PHYSICS OF SENSORS

Q1. Define transducer.

A transducer is a device that receives energy in one form and mostly converts it to some other form of energy.

Q2. 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.

Q3. What is a Resistance Thermometer ?

Temperature is the one of the most measured quantity. Thermometer is a device that measures temperature. The resistance of a conductor changes when its temperature is changed. 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 in order to be used in such thermometers are:

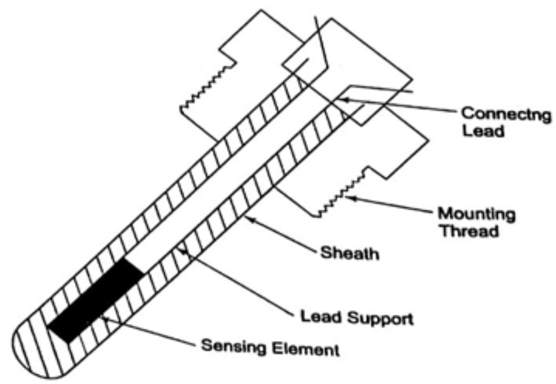
1. The change in resistance of conductor material per unit change in temperature must be as large as possible.
2. The resistance of the conductor material must have a continuous and stable relationship with temperature, that is, neither its resistance nor its temperature coefficient of resistance should undergo permanent change with use or age.
3. The conductor material must have linear change in resistance with change in temperature.
4. For 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. The characteristics of the sensing element, determine the sensitivity and operating temperature range of the instrument. Platinum, Nickel and Copper are the metals 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.

Q4. 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.

The temperature range over which Platinum bar stability is 260^0C -1100 ^{0}C. An industrial Platinum resistance thermometer is as shown in Fig

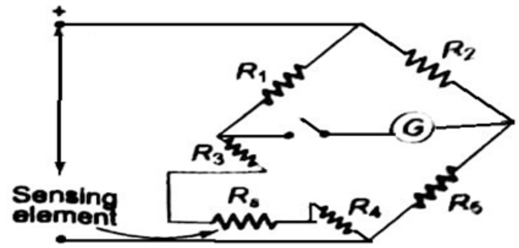


Construction:

1. Platinum thin film sensors are manufactured by a very thin layer of platinum in suitable pattern to achieve smaller dimension and higher resistance, on a ceramic base.
2. Normally, a number of such chips are manufactured on a single large substrate and the chips are properly cut and proper contacts are made.
3. This platinum layer is usually coated with suitable material depending on the operating range to provide protection against mechanical and chemical damages.
4. The advantage of thin film sensors is reduction in the size and simultaneous increase in the nominal resistance. The response time is reduced by nearly 10 times or more because of the reduction in size. The small dimension of thin film platinum sensors allows temperature measurements in very small areas with a much higher accuracy as compared to the thermocouple.
5. By using such a type of sensor, it is possible to manufacture a probe with a stainless steel sheath of 2 mm diameter
6. This sensor probe (Platinum contained in a bulb) is then connected to one leg of the Wheatstone's Bridge.

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, which can be calibrated to give a suitable temperature scale.

3. Thus change in temperature is detected by a Wheatstone's Bridge is shown in Figure.

4. When the sensing element is very near the bridge, and under balanced conditions, the following relationship holds good.

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

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

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

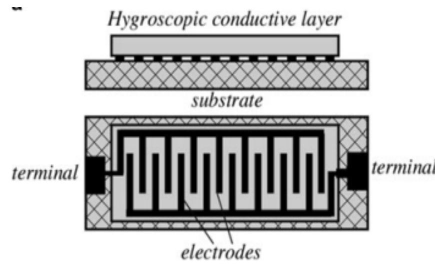
Q5. What are the advantages of thin film resistance thermometers.

Advantages of thin film Resistance Thermometers are

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

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

Humidity is the measure of extent of water vapour present in the sensing area. Resistances of many nonmetal conductors depends on their water content. This phenomenon is the basis of a resistive humidity sensor also called the hygristor or hygrometer. A general concept of a conductive hygrometric sensor is shown in Figure. The sensor is fabricated on a ceramic (alumina) substrate. The moisture-sensing material has relatively low resistivity, which changes significantly under varying humidity conditions. The material is deposited on the top of two interdigitized electrodes to provide a large contact area. When water molecules are absorbed by the upper layer, resistivity between the electrodes changes, which can be measured by an electronic circuit.



Q7. What is a pressure sensor? Explain the concept of pressure sensing using capactive 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.
Pressure sensors are of two types:

1. Analog pressure sensors: The transducer that converts the applied pressure into an analog electrical signal is called analog pressure sensors
2. Digital Pressure sensors: The transducer that is capable of converting applied pressure into a digital signal is called the digital pressure sensor.

Capacitive pressure sensor

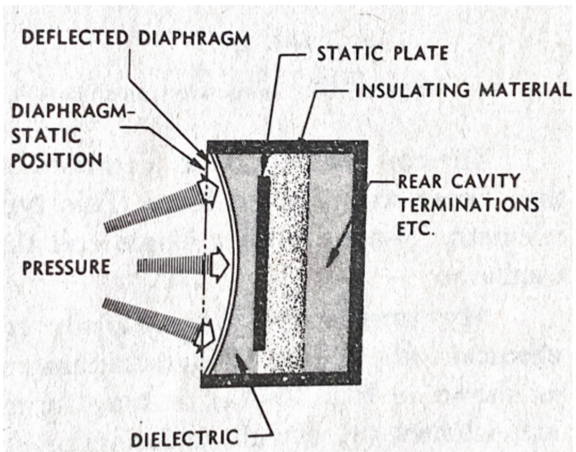
Principle: The capacitive pressure sensor is based on the simple formula of capacitance of a parallel plate capacitor. Applied pressure changes the distance between two plates of a capacitor and the resultant change in capacitance would be the measure of pressure.

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.

Construction and Working:



The capacitance of a parallel plate capacitor is directly proportional to the plate area and inversely proportional to the distance between them. One of the plates of a capacitor is made into a diaphragm as shown in the figure and other is kept static. The diaphragm is subjected to pressure which is to be measure. After application of pressure the diaphragm is displaced from its static position resulting into change in interpolate distance 'd' of the capacitor. The amount of displacement is the measure of pressure and can be measured as change in capacitance of the capacitor.

Inductive pressure sensor

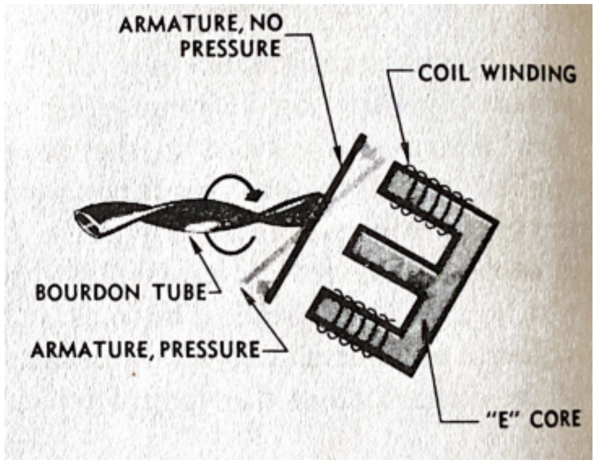
Principle: Inductive pressure sensor are devices where pressure is measured using change in self-inductance of a single coil or mutual inductance between two coils.

Faradays law: If there is rate of change of flux with respect to a coil and 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'.

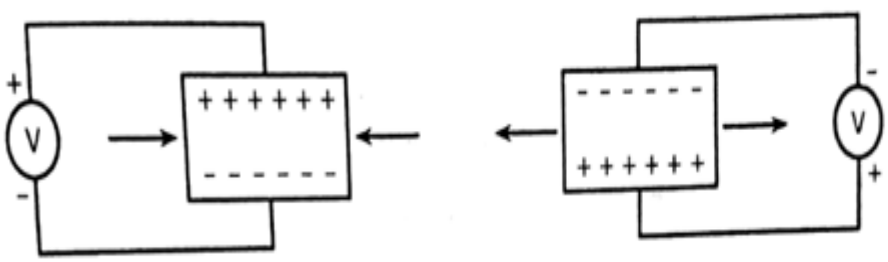
Construction and Working:



A coil and a magnetic material are placed adjacent to each other with a certain air gap between them as shown in the figure. The magnetic material acts as a diaphragm that can be moved such that the air gap changes and because of this movement there is rate of change of flux with respect to coil and as per the faraday's law an emf is induced in the coil. This induced emf is measure of displacement of the magnetic material and displacement in turn is measurement of the pressure applied on the material.

Q8. What is piezoelectric effect? Or Explain the principle of Piezoelectric sensors.

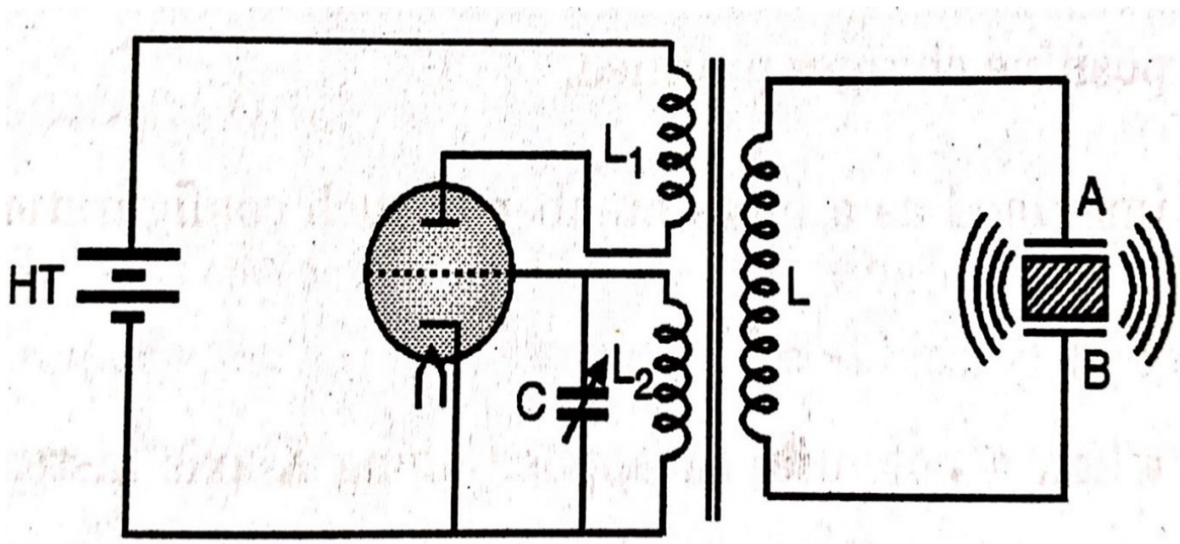
Piezoelectric Effect: When two opposite faces of a thin slice of certain crystals are subjected to distortion, opposite charges are developed on the two faces of the slice and magnitude of potential difference produced is directly proportional to the distortion applied. Also, polarity of charges produced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

Q9. Describe the construction and working piezoelectric ultrasonic generator.

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



Construction & Working:

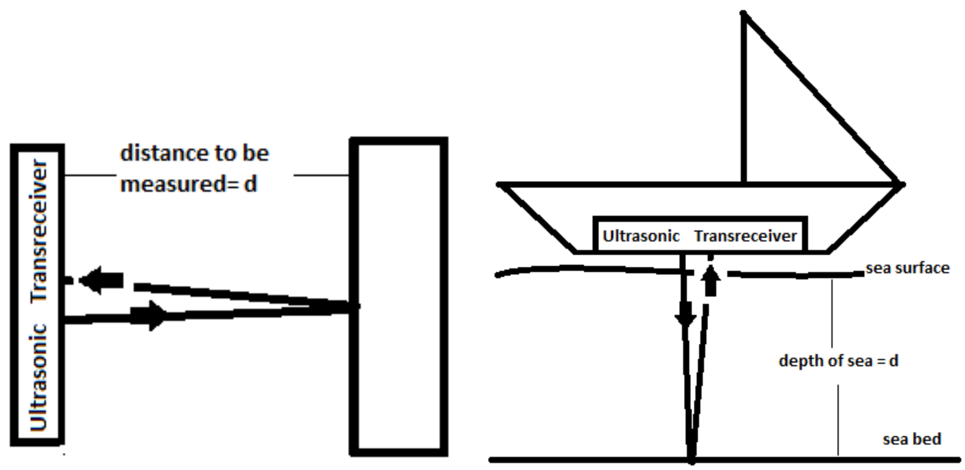
As shown in the figure the plate coil L_1 is inductively coupled to the grid coil L_2, together function like an oscillator. f = $\frac{1}{2\pi\sqrt{L_2C}}$ is the frequency of the emf that is induced in L and applied to the crystal plate by transformer action on the metallic plates enclosing the crystal. 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 = $\frac{1}{2\pi\sqrt{L_2C}}$, the resonance occurs, and amplitude of oscillations is the maximum.

Q10. 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.

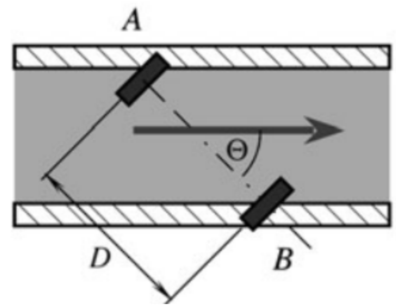
$$\text{Distance}=\frac{Time \times Speed\ of\ sound}{2}$$

the distance of the object from the transducer is measured



Q13. Explain measurement of liquid and air velocity 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 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:



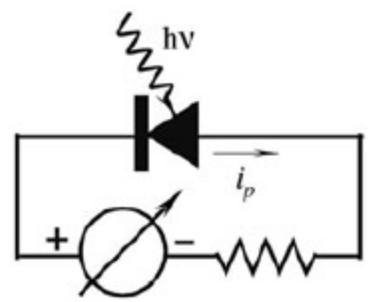
$$T = \frac{D}{c+v\cos\theta} \quad \text{for downstream flow}$$

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

Thus the fluid flow velocity ‘v’ can be measured.

Q11. Write a note on photodiode.

Photodiodes are semiconducting optical sensors. If the junction is reverse biased as shown in figure, when light strikes the semiconductor, the current will increase quite noticeably. Impinging photons create electron– hole pairs on both sides of the junction. When electrons enter the conduction band, they start flowing toward the positive side of the battery. Correspondingly, the created holes flow to the negative terminal, meaning that photocurrent ‘Ip’ flows in the network. Under dark conditions, dark current ‘Io’ is independent of applied voltage and mainly is the result of thermal generation of charge carriers.



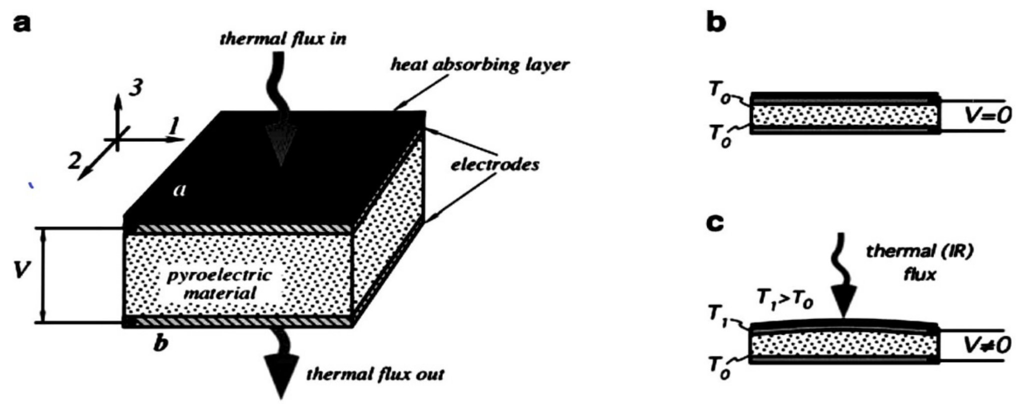
Q12. Explain pyroelectric effect

The pyroelectric materials are crystalline substances capable of generating an electrical charge in response to heat flow. The pyroelectric materials are used in form of thin slices or films with electrodes deposited on the opposite sides to collect the thermally induced charges as shown in the figure. The pyroelectric sensor is essentially a capacitor, which can be electrically charged by flux of heat. The detector does not require any external electrical bias (excitation signal), thus it is a direct converter of heat into electricity. It needs only an appropriate electronic interface circuit to measure the charge.

(a)Pyroelectric sensor has two electrodes at the opposite sides of the crystal.

(b)Pyroelectric sensor in a neutral state;

(c) heat expands the upper layer, resulting in a piezoelectric charge



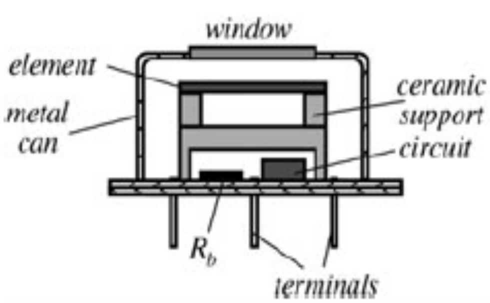
Hand book of modern sensors By Jacob Fraden

Q13. 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 element consists of three essential components: The pyroelectric ceramic plate and two electrodes deposited
on the opposite sides of the plate. The plate is supported inside the sensor's housing with as little contact area with the housing can as possible.
All pyroelectrics are also piezoelectrics; therefore, while being sensitive to thermal radiation, the pyroelectric sensors are susceptible to mechanical stress and vibrations For better noise rejection, the crystalline element must be mechanically decoupled from the outside, especially from the terminals and the metal can. Hence the inner space of the can is filled with dry air or nitrogen. A typical construction of a pyroelectric sensor is shown in Figure



Pyroelectric sensor is connected to a current to voltage converter such that induced pyroelectric current I_p is converted to output voltage that can be measure using ohm's Law (R_b = the bias resistance)

$$V_{out} = I_p * R_b$$

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

Q14. Explain the working of a Bolometer

Bolometers are miniature RTDs or thermistors or other temperature sensitive resistors that are mainly used for measuring rms values of electromagnetic radiation over a very broad spectral range from mid infrared to microwaves.

The operating principle is based on a fundamental relationship between the absorbed electromagnetic signal. The conversion steps 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 resistor's temperature above the ambient.
3. The temperature increase reduces the bolometer's ohmic resistance.

A basic circuit for the voltage-biased-bolometer application is shown in Fig. It consists of a bolometer (a temperature-sensitive resistor) 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 of the circuit. It has the highest value when both resistors are equal. The resistance of RTD bolometer can be represented by a simplified $R = R_0(1 + \alpha\Delta T)$; ΔT is the temperature change due to radiation incident on the bolometer.