant of the medium between two plates, 'A' is the area of the two plates, 'd' is the distance between the plates and '$\in_0$' is the permittivity of free space.

Inductive pressure sensor

Principle: Inductive pressure sensors are devices where pressure is measured using change in self-inductance of a single coil or mutual inductance between two coils. A magnet is placed at a certain distance from the coil. When pressure is induced on the magnet, the distance between the coil and magnet changes. As the magnet comes closer, EMF is induced in the coil and these values in turn represent the value of pressure applied after conversion.

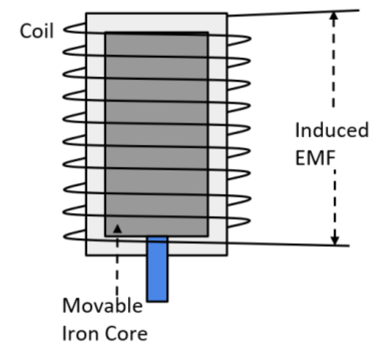

Figure 6.7.2: Inductive Pressure Sensor

Faraday's law: If there is a rate of change of flux with respect to a coil an emf is induced in the coil which is equal to the rate of change of flux.

$$e = -\frac{d\varphi}{dt}$$

Where, electromotive force (emf) is 'e' and flux 'φ'.

Q6.8. What is the piezoelectric effect? Or Explain the principle of Piezoelectric sensors.

Piezoelectric Effect: When two opposite faces of a thin slice of certain crystals are subjected to distortion, opposite charges are developed on the two faces of the slice and magnitude of potential difference produced is directly proportional to the distortion applied as shown in *Figure 6.8.1*. Also, polarity of charges produced is reversed, if the direction of deformation is reversed. Such a phenomenon is called the Piezoelectric effect.

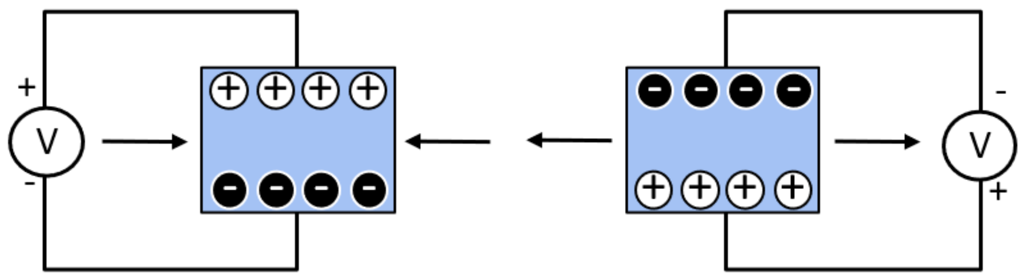

Figure 6.8.1: Piezoelectric Effect

Inverse Piezoelectric Effect: When two opposite faces of a thin slice of certain crystals are subjected to potential difference then, mechanical deformation takes place, such that it is proportional to electric potential. This phenomenon is known as the Inverse Piezoelectric Effect.

Q6.9. Describe the construction and working piezoelectric ultrasonic generator.

Principle: As per inverse piezoelectric effect if alternating voltage is applied across the face of the plate the deformation would be sinusoidal. When the frequency of alternating potential approaches the natural frequency of the crystal plate then deformation approaches resonance condition. At resonance, the amplitude of mechanical vibrations is the maximum.

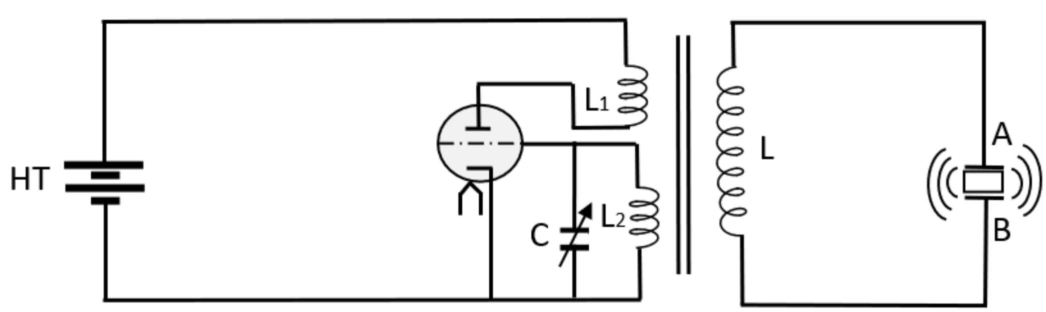

Figure 6.9.1: Piezoelectric Ultrasonic Generator

Construction & Working:

As shown in the *Figure 6.9.1* the plate coil L_1 is inductively coupled to the grid coil L_2, together function like an oscillator. $f = \frac{1}{2\pi\sqrt{L_2 C}}$ is the frequency of the emf that is induced in Land applied to the crystal plate by transformer action on the metallic plates enclosing the crystal. This application of alternating emf results in the deformation of crystal width in accordance with inverse Piezoelectric effect and generation of ultrasonic waves. Whenever the natural frequency of the rod i.e., $\eta = \frac{P}{2L}\sqrt{\frac{Y}{\rho}}$ is equal to applied or induced emf frequency $f = \frac{1}{2\pi\sqrt{L_2 C}}$, the resonance occurs, and amplitude of oscillations is the maximum.

Q6.10. Explain distance measurement by using ultrasonic transducers.

The method of distance measurement using ultrasonic is based on the pulse-echo method. The time taken by the signal to reach the destination and travel back to the trans-receiver after being reflected by the obstacle is measured as 't'. The velocity of ultrasonic waves in air or sea water is found and using the following formula distance is calculated.

$$\text{Distance} = \frac{Time \times Speed\ Of\ Sound}{2}$$

The distance of the object from the transducer is measured as shown in *Figure 6.10.1*.

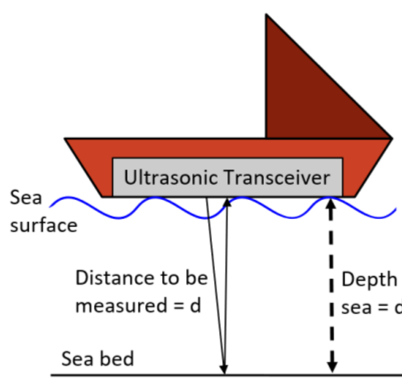

Figure 6.10.1: Distance measurement

Q6.11. Explain measurement of liquid and air velocity using piezoelectric sensors.

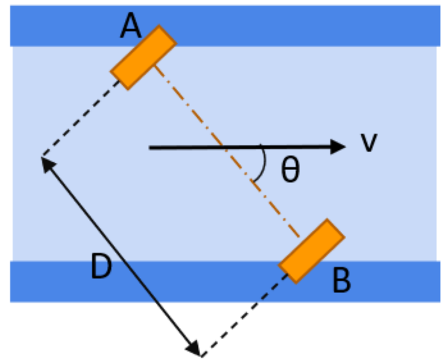

Figure 6.11.1: Measurement Using Piezoelectric sensor

Fluid (Liquid or air) Flow velocity can be measured by employing ultrasonic waves generated by a piezoelectric transducer. The main idea behind the principle is the detection of the increase or decrease in effective ultrasound velocity in the medium. Effective velocity of sound in a moving medium is equal to the velocity of sound relative to the medium plus the velocity of the medium with respect to the source of the sound. Thus, a sound wave propagating upstream will have a smaller effective velocity, while the sound propagating downstream will have a higher effective velocity. *Figure 6.11.1* shows two Piezoelectric ultrasonic generators positioned at a distance 'D' opposite sides of a tube of flow and at an angle 'θ' with the direction of flow. One of them is used for generation of the ultrasonic waves, other for receiving the ultrasonic waves. The transit time of ultrasonic waves between two transducers A and B is measured and noted as 'T', velocity of ultrasonic waves 'c' in the stationary fluid medium is known. Then the velocity of fluid flow 'v' is given by:

$$T = \frac{D}{c + v coscos\,\theta} \quad \text{for downstream flow}$$

$$T = \frac{D}{c - v coscos\,\theta} \quad \text{for upstream flow}$$

Thus, the fluid flow velocity 'v' can be measured.

Q6.12. Write a note on photodiodes.

Photodiodes are semiconducting optical sensors which produce an electric current when light strikes its surface. When light radiation carrying energy equal to the band gap energy of the material strikes, there is an electron-hole pair created. More the intensity of light, greater the number of electron- hole pairs created. This results in the formation of free charge carriers which are responsible for the induced current as shown in *Figure 6.12.1*.

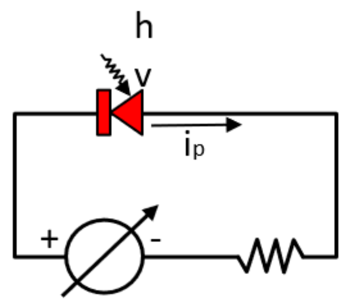

Figure 6.12.1: Photodiode Circuit

Q6.13. Explain pyroelectric effect?

The pyroelectric materials are crystalline substances capable of generating an electrical charge in response to heat flow. Pyroelectric materials are naturally polarized and thus contain large electric fields. The change in temperature causes the position of the atoms of these materials to change. This change in position of the atoms is what causes a voltage to be generated. If the temperature remains constant for a certain while then the pyroelectric effect gradually disappears.

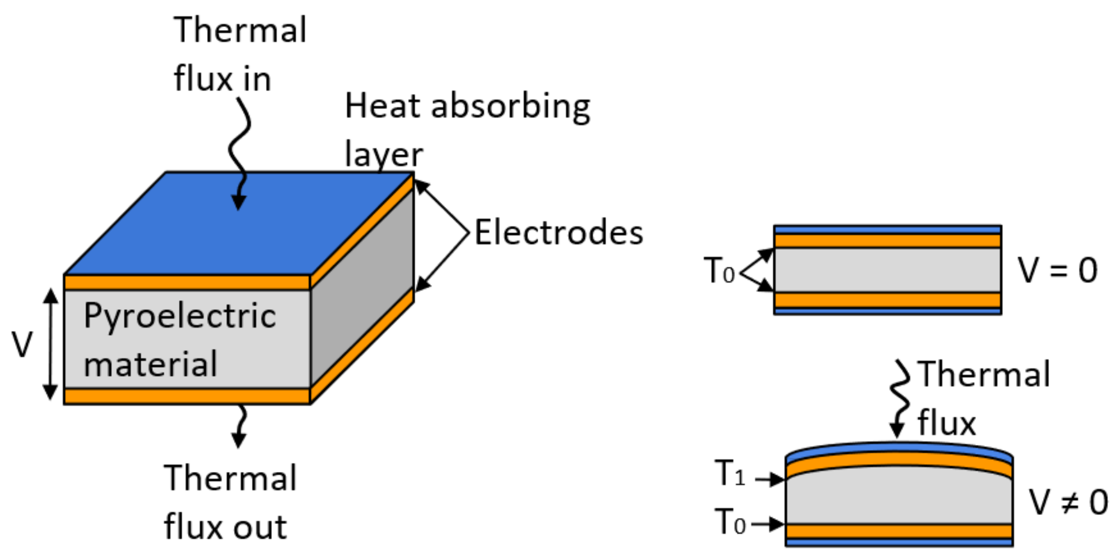

Figure 6.13.1: Pyroelectric effect

Q6.14. Explain working of Pyroelectric sensor

A pyroelectric sensor belongs to a class of PIR detectors. The sensor is only responsive to a change in thermal radiation signal and is based on pyroelectric effect.

Construction:

- The pyroelectric materials are used in the form of thin slices using a single crystal as shown in *Figure 6.14.1*.
- It is essentially a capacitor, which can be electrically charged by variating the temperature.
- It has two electrodes attached to both its sides to collect the electrical charge produced by the pyroelectric effect.
- It needs only an appropriate electronic interface circuit to measure the charge.

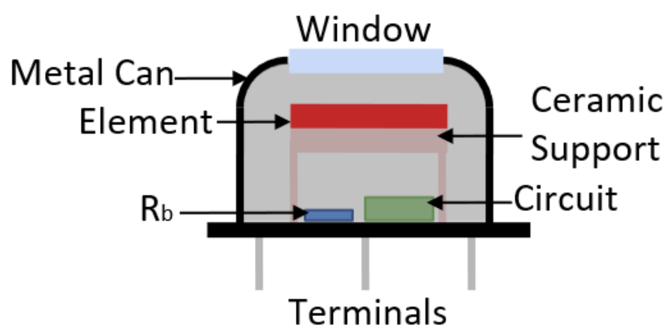

Figure 6.14.1: Construction of Pyroelectric Sensor

Possible Advantages depending on the design

1. Fast sensors detect radiation of high intensity but very short duration
2. Sensitive sensors detect thermal radiation of low intensity

Q6.15. Explain the working of a Bolometer

A Bolometer is a device used to measure the rms value of electromagnetic radiation via the heating of a material with a temperature-dependent electrical resistance.

The operating principle in a bolometer are as follows:

1. An ohmic resistor is exposed to electromagnetic radiation. The radiation is absorbed by the resistor and converted into heat.
2. The heat elevates the resistor's temperature above the ambient.
3. The temperature increase reduces the bolometer’s ohmic resistance.

A basic circuit diagram for the voltage-biased-bolometer application is shown in *Figure 6.15.1*. It consists of a bolometer having resistance R, a stable reference resistor R_0, and a bias voltage source E. The voltage V across R_0 is the output signal and has the highest value when both resistors are equal. The resistance of the bolometer can be represented by a simplified equation: $R = R_0(1 + \alpha\Delta T)$; where ΔT is the temperature change due to a radiation incident on the bolometer.

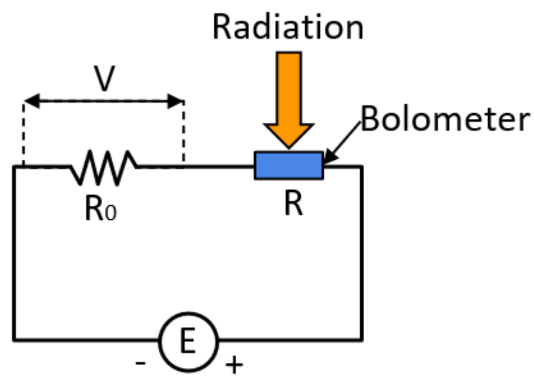

Figure 6.15.1: Working of Bolometer