JAWAHARLAL NEHRU TECHNOLOGICAL UNIVERSITY ANANTAPUR

B.Tech IV-I Sem L T P C

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(20A04704) ELECTRONIC SENSORS

(Open Elective Course –III)

Course Objectives:

- Learn the characterization of sensors
- Known the working of Electromechanical, Thermal, Magnetic and radiation sensors
- Understand the concepts of Electro analytic and smart sensors
- Able to use sensors in different applications

Course Outcomes:

- Learn about sensor Principle, Classification and Characterization.
- Explore the working of Electromechanical, Thermal, Magnetic, radiation and Electro analytic
- Sensors understand the basic concepts of Smart Sensors
- Design a system with sensors.

UNIT I

Sensors / Transducers: Principles, Classification, Parameters, Characteristics, Environmental Parameters (EP), Characterization Electromechanical Sensors: Introduction, Resistive Potentiometer, Strain Gauge, Resistance Strain Gauge, Semiconductor Strain Gauges -Inductive Sensors: Sensitivity and Linearity of the Sensor – Types-Capacitive Sensors: Electrostatic Transducer, Force/Stress Sensors Using Quartz Resonators, Ultrasonic Sensors

UNIT II

Thermal Sensors: Introduction, Gas thermometric Sensors, Thermal Expansion Type Thermometric Sensors, Acoustic Temperature Sensor ,Dielectric Constant and Refractive Index thermo sensors, Helium Low Temperature Thermometer ,Nuclear Thermometer ,Magnetic Thermometer ,Resistance Change Type Thermometric Sensors, Thermo emf Sensors, Junction Semiconductor Types, Thermal Radiation Sensors, Quartz Crystal Thermoelectric Sensors, NQR Thermometry, Spectroscopic Thermometry, Noise Thermometry, Heat Flux Sensors

UNIT III

Magnetic sensors: Introduction, Sensors and the Principles Behind, Magneto-resistive Sensors, Anisotropic Magneto resistive Sensing, Semiconductor Magneto resistors, Hall Effect and Sensors, Inductance and Eddy Current Sensors, Angular/Rotary Movement Transducers, Synchros.

UNIT IV

Radiation Sensors: Introduction, Basic Characteristics, Types of Photo resistors/ Photo detectors, Xray and Nuclear Radiation Sensors, Fibre Optic Sensors Electro analytical Sensors: The Electrochemical Cell, The Cell Potential - Standard Hydrogen Electrode (SHE), Liquid

Junction and Other Potentials, Polarization, Concentration Polarization, Reference Electrodes, Sensor Electrodes, Electro ceramics in Gas Media.

UNIT V

Smart Sensors: Introduction, Primary Sensors, Excitation, Amplification, Filters, Converters, Compensation, Information Coding/Processing - Data Communication, Standards for Smart Sensor Interface, the Automation Sensors –Applications: Introduction, On-board Automobile Sensors (Automotive Sensors), Home Appliance Sensors, Aerospace Sensors, Sensors for Manufacturing – Sensors for environmental Monitoring

Textbooks:

1. “Sensors and Transducers - D. Patranabis” –PHI Learning Private Limited., 2003.

2. Introduction to sensors- John veteline, aravindraghu, CRC press, 2011

References:

1. Sensors and Actuators, D. Patranabis, 2nd Ed., PHI, 2013.

2. Make sensors: Terokarvinen, kemo, karvinen and villeyvaltokari, 1st edition, maker media,2014.

3. Sensors handbook- Sabriesoloman, 2nd Ed. TMH, 2009

UNIT- 1

Sensors/Transducers: Principles, Classification, Parameters, Characteristics, Environmental Parameters (EP), Characterization. Electromechanical Sensors: Introduction, Resistive Potentiometer, Strain Gauge, Resistance Strain Gauge, Semiconductor Strain Gauges -Inductive Sensors: Sensitivity and Linearity of the Sensor –Types-Capacitive Sensors: Electrostatic Transducer, Force/Stress Sensors Using Quartz Resonators, Ultrasonic Sensors

1.1 Introduction & Definitions

Measurement is an important subsystem in any major system, whether it may be a mechanical system or an electronic system. A measurement system consists of sensors, actuators, transducers and signal processing devices. The use of these elements and devices is not limited to measuring systems. These are also used in the systems which perform specific tasks, to communicate with the real world. The communication can be anything like reading the status of a signal from a switch or to trigger a particular output to light up an LED.

Sensor and Transducer Definitions

The words sensors and transducers are widely used in association with measurement systems. The sensor is an element that produces signals relating to the quantity that is being measured. According to Instrument Society of America, "a sensor is a device that provides usable output in response to a specified quantity which is measured.". In simple terms, a sensor is a device that detects changes and events in a physical stimulus and provides a corresponding output signal that can be measured and/or recorded. Here, the output signal can be any measurable signal and is generally an electrical quantity.

Actuators are devices that work opposite to sensors. A sensor converts a physical event into an electrical signal, whereas an actuator converts electrical signal into a physical event. When sensors are used at input of a system, actuators are used to perform output function in a system as they control an external device. Transducers are the devices that convert energy in one form into another form. Generally, the energy is in the form of a signal. Transducer is a term collectively used for both sensors and actuators.

1.2 Parameters to Choose a Sensor

The following are certain features that are considered when choosing a sensor.

1. Type of Sensing: The parameter that is being sensed like temperature or pressure.

2. Operating Principle: The principle of operation of the sensor.

3. Power Consumption: The power consumed by the sensor will play an important role in defining the total power of the system.

4. Accuracy: The accuracy of the sensor is a key factor in selecting a sensor.

5. Environmental Conditions: The conditions in which the sensor is being used will be a factor in choosing the quality of a sensor.

6. Cost: Depending on the cost of application, a low-cost sensor or high cost sensor can be used.

7. Resolution and Range: The smallest value that can be sensed and the limit of measurement are important.

8. Calibration and Repeatability: Change of values with time and ability to repeat measurements under similar conditions.

1.3 Basic Characteristics of a Sensor or Transducer

The basic characteristics of a sensor are:

1. Range: It indicates the limits of the input in which it can vary. In case of temperature measurement, a thermocouple can have a range of 25 – 250 0C.

2. Accuracy: It is the degree of exactness between actual measurement and true value. Accuracy is expressed as percentage of full range output.

3. Sensitivity: Sensitivity is a relationship between input physical signal and output electrical signal. It is the ratio of change in output of the sensor to unit change in input value that causes change in output.

4. Stability: It is the ability of the sensor to produce the same output for constant input over a period of time.

5. Repeatability: It is the ability of the sensor to produce same output for different applications with same input value.

6. Response Time: It is the speed of change in output on a stepwise change in input.

7. Linearity: It is specified in terms of percentage of nonlinearity. Nonlinearity is an indication of deviation of curve of actual measurement from the curve of ideal measurement.

8. Ruggedness: It is a measure of the durability when the sensor is used under extreme operating conditions.

9. Hysteresis: The hysteresis is defined as the maximum difference in output at any measurable value within the sensor's specified range when approaching the point first with increasing and then with decreasing the input parameter. Hysteresis is a characteristic that a transducer has in

being unable to repeat its functionality faithfully when used in the opposite direction of operation.

1.4 Classification of Sensors

The scheme of classifying sensors can range from very simple to very complex. The stimulus that is being sensed is an important factor in this classification. Some of the stimuli are

1. Acoustic: Wave, spectrum and wave velocity.
2. Electric: Current, charge, potential, electric field, permittivity and conductivity.
3. Magnetic: Magnetic field, magnetic flux and permeability.
4. Thermal: Temperature, specific heat and thermal conductivity.
5. Mechanical: Position, acceleration, force, pressure, stress, strain, mass, density, momentum, torque, shape, orientation, roughness, stiffness, compliance, crystallinity and structural.
6. Optical: Wave, wave velocity, refractive index, reflectivity, absorption and emissivity.

The sensors conversion phenomenon is also an important factor in classification of sensors. Some of the conversion phenomena are magneto electric, thermoelectric and photoelectric. Based on the applications of sensors, their classification can be made as follows.

(A) Displacement, Position and Proximity Sensors

1. Resistive Element or Potentiometer
2. Capacitive Elements
3. Strain Gauged Element
4. Inductive Proximity Sensors
5. Eddy Current Proximity Sensors
6. Differential Transformers
7. Optical Encoders
8. Hall Effect Sensors
9. Pneumatic Sensors
10. Proximity Switches
11. Rotary Encoders

(B) Temperature Sensors

1. Thermistors
2. Thermocouple
3. Bimetallic Strips
4. Resistance Temperature Detectors
5. Thermostat

(C) Light Sensors

1. Photo Diode
2. Phototransistor
3. Light Dependent Resistor

(D) Velocity and Motion

1. Pyroelectric Sensors
2. Tachogenerator
3. Incremental encoder

(E) Fluid Pressure

1. Diaphragm Pressure Gauge
2. Tactile Sensor
3. Piezoelectric Sensors
4. Capsules, Bellows, Pressure Tubes

(F) Liquid Flow and Level

1. Turbine Meter
2. Orifice Plate and Venturi Tube

(G) IR Sensor

1. Infrared Transmitter and Receiver Pair

(H) Force

1. Strain Gauge
2. Load Cell

(I) Touch Sensors

1. Resistive Touch Sensor
2. Capacitive Touch Sensors

(J) UV Sensors

1. Ultraviolet Light Detector
2. Photo Stability Sensors
3. UV Photo Tubes
4. Germicidal UV Detectors

All the sensors can be classified into two types based on the power or signal requirement. They are Active sensors and passive sensors.

Commonly used Sensors and Transducers

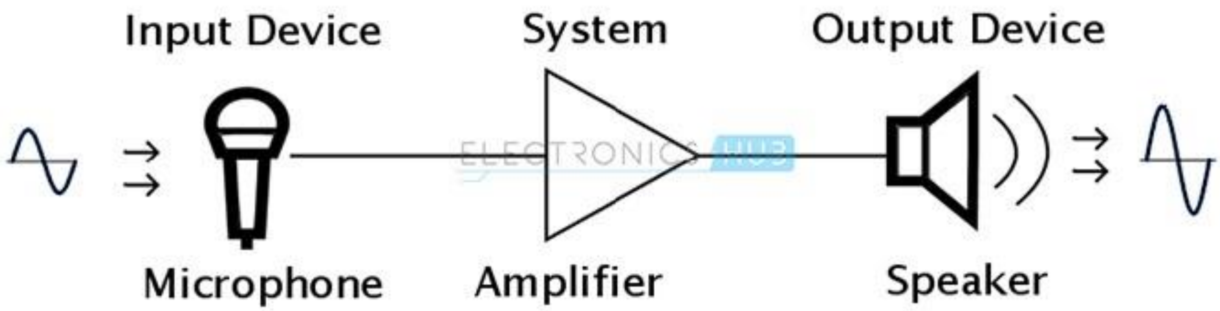
Some of the most used sensors and transducers for different stimuli (the quantity to be measured) are

1. For sensing light, the input devices or sensors are photo diode, photo transistor, light dependent resistor and solar cells. The output devices or actuators are LEDs, displays, lamps and fiber optics.
2. For sensing temperature, the sensors are thermistor, thermocouple, resistance temperature detectors and thermostat. The actuators are heaters.
3. For sensing position, the input devices are potentiometer, proximity sensor, and differential transformer. The output devices are motor and panel meter.
4. For sensing pressure, the sensors are strain gauge and load cell. The actuators are lifts and jacks and electromagnetic vibrations.

5. For sensing sound, the input devices are microphones and output devices are loudspeakers and buzzers.
6. For sensing speed, the sensors used are tachogenerator and Doppler Effect sensors. The actuators are motors and brakes.

A Simple System using Transducers

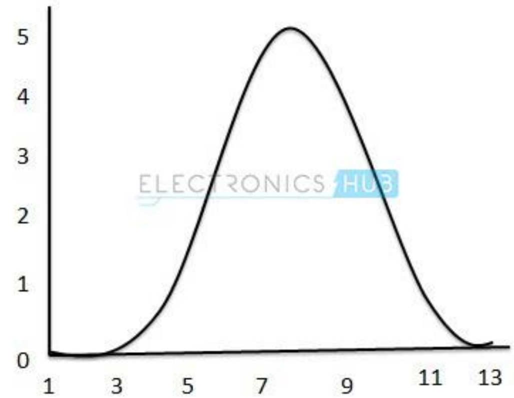
A public addressing system is an example of a system using sensors and actuators.



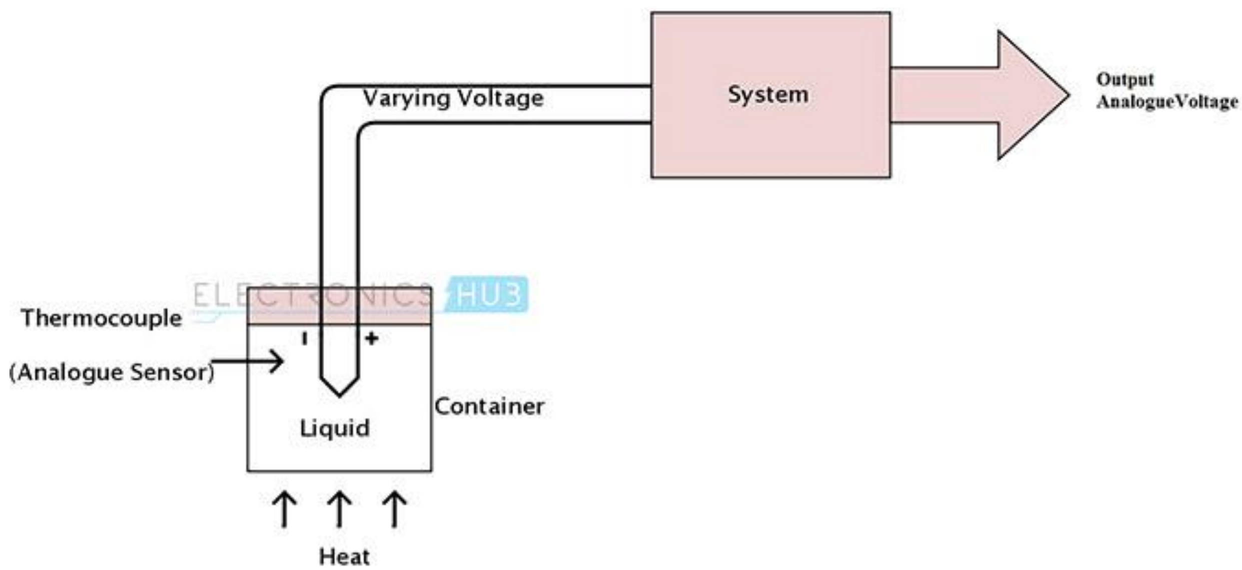
It consists of a microphone, an amplifier and a loudspeaker. The sensor or the device with input function is a microphone. It senses the sound signals and transforms them into electrical signals. The amplifier receives these electrical signals and amplifies their strength. The actuator or the device with output function is loudspeaker. It receives the amplified electrical signals from the amplifier and converts them back into sound signals but with more reach.

Analogue Sensors

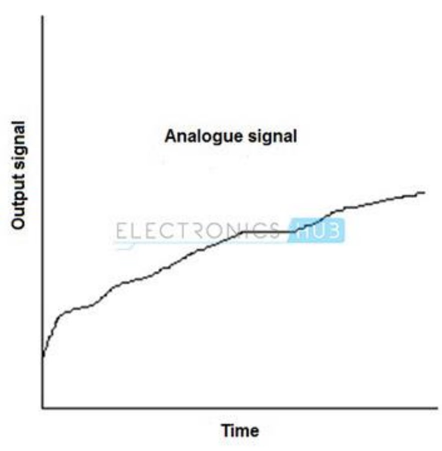
An analogue sensor produces continuously varying output signals over a range of values. Usually the output signal is voltage and this output signal is proportional to the measurand. The quantity that is being measured like speed, temperature, pressure, strain, etc. are all continuous in nature and hence they are analogue quantities. A Cadmium Sulfide Cell (CdS Cell) which is used to measure the intensity of light is an analogue sensor. The resistance of a CdS cell varies according to the intensity of the light incident on it. When connected to a voltage divider network, the change in resistance can be observed through varying output voltage. In this circuit, the output can vary from anywhere between 0 V to 5 V.



A thermocouple or a thermometer is an analog sensor. The following setup is used to measure the temperature of the liquid in the container using a thermocouple.



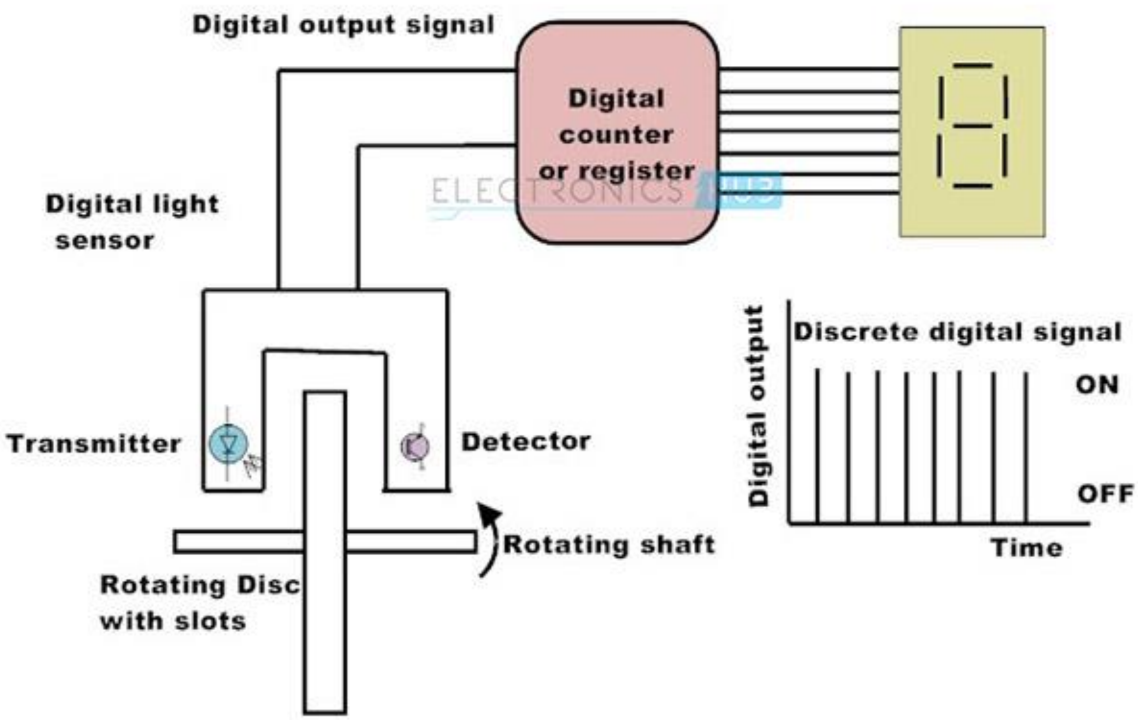
The output signal of the above setup can be depicted as follows:



The output of an analogue sensor tends to change smoothly and continuously over time. Hence the response time and accuracy of circuits employing analogue sensors is slow and less. In order to use these signals in a microcontroller-based system, Analog to Digital converters can be used. Analogue sensors generally require an external power supply and amplification of some form to produce appropriate output signals. Op Amps are very useful in providing amplification and filtering.

Digital Sensors

A digital sensor produces discrete digital signals. The output of a digital sensor has only two states, namely ‘ON’ and ‘OFF’. ON is logic 1 and OFF is logic 0. A push button switch is the best example of a digital sensor. In this case, the switch has only two possible states: either it is ON when pushed or it is OFF when released or not pushed. The following setup uses a light sensor to measure the speed and produces a digital signal.



In the above setup, the rotating disc is connected to the shaft of a motor and has number of transparent slots. The light sensor captures the presence or absence of the light and sends logic 1 or logic 0 signal accordingly to the counter. The counter displays the speed of the disc. The accuracy can be increased by increasing the transparent slots on the disc as it allows more counts over the same amount of time. In general, the accuracy of a digital sensor is high when compared to an analogue sensor. The accuracy depends on the number of bits that are used to represent the measure and. Higher the number of bits, the greater is the accuracy.

1.5 Introduction to Electromechanical Sensors

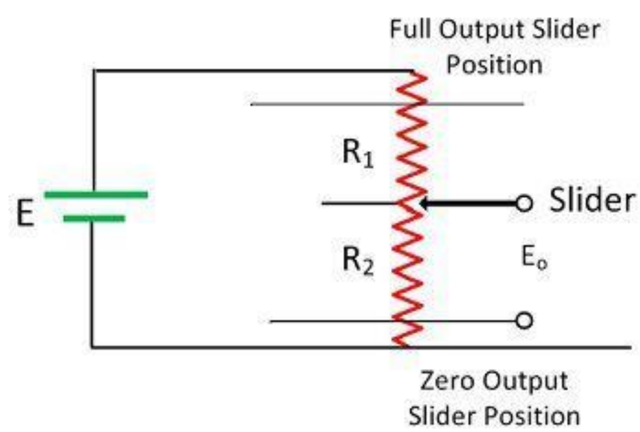
Electromechanical sensor transforms mechanical stimulus into electrical signals. The main electromechanical sensors are strain and pressure sensors, which correspond to two main mechanical stimuli. According to their mechanisms, resistive and capacitive sensor attracts more attentions due to their simple structures, mechanisms, preparation method, and low cost. Various kinds of nanomaterials have been developed to fabricate them, including carbon nanomaterials, metallic, and conductive polymers. They have great potentials on health monitoring, human motion monitoring, speech recognition, and related human-machine interface applications.

1.6 Resistive Potentiometer or Transducer

The transducer whose resistance varies because of the environmental effects such type of transducer is known as the resistive transducer. The change in resistance is measured by the ac or dc measuring devices. The resistive transducer is used for measuring the physical quantities like temperature, displacement, vibration etc.

The measurement of the physical quantity is quite difficult. The resistive transducer converts the physical quantities into variable resistance which is easily measured by the meters. The resistive transducer can work both as the primary as well as the secondary transducer. The primary transducer changes the physical quantities into a mechanical signal, and secondary transducer directly transforms it into an electrical signal.

Example – The circuit of the sliding resistive transducer is shown in the figure below. The sliding contacts are placed on the resistive element. The slider moves horizontally. The movement of the slider changes the value of the resistive element of the transducer which is measured by the voltage source E.



Sliding Resistive Transducer

The displacement of the slider is converted into an electrical signal.

Advantages of Resistive Transducer

The following are the advantages of the resistive transducer.

1. Both the AC and DC, current or voltage is appropriate for the measurement of variable resistance.

2. The resistive transducer gives the fast response.

3. It is available in various sizes and having a high range of resistance.

Working Principle of Resistive Transducer

The resistive transducer element works on the principle that the resistance of the element is directly proportional to the length of the conductor and inversely proportional to the area of the conductor

$$R = \rho L/A$$

.

Where

R – resistance in ohms.

A – cross-section area of the conductor in meter square.

L – Length of the conductor in meter square.

ρ – the resistivity of the conductor in materials in ohm meter.

The resistive transducer is designed by considering the variation of the length, area and resistivity of the metal.

Applications of Resistive Transducer

The following are the applications of the resistive transducer.

1. Potentiometer – The translation and rotatory potentiometer are the examples of the resistive transducers. The resistance of their conductor varies with the variation in their lengths which is used for the measurement of displacement.

2. Strain gauges – 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.

3. Resistance Thermometer – The resistance of the metals changes because of changes in temperature. This property of conductor is used for measuring the temperature.

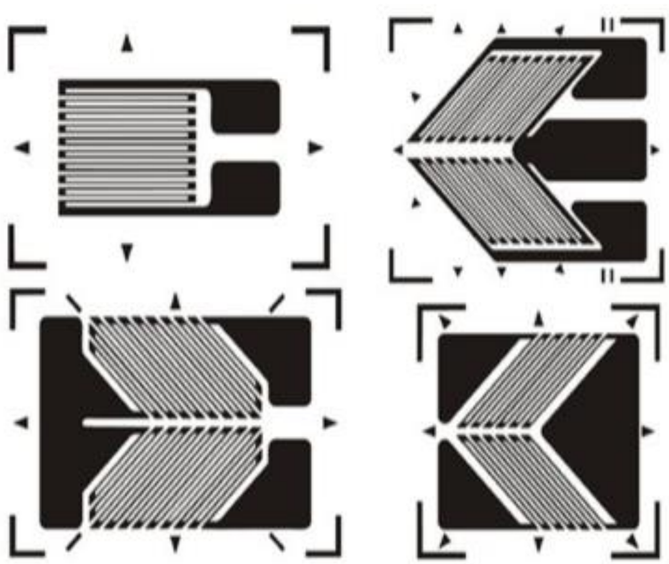
4. Thermistor – It works on the principle that the temperature coefficient of the thermistor material varies with the temperature. The thermistor has the negative temperature coefficient. The Negative temperature coefficient means the temperature is inversely proportional to resistance.

1.7 Strain Gauge

A strain gauge is a type of electrical sensor. Its primary use is to measure force or strain.

The resistance of a strain gauge changes when force is applied, and this change will give a different electrical output. Strain gauges use this method to measure pressure, force, weight and tension.

When external forces are applied to a stationary object there are two forces present: stress and strain. Stress is the resisting force of the object (like a push back) strain is the displacement and deformation of the object and this is the force which can be measured by a strain gauge. Because they are small and highly sensitive strain gauges can measure the contraction or expansion of an object even if it is just a small amount when they are correctly bonded to an object or device.



Strain gauges are very thin and come in a wide range of shapes and sizes making them suitable for a variety of applications.

The Function of a Strain Gauge

A strain gauge is used as a precautionary measure in many testing applications. Usually, when a strain gauge gives a certain reading an alert will be triggered to inform the user that the capacity has been reached, this means that the issue can be addressed before it becomes dangerous.

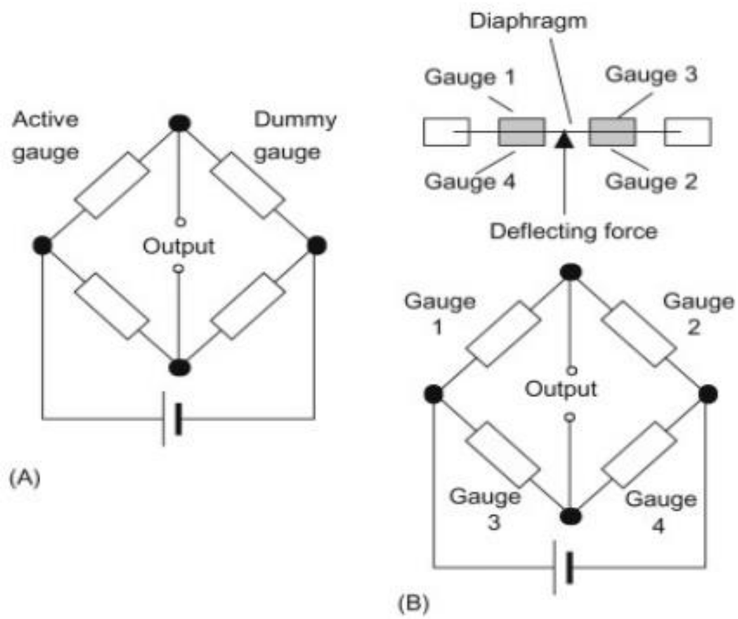
Strain gauge applications

Strain gauge technology has a huge amount of uses - almost unlimited. Strain gauges are a fundamental sensing element and are used within many different types of sensors. They are well used in industries such as; rail, aerospace, mechanical engineering and research and development. Some of the applications they have been used for including.

- Stress on railway lines
- Stresses on aircraft wing deflection
- Aircraft component testing
- Rotational strain on turbines, wheels, fans, propellers and motors
- Testing ships hulls
- Testing structural components for bridges and buildings
- Automotive testing

1.8 Resistance Strain Gauge

The electrical resistance strain gauge is a resistance element which changes resistance when subject to strain. However, it will also change resistance when subject to a temperature change. Thus, in order to use it to determine strain, compensation has to be made for temperature effects. One way of eliminating the temperature effect is to use a dummy strain gauge. This is a strain gauge identical to the one under strain, the active gauge, which is mounted on the same material as the active gauge but not subject to the strain. It is positioned close to the active gauge so that it suffers the same temperature changes. As a result, a temperature change will cause both gauges to change resistance by the same amount. The active gauge is mounted in one arm of a Wheatstone bridge and the dummy gauge in an opposite arm so that the effects of temperature-induced resistance changes cancel out.



Strain gauges are often used with other sensors such as diaphragm pressure gauges or load cells. Temperature compensation is still required. While dummy gauges could be used, a better solution is to use four strain gauges with two of them attached so that the applied forces put them in tension and the other two in compression. The gauges that are in tension, gauges 1 and 3, will increase in resistance while those in compression, gauges 2 and 4, will decrease in resistance. The gauges are connected as the four arms of a Wheatstone bridge As all the gauges and so all the arms of the bridge will be equally affected by any temperature changes the arrangement is temperature compensated. The arrangement also gives a much greater output voltage than would occur with just a single active gauge.

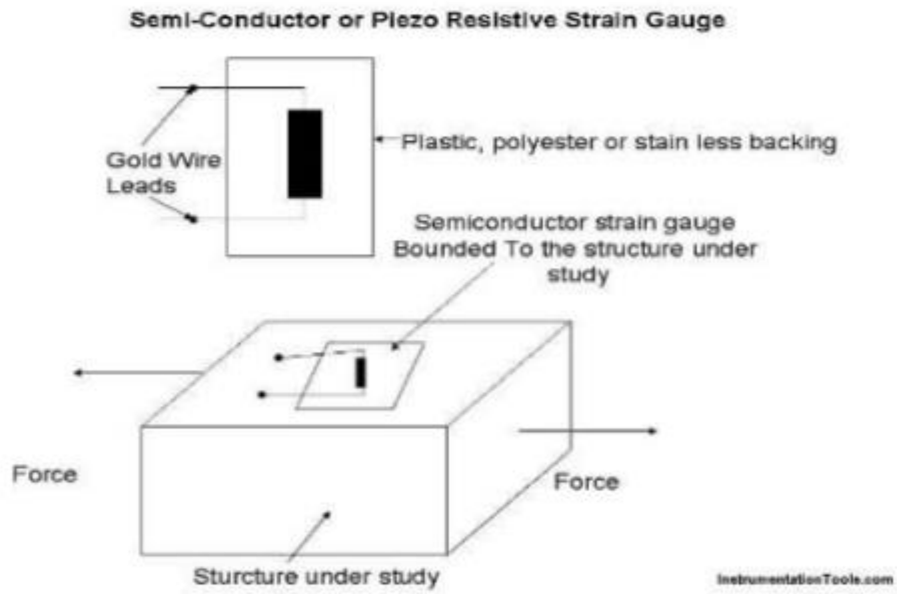
1.9 Semiconductor Strain Gauges

The arrangement of a semi-conductor strain gauge is as follows:

The sensing element is rectangular filament made as a wafer from silicon or geranium crystals. To these crystals, boron is added to get some desired properties and this process is called doping and the crystals are called doped crystals. This sensing element is attached to a plastics or stainless steel backing. Leads made of gold are drawn out from the sensing element for electrically connecting the strain gauge to a measuring instrument (wheat stone bridge).

There are two types of sensing element namely:

- Negative or n-type (resistance decrease with respect to tensile strain).
- Positive or P-type (resistance increase with respect to tensile strain).



Operation

With the help of an adhesive material, the strain gauge is pasted/bonded on the structure under study. Now the structure is subjected to a force (tensile or compressive). Due to the force, the structure will change the dimension. As the strain gauge is bonded to the structure, the stain gauge will also undergo change in both in length and cross-section (that is, it strained). When the sensing element (crystal) of the semiconductor strain gauge is strained, its resistivity changes contributing to a change in the resistance of the strain gauge. The change in the resistance of the strain gauge is measured using a wheat stone bridge. This change in resistance of the strain gauge becomes a measure of the extent to which the structure is strained and a measure of the applied force when calibrated.

Advantages of semi-conductor Strain gauges

- These gauges have high gauge factor and hence they can measure very small strains.
- They can be manufactured to very small sizes.
- They have an accuracy of 2.3%
- They have excellent hysteresis characteristics.
- They have a good frequency of response.
- They have good fatigue life.

Limitation of semi-conductor Strain gauges

- These gauges are brittle and hence they cannot be used for measuring large strain.
- The gauge factor is not constant.
- These gauges have poor linearity.
- These gauges are very costly and are difficult to be bonded onto the structure under study.

1.10 Inductive Sensors: Sensitivity and Linearity of the Sensor

An inductive sensor is a device that uses the principle of electromagnetic induction to detect or measure objects. An inductor develops a magnetic field when a current flows through it; alternatively, a current will flow through a circuit containing an inductor when the magnetic field through it changes. This effect can be used to detect metallic objects that interact with a magnetic field. Nonmetallic substances such as liquids or some kinds of dirt do not interact with the magnetic field, so an inductive sensor can operate in wet or dirty conditions.

The inductive sensor is based on Faraday's law of induction. The temporal variations of the Magnetic Flux through an N turn's circuit will induce a voltage which follows:

$$e = -N\frac{\mathrm{d}\Phi}{\mathrm{d}t}$$

This can be expressed in a simpler way:

By assuming that the induced magnetic field B is homogeneous over a section S (the Magnetic flux will be expressed).

One form of inductive sensor drives a coil with an oscillator. A metallic object approaching the coil will alter the inductance of the coil, producing a change in frequency or a change in the current in the coil. These changes can be detected, amplified, compared to a threshold and use to switch an external circuit. The coil may have a ferromagnetic core to make the magnetic field more intense and to increase the sensitivity of the device. A coil with no ferromagnetic core ("air core") can also be used, especially if the oscillator coil must cover a large area. Another form of inductive sensor uses one coil to produce a changing magnetic field, and a second coil (or other device) to sense the changes in the magnetic field produced by an object, for example, due to eddy currents induced in a metal object.

1.11 Capacitive Sensors: Electrostatic Transducer

A transducer consisting of a fixed electrode and a movable electrode, charged electrostatically in opposit e polarity; motion of the movable electrode changes the capacitance between the electrodes and thereby makes the applied voltage change in proportion to the amplitude of the electrode's motion known as condenser transducer.

Principle of electrostatic sensor detection around electrified object, an electric field that is proportional in strength to the amount of charge is produced. Electrostatic sensors detect the intensity of this electric field and calculate it as electric potential.

Detection of electric field

When a detection electrode is brought close to an electrified body, an electric charge that is proportional to the intensity of the electric field is induced in the detection electrode due to "electrostatic induction”. The electrostatic sensor opens and closes a tuning-fork vibrating plate called a chopper in front of the detection electrode in order to cancel out DC noise and perform higher precision measurement. The sensor detects the intensity of the electric field by receiving the induced electric charge as a communication signal.

Conversion to electric potential

Electric potential is proportional to the intensity of the electric field, but the intensity of the electric field gets smaller as it gets further away from an electrified object. Therefore, the electrostatic sensor sets a distance between the electrified object and the sensor using a controller and a corrected calculation of the electric potential is performed.

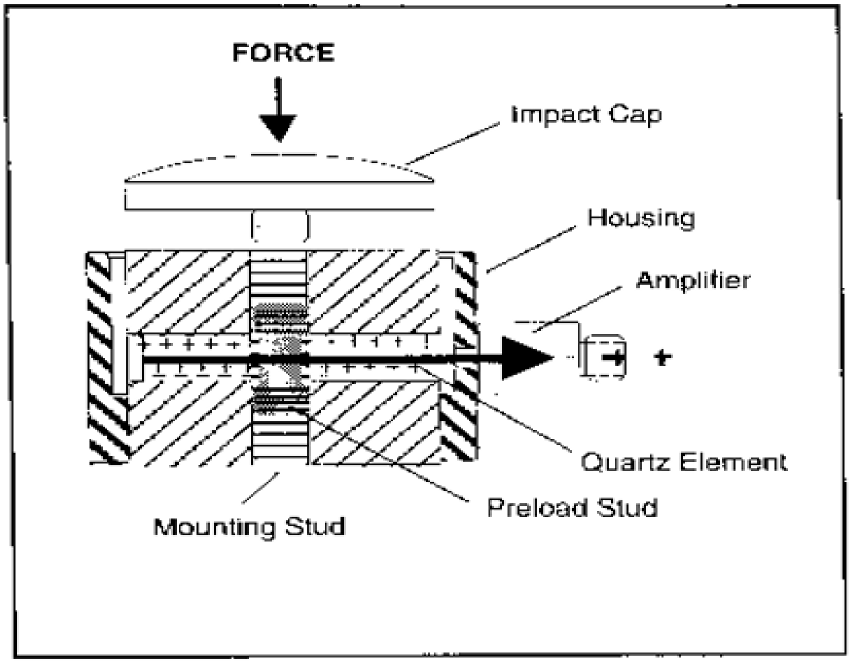
Characteristics based on the principle of electrostatic sensor detection

Since an electric field relies on the measurement distance, you need to fix the sensor at a set distance in order to perform a high precision measurement. The electric field that is produced by an electrified object spreads concentrically out from the electrified object. Therefore, the electrostatic sensor that detects the electric field measures a wider range as the measurement distance increases. Moreover, the existing electrostatic sensors and electrometers have the same range characteristics since they all detect the electric field.

1.12 Force/Stress Sensors Using Quartz Resonators

Quartz Force Sensors are recommended for dynamic force applications. They are not used as 'load cells' for static applications. Measurements of dynamic oscillating forces, impactor high speed compression/tension under varying conditions may require sensors with special capabilities. Fast response, ruggedness, stiffness comparable to solid steel, extended ranges and the ability to also measure quasi-static forces are standard features associated with PCB quartz force sensors.

The following information presents some of the design and operating characteristics of PCB force sensors to help you better understand how they function, which in turn, will "help you make better dynamic measurements". Following Figure illustrates the cross-section of a typical quartz force sensor. This sensor is a General Purpose 208 Series compression/tension model with built-in electronics.



Compression-Tension-Impact

When force is applied to this sensor, the quartz crystals generate an electrostatic charge proportional to the input force. This output is collected on the electrodes sandwiched between the crystals and is then either routed directly to an external charge amplifier or converted to a low impedance voltage signal within the sensor. Both these modes of operation will be examined in the following sections.

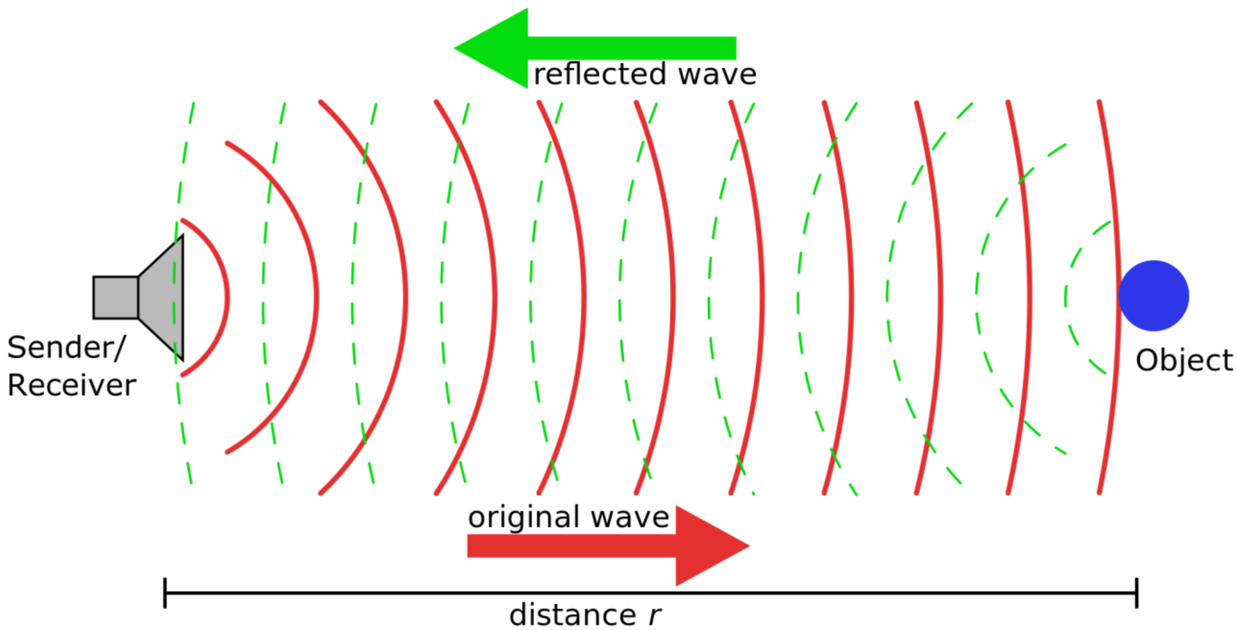
1.13 Ultrasonic Sensors

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. Ultrasonic waves travel faster than the speed of audible sound (i.e. the sound that humans can hear). Ultrasonic sensors have two main components: the transmitter (which emits the sound using piezoelectric crystals) and the receiver (which encounters the sound after it has travelled to and from the target).

In order to calculate the distance between the sensor and the object, the sensor measures the time it takes between the emission of the sound by the transmitter to its contact with the receiver. The formula for this calculation is $D = \frac{1}{2} T \times C$ (where D is the distance, T is the time, and C is the speed of sound ~ 343 meters/second). For example, if a scientist set up an ultrasonic sensor aimed at a box and it took 0.025 seconds for the sound to bounce back, the distance between the ultrasonic sensor and the box would be:

$$D = 0.5 \times 0.025 \times 343$$

or about 4.2875 meters.



Ultrasonic sensors are used primarily as proximity sensors. They can be found in automobile self-parking technology and anti-collision safety systems. Ultrasonic sensors are also used in robotic obstacle detection systems, as well as manufacturing technology. In comparison to infrared (IR) sensors in proximity sensing applications, ultrasonic sensors are not as susceptible to interference of smoke, gas, and other airborne particles (though the physical components are still affected by variables such as heat). Ultrasonic sensors are also used as level sensors to detect, monitor, and regulate liquid levels in closed containers (such as vats in chemical factories). Most notably, ultrasonic technology has enabled the medical industry to produce images of internal organs, identify tumors, and ensure the health of babies in the womb.

UNIT - II

Thermal Sensors: Introduction ,Gas thermometric Sensors ,Thermal Expansion Type Thermometric Sensors ,Acoustic Temperature Sensor ,Dielectric Constant and Refractive Index thermo sensors, Helium Low Temperature Thermometer ,Nuclear Thermometer ,Magnetic Thermometer ,Resistance Change Type Thermometric Sensors, Thermo emf Sensors, Junction Semiconductor Types, Thermal Radiation Sensors, Quartz Crystal Thermoelectric Sensors, NQR Thermometry, Spectroscopic Thermometry, Noise Thermometry, Heat Flux Sensors

2.1 Introduction to Thermal Sensors

A temperature sensor is an electronic device that measures the temperature of its environment and converts the input data into electronic data to record, monitor, or signal temperature changes. There are many different types of temperature sensors. Some temperature sensors require direct contact with the physical object that is being monitored (contact temperature sensors), while others indirectly measure the temperature of an object (non-contact temperature sensors).

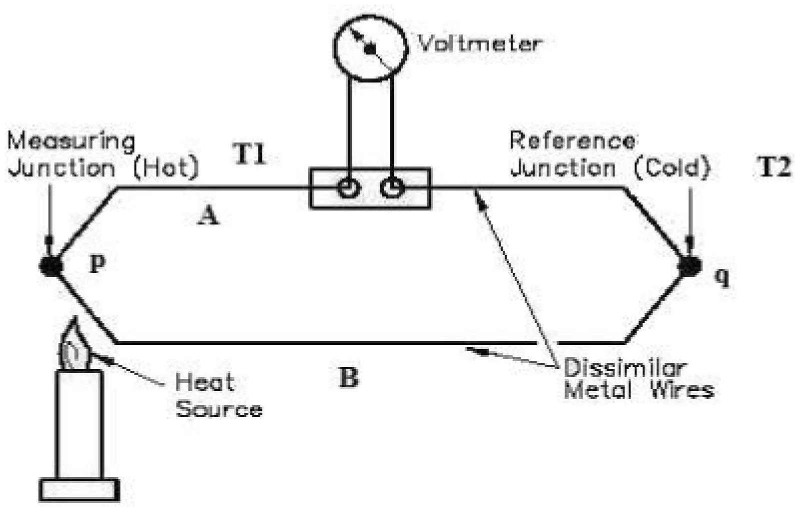


Diagram of a thermocouple

Non-contact temperature sensors are usually infrared (IR) sensors. They remotely detect the IR energy emitted by an object and send a signal to a calibrated electronic circuit that determines the object's temperature. Among the contact temperature sensors are thermocouples and thermistors. A thermocouple is comprised of two conductors, each made of a different type of metal, that are joined at an end to form a junction. When the junction is exposed to heat, a voltage is generated that directly corresponds to the temperature input. This happens on account of the phenomena called the thermoelectric effect. Thermocouples are generally inexpensive, as their design and materials are simple. The other type of contact temperature sensor is called a thermistor. In thermistors, resistance decreases as temperature increases.

There are two main types of thermistors**:** Negative Temperature Coefficient (NTC) and Positive Temperature Coefficient (PTC). Thermistors are more precise than thermocouples (capable of measuring within 0.05-1.5 degrees Celsius), and they are made of ceramics or polymers. Resistance Temperature Detectors (RTD) are essentially the metal counterpart of thermistors, and they are the most precise and expensive type of temperature sensors.

Temperature sensors are used in automobiles, medical devices, computers, cooking appliances, and other types of machinery.

2.2 Helium Gas Thermometric Sensors

A thermometer is an instrument to measure temperature. Temperature cannot be measured directly (for instance, as a length is measured by its segment). Only the measurement of another physical property being a function of temperature may provide temperature determination. A property used to measure temperature is termed a thermometric parameter and must meet the following requirements:

- be independent of the influence of other factors,
- be strictly reproducible,
- be a continuous and monotonic function of temperature,
- be a temperature coefficient of a property which is sufficiently large and its measurement sufficiently simple.

Most often used for temperature measurement are:

- A volume of a liquid or a gas (liquid-in-glass and gas thermometers);

● Electrical resistance of metals, semiconductors (see resistance thermometers); electromotive force.

Gas thermometry reduces temperature measurement (from helium temperatures to 1063°C) to measurement of pressure or a gas volume in a closed vessel (under certain conditions) followed by temperature calculation using the measurement results and the ideal gas laws. A gas thermometer is a primary instrument for determination of thermodynamic temperature. Application of exact relations requires design of complicated devices inconvenient for practical use. In practice, temperature scales are used in which a simple and convenient secondary thermometer is used and methods of transfer of thermodynamic temperature from a primary instrument to the secondary thermometer are employed A schematic drawing of a gas thermometer is shown in figure reservoir 3 is immersed into a medium whose temperature is to be measured; gauge 1 is connected via capillary 2 to the reservoir; the reservoir and the capillary are filled with a working gas. A gas thermometer allows the determination of pressure p and volume V of mass m of the ideal gas with molecular weight μ converting from thermodynamic state 1 to state 2, with the gas mass $m = Vp\mu/TR$ remaining constant in both states. Depending on the character of gas transition from 1-to-2 state, three gas thermometers are distinguished: those of constant volume, constant pressure, and constant temperature. A constant-volume gas thermometer is used at low temperatures (typically with helium as a working substance) and possesses the highest sensitivity. At high temperatures, when gas desorption on reservoir walls becomes pronounced and helium penetrates through the walls, gas thermometers of other design are used with nitrogen as a working substance.

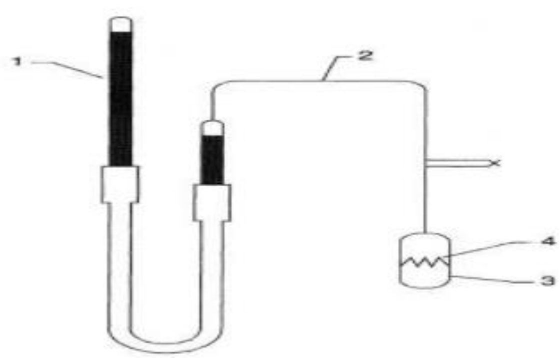


Fig:Schematic diagram of a gas thermometer.

2.3 Thermal Expansion type Thermometric Sensor

Thermal expansion is the basis of which a thermometer works. This is due to the thermodynamic properties "a substance expanding and retracting due to changes in heat". Generally, material expands when it receives heat and contracts at lower temperatures.

● In the case of a thermometer, there is a thin glass tube with a colorful liquid in it (that rises with a certain measurement on the thermometer). The tube is made thin to get a more precise reading. The tube is so thin that the liquid can either move up or down. And this is where thermal expansion comes in as the liquid will rise or fall (generally rise for increased temperature) when the liquid expands or contracts according to temperature.

● When a liquid receives energy in the form of heat, the atoms of the liquid will gain energy and will get "excited", due to this energy they move further apart i.e., they have expanded.

● The expansion rate depends upon various factors like specific heat and coefficients of linear expansion. Higher the coefficient of linear expansion, the more accurate the reading because it gives the highest change in length for a certain change in temperature.

Note:

•Thermal expansion is the internal property of the material

2.4 Dielectric Constant Sensor

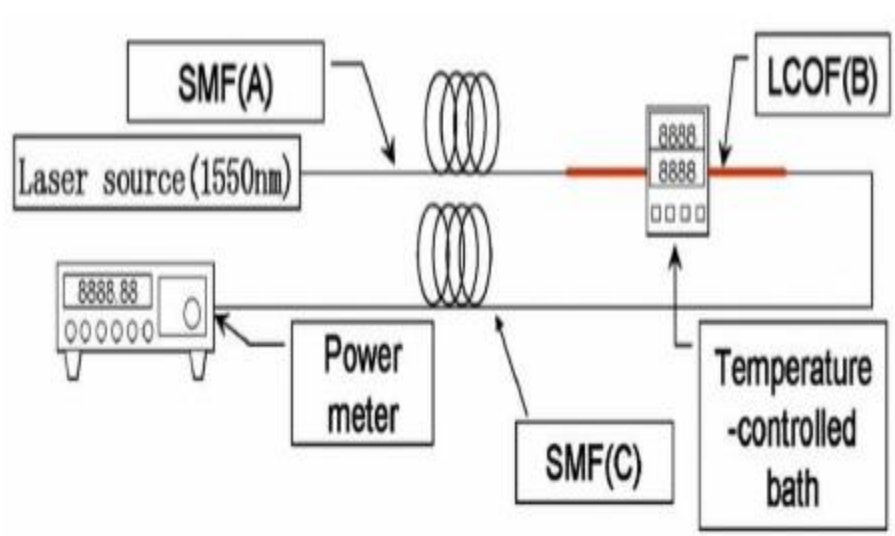
Capacitance sensors (or Dielectric sensors) use capacitance to measure the dielectric permittivity of a surrounding medium. The configuration is like the neutron probe where an access tube made of PVC is installed in the soil; probes can also be modular (comblike) and connected to a logger. The sensing head consists of an oscillator circuit, the frequency is determined by an annular electrode, fringe-effect capacitor, and the dielectric constant of the soil. Each capacitor sensor consists of two metal rings mounted on the circuit board at some distance from the top of the access tube. These rings are a pair of electrodes, which form the plates of the capacitor with the soil acting as the dielectric in between. The plates are connected to an oscillator, consisting of an inductor and a capacitor. The oscillating electric field is generated between the two rings and extends into the soil medium through the wall of the access tube. The capacitor and the oscillator form a circuit, and changes in dielectric constant of surrounding media are detected by changes in the operating frequency. The capacitance sensors are designed to oscillate in excess of 100

MHz inside the access tube in free air. The output of the sensor is the frequency response of the soil's capacitance due to its soil moisture level.

2.5 Refractive Index thermo sensors

An intensive temperature sensor based on a liquid-core optical fiber has been demonstrated for measuring the temperature of the environment. The core of fiber is filled with a mixture of toluene and chloroform in order to make the refractive index of the liquid-core and the cladding of the fiber close. An intensive temperature sensor based on a liquid-core optical fiber has been demonstrated for measuring the temperature of the environment. The core of fiber is filled with a mixture of toluene and chloroform to make the refractive index of the liquid-core and the cladding of the fiber close

The configuration of the liquid-core optical fiber temperature sensor is shown in figure. The light source is a tunable laser emitting a continuous pulse of 1 mw power at a wavelength around 1550 nm. The laser is projected into the lead fiber of the sensor. The output of the sensor is directed through the lead fiber directly into the power meter. The two lead fibers are all inserted into the coating-stripped LCOF and the joint thus forms the sensor. The two lead fibers (A and C) are held at room temperature, whereas the LCOF part can be temperature controlled. The temperature surrounding the LCOF is applied through a heated bath made by ourselves so that uniform temperature changes are ensured.



2.6 Magnetic and Nuclear Thermometer

Thermometer whose operation is based on Curie's law, which states that the magnetic susceptibility of noninteracting (that is, paramagnetic) dipole moments is inversely proportional to absolute temperature. Magnetic thermometers are typically used at temperatures below 1 K (-458°F). The magnetic moments in the thermometric material may be of either electronic or nuclear origin.

A mutual-inductance bridge, originally known as the Hartshorn bridge, has been the most widely employed measuring circuit for precision thermometry. The bridge is driven by a low frequency alternating-current source. The inductance at low temperatures consists of two coils, which are as identical as possible. The voltages induced across them by the drive current are compared by means of a high-input-impedance ratio transformer. The output level of this voltage divider is adjusted to equal that of the midpoint between the two coils, using as null indicator a narrow-band preamplifier and a phase-sensitive (lock-in) detector.

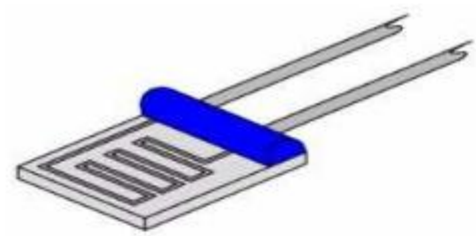
Nuclear magnetic moments are smaller by a factor of 103 and are used for thermometry only in the ultralow-temperature region. For this the Curie-law behavior is generally sufficient down to the lowest temperatures. The nuclear paramagnetic thermometer loses adequate sensitivity for calibration purposes above 50–100 millikelvins unless it is operated in a high polarizing field (H greater than 0.1 tesla). It can be utilized as a self-calibrating primary thermometer if the spinlattice relaxation time is measured in parallel with the nuclear Curie susceptibility.

2.8 Resistance Change Type Thermometric Sensors

Resistance thermometers, also called resistance temperature detectors (RTDs), are sensors used to measure temperature. Many RTD elements consist of a length of fine wire wrapped around a ceramic or glass core but other constructions are also used. The RTD wire is a pure material, typically platinum, nickel, or copper. The material has an accurate resistance/temperature relationship which is used to provide an indication of temperature. As RTD elements are fragile, they are often housed in protective probes. RTDs, which have higher accuracy and repeatability, are slowly replacing thermocouples in industrial applications below 600 °C. Common RTD sensing elements constructed of platinum, copper or nickel have a repeatable resistance versus temperature relationship (R vs T) and operating temperature range.

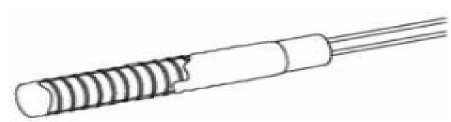
The three main categories of RTD sensors are thin-film, wire-wound, and coiled elements. While these types are the ones most widely used in industry, other more exotic shapes are used; for example, carbon resistors are used at ultra-low temperatures (−273 °C to −173 °C).

Thin-film elements have a sensing element that is formed by depositing a very thin layer of resistive material, normally platinum, on a ceramic substrate (plating). This layer is usually just 10 to 100 ångströms (1 to 10 nanometers) thick. This film is then coated with an epoxy or glass that helps protect the deposited film and also acts as a strain relief for the external lead wires.



Thin-film PRT

Wire-wound elements can have greater accuracy, especially for wide temperature ranges. The coil diameter provides a compromise between mechanical stability and allowing expansion of the wire to minimize strain and consequential drift. The sensing wire is wrapped around an insulating mandrel or core. The winding core can be round or flat but must be an electrical insulator.



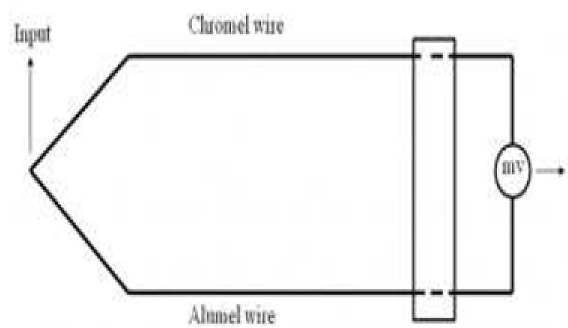
Wire-wound PRT

Coiled elements have largely replaced wire-wound elements in industry. This design has a wire coil that can expand freely over temperature, held in place by some mechanical support, which lets the coil keep its shape. This “strain free” design allows the sensing wire to expand and contract free of influence from other materials.

Coil-element PRT

2.9 Thermo emf Sensors

The thermocouple can be defined as a kind of temperature sensor that is used to measure the temperature at one specific point in the form of the EMF or an electric current. This sensor comprises two dissimilar metal wires that are connected together at one junction. The temperature can be measured at this junction, and the change in temperature of the metal wire stimulates the voltages.



Thermocouple

The amount of EMF generated in the device is very minute (millivolts), so very sensitive devices must be utilized for calculating the e.m.f produced in the circuit. The common devices used to calculate the e.m.f are voltage balancing potentiometer and the ordinary galvanometer. From these two, a balancing potentiometer is utilized physically or mechanically.

Thermocouple Working Principle

The thermocouple principle mainly depends on the three effects

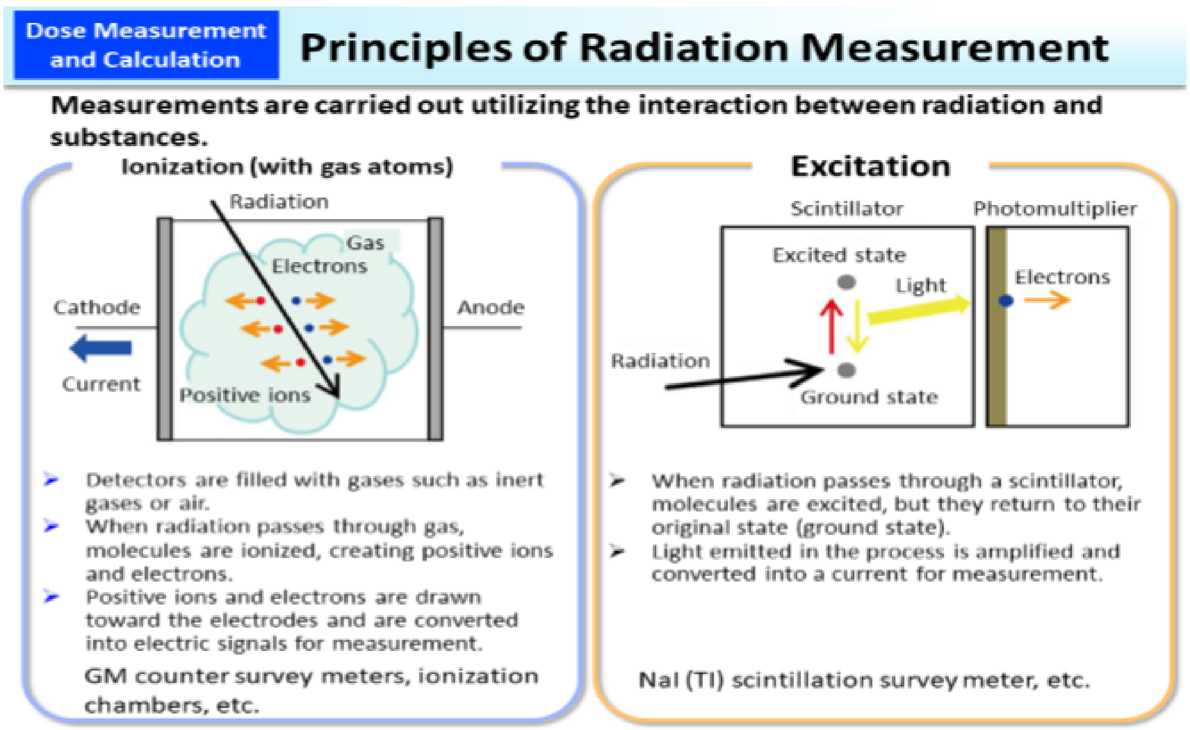
See beck-effect This type of effect occurs among two dissimilar metals. When the heat offers to any one of the metal wires, then the flow of electrons supplies from hot metal wire to cold metal wire. Therefore, direct current stimulates the circuit.

Peltier-effect This Peltier effect is opposite to the Seebeck effect. This effect states that the difference of the temperature can be formed among any two dissimilar conductors by applying the potential variation among them.

Thompson-effect This effect states that as two disparate metals fix together & if they form two joints then the voltage induces the total conductor's length due to the gradient of temperature. This is a physical word that demonstrates the change in rate and direction of temperature at an exact position.

2.10 Thermal Radiation Sensors

When radiation passes inside a detector, it causes ionization of gas atoms, separating atoms into positive ions and electrons. Separated electrons and positive ions are attracted to the electrodes, causing a current to flow. This is converted into electric signals, which are then measured as the amount of radiation.



2.11 Quartz Crystal Thermoelectric Sensors

It has long been recognized that the temperature dependence of quartz crystal resonators was a potential basis for the accurate measurement of temperature .In practice, however, it has not previously been satisfactory to make wide-range temperature-measuring systems based on quartz resonators because of the large non-linearity in the temperature coefficient of frequency of available quartz wafers. Recently, however, an orientation in quartz was predicted and verified in the HP laboratories which resulted in a crystal wafer having a linear temperature coefficient over a wide temperature range. The new orientation is called "LC" cut. LC stands for linear coefficient.

This new orientation has permitted development of a "quartz thermometer" that measures temperatures automatically, quickly, and with very high resolutions. Temperatures can be measured over a range from -4O°C to +23O°C to a resolution of °C in 10 seconds or faster.

There are two types of quartz thermometers one of which has two inputs and can take differential measurements of temperature. They can be made to read in Celsius as well as in Fahrenheit. Temperature-measuring instrument with the above capabilities has great value in many fields.

Construction The thermometer's temperature sensing quartz resonator is in a small sensor probe which connects through a length of cable to its oscillator. The oscillator is in the main cabinet but can be physically removed as a unit to permit measuring temperatures at a distance from the cabinet. The cabinet, otherwise, contains what is essentially a special frequency counter which displays the measured temperature directly in numerical form on a digital readout. The temperature measurements are made automatically, either repetitively or initiated singly. Three styles of sensor probes have been designed to accommodate measurements including even at high pressure environment

Sensor Construction Gold is deposited on electrodes on the surface of the quarter inch diameter quartz wafer. Each wafer is brazed to three small ribbons so that it can be placed in a transistor case. The wafer case is hermetically sealed in a helium atmosphere which provides both a good heat conduction path and a passive atmosphere for long term resonator stability.

Sensor Probe Construction The outer shell of the sensor probes are fabricated from stainless steel for chemical stability. The quartz wafer is situated parallel to and about inch away from the flat circular end of the probe and is sealed in a helium atmosphere.

2.12 NQR Thermometry

Nuclear quadrupole resonance spectroscopy or NQR is a chemical analysis technique related to nuclear magnetic resonance (NMR). Unlike NMR, NQR transitions of nuclei can be detected in the absence of a magnetic field, and for this reason NQR spectroscopy is referred to as "zero Field NMR". The NQR resonance is mediated by the interaction of the electric field gradient (EFG) with the quadrupole moment of the nuclear charge distribution. Unlike NMR, NQR is applicable only to solids and not liquids, because in liquids the quadrupole moment averages out. Because the EFG at the location of a nucleus in a given substance is determined primarily by the valence electrons involved in the particular bond with other nearby nuclei, the NQR frequency at which transitions occur is unique for a given substance. A particular NQR frequency in a compound or crystal is proportional to the product of the nuclear quadrupole moment, a property of the nucleus, and the EFG about the nucleus. It is this product which is termed the nuclear quadrupole coupling constant for a given isotope in a material and can be found in tables of known NQR transitions. In NMR, an analogous but not identical phenomenon is the coupling constant, which is also the result of an internuclear interaction between nuclei in the analyte.

2.13 Johnson Noise Thermometry

Johnson noise thermometry (JNT) is a primary temperature measurement technique based on the fundamental properties of thermal fluctuations in conductors. These fluctuations are measured with respect to quantum voltage noise sources (QVNS). The results are useful for both temperature scale metrology and for the development of reliable thermometers for harsh environments. We apply new technologies and methodologies to JNT using wide-band spectral analysis, digital signal processing, and pulse-quantized voltage synthesis. The new NIST JNT methods directly compare measured thermal noise voltages to an AC Josephson Quantized Voltage Noise Source (QVNS) (see Figure). Specific advances of the JNT systems are:

● high resolution (~1 Hz) spectral densities with a bandwidth approaching 1MHz.

● application of the fastest available Fast Fourier Transform (FFT) subroutines for near-real time processing.

● frequency domain cross-correlation analysis.

● QVNS synthesized pseudo-noise waveforms of matched spectral densities.

● ultra-low noise and high common-mode rejection pre-amplifiers.

● Simultaneous matching of both noise powers and time constants.

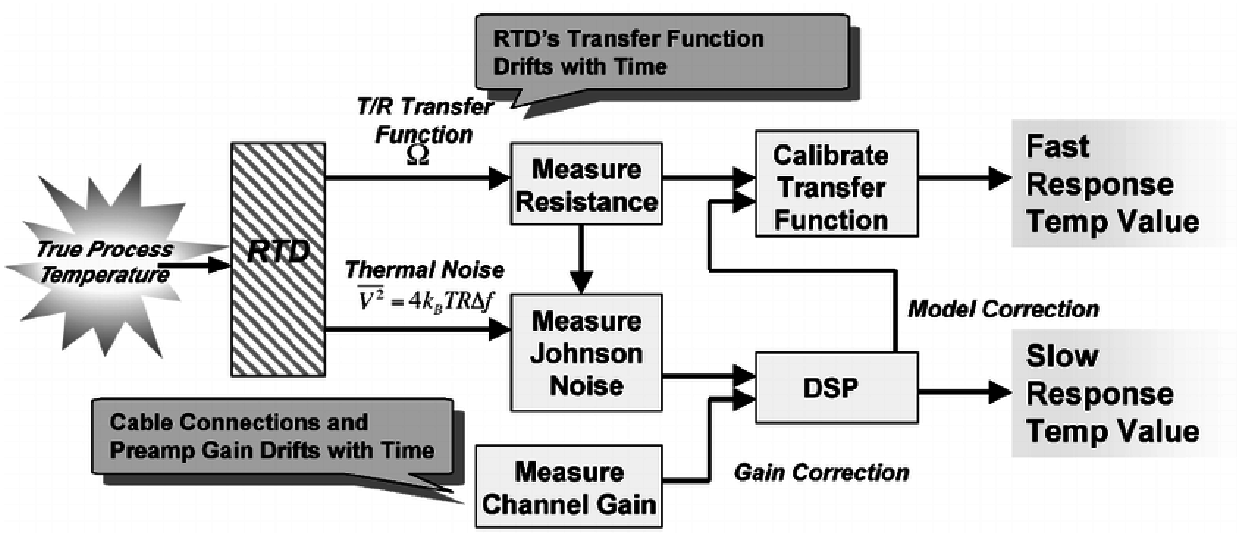
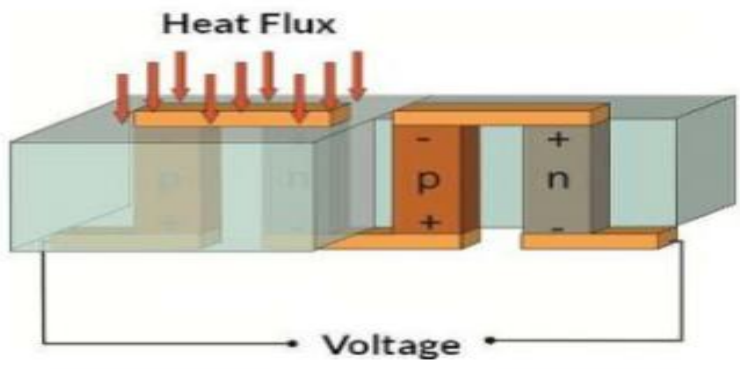


Fig: Johnson noise Thermometry

2.14 Heat Flux Sensors

Heat Flux Sensors are based on the Seebeck effect. When heat passes through the sensor, the sensor generates a voltage signal. This voltage signal is proportional to the heat passing through the sensor. Heat Flux Sensors can resolve heat fluxes < 0.01 W/m2. The sensitivity of Sensor depends on the thermocouple material quality used in the sensor and the number of thermocouples used. A thermocouple consists of two separate thermopiles (n-type and p-type). These thermopiles are highly integrated in the sensor substrate, which leads to high sensitivity sensor modules.



$$HF \propto V$$

where

HF = Heat Flux, in W/m²

V = Voltage, in V

All Heat Flux Sensors generate a voltage signal which is proportional to the heat that passes through the sensor element. In most applications, this voltage signal is in the µV range. The voltage signal is converted into the heat flux value by dividing it by the sensor sensitivity.

HF = V / S

where

HF = Heat Flux, in W/m2

V = Voltage, in µV

S = Sensor sensitivity, in µV/(W/m2)

2.15 Electrostatic transducer:

An electrostatic transducer comprising a vibrating plate or electrets diaphragm which has a mono charge on its surface and including a pair of back electrodes clamping the electret there between and including an electrically conductive electrostatic shield covering the back electrodes so as to increase the fidelity life of the transducer.

An electrostatic transducer comprising:

a. an electret diaphragm made of a film having a mono charge;

b. a first back electrode having a number of air holes and mounted adjacent one surface of said electret diaphragm and spaced a predetermined distance there from, said first back electrode consisting of a conductive body on one side adjacent said electret diaphragm and an insulating body on the side opposite said electret diaphragm and supporting said conductive body;

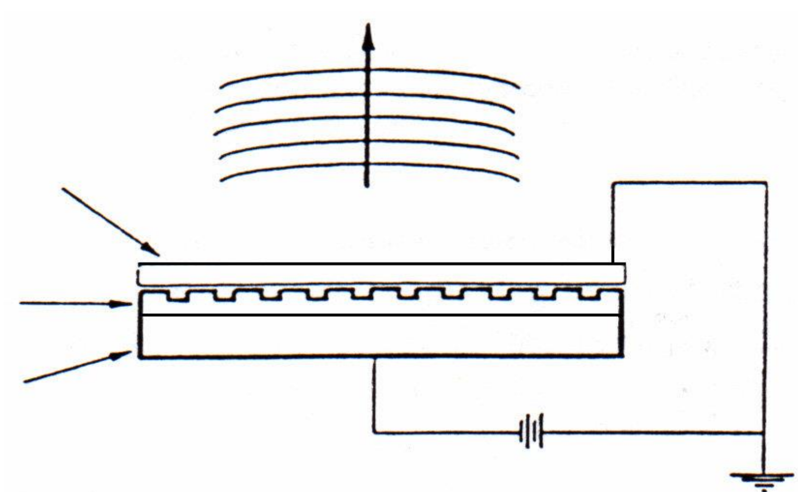
c. a second back electrode having a number of air holes and adjacent the other surface of said electret diaphragm, said second back electrode consisting of a second conductive body on one side adjacent said electret diaphragm and a second insulating body on the side opposite said electret diaphragm and supporting said second conductive body;

d. a pair of frames supporting said first and second back electrodes, respectively;

e. means for attaching said frames together;

f. electrically conductive mesh-like shielding means covering the surfaces of said insulating bodies, and

g. means for electrically connecting said shielding means to said first and second back electrodes to maintain them at the same potential.



The most obvious application for an electrostatic transducer is that of a position sensor: with a constant charge on the capacitor plates the voltage will be proportional to the distance between the plates.

2.16 Acoustic temperature Sensor

An acoustic temperature sensor measures temperature by detecting changes in the speed and frequency of sound waves. The sensor works by using the relationship between the temperature, speed, and propagation characteristics of sound waves in a medium. As the temperature of the medium changes, so do the speed and frequency of the sound waves. The sensor then measures these changes to calculate the temperature.

Acoustic sensors can detect changes in parameters like temperature, mass, and viscosity. They are used in many industries, including healthcare diagnostics, environmental monitoring, and industrial process control.

Here are some types of acoustic sensors:

- **Flexural Plate Wave (FPW) sensors**

These sensors are known for their high sensitivity, especially at lower frequencies. They work by creating a wave inside a thin membrane, which causes a flexural wave. FPW sensors can work in high temperatures because they have a high temperature PCB.

- **Surface Acoustic Wave (SAW) sensors**

SAW sensors can be used for wireless temperature measurement. For example, one study developed an LGS SAW sensor that could measure temperatures up to 1200 °C.

UNIT- III

Magnetic sensors: Introduction, Sensors and the Principles Behind, Magneto-resistive Sensors, Anisotropic Magneto resistive Sensing, Semiconductor Magneto resistors, Hall Effect and Sensors, Inductance and Eddy Current Sensors, Angular/Rotary Movement Transducers.

3.1 Introduction to Magnetic Sensors and it's Principles

Magnetic sensor definition is a sensor which is used to notice disturbances as well as changes within a magnetic field such as strength, direction, and flux. There are different types of detection sensors which can work on some of the characteristics like light, pressure, temperature. These sensors are separated into two groups. The first one is used to calculate the total magnetic field, whereas the second one is used to calculate vector components of the field.The vector components in the magnetic field are individual points and the techniques which are used for making these sensors mainly involved in a variety of blends of electronics and physics.

Magnetic Sensor Working Principle

The magnetic sensor comprises a chip with a magneto-resistive component which is used to detect a magnetic vector & a magnet intended for magnetic vector biasing which can be detected by the magneto-resistive component. The chip which is used in the sensor can be used for sensing the change within the magnetic vector. This vector notices the behavior of a magnetic body depending on a change of resistance value of the magneto-resistive component.

Whenever the magnetic vector biasing is occurred due to the magnet in co-operation by the magnetic body, then it will be the motion inside the sensing chip. This sensor can be used to compass functionality, which is accessible during Navigation menu.

Types of Magnetic Sensors

The classification of Magnetic sensors can be done based on detecting the dissimilarity of magnetic sensors like a low field, earth field, and bias magnetic field sensors.

1). Low Field Sensors

These sensors are used to detect extremely low values of the magnetic fields like 1uG (1 Gauss is equal to 10-4 Tesla. The best examples of this are nuclear procession, Fiber optic, and SQUID. The applications of low field sensors mainly include in nuclear as well as medical fields.

2). Earth Field Sensors

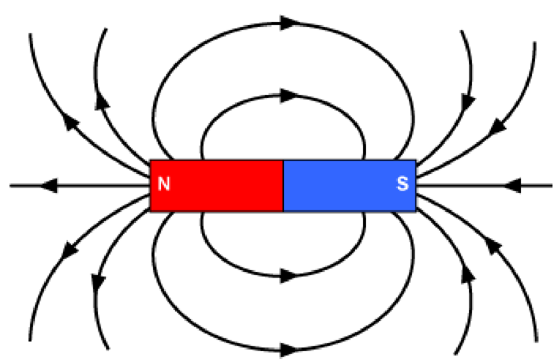
The range of magnetic for this type of sensor ranges from 1uG to 10 G. This sensor uses the magnetic field of the earth in several applications like the vehicle as well as navigation detection.

3). Bias Magnet Field Sensors

These sensors are used to sense the enormous magnetic fields above 10 Gauss. Most of the sensors used in industries use permanent magnets like a source of the noticed magnetic field. These magnets will bias otherwise magnetize the ferromagnetic objects which are close to the sensor. The sensors which are in this type mainly include hall devices, GMR sensors, and reed switches.

How to Measure Magnetic Field?

Generally, the magnetic field can be surrounded by an electric current, and it is noticeable through its strength otherwise communication on magnets, electrical charges, as well as magnetic products. Here, the magnetic field direction, as well as strength, can be calculated. The variations within the field are detected as well as changes are made inside the response of machines. The best example of this is the magnetic field of the earth, which is measured & tracked with the help of magnetic sensors. These are elements of the navigational tools which are designed by different manufacturer companies like Honeywell. Most of these sensors are applicable for measurement within navigational tools, scientific measuring, and industrial processes.



The magnetic sensor applications include magnetic flux measuring & the direction as well as the strength of a magnetic field.

<u>3.2 Magneto-resistive Sensors and Anisotropic Magneto resistive Sensing</u>

A magneto-resistive sensor uses the fact that the electrical resistance in a ferromagnetic thin film alloy is changed through an external magnetic field. “Ferrum” is Latin and stands for “iron”. Generally, mixed alloys are used, for example iron and nickel. These sensors are exceptionally small, and due to their special material, they are robust and consume very little energy. They are especially useful in areas where there is no continuous energy supply.

A magneto-resistive sensor can be used for the following areas of application:

- Path and angle measurement
- Determination of magnetic fields
- Highly dynamic current measurement
- Contactless switches
- Dynamic measurements under extreme conditions (e.g. in vehicle engines)

How does a magneto-resistive sensor carry out measurements?

The utilization of the AMR-effect ("anisotropy magneto-resistive effect") is particularly well-known. The resistance in this case is dependent on the angle between the current direction and the magnetization (M), which can be influenced through an external magnetic field. The resistance is smallest at a 90-degree angle and highest when the current flows in parallel.

In simplified form, a magneto-resistive sensor functions as follows: An object with its own magnetic field approaches the sensor. As a result, the electrical resistance changes. This makes it possible to detect at what angle the external magnetic field (and thus the object) is positioned in relation to the sensor. The magnetization of the field also makes it possible to determine the distance.

How is a magneto-resistive sensor constructed?

A simple ferromagnetic layer is not sufficient to carry out an optimal magnetic field measurement. Instead, a magnetic preferred direction in the X-axis (the horizontally aligned axis) of the ferromagnetic material of the sensor is used. This so-called magnetic anisotropy has a single-axis anisotropic field strength of approx. 250A/m. This makes it possible to stop the magnetization again, even if its direction was rotated by the external field.

The conductive materials used in magneto-resistive sensors are iron, copper, nickel, gold or aluminum.

Advantages and disadvantages of magneto-resistive sensors

Advantages:

- Extremely precise measurements

- Robust
- Very small
- Energy-efficient
- Wide range of applications
- Suitable for extreme environment

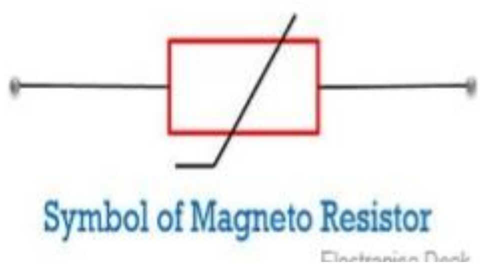
Disadvantages:

- Complicated to set up

3.3 Semiconductor Magneto resistors

Magneto resistors are those components that exhibit the property of magneto resistance. Basically, magneto resistance is the phenomenon of change in resistance of a material when a magnetic field is applied. The current that flows through a magneto resistor, varies with the variation in the applied magnetic field. The resistivity of magneto-resistor depends on the mobility of electrons. Semiconductor materials like indium antimonide or indium arsenide are used for fabrication of magneto resistors. Usually, the effect of magnetic field on the resistance of a material depends on the strength as well as the orientation of the magnetic field w.r.t current. It is noteworthy here that, the sensitivity of magneto resistors depends on the total applied magnetic field and do not rely on the rate of change of the magnetic field.

The figure below shows the symbolic representation of magneto-resistor:



Construction and Working principle of Magneto-resistors

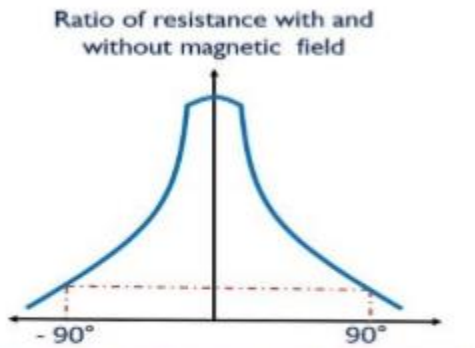
A magneto-resistor is basically formed by the deposition of a film of indium antimonide or nickel antimonide over a substrate of 0.1 m thickness. The thickness of the depositing film is about 25 µm.

A magneto-resistor operates on the law of electrodynamics. According to this law, in the presence of a magnetic field, Lorentz force is experienced by charge carriers. Hence, the electrons move in a different manner thereby causing the resistivity of increase with a decrease in current. With the increase in strength of the magnetic field, resistance also increases and vice-versa.

When an external magnetic field is not applied, then the mobile charge carriers present inside the material follows a direct straight path. Due to this, electric current also flows in a straight path thus resistance, in that case, will be low.

As against, when a magnetic field is applied externally, then due to Lorentz force the electrons instead of flowing through direct path now starts following an indirect path. This causes the resistance of the material to increase.

The value of magnetoresistance depends on the magnetic field direction. The figure below shows the effect of the magnetic field direction on magneto resistors:

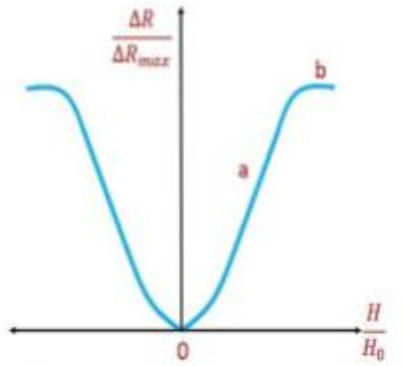


Effect of magnetic field direction on magneto-resistor

It is to be noted here that when the crystals of indium antimonide are parallelly placed wrt each other. Also, the magnetic and electric field are perpendicular to each other, then maximal resistance change in the material occurs.

Characteristic curve of Magneto resistor

The figure here represents the basic magneto-resistive characteristics:



Magneto Resistive Characteristic Curve

Here, H0 represents the effective anisotropy field in the material. When no external field is applied then the magnetization of the field exists at elemental length 0. But, with the increase in the applied field, the resistance also increases, this is represented by point a, in the above curve.

Applications of magneto resistors

These are widely used in magnetometers in order to determine the direction and intensity of magnetic field. Also, these are used in position sensors and ferrous metal detection.

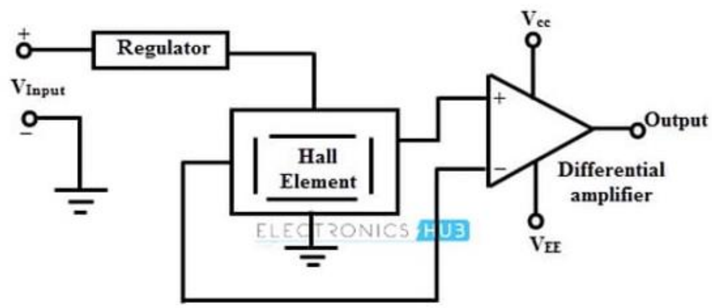
3.4 Hall Effect and Sensors

A Hall effect sensor is an electronic device that is designed to detect the Hall effect, and convert its findings into electronic data, either to switch a circuit on and off, provide a measurement of a varying magnetic field, be processed by an embedded computer or displayed on an interface. In 1879, scientist Edwin Hall discovered that if a magnet is placed perpendicular to a conductor with a steady flow of current, the electrons flowing within the conductor are pulled to one side, thus creating a potential difference in charge (i.e., voltage). The Hall effect, then, is indicative of the presence and magnitude of a magnetic field near a conductor.

Using magnetic fields, Hall effect sensors are used to detect variables such as the proximity, speed, or displacement of a mechanical system. Hall effect sensors are non-contact, which means that they do not have to meet a physical element. They can produce either a digital (on and off) or analogue (continuous) signal depending on their design and intended function.

A Hall effect switch turns on in the presence of a magnetic field and turns off when the magnet is removed. A Hall effect latch turns on (closes) when a positive magnetic field is applied and remains on even when the magnet is removed. When a negative magnetic field is applied, the Hall effect latch turns off (opens) and remains off even when the magnet is removed.

Linear Hall sensors (analog) render precise and continuous measurements based on magnetic field strength; they do not switch on and off. Within the Hall effect sensor, the Hall element sends the electric potential difference (voltage brought about by the magnetic interference) to an amplifier to make the change in voltage large enough to be perceived by the embedded system.



Hall effect sensor diagram

Hall effect sensors can be found in cell phones and GPS, assembly lines, automobiles, medical devices and many IoT devices.

3.5 Inductance and Eddy Current Sensors

(A) Inductive sensors

They are based on the eddy current principle and designed for non-contact measurement of displacement, distance, position, oscillation and vibrations. They are particularly suitable when high precision is required in harsh industrial environments (pressure, dirt, temperature). Inductive sensors offer extremely precise measurements where sub-micron accuracy is required.

Characteristics

- Non-contact measurement of displacement, distance and position on ferromagnetic and non-ferromagnetic materials
- For demanding, industrial environments: dirt, pressure, temperature
- High resolution and temperature stability
- High frequency response for fast measurements
- Customer-specific sensors and controllers
- Robust and industrial-grade sensor designs
- Versatile application possibilities due to comprehensive product range

(B) Eddy Current Sensor

Eddy Current is a type of non-contacting sensor technology. Eddy Current Sensors are non-contacting position sensors used for measuring the change of position of a specified target. Eddy Current sensors are capable of high resolution measurement and are also referred to as inductive sensors. Eddy Current Sensors work in magnetic fields. The driver creates an alternating current in a sensing coil at the end of a probe. The alternating current then creates an alternating magnetic field which induces smaller currents within the target material, these currents are referred to as Eddy Currents. The Eddy Currents then create an opposing magnetic field which resists the field being generated by the probe coil. The distance between the probe and the target will determine the interaction of the magnetic field. The distance between the probe and the target can then be determined by the change in the field interaction and an output is produced proportional to the change in the distance.

Eddy Current sensors are a type of position measuring device and are useful in the following applications.

- Automation applications
- Machine tool mounting
- Precision stage positioning
- Final assembly of delicate machinery
- Monitoring drive shafts
- Monitoring vibration measurements

3.6 Angular/Rotary Movement Transducers

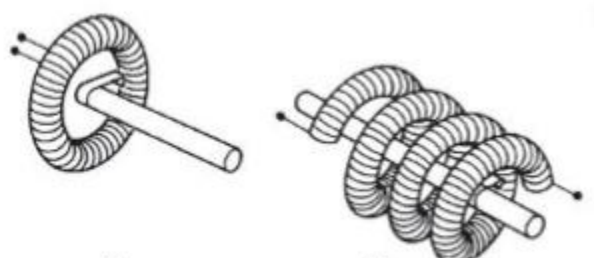
Rotational displacement transducers measure the angular motion of a body about some rotation axis. They are important not only for measuring the rotation of bodies such as shafts, but also as a part of systems that measure translational displacement by converting the translational motion to a rotary form.

Circular and Helical Potentiometers

The circular potentiometer is the least expensive device available for measuring rotational displacements. It works on almost the same principles as the translational motion potentiometer except that the track is bent round into a circular shape. The measurement range of individual devices varies from 0-10 deg to 0-360 deg depending on whether the track forms a full circle or only part of a circle. Where a greater measurement range than 0-360 deg. is required, a helical potentiometer is used. The two forms of devices are shown in Figure 1.

Both kinds of devices give a linear relationship between the measured quantity and the output reading because the output voltage measured at the sliding contact is proportional to the angular displacement of the slider from its starting position. However, as with linear track potentiometers, all rotational potentiometers can give performance problems if dirt on the track causes loss of contact. They also have a limited life because of wear between sliding surfaces.

The typical inaccuracy of this class of devices varies from +-1% of full scale for circular potentiometers down to +-0.002% of full scale for the best helical potentiometers.



(a) (b)

Figure 1

3.7. Synchros:

Definition: The Synchro is a type of transducer which transforms the angular position of the shaft into an electric signal. It is used as an error detector and as a rotary position sensor. The error occurs in the system because of the misalignment of the shaft. The transmitter and the control are the two main parts of the synchro.

Synchros System Types

The synchro system is of two types. They are

1. Control Type Synchro.
2. Torque Transmission Type Synchro.

Torque Transmission Type Synchros

This type of synchros has small output torque, and hence they are used for running the very light load like a pointer. The control type Synchro is used for driving the large loads.

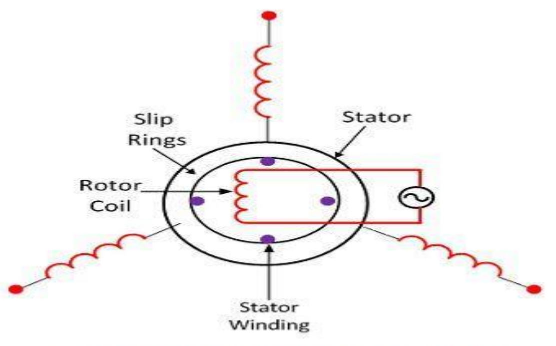
Control Type Synchros System

The controls synchros is used for error detection in positional control systems. Their systems consist two units. They are

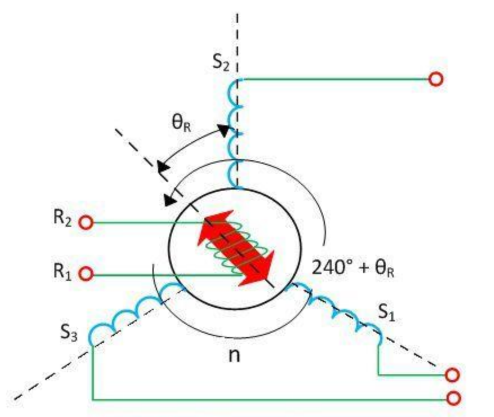
1. Synchro Transmitter
2. Synchro receiver

The synchro always works with these two parts. The detail explanation of synchros transmitter and receiver is given below.

Synchros Transmitter – Their construction is similar to the three phase alternator. The stator of the synchros is made of steel for reducing the iron losses. The stator is slotted for housing the three phase windings. The axis of the stator winding is kept 120º apart from each other.



The coils of the stator windings are connected in star. The rotor of the synchros is a dumbbell in shape, and a concentric coil is wound on it. The AC voltage is applied to the rotor with the help of slip rings. The constructional feature of the synchros is shown in the figure below



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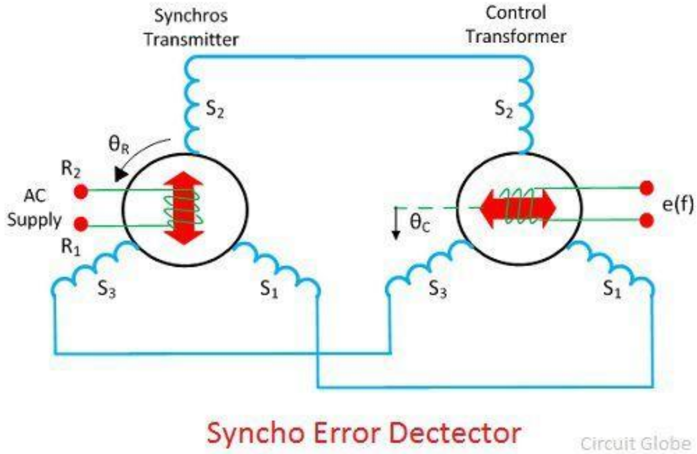
Consider the voltage is applied to the rotor of the transmitter as shown in the figure



Syncho Error Dectector

The voltage applied to the rotor induces the magnetizing current and an alternating flux along its axis. The voltage is induced in the stator winding because of the mutual induction between the rotor and stator flux. The flux linked in the stator winding is equal to the cosine of the angle between the rotor and stator. The voltage is induced in the stator winding.

Let V_{s1}, V_{s2}, V_{s3} be the voltages generated in the stator windings S_1, S_2, and S_3 respectively. The figure below shows the rotor position of the synchro transmitter. The rotor axis makes an angle θ_r concerning the stator windings S_2.

$$V_{s1n} = kV_r Sin\omega_c t cos(\theta_R + 120°)$$

$$V_{s2n} = kV_r Sin\omega_c t cos\theta_R$$

$$V_{s1n} = kV_r Sin\omega_c t cos(\theta_R + 240°)$$

The three terminals of the stator windings are

$$V_{s1s2} = V_{s1n} - V_{s2n}$$

$$V_{s1s2} = \sqrt{3} kV_r Sin(\theta_R + 240°) Sin\omega_c t$$

$$V_{s3s2} = V_{s2n} - V_{s3n}$$

$$V_{s1s2} = \sqrt{3} kV_r Sin(\theta_R + 120°) Sin\omega_c t$$

$$V_{s3s1} = V_{s3n} - V_{s1n}$$

$$V_{s3s1} = kV_r Sin\omega_c t Sin\theta_R$$

The variation in the stator terminal axis concerning the rotor is shown in the figure below.

$$e(t) = k'V_r Cos(90° - \theta_R + \theta_C) Sin\omega_c t$$

$$e(t) = k'V_r Sin(\theta_R - \theta_C) Sin\omega_c t$$

When the rotor angle becomes zero, the maximum current is produced in the stator windings S_2. The zero position of the rotor is used as a reference for determining the rotor angular position.

The output of the transmitter is given to stator winding of the control transformer which is shown in the above figure.

The current of the same and magnitude flow through the transmitter and control transformer of the synchros. Because of the circulating current, the flux is established between the air gap flux of the control transformer.

The flux axis of the control transformer and the transmitter is aligned in the same position. The voltage generates by the rotor of control transformer is equal to the cosine of the angle between the rotors of the transmitter and the controller. The voltage is given as

$$e(t) = k'V_r Cos\emptyset Sin\omega_c t$$

Where φ – angular displacement between the rotor axes of transmitter and controller. Φ – 90º the axis between the rotor of transmitter and control transformer is perpendicular to each other. The above figure shows the zero position of the rotor of transmitter and receiver.

Consider the position of the rotor and the transmitter is changing in the same direction. An angle θ_R deflects the rotor of the transmitter and that of the control transformer is kept θ_C. The total angular separation between the rotors is $\Phi = (90° - \theta_R + \theta_C)$

The rotor terminal voltage of the Synchro transformer is given as

$$e(t) = k'V_r Cos(90° - \theta_R + \theta_C) Sin\omega_c t$$

$$e(t) = k'V_r Sin(\theta_R - \theta_C) Sin\omega_c t$$

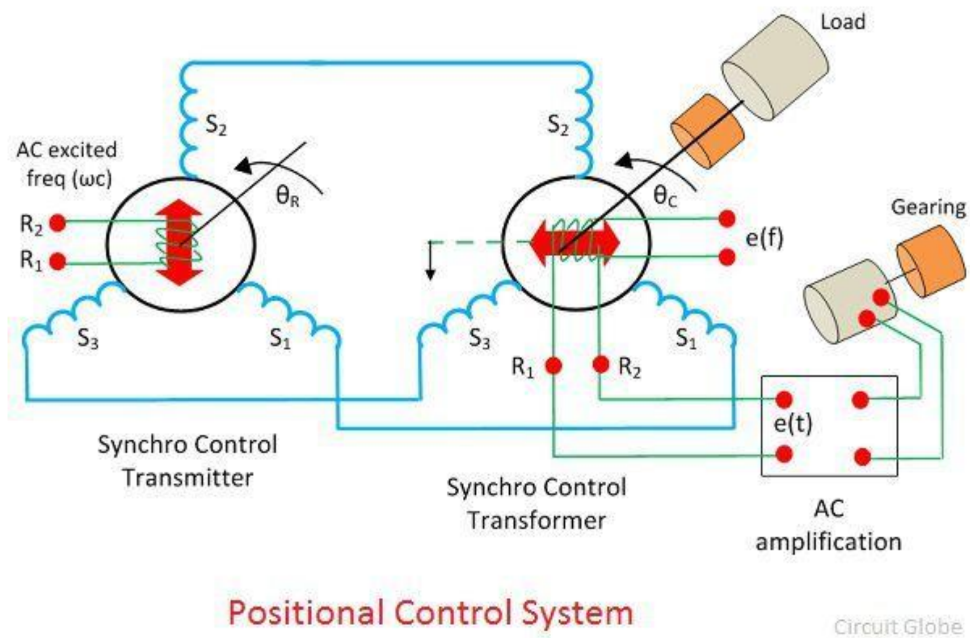
The small angular displacement between their rotor position is given as

$Sin(\theta_R - \theta_C) = (\theta_R - \theta_C)$

On substituting the value of angular displacement in equation (1) we get

$$e(t) = k'V_r Cos\emptyset Sin\omega_c t$$

The synchro transmitter and the control transformer together used for detecting the error. The voltage equation shown above is equal to the shaft position of the rotors of control transformer and transmitter



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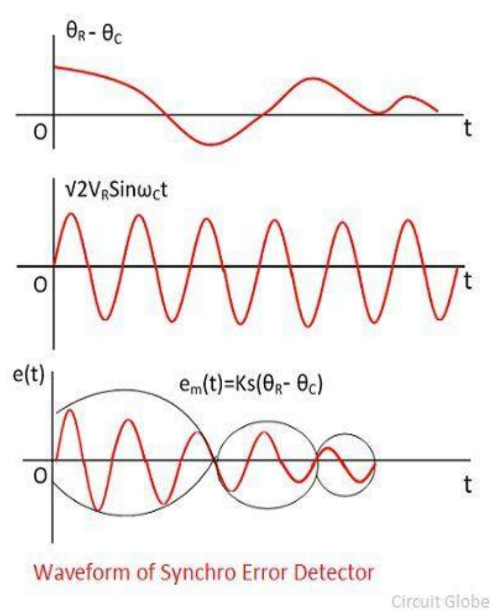
The error signal is applied to the differential amplifier which gives input to the servo motor. The gear of the servo motor rotates the rotor of the control transformer



The figure above shows the output of the synchro error detector which is a modulated signal. The modulating wave above shown the misalignment between the rotor position and the carrier wave.

$$e(t) = (\theta_R - \theta_C)$$

Where K_s is the error detector.

UNIT-IV

4.1 Radiation sensors

Intro Radiation sensors are devices used to detect and measure different types of radiation, such as alpha, beta, gamma, and x-rays. They are used in a variety of applications, including nuclear power plants, medical imaging, and radiation therapy. Some common types of radiation sensors include Geiger counters, scintillation detectors, and gas-filled detectors.

Working

Radiation sensors work by detecting ionizing radiation, which is a type of energy that can knock electrons out of atoms, creating ions. The basic working principle of a radiation sensor is that ionizing radiation interacts with a detector material, causing a change in electrical properties, such as current or voltage. This change is then processed and converted into a measurement of the radiation's strength and type. Different types of radiation sensors use different detector materials, such as gas, scintillators, or semiconductors, and employ different methods to measure the electrical properties of the detector material, such as ionization or excitation.

Characteristics

characteristics that determine their performance and suitability for different applications. These include:

Sensitivity: This is the minimum amount of radiation that a sensor can detect. The lower the sensitivity, the more sensitive the sensor is.

Linearity: This is the degree to which the sensor's output is proportional to the radiation's strength. A sensor with high linearity will produce accurate measurements over a wide range of radiation levels.

Energy response: This is the range of radiation energies that a sensor can detect. Some sensors are only able to detect specific types of radiation, such as gamma or beta, while others have a broader energy response.

Spectral response: This is the range of radiation wavelengths that a sensor can detect. Some sensors are sensitive to a broad range of wavelengths, while others are only sensitive to specific wavelengths.

Dynamic range: This is the range of radiation levels that a sensor can measure. A sensor with a high dynamic range can measure both low and high levels of radiation.

Temperature sensitivity: This is the degree to which a sensor's performance is affected by changes in temperature. Some sensors are more temperature-sensitive than others.

Time response: This is the amount of time it takes for a sensor to respond to a change in radiation levels. Some sensors have a faster time response than others.

Size and weight: This is the physical size and weight of a sensor. Some sensors are small and lightweight, making them suitable for portable applications, while others are larger and heavier, making them more suitable for fixed installations

4.2 Photoresistor:

A photoresistor, also known as a light-dependent resistor (LDR), is a type of resistor whose resistance changes in response to the amount of light that falls on it. Photoresistors are widely used in applications such as light-sensitive alarms and automatic lighting control systems. They are typically made of semiconductor materials, such as cadmium sulfide (CdS) or cadmium selenide (CdSe)

Working

Photoresistors are made of a semiconductor material, such as cadmium sulfide or cadmium selenide, that changes its electrical resistance in response to light.

When light is shone on the semiconductor material, it excites electrons in the material, making them more mobile.

As the number of mobile electrons increases, the resistance of the material decreases.

The resistance of a photoresistor changes in proportion to the intensity of the light falling on it.

Photoresistors can be used in a circuit to control the amount of current flowing through it, depending on the light level.

They can be used in applications such as light-sensitive alarms, automatic lighting control systems, and exposure meters in photography.

Photoresistors are typically small, inexpensive, and easy to use, making them a popular choice for many applications requiring light sensing.

There are several types of photoresistors, including:

Cadmium sulfide (CdS) photoresistor: This is one of the most common types of photoresistor. It is made of a thin film of cadmium sulfide that changes its resistance in response to light. CdS photoresistors have a wide spectral response and are relatively inexpensive.

Cadmium selenide (CdSe) photoresistor: This type of photoresistor is similar to CdS photoresistor but it is made of cadmium selenide.

Lead sulfide (PbS) photoresistor: This type of photoresistor is made of a thin film of lead sulfide. It has a lower sensitivity than CdS or CdSe photoresistor but it has a higher spectral response.

Silicon photoresistor: This type of photoresistor is made of silicon and it is sensitive to light in the infrared range. It has a higher sensitivity than CdS or CdSe photoresistor but it has a lower spectral response.

Organic Photoresistor: These are photoresistor made from organic materials and have a wide range of spectral response, low cost, and flexibility to suit different application requirements

The **photovoltaic effect** is the phenomenon where a material generates a voltage and/or electric current when exposed to light. This effect occurs in certain semiconducting materials, such as silicon, when photons of light are absorbed by the material, exciting electrons from the valence band to the conduction band. This creates a flow of current, or photocurrent, which can be harnessed to generate electricity. Photovoltaic cells, also known as solar cells, are devices that utilize the photovoltaic effect to convert sunlight into electricity. They are made of semiconductor materials such as silicon, and they can be connected together in a solar panel to generate a higher voltage or current.

A **photodetector** is a device that converts light energy into an electrical current or voltage. Photodetectors are used in a wide range of applications, including optical communication systems, medical imaging, and scientific research. There are several **types of photodetectors,** including:

Photoconductive detectors: These detectors are made of a semiconductor material, such as silicon or germanium, that changes its electrical conductivity when exposed to light.

Photovoltaic detectors: These detectors use the photovoltaic effect to convert light energy into electrical energy. They are commonly made of materials such as silicon, cadmium telluride, and copper indium gallium selenide.

Photodiode: A p-n junction diode that generates a current when exposed to light, this is the most common type of photodetector.

Photomultiplier: A vacuum tube device that amplifies the current generated by a single photon of light, used mainly in low light level applications.

Avalanche Photodiode: A photodiode that uses the avalanche effect to provide a high gain, used mainly in fiber optics communication and other high-speed applications.

Each type of photodetector has its own unique set of characteristics, such as sensitivity, linearity, spectral response, and dynamic range, which determine its suitability for different applications.

Working of photodiode: Photodiodes are semiconductor devices that convert light energy into an electrical current.

They consist of a p-n junction, which is a boundary between a p-type semiconductor and an ntype semiconductor.

When light is shone on the photodiode, it creates electron-hole pairs in the p-n junction.

These electron-hole pairs generate a current that flows through an external circuit.

4.3 X- Ray sensors An X-ray sensor is a device that detects X-rays and converts them into an electrical signal. They are used in a wide range of applications such as medical imaging, security scanners, and industrial inspection. There are several types of X-ray sensors, including flat panel detectors, computed radiography systems, and film-based systems.

Working: X-ray sensors work by detecting X-ray radiation and converting it into an electrical signal.

They consist of a scintillator material, which absorbs X-rays and emits light in response.

The emitted light is then detected by a photodetector, such as a photodiode, which converts it into an electrical signal.

The electrical signal is then processed and analyzed to produce an image of the object being scanned.

The X-ray sensors are used in various applications such as medical imaging, industrial inspection, and security imaging.

4.4 Nuclear radiation sensors

Nuclear radiation sensors detect and measure ionizing radiation, which includes alpha particles, beta particles, gamma rays, and x-rays.

They typically consist of a detector material, such as scintillator, gas, or solid-state, that absorbs the ionizing radiation and produces an electrical signal.

They typically consist of a detector material, such as scintillator, gas, or solid-state, that absorbs the ionizing radiation and produces an electrical signal.

The electrical signal is then processed and analyzed to produce a measurement of the radiation level.

They can be classified into two types: gas-based detectors and solid-state detectors, each with their own advantages and disadvantages.

They are commonly used in nuclear power plants, medical imaging, and radiation protection.

Nuclear radiation sensors are important for monitoring and controlling exposure to ionizing radiation to ensure safety for both people and the environment.

4.5 Fiber optics sensors

● Fiber optic sensors are devices that use optical fibers as the sensing element to detect various physical, chemical, and biological parameters.

● They are based on the principle that light traveling through an optical fiber can be modulated by changes in the surrounding environment.

● The sensor converts the physical parameter of interest (such as temperature, pressure, or strain) into a change in the light intensity, phase, or wavelength, which is then detected by a photodetector and converted into an electrical signal.

● Fiber optic sensors are highly sensitive, immune to electromagnetic interference, and can be used in harsh environments. They are used in a wide range of applications including telecommunications, medicine, industrial process control, and structural monitoring.

Working

● The sensor consists of an optical fiber that is made of a core of a transparent material (such as glass or plastic) surrounded by a cladding material with a lower refractive index.

● Light is launched into the optical fiber through one end, and it travels through the core due to the total internal reflection at the core-cladding interface.

● When the physical parameter of interest (such as temperature, pressure, or strain) changes, it causes a change in the refractive index of the core or the cladding.

● This in turn causes a change in the intensity, phase or wavelength of the light travelling through the fiber.

● The sensor detects this change by measuring the light at the other end of the fiber using a photodetector, which converts the light into an electrical signal.

● This electrical signal can be further analyzed to extract the desired measurement of the physical parameter.

4.6 Electro analytical sensors

Electroanalytical sensors are a type of sensor that utilizes an electrical measurement method to detect and quantify a specific analyte (a substance or ion being measured). They use the principle of electrochemical reactions and the subsequent changes in electrical current, voltage, or impedance to detect the presence of an analyte. Examples include pH sensors, glucose sensors, and oxygen sensors.

The Electrochemical Cell

● An electrochemical cell is a device that converts chemical energy into electrical energy or vice versa.

● It comprises of two electrodes, one is called the anode and the other is called the cathode, separated by an electrolyte.

● The anode is the electrode where oxidation takes place and the cathode is the electrode where reduction takes place.

● The electrolyte is a solution or a solid that conducts ions and allows the flow of electric current between the electrodes.

● The overall process that takes place in the electrochemical cell is called an electrochemical reaction.

● When the two electrodes are dipped into the electrolyte, an electric current flows through the external circuit.

● The overall cell reaction is the sum of the half-cell reactions, and the direction of the overall cell reaction is determined by the relative Gibbs free energy change of the halfcell reactions.

Sensors using electrochemical cell:

pH sensors: These sensors use an electrochemical cell consisting of a glass electrode and a reference electrode, which are both immersed in an electrolyte solution. The sensor measures the potential difference between the electrodes, which is related to the pH of the solution.

Glucose sensors: These sensors use an electrochemical cell to measure the glucose concentration in blood or other bodily fluids. The sensor typically consists of a glucose oxidase enzyme-coated electrode that catalyzes the oxidation of glucose, generating hydrogen peroxide and an electron. The resulting current is proportional to the glucose concentration.

Oxygen sensors: These sensors use an electrochemical cell to measure the concentration of dissolved oxygen in a liquid or gas. The sensor typically consists of a cathode and an anode, which are both immersed in the sample. The cathode catalyzes the reduction of oxygen, generating an electron, while the anode catalyzes the oxidation of a chemical species, generating a current that is proportional to the oxygen concentration.

Carbon Monoxide (CO) sensors: These sensors use electrochemical cells to detect the presence of CO. The sensor typically consists of an electrode coated with a catalytic material that reacts with CO to generate an electrical signal that is proportional to the amount of CO present.

Chlorine (Cl_2) sensors: These sensors use an electrochemical cell to detect the presence of chlorine gas.

4.7 Cell potential

Cell potential, also known as electrode potential or electromotive force (EMF), is a measure of the driving force for an electrochemical reaction in an electrochemical cell. It is the difference in electric potential between the anode and cathode of an electrochemical cell. The cell potential is measured in volts (V) and it is the energy per unit charge that is required to move an electron from the anode to the cathode. In other words, it is the energy required to move an electron from the anode material to the cathode material. The cell potential is determined by the standard electrode potentials of the anode and cathode, as well as the concentrations of the species involved in the half-cell reactions and the temperature.

Standard hydrogen electrode (SHE):

- The Standard Hydrogen Electrode (SHE) is a reference electrode used in electrochemistry. It is defined as having a potential of zero volts with respect to the vacuum level of the electron.

- The electrode is made up of a platinum wire that is dipped in a solution of hydrogen ions (H^+) and used to measure the potential of other electrodes.

- The SHE is based on the reaction of hydrogen gas with an electrode material, where H_2 gas is converted to H^+ ions and electrons at the electrode surface.

- The electrode reaction is given by: $H_2\ (g) + 2e^- \rightarrow 2H^+\ (aq)$, where the electrons are transferred from H_2 to the electrode.

- The standard hydrogen electrode is widely used as a reference electrode in many electrochemical measurements, and it is often used to measure the standard electrode potentials of other metal ions.

4.8 Liquid junction potential

A liquid junction potential (LJP) is the potential difference that develops across the interface of two immiscible electrolyte solutions (IES) when they are in contact. This potential difference arises due to the difference in ion concentrations between the two solutions, and it can affect the measurement of electrochemical sensors such as pH sensors and reference electrodes. The liquid junction potential depends on the ionic strength, temperature, and composition of the solutions. It is usually small, but it can become significant when the solutions have a large difference in ionic strength, or when the electrochemical sensor has a high internal resistance.

The liquid junction potential can be minimized by using a salt bridge, which is an electrolyte solution that connects the two solutions, and helps to balance the ionic concentrations across the interface. Another method to minimize the LJP is by using a reference electrode with a high internal resistance, which can help to reduce the current flowing through the junction. This can help to minimize the effect of LJP on the measurement

4.9 Polarization

Polarization in electroanalytical sensors refers to the phenomenon where the current measured by the sensor deviates from the ideal behavior due to the interaction of the electrode surface with the analyte species. This interaction results in the formation of a layer of adsorbed species on the electrode surface, which can affect the transfer of electrons between the electrode and the analyte.

There are two main types of polarization:

Activation polarization: This type of polarization occurs due to the activation energy required to initiate the electrochemical reaction at the electrode surface. It results in a reduction of the current measured by the sensor.

4.10 Concentration polarization: This type of polarization occurs when the analyte concentration near the electrode surface becomes different from the bulk concentration. It results in a reduction of the current measured by the sensor.

Polarization can be reduced by using higher electrode surface area, increasing the scan rate, and using a suitable modifier on the electrode surface.

Polarization can also be minimized by using more sensitive electrode materials, such as carbon nanotubes, or by using advanced techniques such as electrochemical impedance spectroscopy (EIS) to probe the electrode-analyte interface.

Concentration polarization:

● Concentration polarization is a phenomenon that occurs when the concentration of an analyte near the electrode surface is different from the bulk concentration. This can occur due to the slow mass transport of the analyte towards the electrode surface.

● It leads to a reduction of the current measured by the sensor and can affect the accuracy of the sensor measurement.

● The degree of concentration polarization is dependent on the rate at which the analyte can reach the electrode surface, which is related to the physical properties such as the diffusivity of the analyte in the solution.

● Concentration polarization can be reduced by increasing the rate of mass transport of the analyte to the electrode surface, for example, by increasing the stirring rate, or by using a porous electrode.

● Another method to minimize concentration polarization is by using a reference electrode with a high internal resistance, which can help to reduce the current flowing through the junction. This can help to minimize the effect of concentration polarization on the measurement.

4.11 Reference electrode:

A reference electrode is an electrode that is used as a reference point for measuring the potential of other electrodes in an electrochemical circuit.

Reference electrodes are usually constructed with a stable and well-defined electrode potential, and they are chosen based on their stability and reproducibility.

They are typically composed of a metal or metal salt that is in contact with an st commonly used reference electrode is the silver chloride electrode, which has a stable electrode potential of about 0.222V.

Other common reference electrodes include the Ag/AgCl electrode, and the saturated calomel electrode (SCE).

The reference electrode is usually connected to the electrochemical cell through a salt bridge or porous frit, which helps to balance the ionic concentrations between the cell and the reference electrode.

The choice of reference electrode depends on the application, and it should be compatible with the electrolyte solution and the measurement conditions.

The **relationship between reference electrodes and sensors** is that reference electrodes are used as a reference point for measuring the potential of other electrodes in an electrochemical sensor.

An electrochemical sensor typically consists of a working electrode, a counter electrode, and a reference electrode. The working electrode is where the electrochemical reaction takes place, the counter electrode completes the circuit and the reference electrode provides a stable and well-defined electrode potential for measuring the potential of the working electrode.

The reference electrode is used as a benchmark for measuring the potential of the working electrode, which is directly related to the concentration of the analyte being measured. The potential difference between the working electrode and the reference electrode is measured, and this measurement is used to calculate the concentration of the analyte.

Reference electrodes are essential for accurate and precise measurements in electrochemical sensors, as they provide a stable and well-defined electrode potential, which is necessary for accurate and reproducible measurements.

4.12 Sensor electrodes

Sensor electrodes are components of sensors that are used to detect and measure a specific physical or chemical property. They are typically made of a conductive material, such as metal or semiconductor, and are used to convert the measured physical or chemical property into an electrical signal that can be read by the sensor.

There are two main types of sensor electrodes: working electrodes and counter electrodes. The working electrode is the electrode that comes into direct contact with the analyte and is responsible for the electrochemical reaction that takes place. The counter electrode completes the circuit and provides a path for the electrons to flow.

Sensor electrodes can come in different forms and shapes, such as planar, disk, wire, or nanoparticles. They can also be made from different materials, such as gold, platinum, carbon, or semiconductors like silicon. The choice of electrode material depends on the application and the analyte being measured.

Sensor electrodes are used in a wide range of sensors, including electrochemical sensors, potentiometric sensors, and amperometric sensors, to name a few. They are used to detect and measure a wide range of physical and chemical properties, such as pH, glucose, oxygen, and many more.

4.13 Electro ceramics in gas media

● Electroceramics in gas media refers to the use of ceramic materials in gas sensing applications.
● Ceramic materials are used in gas sensors because of their high thermal stability, chemical durability, and ability to withstand harsh environments.

● The most common type of electroceramic gas sensor is the solid-state gas sensor, which uses a ceramic material as the sensing element.

● These sensors operate by measuring the electrical properties of the ceramic material, such as resistance or conductivity, which change in response to the presence of a gas.

● The most common types of electroceramic materials used in gas sensing applications are metal oxides, such as tin oxide (SnO_2), zinc oxide (ZnO), and tungsten oxide (WO_3).

● These materials have a high sensitivity to a wide range of gases, including oxygen, carbon monoxide, and nitrogen oxides.

● Electroceramic gas sensors can be used in a wide range of applications, including environmental monitoring, industrial process control, and automotive emissions control.

● They are also used in the detection of volatile organic compounds (VOCs), which are found in many industrial and household products.

Working:

● The sensor has a ceramic material such as metal oxides (SnO_2, ZnO, WO_3) as the sensing element.

● When the sensor is exposed to a specific gas, the ceramic material interacts with the gas molecules, resulting in a change in its electrical properties.

● The sensor measures the electrical properties (resistance or conductivity) of the ceramic material.

● The sensor circuit compares the measured electrical properties with a reference value to determine the concentration of the gas present in the environment.

● The sensor outputs a signal that can be read by an external device or a control system, indicating the concentration of the gas in the environment.

UNIT-V

5.1 Smart sensors

● Smart sensors are devices that can detect, measure, and transmit information about the environment or a specific physical or chemical phenomenon.

● They often include a microcontroller and other electronic components to process and transmit the data they collect.

● Smart sensors are used in a wide range of applications, including industrial automation, medical devices, smart homes, and the Internet of Things (IoT).

● They are also used in cars, appliances and other everyday objects to collect data and improve functionality.

Characteristics of smart sensors

Intelligence: Smart sensors have the ability to process and analyze sensor data, making decisions and taking actions based on that data.

Connectivity: Smart sensors are connected to a network, allowing them to communicate with other devices and systems.

Autonomy: Smart sensors are able to operate independently, without the need for constant human monitoring or intervention.

Adaptability: Smart sensors are able to adapt to changing conditions and environments, making them highly flexible and versatile.

Self-diagnostics: Smart sensors are able to perform self-diagnostics, detecting and reporting any issues or malfunctions.

Low power consumption: Smart sensors are designed to be energy efficient, consuming minimal power while in operation.

Miniaturization: Smart sensors are often small and compact, making them easy to install and integrate into various environments.

Multi-functional: Smart sensors are able to perform multiple functions, such as sensing, processing, and communication.

Robustness: Smart sensors are designed to be durable and resistant to harsh environments, ensuring long-term reliability.

Scalability: Smart sensors can be easily integrated into larger systems, allowing for scalability and flexibility in deployment.

Working of smart sensors:

1. Smart sensors gather data from the environment through a variety of sensing mechanisms.

2. The sensor then processes and analyzes the data, making decisions and taking actions based on that data.

3. Smart sensors communicate with other devices and systems through a network connection, allowing for the sharing of data and control.

4. Smart sensors can operate independently, without the need for constant human monitoring or intervention, making them highly efficient and effective.

Components of smart sensors:

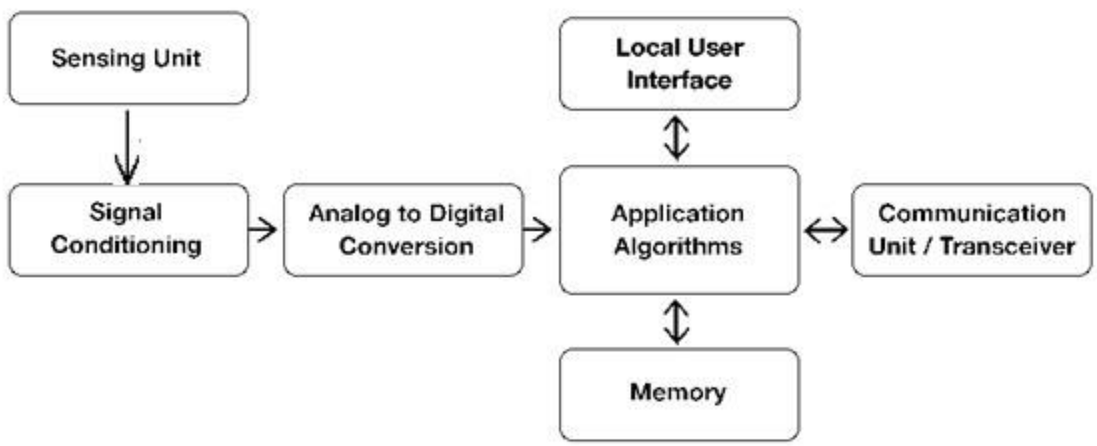


Fig: Smart Sensor Block Diagram

Sensing Element: The part of the sensor that directly interacts with the environment and converts physical parameters (such as temperature, humidity, light, etc.) into a measurable signal.

Signal Conditioning Circuit: This circuit processes the raw signal from the sensing element to provide a stable and accurate output signal that can be easily read and interpreted by other electronic devices.

Microcontroller or Processor: This is the brain of the sensor, responsible for the decision making and data processing, it can be a microcontroller or a microprocessor.

Memory: This stores the sensor's program, data, and settings.

Power Management: A power management circuit that regulates the sensor's power supply and ensures that the sensor has a stable and consistent power source.

Communication Interface: This allows the sensor to communicate with other devices and systems, it could be wired or wireless, such as USB, Ethernet, Zigbee, Z-wave, Bluetooth, etc.

Enclosure: The physical housing or casing that protects the sensor's components from external factors such as dust, moisture, and impact.

Additional features such as security, encryption and self-diagnostics could be added to the sensor depending on its application.

5.2 Primary sensors

Temperature sensors: These sensors measure the temperature of the environment or an object. They can be used in a wide range of applications, including HVAC systems, medical devices, and industrial processes.

Humidity sensors: These sensors measure the amount of moisture in the air. They are commonly used in weather stations, HVAC systems, and agriculture.

Light sensors: These sensors measure the intensity of light in the environment. They can be used to control lighting systems, measure visibility, and determine the time of day.

Pressure sensors: These sensors measure the force exerted on a surface. They can be used to measure blood pressure, altitude, and the pressure of gases and liquids.

Proximity sensors: These sensors detect the presence or absence of objects within a certain distance. They can be used in automation systems, robotics, and mobile devices.

Accelerometer: These sensors detect changes in acceleration and can be used to measure vibration, tilt, and movement.

Gyroscopic sensors: These sensors detect changes in rotation and can be used to measure orientation and angular velocity.

Magnetic sensors: These sensors detect changes in magnetic field and can be used to measure direction, position and motion.

Chemical sensors: These sensors detect the presence of specific chemicals or gases in the environment and can be used in a wide range of applications such as environmental monitoring, medical diagnostics, and industrial process control

5.3 Excitation

In smart sensors, the excitation is the process of applying a stimulus or input to the sensor in order to measure or detect a specific physical or chemical phenomenon. The type of excitation used will depend on the sensor and the application.

For example, in a **temperature sensor**, the excitation may be a small electrical current that is passed through a thermistor (a type of resistor that changes resistance with temperature). The change in resistance is then measured and used to determine the temperature of the environment.

In a **pressure sensor**, the excitation may be a small amount of pressure applied to a diaphragm, which then moves and changes the resistance of a strain gauge. The change in resistance is then used to determine the pressure being applied.

In a **chemical sensor**, the excitation may be a change in temperature, light, or an applied electrical current, which causes a chemical reaction in the sensor and produces a measurable signal.

In a **smart door lock**, the excitation may be the fingerprint or the code entered by the user, the sensor will detect this and send a signal to the home automation system to unlock the door.

In a **smart window sensor**, the excitation may be the change in light or temperature, this will allow the sensor to send a signal to the home automation system to open or close the window accordingly.

In **humidity sensors**, the excitation is the process of applying a stimulus or input to the sensor in order to measure the moisture content in the air.

The excitation can also be a change in movement, angle, or direction, etc. It is important that the excitation applied is within the range of the sensor and also the excitation should be stable and consistent, otherwise the measurement will be affected.

5.4 Amplification

1. Amplification in smart sensors refers to the process of increasing the amplitude or strength of a weak electrical signal from the sensing element.

2. This is done to make the signal stronger and more easily readable by the other electronic components in the sensor, such as the microcontroller or processor.

3. The amplification process is typically performed by an amplifier circuit, which is a type of electronic circuit that uses transistors or operational amplifiers (op-amps) to increase the amplitude of the input signal.

4. The amplifier circuit takes the weak output signal from the sensing element and applies a voltage or current gain to it, making it stronger.

5. There are different types of amplifier circuits that can be used in smart sensors, depending on the specific requirements of the sensor and the application.

6. For example, some sensors use a differential amplifier circuit, which amplifies the difference between two input signals, while others use an operational amplifier circuit, which is a versatile and widely used type of amplifier circuit.

7. In some cases, the amplification process is also used to change the impedance of the sensor output to match the input impedance of the signal processing circuit. This is done to prevent loss of signal and noise pickup.

Differential amplification:

1. Differential Amplification is a type of amplification that amplifies the difference between two input signals, rather than amplifying a single input signal.

2. It is used to reject common-mode signals that appear on both inputs and to provide high common-mode rejection ratio (CMRR) which makes it useful in smart sensors. 3. It is common in smart sensors which use multiple sensing elements and sensors that measure physical parameters with high precision.

Operational amplification:

1. Operational Amplifiers (Op-amps) are integrated circuits that are designed to perform mathematical operations on electrical signals.

2. They are widely used in smart sensors for various signal processing applications such as amplification, filtering, and signal conditioning.

3. Op-amps have high input impedance and low output impedance which allows them to amplify weak signals from the sensing element.

4. They are voltage amplifiers, meaning that they amplify the voltage difference between the input and output terminals.

5. Op-amps are versatile and can be configured in many different ways, such as single-ended, differential, and instrumentation amplifiers.

5.5 Filters

Filters are electronic circuits that are used to separate or isolate certain frequency components of a signal from others. In smart sensors, filters are used to remove unwanted noise or interference from the sensor's output signal, making the signal more accurate and reliable. There are different types of filters that can be used in smart sensors, depending on the specific requirements of the sensor and the application.

Low-Pass Filter: This type of filter allows low-frequency signals to pass through while attenuating high-frequency signals. This is useful for removing highfrequency noise from the sensor's output signal.

High-Pass Filter: This type of filter allows high-frequency signals to pass through while attenuating low-frequency signals. This is useful for removing lowfrequency noise or DC offset from the sensor's output signal.

Band-Pass Filter: This type of filter allows signals within a specific frequency range to pass through while attenuating signals outside of that range. This is useful for isolating a specific frequency component of the sensor's output signal.

Band-Stop Filter: This type of filter attenuates signals within a specific frequency range while allowing signals outside of that range to pass through. This is useful for removing a specific frequency component of the sensor's output signal.

Digital filters: These are filters that are implemented using digital signal processing (DSP) techniques, they are often used in smart sensors because of the flexibility, precision and low power consumption.

Overall, filters are an important component of smart sensors, helping to improve the accuracy and reliability of the sensor's output signal by removing unwanted noise or interference.

5.6 Converters

Converters, also known as signal converters, are electronic circuits that are used to convert the sensor's output signal from one form to another. In smart sensors, converters are used to convert the sensor's output signal from an analog form to a digital form, or vice versa, depending on the specific requirements of the sensor and the application.

Analog-to-Digital Converter (ADC): This type of converter is used to convert an analog signal, such as a voltage or current, into a digital signal, such as a stream of binary digits (bits). This is useful for sensors that output an analog signal, but the processing and storage of the data is done digitally.

Digital-to-Analog Converter (DAC): This type of converter is used to convert a digital signal, such as a stream of binary digits (bits), into an analog signal, such as a voltage or current. This is useful for sensors that output a digital signal, but the display or control of the data is done in an analog form.

Pulse Width Modulation(PWM) Converters: These are converters that are used to convert an analog signal into a digital signal that represents the duty cycle of the signal. This is useful for controlling the power and speed of motors and other devices that consume a lot of power.

Frequency-to-Voltage Converters: These are converters that are used to convert a frequency signal into a voltage signal. This is useful for sensors that measure rotation or speed, for example, tachometer sensors.

Current-to-Voltage Converters: These are converters that are used to convert a current signal into a voltage signal. This is useful for sensors that measure current and voltage, for example, Hall effect sensors.

5.7 Compensation

Compensation in smart sensors refers to the process of adjusting or calibrating the sensor's output signal to account for factors that can affect the accuracy and reliability of the sensor's measurement. This can include factors such as temperature, humidity, pressure, and other environmental conditions, as well as the sensor's own characteristics and limitations.

Temperature Compensation: Smart sensors that are sensitive to temperature changes need to have a way of compensating for the changes in order to maintain accuracy. This can be done by using a temperature sensor in conjunction with the primary sensor, and using the temperature sensor's output to adjust the primary sensor's output.

Humidity Compensation: Smart sensors that are sensitive to humidity changes need to have a way of compensating for the changes in order to maintain accuracy. This can be done by using a humidity sensor in conjunction with the primary sensor, and using the humidity sensor's output to adjust the primary sensor's output.

Zero and Span Adjustment: Smart sensors need to have a way of adjusting their output signal to account for any drift or offset that may occur over time. This can be done by adjusting the sensor's zero and span settings to match the expected range of the sensor's output signal.

Nonlinearity Correction: Smart sensors that have a non-linear output need to have a way of compensating for this non-linearity in order to maintain accuracy. This can be done by using a look-up table or a mathematical algorithm to correct the sensor's output signal.

Aging Compensation: Smart sensors that degrade over time need to have a way of compensating for this aging in order to maintain accuracy. This can be done by using a calibration procedure to adjust the sensor's output signal over time.

5.8 Information coding processing

Information processing in smart sensors refers to the process of analyzing, interpreting, and making decisions based on the sensor's output signal. This can include a variety of tasks such as data filtering, data conversion, data compression, data fusion, and decision-making.

Data Filtering: Smart sensors can use data filtering techniques to remove noise or unwanted signals from the sensor's output signal, which can improve the accuracy and reliability of the sensor's measurement.

Data Conversion: Smart sensors can use data conversion techniques to convert the sensor's output signal from one form to another, such as analog-to-digital conversion, digital-to-analog conversion, or frequency-to-voltage conversion. This can help to make the sensor's output signal more compatible with the sensor's processing and control system.

Data Compression: Smart sensors can use data compression techniques to reduce the amount of data that needs to be transmitted or stored, which can help to save on bandwidth and storage space.

Data Fusion: Smart sensors can use data fusion techniques to combine the output of multiple sensors to create a more accurate and reliable measurement. This can be done by using techniques such as Kalman filtering or fuzzy logic.

Decision-Making: Smart sensors can use decision-making techniques to analyze the sensor's output signal and make decisions based on the sensor's measurement. This can include tasks such as pattern recognition, anomaly detection, or control.

5.9 Data communication

Data communication in smart sensors refers to the process of transmitting the sensor's output signal from the sensor to other devices or systems for further processing and analysis. This can include a variety of tasks such as data transmission, data protocol, data security, and data management.

Data Transmission: Smart sensors can use various data transmission methods such as wired or wireless communication to transmit the sensor's output signal to other devices or systems.

Data Protocol: Smart sensors can use various data protocols such as TCP/IP, HTTP, or MQTT to ensure that the sensor's output signal is transmitted in a standardized format that can be easily understood by other devices or systems.

Data Security: Smart sensors can use various data security methods such as encryption, authentication, and access control to protect the sensor's output signal from unauthorized access or tampering.

Data Management: Smart sensors can use various data management methods such as data storage, data backup, and data recovery to ensure that the sensor's output signal is properly stored and can be retrieved if needed.

Remote Access: Smart sensors can allow remote access for monitoring and control by using internet connectivity.

Data communication process in 5 steps

The data communication process in smart sensors can typically be broken down into the following 5 steps:

Data Acquisition: The sensor acquires data from the environment and converts it into an electrical signal.

Data Processing: The sensor processes the acquired data to extract relevant information, such as filtering out noise or converting the data into a more useful format.

Data Transmission: The sensor transmits the processed data to a remote device or system using a wired or wireless communication method such as WiFi, Zigbee, or Bluetooth.

Data Reception: The remote device or system receives the transmitted data and processes it for further analysis or control.

Data Utilization: The received data is used by the remote device or system for various purposes such as monitoring, control, or data analysis.

Overall, the smart sensors data communication process is designed to efficiently transfer sensor data from the sensor to the device or system. The data is processed, filtered, converted and sent in a format that can be easily understood by the remote device or system. The data is then received, processed and used for monitoring, control or further analysis.

Interface

Smart sensor interface are designed to provide a convenient and user friendly way for users to interact with the sensor, allowing them to control, configure or monitor the sensor output signal. A smart sensor interface can include a display, buttons, connectivity options and remote access capabilities.

5.10 Standards for smart sensors interface: IEEE 1451: This standard defines a common interface for smart transducers, which are sensors that include the capability to process and transmit data.

Zigbee: Zigbee is a wireless communication protocol that is widely used in smart home and building automation applications. It provides a standard for wireless communication between smart sensors and other devices.

Bluetooth: Bluetooth is another wireless communication protocol that is widely used in smart home and building automation applications. It provides a standard for wireless communication between smart sensors and other devices.

MQTT: MQTT is a lightweight publish-subscribe messaging protocol that is widely used in the Internet of Things (IoT) for data communication between devices.

OPC UA: OPC UA is a standard for data communication between devices in industrial automation. It provides a secure and reliable communication protocol.

WSN: Wireless sensor network (WSN) standards provide guidelines for the communication between wireless sensors and other devices in a network.

ISO/IEC 14496-10: This standard defines a common interface for multimedia content processing and management.

ISO/IEC 15408: This standard provides guidelines for the evaluation of the security of IT products and systems.

ISO/IEC 27000: This standard provides guidelines for the management of information security.

ISO/IEC 11073: This standard defines a common interface for the management of health informatics devices.

5.11 Automation

Automation using smart sensors involves the use of sensors to gather information about the environment or a specific process, and then using that information to control or adjust the process automatically. This can be done through the use of embedded systems and control systems, which use the sensor data to make decisions and take actions.

Environmental monitoring: Smart sensors can be used to monitor various environmental factors such as temperature, humidity, and air quality, and then take actions to adjust the HVAC system or notify maintenance staff of any issues.

Industrial automation: Smart sensors can be used in industrial settings to monitor and control equipment, such as motors, pumps, and conveyors. This can help to increase efficiency and reduce downtime.

Building automation: Smart sensors can be used in buildings to control lighting, security, and HVAC systems, which can save energy and reduce operating costs.

Transportation: Smart sensors can be used in transportation systems to monitor traffic flow and adjust traffic signals accordingly, reducing congestion and improving safety.

Healthcare: Smart sensors can be used in healthcare settings to monitor vital signs and alert healthcare staff of any issues.

Home sensors

Home automation smart sensors are sensors that are used to automate various functions in a home, such as lighting, temperature control, and security. These sensors use technology such as Zigbee, Z-Wave, or Wi-Fi to communicate with a central hub or controller, which can then be controlled remotely through a smartphone app or voice commands. Some examples of home automation smart sensors include:

Temperature sensors: These sensors can be used to monitor and control the temperature of a room or a whole house, by adjusting the thermostat or turning on/off heating/cooling systems.

Motion sensors: These sensors can detect movement in a room and can be used to turn on lights, adjust the temperature, or trigger an alarm.

Door and window sensors: These sensors can detect when a door or window is opened or closed and can be used to trigger an alarm or send a notification to a smartphone.

Smoke and Carbon Monoxide sensors: These sensors can detect smoke or carbon monoxide and can be used to trigger an alarm or send a notification to a smartphone.

Light sensors: These sensors can detect the level of ambient light and can be used to adjust the brightness of lights in a room or turn them off when not needed.

Water Leak sensors: These sensors can detect water leaks and can be used to trigger an alarm or send a notification to a smartphone.

Sensors Applications

Sensors applications in aerospace Areas such as flight control, navigation, and propulsion.

Accelerometers: These sensors are used to measure acceleration and are used in flight control systems to provide information on the aircraft's speed and direction, as well as in navigation systems to help determine the aircraft's position.

Pressure sensors: These sensors are used to measure the pressure of air or other fluids and are used in propulsion systems to monitor the performance of engines, as well as in navigation systems to help determine the aircraft's altitude.

Temperature sensors: These sensors are used to measure the temperature of the air or other fluids and are used in propulsion systems to monitor the performance of engines, as well as in navigation systems to help determine the aircraft's position.

Proximity sensors: These sensors are used to detect the presence of objects in the aircraft's vicinity, such as other aircraft or obstacles on the runway.

Optical sensors: These sensors use light to detect and measure various parameters, such as distance, position, and velocity. They are used in navigation systems, such as Lidar and cameras, to detect and track other aircraft and obstacles in the airspace.

Magnetic sensors: These sensors are used to measure the strength and direction of magnetic fields and are used in navigation systems to help determine the aircraft's position.

Chemical Sensors: These sensors are used to detect the presence of certain chemicals such as oxygen, fuel, oil, etc. They are used in propulsion systems to monitor the performance of engines and alert the pilot of any issues.

5.12 Sensors in on board automobile

providing real-time information on various parameters that help to improve the performance, safety, and efficiency of vehicles.

Accelerometers: These sensors are used to measure the vehicle's acceleration and are used in systems such as traction control, stability control, and airbag deployment.

Wheel speed sensors: These sensors are used to measure the rotational speed of the wheels and are used in systems such as ABS (Anti-lock Braking System), TCS (Traction Control System), and ESP (Electronic Stability Program)

Engine sensors: These sensors are used to measure various parameters of the engine such as temperature, oil pressure, and airflow. They are used in engine management systems to optimize fuel efficiency and performance.

Oxygen sensors: These sensors are used to measure the level of oxygen in the exhaust and are used in emission control systems to help reduce pollution.

Temperature sensors: These sensors are used to measure the temperature of various components such as the engine, transmission, and brakes. They are used to monitor the performance of these components and alert the driver of any issues.

Position sensors: These sensors are used to measure the position of various components such as the throttle, steering, and transmission. They are used in systems such as cruise control, power steering, and automatic gearbox.

Proximity sensors: These sensors are used to detect the presence of objects in the vehicle's vicinity, such as other vehicles, pedestrians, or obstacles on the road. They are used in systems such as parking assist, lane departure warning, and automatic emergency braking.

Light sensors: These sensors are used to detect the level of ambient light and can be used to adjust the headlights and head-up display.

5.13 Environmental monitoring sensors

Environmental monitoring sensors are used to measure various parameters of the environment such as temperature, humidity, air quality, and atmospheric pressure. These sensors can be used in a variety of applications such as weather forecasting, air pollution monitoring, and climate change research. Some examples of environmental monitoring sensors include:

Temperature sensors: These sensors are used to measure the temperature of the air, water, or soil. They are commonly used in weather forecasting, agriculture, and industrial processes.

Humidity sensors: These sensors are used to measure the relative humidity of the air. They are commonly used in weather forecasting, agriculture, and industrial processes.

Air quality sensors: These sensors are used to measure the concentration of pollutants in the air. They are commonly used in air pollution monitoring, industrial processes, and building ventilation systems.

Atmospheric pressure sensors: These sensors are used to measure the pressure of the atmosphere. They are commonly used in weather forecasting, aviation, and meteorology.

Water quality sensors: These sensors are used to measure various parameters of water such as pH, dissolved oxygen, and conductivity. They are commonly used in water treatment plants, industrial processes, and environmental monitoring.

Soil moisture sensors: These sensors are used to measure the moisture content of the soil. They are commonly used in agriculture and landscaping to optimize irrigation and fertilization.

Radiometric sensors: These sensors are used to measure the amount of radiation in the environment. They are commonly used in weather forecasting, agriculture and industrial processes, and radiation monitoring.

Noise sensors: These sensors are used to measure the level of noise pollution in the environment. They are commonly used in industrial processes, and building acoustics.

Manufacturing environmental monitoring sensors

Manufacturing environmental monitoring sensors typically involves several steps:

Design and development: The first step in manufacturing environmental monitoring sensors is to design and develop the sensor. This involves determining the specific parameters that the sensor will measure and selecting the appropriate sensing technology. Engineers will also design the sensor's electronic circuit, and write software for data processing and communication.

Sourcing materials: Once the sensor design is complete, the manufacturer will source the necessary materials such as semiconductors, electronic components, and mechanical parts.

Assembly: The sensor is then assembled using a combination of manual and automated processes. This may include soldering, bonding, and packaging the sensor.

Testing: After assembly, the sensor is tested to ensure that it is functioning correctly and meets the specifications. The sensor will be calibrated, and the software will be tested to check for any bugs or errors.

Quality control: The sensor will then undergo a series of quality control checks to ensure that it meets the standards set by the manufacturer.

Packaging and shipping: Once the sensor has passed all quality control checks, it will be packaged and shipped to the customer.