MODULE 2: SENSORS, TRANSDUCERS, AND ACTUATORS

Sensors - Introduction, Classification of sensors with examples, Characteristics, Construction and working of Photo-resistive sensor and Thermistor, their applications (qualitative). Numerical Problems.
Transducers: Introduction to Transducers, Types of Transducers. Principle, construction and working of Linear Variable Differential Transformer, Difference between sensor and transducer
Actuators: Introduction to Actuators, Types of Actuators, Working principle of piezoelectric actuator

Sensors: Sensors are devices that detect and measure physical properties or inputs from the physical environment. Sensors can detect various parameters such as temperature, pressure, light, humidity, motion, and many more.

Example: Thermistors: They measure temperature by measuring the change in resistance of the electric current, Photosensors: detect the presence of visible light, infrared transmission, or ultraviolet energy

Transducers: Transducers are a type of sensor that not only detects physical quantities but also converts one form of energy into another. They act as both sensors and actuators, allowing the measurement of a physical parameter and the conversion of that measurement into a usable form. For example, a microphone is a transducer that converts sound waves into electrical signals

Actuators: Actuators are devices that convert electrical signals into physical action or movement. Unlike sensors that measure physical properties, actuators generate a physical response based on the signals they receive. Examples of actuators include motors, solenoids, valves, and relays.

INTRODUCTION – SENSORS

We can find sensors everywhere, and the whole world is full of sensors and their applications. There are many types of sensors available around us, in our offices, gardens, shopping malls, homes, cars, toys etc. These sensors make our lives so easy and comfortable, starting from applications such as switching on the lights, fans, television (TV), automatic adjustment of the room temperature by air conditioning (AC), fire alarm, detecting obstacles when the car is reversing, making a thumb impression etc. A sensor is a device that receives signals as well as responds to a signal or stimulus. We also can say that a sensor is a transducer that converts a nonelectrical value to an electrical value. The output signal of a sensor may be in the form of voltage, current, or charge. A sensor has many forms of input properties and electrical output properties. If there is a small change in the sensed quantity, it will cause a small change in the electrical output and the changes can be detected with their measuring capabilities.

CLASSIFICATION OF SENSORS

All the sensors are categorized on the basis of their uses, applications, materials used, and some production technologies. Some sensors are classified also by their characteristics such as cost, accuracy, or range of the sensor.

Types of Sensors

Passive sensors: A passive sensor does not require any extra energy source for their operation passive sensors rely on the natural energy emitted or reflected by the target. They capture this energy and convert it into electrical signals for measurement. Examples of natural energy sources that passive sensors detect include light, heat, and sound. Since passive sensors do not emit signals themselves, they do not require an external power source to operate. Instead, they rely on the existing energy in the environment to sense and measure physical properties. Examples of passive sensors include camera, infrared sensor, light sensor, Thermometer, and Microphone.

Active sensors: The active sensors need external sources of energy for their operation, known as excitation signals. Unlike passive sensors that rely solely on the energy emitted or reflected by the target, active sensors generate their own signals and emit them towards the target. This means that active sensors need a power source to generate and transmit these signals.

Examples of Active sensors include LiDAR (Light Detection and Ranging): Emits laser pulses and measures the time it takes for the pulses to return after hitting objects.

Sonar sensor: Emits sound waves underwater and measures the time it takes for the waves to bounce back. Used in marine navigation, fish finders, and submarine detection

Analog Sensors: Analog sensors convert an input physical phenomenon into an analogue output, i.e. continuous output signals are produced with respect to the measured quantity, Example, strain gauge, LVDT, thermocouple, or thermistor

Digital sensors: Digital sensors convert input physical phenomena into discrete steps of electrical output which is in the form of pulses.

Examples: Digital temperature sensors, Digital accelerometers

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Difference between passive and active Sensor

Passive sensor	Active sensor
Does not require external power	It requires power
It can only be used to detect energy when the naturally occurring energy is available	Provides its own energy source for illumination
No interference problem in the environment	Less interference problem
Can operate in the same environment condition	Can operate in different environment conditions
Sensitive to weather condition	Not sensitive
Not well suited for darkness conditions	Works well in darkness conditions
Difficulties in interpreting the output signals	Easy to interpret
Less control of noise	Better control of noise
Low price	High price
Examples: camera, Sonar	Examples: LASER, Radar etc

Sensors are also divided by their detection properties

Sensors based on their detection properties

Types	Properties
Thermal sensor	Temperature, heat, flow of heat etc
Electrical sensor	Resistance, current, voltage, inductance, etc
Magnetic sensor	Magnetic flux density, magnetic moment, etc
Optical sensor	Intensity of light, wavelength, polarization, etc
Chemical sensor	Composition, pH, concentration, etc
Pressure sensor	Pressure, force etc
Vibration sensor	Displacement, acceleration, velocity, etc
Rain/moisture sensor	Water, moisture, etc
Speed sensor	Velocity, distance etc

Characteristics

1. **Measurement Range:** The range of values within which a sensor can accurately measure a physical quantity, such as temperature, pressure, or distance. Eg: The temperature range of a thermocouple is 25-225°C
2. **Resolution:** The smallest change the sensor that can be sensed by a sensor. It is also frequently known as the least count of the sensor. The resolution of a digital sensor is easily determined.
3. **Sensitivity:** It is the ratio of change in output to a unit change of the input. The sensitivity of digital sensors is closely related to the resolution. The sensitivity of an analog sensor is the slope of the output vs input line, or a sensor exhibiting truly linear behavior has a constant sensitivity over the entire input range.
4. **Error:** It is the difference between the result of the measurement and the true value of the quantity being measured. The classification of errors are as follows:

- Absolute errors
- Relative error
- Absolute errors = Measured value – True Value
- Relative error = Absolute errors / True Value

5. **Accuracy:** It is the difference between the measured value and true value. The accuracy defines the closeness between the actual measured value and a true value.
6. **Precision:** Precision is the ability to reproduce repeatedly with a given accuracy.
7. **Repeatability:** The ability of a sensor to give the same output for repeated applications of the same input value
8. **Impedance:** It is the ratio of voltage and current flow for the sensor. For a resistive sensor, the impedance Z is the same as the resistance R& its unit is ohms.

   $Z = V/I = R$
9. **Response time:** Response time is the amount of time required for a sensor to respond completely to a change in input. It describes the speed of change in the output on a step-wise change of the measurand
10. **Linearity:** Percentage of deviation from the best fit linear calibration curve. Linearity indicates how well the sensor maintains proportional accuracy

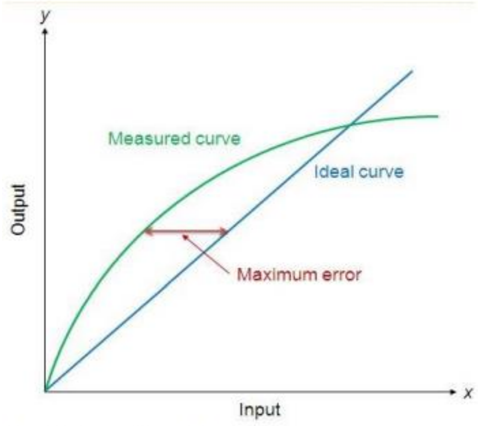


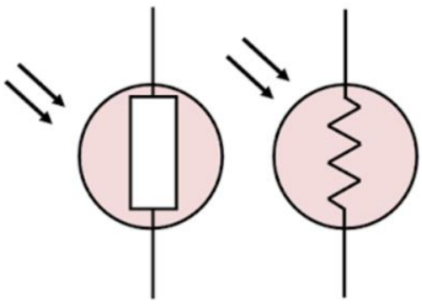
Fig. 3. Non linearity

11. **Dead band/time:** The dead band or dead space of a sensor is the range of input values for which there is no output. The dead time of a sensor device is the time duration from the application of an input until the output begins to respond or change.
12. **Robustness:** The sensor's ability to withstand and operate reliably under various environmental conditions, such as temperature, humidity, or vibration.

Photo-resistive sensor or Light Dependent Resistor (LDR)

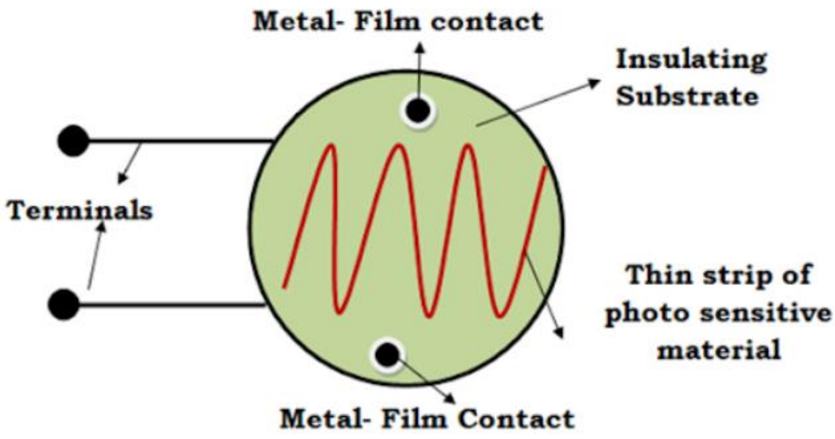
Light Dependent Resistor is called by many names such as photoresistor, photocell, photoconductor, and photoconductive cells. The resistivity of LDR depends on the light incident on it and the sensitivity of LDR depends on the wavelength of the incident light. Thus it is a light-sensitive device. Mostly it is used in circuits to detect the presence of the level of the light.

Symbol of LDR:

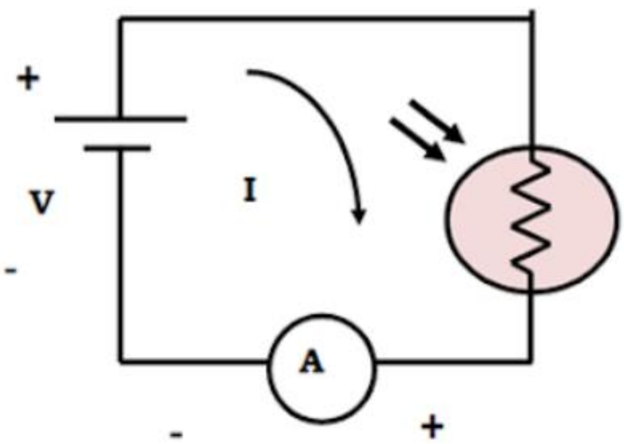


There are many symbols. The most commonly used symbol of LDR is shown in the figure. The arrow in the symbol indicates the light falling on it.

Construction of LDR:



The structure of a light-dependent resistor consists of a light-sensitive material that is deposited on an insulating substrate such as ceramic. The material is deposited in a zigzag pattern in order to obtain the desired resistance and power rating. This zigzag area separates the metal-deposited areas into two regions. Then the ohmic contacts are made on either side of the area. The resistances of these contacts should be as less as possible to make sure that the resistance mainly changes due to the effect of light only. Materials normally used are cadmium sulfide, cadmium selenide, indium antimonide. The whole structure is placed inside a plastic or resin case to have direct exposure to the sunlight. When there is no light the resistance is very high in Mega Ohms. When the light is incident the resistance value decreases and the conductivity increases.

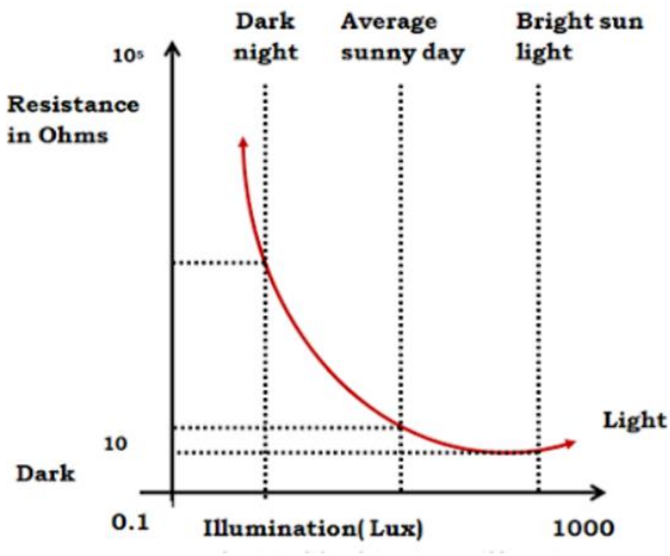


Working Principle of Photo-resistive Sensor or Light Dependent Resistor (LDR):

A **light dependent resistor** works on the principle of photoconductivity. Photo conductivity is an optical phenomenon in which the material's conductivity is increased when light is absorbed by the material. The photoconductive material does not consists of any free electrons or it consists of few free electrons when it is not exposed to light. When light falls i.e. when the photons fall on the device, the electrons in the valence band of the semiconductor material are excited to the conduction band. These photons in the incident light should have energy greater than the band gap of the semiconductor material to make the electrons jump from the valence band to the conduction band. Hence when light having enough energy strikes on the device, more and more electrons are excited to the conduction band which results in large number of charge carriers. The result of this process is more and more current starts flowing throgh the device.Thus resistivity of LDR decreases with increase in the incident light.

Characteristics of LDR

When a **light dependent resistor** is kept in dark, its resistance is very high. This resistance is called as dark resistance. It can be as high as 10^{12} **Ω** and if the device is allowed to absorb light its resistance will be decreased drastically. If a constant voltage is applied to it and intensity of light is increased the current starts increasing. The figure below shows resistance vs. illumination curve for a particular **LDR**. When light is incident on a photocell it usually takes about 8 to 12 ms for the change in resistance to take place, while it takes one or more seconds for the resistance to rise back again to its initial value after removal of light. This phenomenon is called as resistance recovery rate. This property is used in audio compressors. Also, **LDR**'s are less sensitive than photo diodes and photo transistor.



Advantages:

- Low cost
- Available in many shapes and sizes
- Low power operation
- High sensitivity

Disadvantages:

- Large response time- The variation in resistance value is slow to the light action.

Application:

- Used in automatic street lighting
- Used in cameras
- Used in alarm clocks
- Used in burglar circuits
- Used to count objects in conveyor belts

Thermistor

Thermistors, are the device whose resistance changes rapidly with the corresponding change in temperature**.** These are highly sensitive to changes in temperature and, thus widely used in all such applications where temperature measurement is needed. They are made of semiconducting materials.

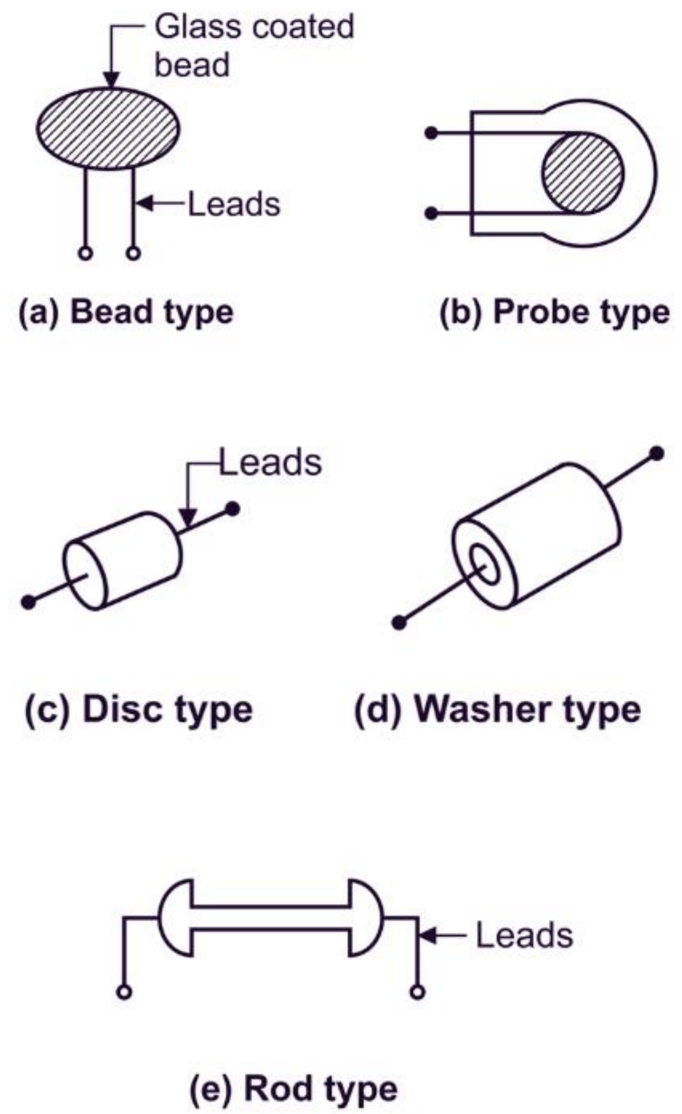
Symbol of Thermistor:

The circuit symbol of the thermistor is shown in the figure.

Construction of Thermistors:

A thermistor is made of oxides of metals such as Nickel, Manganese, Cobalt, Copper, Uranium etc. These metal oxides are mixed in suitable proportion with binders to form a slurry and compressed into desired shapes and sizes. This slurry in the form of small drops is formed over the lead wire after which it is dried and put in a sintering furnace. During sintering, the metallic oxide shrunk onto lead wires and formed electrical connections.

Thermistors are fabricated in different shapes and sizes such as bead, probe, disk, rod washer type etc. The smallest thermistor in these configurations is the bead-type thermistor its diameter is as low as 0.15 mm. The measurement element is typically encapsulated in a glass probe. It is commonly used for measuring the temperature of liquids. The disc, washer-type thermistor, and rod-type thermistor are made into flat cylindrical shapes with diameters of 3mm to 25mm by pressing thermistor material at high pressure. It is used when greater power dissipation is required.



Different forms of thermistors

Working Principle of Thermistors

The thermistor works on the simple principle of change in resistance due to a change in temperature. When the ambient temperature changes the thermistor starts self-heating its elements. Its resistance value is changed with respect to this change in temperature. This change depends on the type of thermistor used. The resistance temperature characteristics of different types of thermistors are given in the following section.

Types of Thermistors

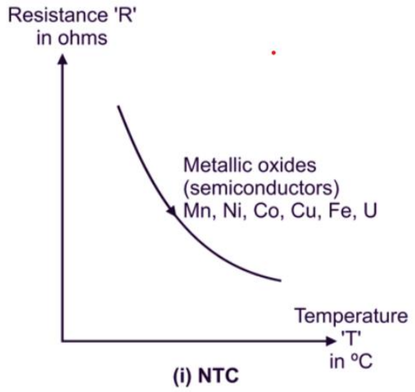
The two basic types of thermistors available are the NTC and PTC types.

NTC Thermistor

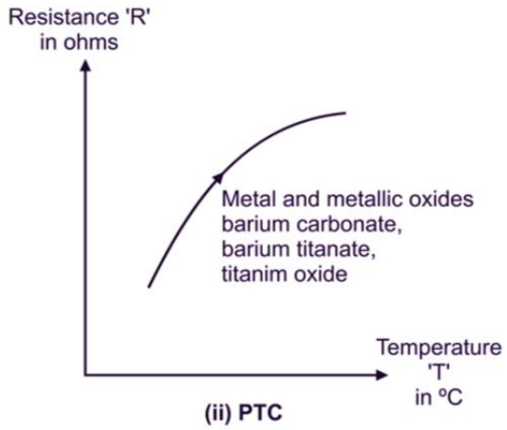
NTC stands for Negative Temperature coefficient. They are ceramic semiconductors that have a high Negative Temperature Coefficient of resistance. The resistance of an NTC will decrease with increasing temperature in a non-linear manner. Materials possessing the property NTC are composed of metallic oxides such as manganese, nickel, cobalt, copper, iron uranium.

PTC Thermistor

PTC thermistors are Positive Temperature Coefficient resistors and are made of polycrystalline ceramic materials. The resistance of a PTC will increase with increasing temperature in a non-linear manner. Materials possessing the property PTCR composed of metals and metal oxides, such as powdered barium carbonate, barium titanate and titanium oxide



(i) NTC



(ii) PTC

Resistance Temperature characteristics of Thermistors

The expression below shows the relationship between the resistance and temperature of thermistors

For PTC

$$R_{T1} = R_{T2} exp[\alpha(T1 - T2)]$$

For NTC

$$R_{T1} = R_{T2} exp\left[\beta\left(\frac{1}{T1} - \frac{1}{T2}\right)\right]$$

R_{T1} = resistance of the thermistor at absolute temperature T_1; ˙K

R_{T2} = resistance of the thermistor at absolute temperature T_2; ˙K

β and α = a constant that depends on thermistor material, typically 3500 to 4500 ˙K

Application of Thermistors:

- PTC Thermistors can be used as current limiting devices for circuit protection, as replacement for fuses
- PTC thermistor can be used as heating element in small temperature controlled ovens
- NTC thermistor are used as resistance thermometers in low temperature measurement of order of 10 K
- NTC thermistor are regularly used in automatic applications

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TRANSDUCERS

Introduction to Transducers:

A transducer is an electronic device that converts energy from one form to another. The process of converting energy from one form to another is known as transduction. In general, these devices deal with different types of energies such as mechanical, electrical energy, light energy, chemical energy, thermal energy, acoustic energy, electromagnetic energy, and so on

Need of a transducer

The input quantity for most instrumentation systems is nonelectrical. In order to use electrical methods and techniques for measurement, the nonelectrical quantity is converted into a proportional electrical signal by a device called a “transducer”.

Advantages of converting a physical quantity into an electrical signal

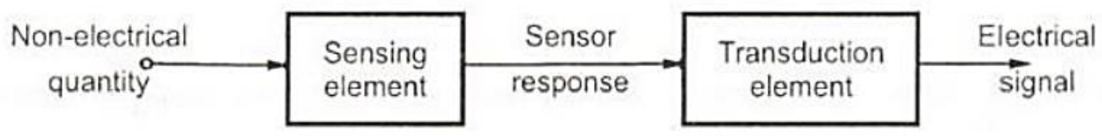
Here, we have listed the various advantages of converting a physical quantity into an electrical signal:

- Electrical signals are easily transmitted and processed for measurement.
- Electrical signals process less friction error.
- Small power is needed to control the electrical systems.
- Amplification and attenuation of electrical signals are easy.
- The measuring instrument used for measuring the electrical signal is very compact and accurate.

Parts of Transducer

An electrical transducer consists of two parts that are very closely related to each other. These two parts are the sensing or detecting element and the transduction element. The sensing or detecting element is commonly known as sensor.

Transducers have other vital parts such as signal processing equipment, amplifiers and power supplies.



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Sensing Element

It is the part of a transducer that responds to the physical sensation. The response of the sensing element depends on the physical phenomenon.

Transduction Element

The transduction element of the transducer converts the output of the sensing element into an electrical signal. The transduction element is also called the secondary transducer

Classifications:

Transducers are classified into several types. However, these can be categorized into five types. They are,

1. Classification on the basis of the transduction principle used.
2. Active and passive transducers
3. Analog and digital transducers
4. Primary and secondary transducers
5. Transducers and inverse transducers.

1. Classification on the Basis of Transduction Principle Used:

This classification is done depending on the transduction principle i.e., how the input variable is being converted into capacitance, resistance, and inductance values. (These are named as capacitive transducer, resistive transducer, and inductive transducer respectively).

Examples of Capacitive Transducer	**Applications**
1. Dielectric gauge. 2. Capacitor Microphone.	1.It is used to measure, (i) Thickness and (ii) Liquid level. 2.It is used to measure, (i) Noise (ii) Speech and Music
Examples of Resistive Transducer	**Applications**
1. Resistance thermometer. 2. Potentiometer device.	1. Used in the measurement or, (i) Temperature and (ii) Radiant heat.

	2. (i) Used in displacement measurement and (ii) Used in pressure measurement
Examples of Inductive Transducer	**Applications**
1. Reluctance pick up. 2. Magnetostriction gauge.	1. It is used to measure, (i) Pressure, (ii) Vibrations,(iii) Position and (iv) Displacement. 2. It is used to measure, (i) Sound, (ii) Force, and (iii) Pressure.

2. Active and Passive Transducers

Active Transducer

The transducer which does not require any external excitation to provide its outputs are referred as an active transducer or self-generating type.

Passive Transducer

The transducer which requires an external excitation to provide its output is referred as passive transducer

Examples of Active Transducer	Applications
1. Photo voltaic cell. 2. Thermocouple.	1. (i) Used in light meters (ii) Used in solar cells. 2. Used to measure, (i) Temperature, (ii) Radiation and (iii) Heat flow.
Examples of Passive Transducer	**Applications**
1. Capacitive transducers. 2. Resistive transducers. 3. Inductive transducers.	1. Used to measure liquid level, noise, thickness etc. 2. Used to measure temperature, pressure, displacement etc. 3.Used to measure pressure, vibration, position, displacement etc.

3. Analog and Digital Transducers

Analog Transducer

The transducer which produces its outputs in analog form or a form which is a continuous function of time is referred as analog transducer.

Digital Transducer

The transducer which produces their outputs in digital form or a form of pulses is referred as a digital transducer.

Examples of Analog Transducers	Applications
1. Strain gauge 2. Thermistor 3. LVDT	1. Used to measure, (i) Displacement (ii) Force and (iii) Torque. 2. Used to measure, (i) Temperature 3. Used to measure i)Displacement
Examples of Digital Transducer	**Applications**
Turbine meter	Used in flow measurement

4. Primary and Secondary Transducers

Primary Transducer

The transducer which sends the measurements and converts them into another variable (like displacement, strain etc.) and whose output forms the input of another transducer is called as primary transducer.

Secondary Transducer

The transducer which converts the output of the first transducer into an electrical output called secondary transducer.

Examples of Primary Transducer	Applications
1. Bourdon tube 2. Strain gauge	1. Used in pressure 2. Used in measurements

Examples of Secondary Transducer	Applications
LVDT	Used to measure, (i) Displacement (ii) Force (iii) Pressure and (iv) Position

5. Transducers and Inverse Transducers

Transducers

A measuring device which measures and converts non-electrical variables into electrical variables is known as a transducer

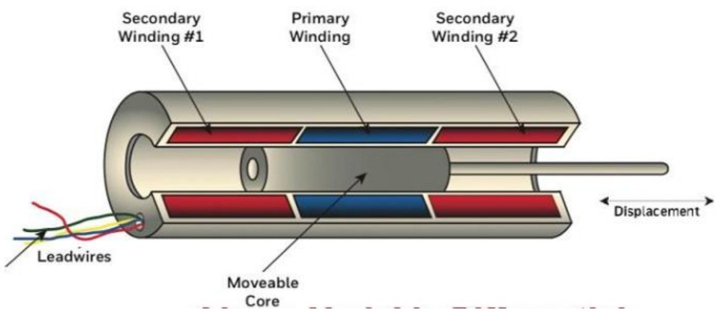
Inverse Transducer

A measuring device which measures and converts an electrical variable into a non-electrical variable is known as an inverse transducer

Example of Transducer	Applications
Thermocouple	Used to measure, (i) Temperature (ii) Radiation and (iii) Heat flow
Example of Inverse Transducers	**Applications**
Piezo-electric crystal	Used to measure, (i) Pressure (ii) Vibration and acceleration

Linear Variable Differential Transformer

The term LVDT stands for the Linear Variable Differential Transformer. It is the most widely used inductive transducer that converts a mechanical displacement proportionally into electrical signal. Its electrical output is obtained because of the difference in secondary voltages, hence it is called a Differential Transformer. It is very accurate inductive transducer as compared to other inductive transducers



Construction of LVDT

•The transformer consists of a primary winding P and two secondary windings S1 and S2 wound on a cylindrical former (which is hollow in nature and contains the core).

• Both the secondary windings have an equal number of turns, and we place them on either side of primary winding

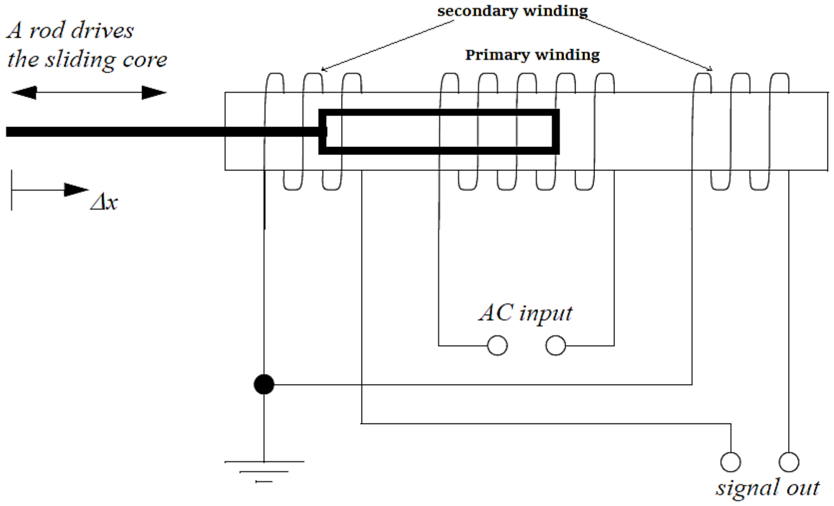
• The primary winding is connected to an AC source which produces a flux in the air gap and voltages are induced in secondary windings.

• A movable soft iron core is placed inside the former and displacement to be measured is connected to the iron core.

• The iron core is generally of high permeability which helps in reducing harmonics and high sensitivity of LVDT.

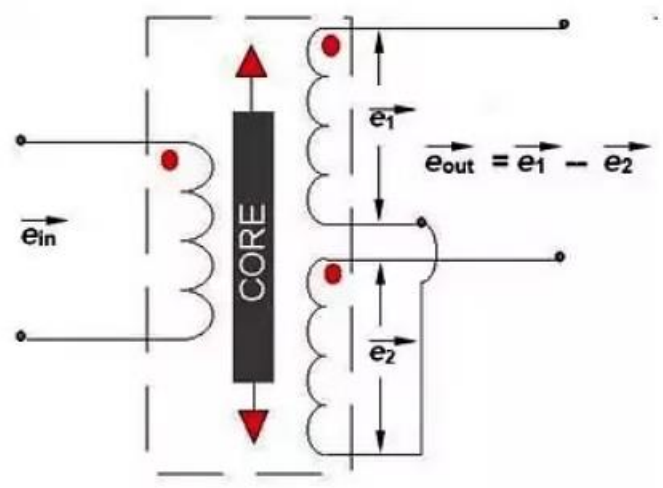
• The LVDT is placed inside a stainless steel housing because it will provide electrostatic and electromagnetic shielding.

• Both the secondary windings are connected in such a way that resulted output is the difference between the voltages of two windings.



Working principle of LVDT

The **working principle of LVDT is based on the mutual induction principle**. When AC excitation of 5-15 Volts at a frequency of 50-400Hz is applied to the primary winding, a magnetic field is produced. This magnetic field induces a mutual current in secondary windings. Due to this, the induced voltages in secondary windings (S1 & S2) are E1 & E2 respectively. Since both the secondary windings are connected in series opposition, the net output voltage will be the difference of both induced voltages (**E1 & E2**) in secondary windings. Hence Differential Output of LVDT will be **E0 = E1 – E2**



Now according to the position of the core, there are three cases that arise

1. **When the core moves towards s1 (max left)**

When the LVDT core moves towards the S1 secondary winding, the flux linkage with S1 is greater than that of S2. As a result, the EMF induced in S1 is larger and E1 > E2. Hence, the net differential output voltage (E0 = E1 – E2) is positive This means the output voltage E0 will be in phase with the primary voltage

2. When the core is at the null position

When the LVDT core is at the null position, the flux linkage with both secondary windings is equal. As a result, the EMF induced in both windings will be the same. Hence, the net differential output voltage (E0 = E1 – E2) is zero, indicating that there is no displacement of the core

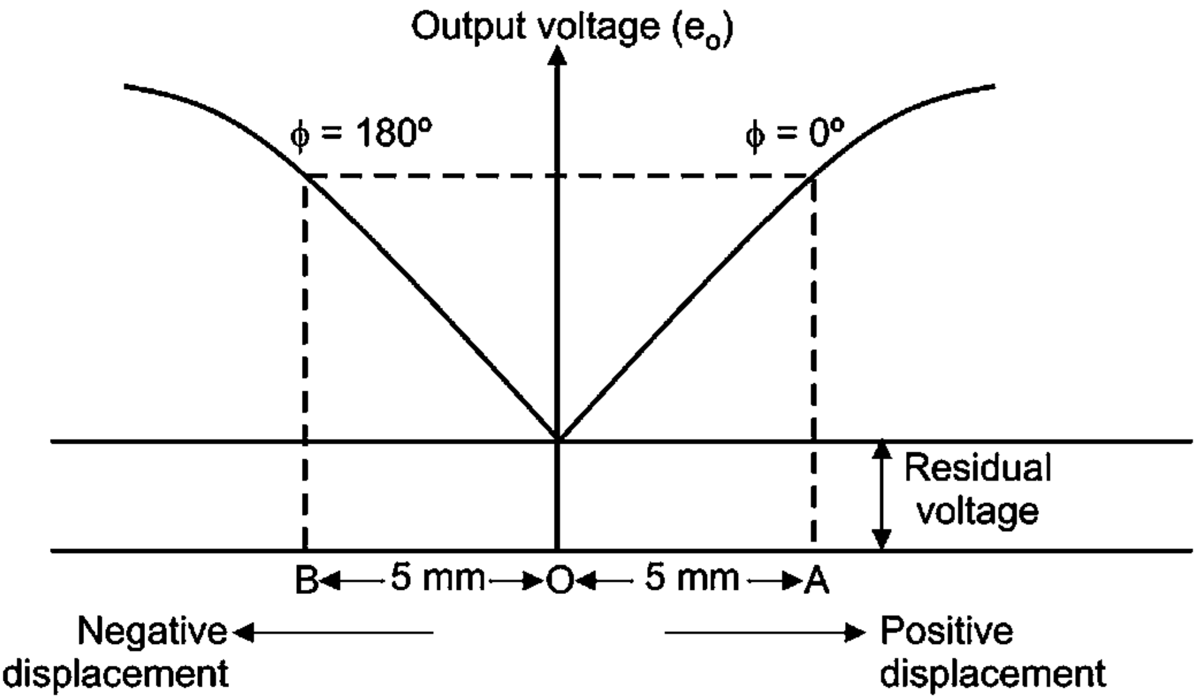
3. **When the core moves towards s2 (max right)**

When the LVDT core moves towards the S2 secondary winding, the flux linkage with S2 is greater than that of S1. As a result, the EMF induced in S2 is larger and E2 > E1. Hence, the net differential output voltage (E0 = E1 – E2) is negative It means the output voltage **E0** will be in phase opposition (**180** degrees out of phase) with the primary voltage.

From all these three cases, we can have the following conclusions:

- The direction of the movement of an object can be identified with the help of the differential output voltage of LVDT. If the output voltage E0 is positive then this means an object is moving towards the Left from the Null position.
- Similarly, If the output voltage E0 is negative then this means the object is moving towards the Right of the Null position.
- The amount or magnitude of displacement is proportional to the differential output of LVDT. The more the output voltage, the more will be the displacement of the object.
- If we take the core out of the former then the net differential of the output of LVDT will be zero.
- In fact corresponding to both cases, whether the core is moving either Left or Right to the Null position. Then the output voltage will be increased linearly up to 5mm from the Null position and after 5 mm, output E0 will be non-linear.

The Graph of variation of output with respect to its position is shown in the below figure



Applications of LVDT

- **LVDT** is used to measure physical quantities such as Force, Tension, Pressure, Weight, etc. These quantities are first converted into displacement by the use of primary transducers and then it is used to convert the displacement to the corresponding Electrical voltage signal.
- It is mostly used in industries as well as a servomechanism.
- It is also used in Industrial Automation and aircraft. Turbine, Satellite, hydraulics, Nuclear Turbines, and Aerospace. etc

MODULE 2: SENSORS, TRANSDUCERS, AND ACTUATORS

ACTUATORS

Introduction :

An actuator is something that actuates or moves something. More specifically, an actuator is a device that converts input energy into motion or mechanical energy. Here source energy can be pneumatic, hydraulic, or electric type, and motion produced (by actuator) can be either linear or rotary. For example, an electric motor uses electrical energy to create a rotational movement to turn on an object, or to move an object. A tire jack or screw jack uses mechanical energy to provide enough force to lift a car. In short, an actuator converts some type of energy into motion. Actuators include motors, gears, pumps, pistons, valves, and switches.

An actuator needs a control device that is governed by a control signal and an energy source. - When an actuator accepts a control signal, it needs to respond by converting the energy from the source into mechanical movement.The required source of energy may be electrical voltage or current signal, pneumatic signal, hydraulic fluid pressure, human power, or other mechanical forces. A block diagram of a simple actuator is shown below

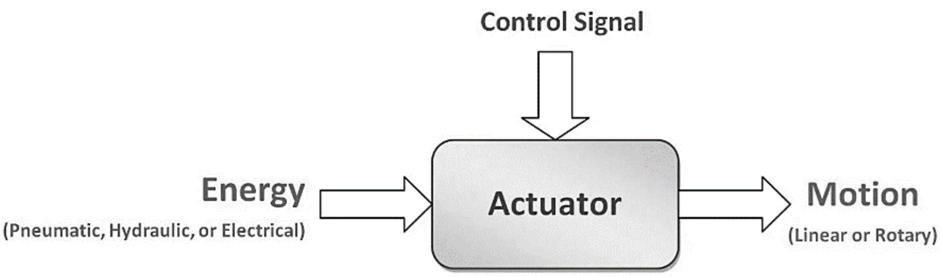


Figure- Block diagram of an actuator

Types of Actuators

Basically, Actuators are classified based on the nature of their output motion.Actuators are categorized into two groups such as linear and rotary

Linear Actuators :

- A linear actuator continues to move a component in a straight line path, most likely back and forth.
- It employs belt and pulley, rack and pinion, or ball screw mechanisms to transform electric motor motion from rotary into linear.

- They are intended to travel a fixed linear path length and then come to an original position.

Rotary Actuators

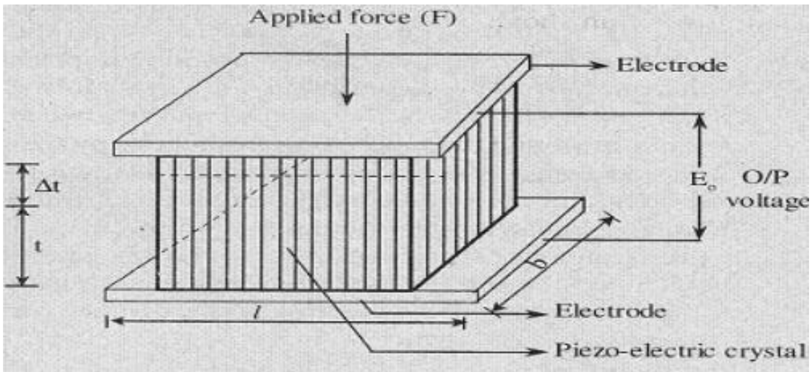
- Rotary actuators convert the energy into rotary motion via a shaft that regulates the speed, position, and rotation of the attached equipment.
- Because the applied force is aimed away from the axis of rotation, the permitted force is not limited by the distance traveled, resulting in greater flexibility in application.
- A typical case of a rotary actuator is an electric motor.
- The electric signal generates a magnetic field in the motor's stator, and the rotor rotates in rebuttal to this input.

Piezoelectric actuator

Working principle of piezoelectric actuator

A piezoelectric transducer is based on the principle of the piezoelectric effect. When some pressure or stress is applied to the surface of the piezo-electric crystal, the dimensions of the crystal change, and an electric charge voltage will be developed across certain surfaces of the piezo-electric crystal. The rate of charge produced will be proportional to the rate of change of mechanical stress applied to it

Conversely, when an electric charge voltage or potential is applied to the crystal, the crystal gets deformed and hence, the dimensions of it will change. This effect is referred as the piezoelectric effect.



Construction

The construction of a piezoelectric actuator typically consists of a piezoelectric material such as quartz, Rochelle salt, dipotassium titrate, lithium sulphate, barium titanate etc. is sandwiched between two electrodes. When an electric voltage is applied across the electrodes, the piezoelectric material experiences an electric field, causing it to deform or change shape. This deformation can be in the form of elongation, contraction, or bending, depending on the design of the actuator. To amplify the movement, multiple layers of piezoelectric material may be stacked together to create a multilayer actuator. The layers are alternately connected to the positive and negative electrodes, allowing for more displacement and force output.

Application of Piezoelectric actuators

Piezoelectric actuators find applications across various industries due to their unique properties and advantages.

1. **Precision positioning:** Piezoelectric actuators are used in fields such as microscopy, nanotechnology, and semiconductor manufacturing, where precise and fine positioning is crucial. Their quick response, high resolution, and ability to hold positions without power make them ideal for achieving sub-nanometer accuracy.

3. Inkjet printing: Piezoelectric actuators are widely used in inkjet printers to control the precise ejection of ink droplets onto the print media. Their rapid response enables high-speed printing with accurate droplet placement, resulting in high-resolution prints.

4. Ultrasonic cleaning and welding: Piezoelectric actuators generate ultrasonic vibrations used in cleaning applications, like ultrasonic baths and jewelry cleaners. They also play a role in ultrasonic welding, where two materials are bonded together using high-frequency vibrations generated by the actuator.

5. Precision valves and pumps: Piezoelectric actuators find application in various fluid control systems, such as precision valves and pumps. The ability to precisely control fluid flow by modulating actuator deformation allows for accurate dosing, metering, and regulation in fields like medical devices, analytical instruments, and chemical processing.