

MODULE 2: Sensors, Transducers and Actuators

Sensors: Introduction, Classification, Examples, Construction and Working of Gyroscope, Construction and Working of Intensity-Based Displacement Fiber Optic Sensor.

Transducers: Introduction, Types, Construction and Working of Linear Variable Differential Transformer

Actuators: Introduction, Types, Construction and Working of Piezoelectric Actuator and its Applications.

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.

SENSORS

Introduction:

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 can also say that a sensor is a transducer that converts a non-electrical 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 also classified 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 its 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.

Examples: camera, infrared sensor, light sensor, Thermometer, and Microphone.

Active sensors: 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.

Examples: Thermistors, strain gauges, LiDAR (Light Detection and Ranging, and ultrasonic sensors.

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.

Examples: Light-dependent resistor (LDR), accelerometers, and thermocouple.

Digital sensors: Digital sensors convert input physical phenomena into discrete (binary) output signals, usually in the form of 0s and 1s.

Examples: Digital temperature sensors, Digital accelerometers and Digital IR Sensor

Contact Sensors: Contact sensors are devices that must physically touch the object to measure the required quantity. For example, if the temperature of a liquid is to be measured, there are sensors that can be placed inside the container itself.

Examples: Thermocouple, RTD (Resistance Temperature Detector), Potentiometer, and Limit switch.

Non-Contact Sensors: A non-contact sensor is a sensor that can detect and measure information

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such as an object's position, motion, temperature, and pressure without physically touching the target. They use electromagnetic waves, light, sound, or magnetic fields.

Examples: Infrared (IR) sensor, Hall-effect sensor, and Laser sensor

Gyroscope:

A gyroscope sensor is a device that detects rotation or change in direction of an object. Gyroscope sensors are also called as Angular Rate Sensor or Angular Velocity Sensors. These sensors are installed in applications where the orientation of the object is difficult to sense by humans.

Examples: Smartphones, drones, aircraft, robots, gaming controllers, navigation systems.

Type of Gyroscope	Working Principle	Applications
Mechanical Gyroscope	Uses a rapidly spinning rotor and works on the principle of conservation of angular momentum to maintain its orientation.	Aircraft, ships, submarines, navigation systems
Optical Gyroscope	Uses the Sagnac effect , where two light beams travel in opposite directions to measure angular rotation.	Aircraft, spacecraft, missiles, precision navigation
MEMS Gyroscope	Uses the Coriolis effect . A tiny vibrating proof mass on a silicon chip experiences a Coriolis force when the sensor rotates, producing an electrical signal proportional to angular velocity.	Smartphones, drones, robots, gaming controllers, automobiles, wearable devices

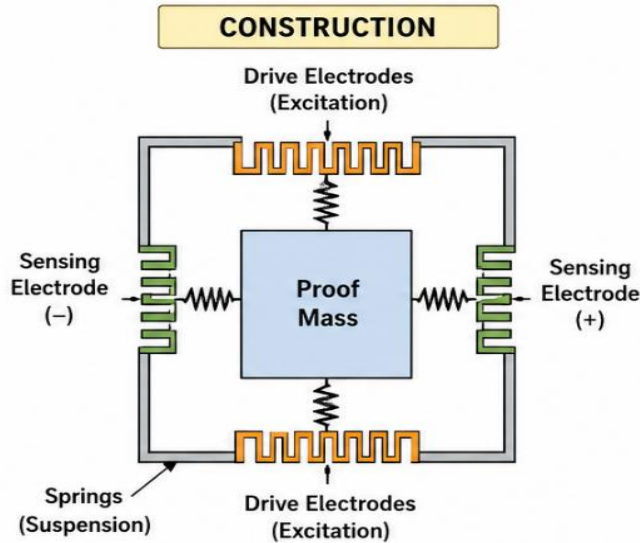
MEMS (Micro-Electro-Mechanical System) Gyroscope:

Construction:

A modern gyroscope sensor is usually a MEMS (Micro-Electro-Mechanical System) gyroscope.

A MEMS gyroscope **consists of the following parts:**

1. **Silicon substrate**
 - Forms the base of the sensor.
 - Supports all the MEMS components.



2. Vibrating proof mass

- A tiny movable mass that vibrates continuously.
- It is the sensing element of the gyroscope.

3. Suspension springs

- Hold the proof mass in position.
- Allow the mass to move only in the required direction.

4. Drive electrodes

- Supply an alternating voltage.
- Make the proof mass vibrate at a fixed frequency.

5. Sense electrodes

- Detect the movement of the proof mass.
- Convert mechanical motion into electrical signals.

6. Signal processing circuit

- Amplifies and processes the sensor output.
- Produces angular velocity in digital or analog form.

Working

Principle: The working is based on the Coriolis effect.

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Coriolis Effect: When a body is vibrating and the system rotates, a force called the Coriolis force acts on the vibrating body, causing it to move in a direction perpendicular to both its vibration and the axis of rotation.

The Coriolis force is given by:

$$F = 2mv\omega$$

where:

- F_c = Coriolis force (N)
- m = mass of vibrating element
- v = velocity of vibration
- ω = angular velocity

Step 1: No rotation

- The drive electrodes continuously vibrate the proof mass in one direction.

Step 2: Rotation of the Sensor

- When the sensor rotates about an axis, the vibrating proof mass experiences a Coriolis force.

Step 3: Deflection of the Mass

- Due to the Coriolis force, the proof mass moves slightly in a direction perpendicular to its vibration.

Step 4: Detection

- **The sense electrodes detect this small displacement.**

The change in capacitance is measured:

$$C = \frac{\epsilon A}{d}$$

where:

- C = Capacitance(F)
- ϵ = Permittivity of dielectric medium (F/m)
- A = Area of the plates
- d = distance between plates

The circuit converts this change into an electrical signal.

The output signal tells:

- direction of rotation

- amount of rotation

Applications:

1. Mobile Phones

- Auto screen rotation
- Motion sensing

2. Drones

- Maintains stability and balance

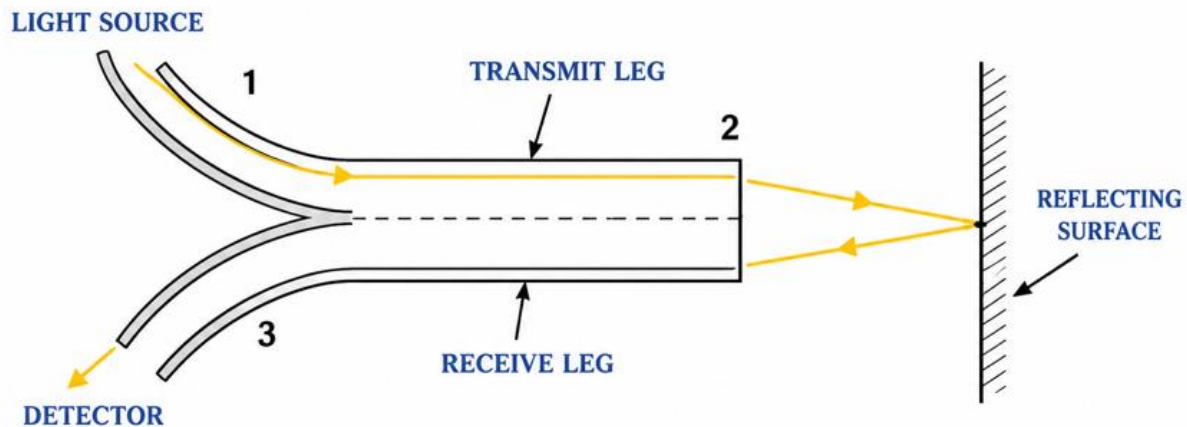
3. Autonomous Vehicles

- Measures turning angle and vehicle orientation

4. Aircraft

- Navigation and stabilization

Fiber Optic Displacement Sensor



It is an **intensity-modulated fiber optic sensor** used to measure the displacement of an object by detecting the change in the intensity of light reflected from a reflecting surface.

Construction

The sensor consists of:

- **Light Source (LED/Laser):** Produces the light signal.
- **Y-coupler Fiber:** Formed by **two multimode optical fibers** fused or cemented together along a part of their length.
- **Transmit Leg:** Carries light from the source to the reflecting target.
- **Receive Leg:** Collects the reflected light from the target.

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- **Reflecting Surface (Target):** The object whose displacement is to be measured.
- **Photodetector:** Receives the reflected light and converts it into an electrical signal.

Working

The fiber-optic displacement sensor operates on the intensity-modulation **principle**.

1. Light from the LED/Laser is injected through Port 1 into the transmit leg.
2. The transmitted light reaches the reflecting surface (target).
3. The target reflects a portion of the incident light back towards the sensor.
4. The reflected light enters the receive leg and exits through Port 3.
5. The photodetector converts the reflected light into an electrical signal.
6. The intensity of the reflected light depends on the distance between the fiber probe and the reflecting surface.
7. As the target moves closer or farther away, the reflected light intensity changes. This change is calibrated to determine the displacement of the target.

Applications

- Medical catheters as **inter-cardiac pressure transducers**.
- Robotics and automation.
- Precision machine tools.
- Endoscopy(Medical imaging)
- Aerospace navigation and stabilization systems

TRANSDUCERS

Introduction:

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.



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: Variable capacitance pressure gauge, Dielectric gauge, and capacitor microphone.

Examples of Resistive Transducer: Resistance thermometer, Potentiometer device, and thermistors

Examples of Inductive Transducers: Linear Variable Differential Transformer (LVDT), Rotary Variable Differential Transformer (RVDT), and inductive proximity sensors.

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.

Examples: Photovoltaic cell and Thermocouple

Passive Transducer

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

Examples: Resistive, Capacitive, Inductive transducers

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 to as an analog transducer.

Examples: strain gauge, LVDT, and Thermocouple

Digital Transducer

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

Examples: Turbine meter

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 a primary transducer.

Examples: Bourdon tube and strain gauge

Secondary Transducer

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

Examples: LVDT

5. Transducers and Inverse Transducers

Transducers

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

Examples: Thermocouple

Inverse Transducer

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

Examples: Piezoelectric crystal

Linear Variable Differential Transformer (LVDT):

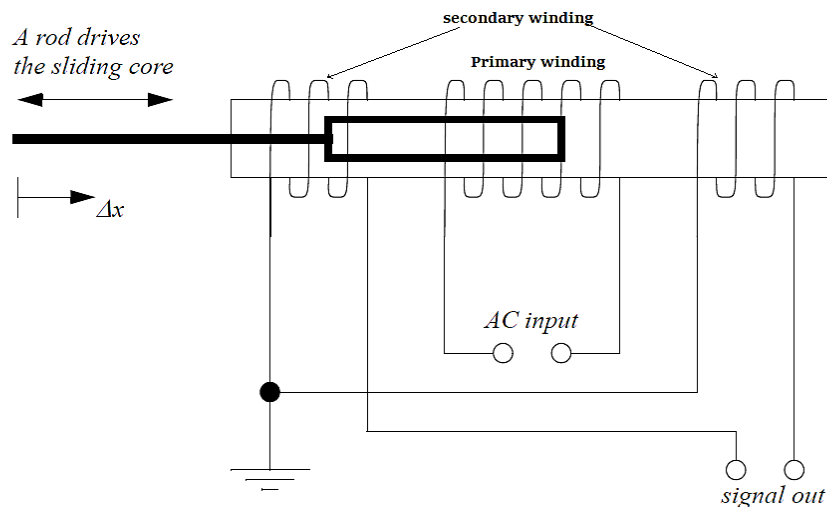
The term LVDT stands for the Linear Variable Differential Transformer. It is the most widely used inductive transducer that converts a mechanical displacement proportionally into electrical signal. Its electrical output is obtained because of the difference in secondary voltages, hence it is called a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

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



Working principle of LVDT

The **working principle of LVDT is based on the mutual induction principle**. When an AC supply (5-15 V, 50- 400 Hz) is applied to the primary winding, an alternating magnetic flux is produced. This magnetic flux induces voltages E_1 and E_2 in the two secondary windings S_1 and S_2 , respectively. Since the secondary windings are connected in series opposition, the net output voltage will be the difference of both induced voltages (E_1 & E_2) in the secondary windings.

Hence, the differential output of the LVDT will be **$E_0 = E_1 - E_2$**

Now, according to the position of the core, three cases arise

1. When the core moves towards S_1 (max left):

When the core moves towards the secondary winding S_1 , the magnetic flux linking S_1 becomes greater than that linking S_2 . As a result, the induced voltage E_1 becomes greater than E_2 .

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Hence, the differential output voltage ($E_0 = E_1 - E_2$) is positive, indicating that the core has moved towards the left of the null position and output voltage E_0 will be in phase with the primary voltage

2. When the core is at the null position:

When the core is exactly at the centre, equal magnetic flux links both secondary windings. Therefore, the induced voltages are equal ($E_1 = E_2$), and the differential output voltage becomes zero. This condition indicates that there is no displacement of the core.

3. When the core moves towards S_2 (max right):

When the core moves towards the secondary winding S_2 , the magnetic flux linking S_2 becomes greater than that linking S_1 . Hence, E_2 becomes greater than E_1 , making the differential output voltage negative. This indicates that the core has moved towards the right of the null position and output voltage E_0 will be in phase opposition (180 degrees out of phase) with the primary voltage. Thus, the magnitude of the differential output voltage is directly proportional to the displacement of the core, while the polarity of the output voltage indicates the direction of displacement.

Applications of LVDT

Elevators (Lifts)

- LVDT measures the position of the elevator car to ensure accurate stopping at each floor.

Aircraft Landing Gear

- LVDT monitors the position of the landing gear and confirms whether it is fully extended or retracted

Water Level Monitoring

- LVDT measures the movement of a float to determine the water level in tanks, reservoirs, and dams.

Robotic Arms

- LVDT provides position feedback to ensure accurate movement and placement of robotic arms.

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

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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

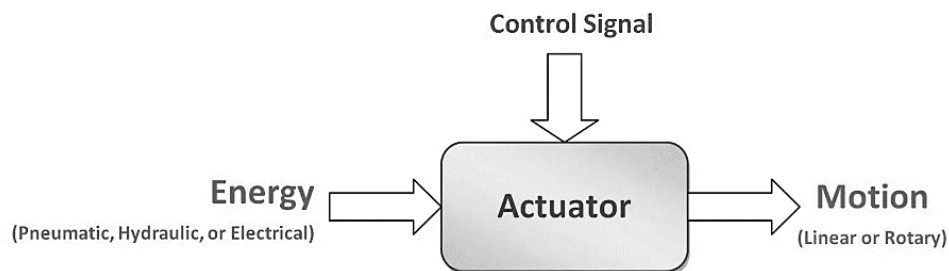


Figure- Block diagram of an actuator

Types of Actuators:

Based on the source of energy used, actuators are classified into the following types:

1. Electrical Actuator

An electrical actuator converts **electrical energy into mechanical motion**. It operates using electric motors, solenoids, or relays and provides precise and fast control.

Examples:

- Automatic sliding door
- Robotic Arm
- Servo motor

2. Hydraulic Actuator

A hydraulic actuator converts the **pressure of an incompressible liquid (hydraulic oil)** into mechanical motion. It is capable of producing **high force and high torque**.

Examples:

- Hydraulic lifts
- Excavator
- crane

3. Pneumatic Actuator

A pneumatic actuator converts the **energy of compressed air** into mechanical motion. It is simple, lightweight, and operates at high speed.

Examples:

- Bus/Truck air brakes
- Packaging machine
- Air-powered gripper

4. Thermal Actuator

A thermal actuator converts **heat energy into mechanical motion**. The movement occurs due to the expansion of materials when heated.

Examples:

- Thermostats
- Electric iron
- Shape Memory Alloy (SMA) actuator

5. Piezoelectric Actuator

A piezoelectric actuator converts **electrical energy into very small and precise mechanical displacement** using the piezoelectric effect.

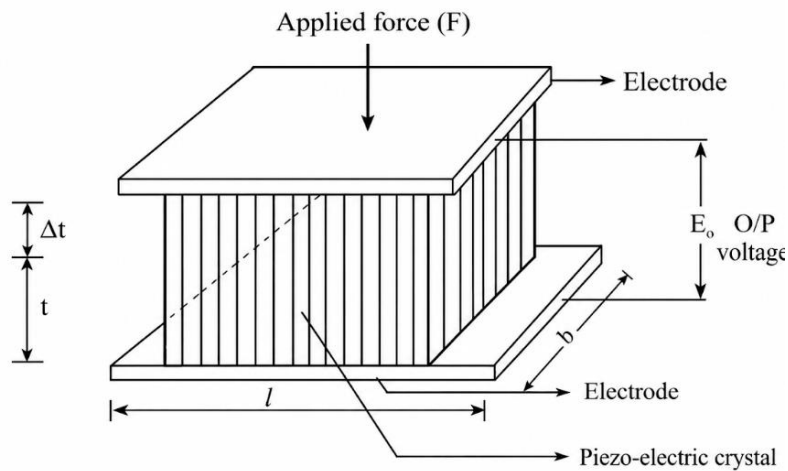
Examples:

- Piezoelectric buzzer
- Inkjet printers
- Ultrasonic Transducer

Piezoelectric Actuator:

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., which 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.



Working principle of

piezoelectric actuator

A piezoelectric actuator 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.

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.
3. **Inkjet printing:** Piezoelectric actuators are widely used in inkjet printers to control the precise ejection of ink droplets onto the print media. .
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
5. **Precision valves and pumps:** Piezoelectric actuators find application in various fluid control systems, such as precision valves and pumps to control the flow of fluids with high accuracy.

Solved Numerical Problems:

1. **An LVDT has a sensitivity of 2.5 mV/mm. Calculate the output voltage when the core is displaced by 8 mm.**

Solution:

Formula : The sensitivity of an LVDT is given by

$$S = \frac{V}{x}$$

where:

S = Sensitivity

V= Output voltage

x= Displacement

Given:

Sensitivity S = **2.5 mV/mm**

Displacement x = **8 mm**

Output voltage V = ?

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$$S = \frac{V}{x}$$

$$V = S \times x$$

$$\begin{aligned} V &= 2.5 \text{ mV/mm} \times 8 \text{ mm} \\ &= 20 \text{ mV} \end{aligned}$$

2. A displacement of 15 mm produces an output voltage of 75 mV in an LVDT. Calculate its sensitivity.

Soln:

Given:

- Sensitivity $S = ?$
- Displacement $x = 15 \text{ mm}$
- Output voltage $V = 75 \text{ mV}$

$$S = \frac{V}{x}$$

$$\begin{aligned} S &= \frac{75 \text{ mV}}{15 \text{ mm}} \\ &= 5 \text{ mV/mm} \end{aligned}$$

3. An LVDT has a sensitivity of 4 mV/mm. Determine the displacement if the output voltage is 48 mV

Soln:

Given:

- Sensitivity $S = 4 \text{ mV/mm}$
- Displacement $x = ?$
- Output voltage $V = 48 \text{ mV}$

$$S = \frac{V}{x}$$

$$x = \frac{V}{S}$$

$$\begin{aligned} X &= \frac{48 \text{ mV}}{4 \text{ mV/mm}} \\ &= 12 \text{ mm} \end{aligned}$$

4. A 40 mV output produced by an LVDT When the core displacement is 8 mm from it zero position. Calculate the core displacement when the output is 25 mV.

Soln:

Given:

- Displacement $x = 8 \text{ mm}$
- Output voltage $V = 40 \text{ mV}$
- Displacement x when output is $25 \text{ mV} = ?$

$$S = \frac{V}{x}$$
$$S = \frac{40 \text{ mV}}{8 \text{ mm}}$$
$$= 5 \text{ mV/mm}$$

Displacement x when output is 25 mV

$$x = \frac{V}{S}$$
$$x = \frac{25 \text{ mV}}{5 \text{ mV/mm}}$$
$$x = 5 \text{ mm}$$

5. An LVDT has a sensitivity of 0.25 V/cm . The core moves from -10 cm to $+8 \text{ cm}$.

Calculate:

1. The output voltage at -10 cm .
2. The output voltage at $+8 \text{ cm}$.
3. The total change in output voltage.

Soln: The sensitivity of an LVDT is given by

$$S = \frac{V}{x}$$

where:

- $S = \text{Sensitivity}$
- $V = \text{Output voltage}$

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- x = Displacement

Hence,

$$V = Sx$$

Given:

- Sensitivity, $S = 0.25 \text{ V/cm}$
- Initial displacement, $x_1 = -10 \text{ cm}$
- Final displacement, $x_2 = +8 \text{ cm}$

(i) Output voltage at -10cm

$$V_1 = 0.25 \times (-10)$$

$$V_1 = -2.5 \text{ V}$$

(ii) Output voltage at $+8\text{cm}$

$$V_2 = 0.25 \times 8$$

$$V_2 = 2.0 \text{ V}$$

(iii) Total change in output voltage

$$\Delta V = V_2 - V_1$$

$$\Delta V = 2.0 - (-2.5)$$

$$\Delta V = 4.5 \text{ V}$$

Final Answers

1. Output voltage at -10cm :

$$\boxed{-2.5 \text{ V}}$$

2. Output voltage at $+8\text{cm}$:

$$\boxed{2.0 \text{ V}}$$

3. Total change in output voltage:

4.5 V

Note: The negative sign indicates that the core is displaced in the opposite direction from the null (central) position. The polarity reverses as the core crosses the null position, which is a characteristic feature of an LVDT.

6.A piezoelectric actuator has a stiffness of $k_a = 8 \times 10^5$ N/m. The free displacement is 20 μm . Calculate the blocking force.

Soln:

Given

actuator stiffness $k_a = 8 \times 10^5$ N/m

displacement $\Delta L = 20 \mu\text{m}$.

Formula : Blocking force $= F_b = k_a \times \Delta L$

Where ($k_a = \frac{AY}{L}$, A = cross-sectional area,

Y= Young's modulus, L = length)

$$= 8 \times 10^5 \times 20$$

$$= 16\text{N}$$

7.A piezoelectric actuator has a cross-sectional area 3×10^{-4} m, a Young's Modulus of 5×10^{10} N/m², and a length of 15mm. The actuator has free displacement of 18 μm .

Calculate the stiffness k_a of the actuator and the blocking force F_b

Soln:

Given

Area A = 3×10^{-4} m²

Young's Modulus Y = 5×10^{10}

Length L = 15mm

displacement $\Delta L = 18 \mu\text{m}$.

Formula

$$\begin{aligned}k_a &= \frac{AY}{L} \\&= \frac{3 \times 10^{-4} \times 5 \times 10^{10}}{0.015} \\&= 1 \times 10^9 \text{ N/m}\end{aligned}$$

Blocking Force

$$\begin{aligned}F_b &= k_a \times \Delta L \\&= 1 \times 10^9 \times 18 \times 10^{-6} \\&= 18,000 \text{ N}\end{aligned}$$

8. A multilayer piezoelectric actuator is made up of 100 layer. The electrode area of each layer is $2 \times 10^{-4} \text{ m}^2$ and thickness 0.5mm. If the relative permittivity of the material is 1200 , Calculate its capacitance.

Soln:

Given:

- Number of layers, $n=100$
- Relative permittivity, $\epsilon_r=1200$
- Electrode area, $A = 2 \times 10^{-4} \text{ m}^2$
- Layer thickness, $d=0.5 \text{ mm}$

($\epsilon_0=8.85 \times 10^{-12} \text{ F/m}$).

Formula,

$$\begin{aligned}C &= \frac{n\epsilon_0\epsilon_r A}{d} \\C &= \frac{100 \times 8.85 \times 10^{-12} \times 1200 \times 2 \times 10^{-4}}{0.5 \times 10^{-3}} \\&= 0.425 \mu\text{F}\end{aligned}$$

9. Piezoelectric actuator has the capacitance of 0.90 μF . The electrode area of each layer is $3 \times 10^{-4} \text{ m}^2$, the layer thickness is 0.6mm, and the relative permittivity is 1500. If the permittivity of free space is $8.85 \times 10^{-12} \text{ F/m}$, Calculate the number of layers.

Soln:

Given:

- Number of layers, $n = ?$
- Capacitance $C = 0.90 \mu\text{F}$
- Relative permittivity, $\epsilon_r = 1500$
- Electrode area, $A = 3 \times 10^{-4} \text{ m}^2$
- Layer thickness, $d = 0.6 \text{ mm}$

($\epsilon_0 = 8.85 \times 10^{-12} \text{ F/m}$).

Formula,

$$C = \frac{n \epsilon_0 \epsilon_r A}{d}$$

$$n = \frac{dC}{\epsilon_0 \epsilon_r A}$$

$$n = \frac{0.6 \times 10^{-3} \times 0.90 \times 10^{-6}}{8.85 \times 10^{-12} \times 1500 \times 3 \times 10^{-4}}$$
$$\approx 136$$

10. A piezoelectric actuator has a piezoelectric strain coefficient $d_{33} = 450 \times 10^{-12} \text{ m/V}$. If a voltage of 200 V is applied across the actuator, calculate the displacement produced.

Soln : Given:

strain coefficient $d_{33} = 450 \times 10^{-12} \text{ m/V}$

voltage $V = 200 \text{ V}$

Formula

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$$\text{Displacement } \Delta L = d_{33}V$$

$$\Delta L = 450 \times 10^{-12} \times 200$$

$$= 90 \times 10^{-9} \text{ m}$$

$$\boxed{\Delta L = 90 \text{ nm}}$$

11. A piezoelectric actuator has a piezoelectric coefficient of $350 \times 10^{-12} \text{ m/V}$. Determine the voltage required to produce a displacement of 70 nm.

Soln : Given:

strain coefficient $d_{33} = 350 \times 10^{-12} \text{ m/V}$

displacement $\Delta L = 70 \text{ nm}$.

Formula

$$V = \frac{\Delta L}{d_{33}}$$

$$\begin{aligned} V &= \frac{70 \times 10^{-9}}{350 \times 10^{-12}} \\ &= 200 \text{ V} \end{aligned}$$

Sample Questions:

1. Explain the classifications of Sensors with examples.
2. Elucidate the difference between passive and active sensors.
3. Explain the construction and working of MEMS Gyroscope with application
5. Explain the construction and working of a Fiber Optic Intensity-Based displacement Sensor with application
6. Define transducer. Explain the parts of a transducer with the help of a diagram.
7. Explain the classification of transducers with examples
8. Explain the construction and working of Linear Variable Differential Transformer with the help of diagrams.
9. Define Actuator and explain the types of actuators.
10. Explain the construction and working principle of a piezoelectric actuator with application.

MODULE 2: Sensors, Transducers and Actuators
