Mechatronics

Unit –I. Introduction to Sensors & Actuators

Syllabus

• Introduction to Mechatronics, Measurement characteristics: - Static and Dynamic

• Sensors:

  Position Sensors: - Potentiometer, LVDT, Encoders;
  Proximity sensors:- Optical, Inductive, Capacitive;
  Motion Sensors: - Variable Reluctance;
  Temperature Sensor: RTD, Thermocouples;
  Force / Pressure Sensors:- Strain gauges;
  Flow sensors: - Electromagnetic

• Actuators: Stepper motor, Servo motor, Solenoids

Introduction of Mechatronics

✓ Mechatronics is the synergistic combination of Mechanical engineering (“mecha” for mechanisms), Electronic engineering (“tronics” for electronics), and software engineering.

✓ The word “Mechatronics” was first coined by Mr. Tetsuro Moria, a senior engineer of a Japanese company, Yaskawa, in 1969.
✓ It is a multi-disciplinary approach to **product and manufacturing system design**.

✓ It involves application of electrical, mechanical, control and computer engineering to develop products, processes and systems with **greater flexibility**, ease in redesign and ability of reprogramming. It concurrently includes all these disciplines.

✓ Mechatronics can also be termed as **replacement of mechanics with electronics or enhance mechanics with electronics**.

✓ With the help of **microelectronics and sensor technology**, mechatronics systems are providing **high levels of precision and reliability**.

For example, in modern automobiles, mechanical fuel injection systems are now replaced with electronic fuel injection systems. This replacement made the automobiles more efficient and less pollutant.

✓ By employment of **reprogrammable microcontrollers or PLC**, it is now easy to **add new functions and capabilities to a product** or a system.

✓ Today’s domestic washing machines are “**intelligent**” and four-wheel passenger automobiles are equipped with safety installations such as air-bags, parking (proximity) sensors, antitheft electronic keys etc.
**Objective of Mechatronics system**

1. Integration of mechanical systems with electronic and computer systems.
2. To **improve efficiency** of the system.
3. To **reduce cost** of production.
4. To achieve **high accuracy and precision**.
5. For **easy control** of the system.
6. Customer **satisfaction and comfort**.

**Mechatronics has evolved through the following stages:**

1. *Primary Level Mechatronics*: Integrates electrical signaling with mechanical action at the basic control level for e.g. fluid valves and relay switches

2. *Secondary Level Mechatronics*: Integrates microelectronics into electrically controlled devices for e.g. cassette tape player.

3. *Tertiary Level Mechantronics*: Incorporates advanced control strategy using microelectronics, microprocessors and other application specific integrated circuits for e.g. microprocessor based electrical motor used for actuation purpose in robots.

4. *Quaternary Level Mechatronics*: This level attempts to improve smartness a step ahead by introducing intelligence (artificial neutral network and fuzzy logic) and fault detection and isolation (F.D.I.) capability into the system. eg: artificial neural network and fuzzy logic technologies.

**Why Mechatronics ? (Advantages)**
1. High level of integration.

2. Increased functionality and better design.

3. More use of electronics and software.

4. Use of artificial intelligence and intelligent process control

5. Assume responsibility for a process and operation with little interference of operators.

6. Multisensory and programs environments.


8. The products produced are cost effective and very good quality.

9. High degree of flexibility

10. Greater extent of machine utilization

11. Greater productivity

12. High life expected by proper maintenance.

13. The integration of sensor and control system in a complex system reduces capital expenses

**Disadvantages of Mechatronics System**

1. The initial cost is very high.

2. The complicated design and system.

3. The repair and maintenance in complex.

4. Its replacement is difficult, that it is difficult to change old system to new system.

5. Higher initial cost of the system

6. Imperative to have Knowledge of different engineering fields for design and implementation.

7. It is expenses to incorporate Mechatronics approaches to existing/old systems

8. Specific problem of various systems will have to be addressed separately and properly
Mechatronics Applications:

1. **Smart consumer products**: home security, camera, microwave oven, toaster, dish washer, laundry washer-dryer, climate control units, etc.

2. **Medical**: implant-devices, assisted surgery, haptic, etc.

3. **Defense**: unmanned air, ground, and underwater vehicles, smart munitions, jet engines, etc.

4. **Manufacturing**: robotics, machines, processes, etc.

5. **Automotive**: climate control, antilock brake, active suspension, cruise control, air bags, engine management, safety, etc.

6. **Network-centric, distributed systems**: distributed robotics, tele-robotics, intelligent highways, etc.
Measurement System

- Concentrate only on output & Input device, Not concentrate on what goes on inside

Measurement Characteristics

- Shows the performance of instruments to be used.
- Divided into two categories: static and dynamic characteristics.

A) Static characteristics -

Refer to the comparison between steady output and ideal output when the input is constant.

Eg- Linearity, Sensitivity of measurement, Resolution, Threshold

B) Dynamic characteristics -

Refer to the comparison between instrument output and ideal output when the input changes.

Eg- Frequency response/Bandwidth, Delay, Stability/undershoot

A) Static characteristics -

1. Accuracy -

- is the closeness of a measurement (or a set of observations) to the true value.
- Higher the accuracy, lower the error
- Accuracy is the ability of an instrument to show the exact reading.
- Always related to the extent of the wrong reading/non accuracy.
- Normally shown in percentage of error which of the full scale reading percentage.

\[ E = \text{measured value} - \text{true value} \]

= system output – system input
Accuracy depends on inherent limitations of instrument and shortcomings in measurement process.

![Unit of accuracy]

\[
1. \text{Percentage of true value (} \% \text{ of T.V.)} = \frac{(\text{Measured value} - \text{True value}) \times 100}{\text{True value}}
\]

\[
2. \text{Percentage of Full Scale Deflection (} \% \text{ of fsd) = } \frac{(\text{Measured value} - \text{True value}) \times 100}{\text{Maximum Scale value}}
\]

2. **Precision**

- Defined as the capability of an instrument to show the same reading when used each time (reproducibility of the instrument).
- An equipment which is precise is not necessarily accurate.

![Precision Diagram]

**Precision is often confused with accuracy. High precision does not imply anything about measurement accuracy.**

<table>
<thead>
<tr>
<th>Accuracy</th>
<th>Precision</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Accuracy represents degree of correctness of the measured value w.r.t. true value.</td>
<td>- Precision represents degree of repeatability of several independent measurements of desired input at the same reference conditions.</td>
</tr>
<tr>
<td>- Accuracy of instrument depends on systematic errors.</td>
<td>- Precision of instruments depends on factors that cause random or accidental errors.</td>
</tr>
</tbody>
</table>
3. **Range & Span**

**a. Range**

- The region between the limits within which an instrument is designed to operate for measuring, indicating or recording a physical quantity is called the range of the instrument.

- The range is expressed by stating the lower and upper values.
  
  eg- Range -100°C to 100°C

**b. Span**

- Span represents the algebraic differences between the upper and lower range values of the instrument.

- An instrument which has a reading range of -100°C to 100 °C span is 200 °C.

4. **Linearity**

- Most instruments are specified to function over a particular range and the instruments can be said to be linear when incremental changes in the input and output are constant over the specified range.

- Linearity = maximum deviation from the reading of x and the straight line.
5. **Resolution / Discrimination**-

- The smallest change in input reading that can be traced accurately.
- Given in the form ‘% of full scale (% fs)’.

6. **Sensitivity**-

- This is the relationship between a change in the output reading for a given change of the input (This relationship may be linear or non-linear.)
- Sensitivity is often known as scale factor or instrument magnification and an instrument with a large sensitivity (scale factor) will indicate a large movement of the indicator for a small input change.

\[
Sensitivity = K = \frac{change \text{ in the output signal}}{change \text{ of the input signal}}
\]

7. **Dead Zone**-

Defined as the range of input reading when there is no change in output (unresponsive system).
8. **Threshold**

If the instrument input is very gradually increased from zero there will be a minimum value required to give a detectable output change. This minimum value defines the threshold of the instrument.

![Graph showing threshold](image)

9. **Hysteresis**

Hysteresis exists not only in magnetic circuits, but in instruments also. For example, the deflection of a diaphragm type pressure gage may be different for the same pressure, but one for increasing and other for decreasing, as shown in Fig.. The hysteresis is expressed as the maximum hysteresis as a full scale reading, i.e., referring fig.

![Graph showing hysteresis](image)

\[
Hysteresis = \frac{H}{O_{\text{max}} - O_{\text{min}}} \times 100.
\]

- Mechanical systems will often show a small difference in length as the direction of the applied force is reversed.
- The same effect arises as a magnetic field is reversed in a magnetic material. This characteristic is called *hysteresis*. 
Hysteresis is defined as the magnitude of error caused in the output for a given value of input, when this value is approached from opposite directions; i.e., from ascending order & then descending order.

Causes are backlash, elastic deformations, magnetic characteristics, frictional effects (mainly).

Hysteresis can be eliminated by taking readings in both direction and then taking its arithmetic mean.

10. Drift-

Zero drift is variation in the output of an instrument which is not caused by any change in the input.

It is commonly caused by internal temperature changes and component instability.

fig. Effects of disturbance: (a) zero drift; (b) sensitivity drift; (c) zero drift plus sensitivity drift.
11. **Repeatability**-

- It is the ability of the measuring instrument to give the same value every time, the measurement of given quantity is repeated, under the same conditions.
- Repeatability refers to a sensor’s ability to give identical outputs for the same input.
- Precision (or random) errors cause a lack of repeatability

12. **Backlash**-

- It is maximum distance or angle through which any part of a mechanical system may be moved in one direction without applying appreciable force or motion to the next part in mechanical sequence.
- Can be minimized if components are made to very close tolerances.

![Diagram of Backlash](image)

**B) Dynamic Characteristics**

1. **Speed of Response**-

   It is defined as the rapidity with which an instrument responds to a change in the value of the quantity being measured.

2. **Fidelity**-

   Fidelity of an instrumentation system is defined as the degree of closeness with which the system indicates or records the signal which is impressed upon it.

   It refers to the ability of the system to reproduce the output in the same form as the input.
3. Overshoot -

Because of mass and inertia of moving part, i.e., the pointer of the instrument does not immediately come to rest in the final deflected position. The pointer goes beyond the steady state i.e., it overshoots.

4. Dynamic Error -

The difference between the indicated quantity and the true value of the time varying quantity is the dynamic error, here static error of the instrument is assumed to be zero.

1. Static Error \[ E = V_m - V_t \]

2. Relative Error \[ E = \left( \frac{V_m - V_t}{V_t} \right) \times 100 \]

Where,

\[ V_m \] - Measured Value, \[ V_t \] - True Value

Sources of Error -

1. Defect in instrument.
2. Adjustment of an instrument.
3. Imperfection in design of instrument.
4. Method of location.
5. Environmental effects.
6. Error due to properties of object.
7. Error due to surface finish of object.
8. Observational error.
**Basic Principle of Sensor-**

Sensor is a device that when exposed to a physical phenomenon (temperature, displacement, force, etc.) produces a proportional output signal (electrical, mechanical, magnetic, etc.).

A sensor converts a state variable of a technical process of a quality which is not suitable as a signal into a signal which can be transmitted, further processed.

*When input is a physical quantity and output electrical → Sensor*

*When input is electrical and output a physical quantity → Actuator*
A. Position Sensors

1. Potentiometer-

The measuring instrument called a potentiometer is essentially a voltage divider used for measuring electric potential (voltage); the component is an implementation of the same principle, hence its name.

A potentiometer, is a three-terminal resistor with a sliding or rotating contact that forms an adjustable voltage divider. If only two terminals are used, one end and the wiper, it acts as a variable resistor or rheostat.

Potentiometers are commonly used to control electrical devices such as volume controls on audio equipment. Potentiometers operated by a mechanism can be used as position transducers, for example, in a joystick. Potentiometers are rarely used to directly control significant power (more than a watt), since the power dissipated in the potentiometer would be comparable to the power in the controlled load.

\[ e_o = \left( \frac{x_i}{x_t} \right) E \]

where, \( x_i \) is the input displacement,

\( x_t \) is the total displacement and \( E \) is the supply voltage.

Resistive material has a uniform resistivity so that the ohms-per-inch value along its length is constant.
The important parameters while selecting a potentiometer are:

- Operating temperature
- Shock and vibration
- Humidity
- Contamination and seals
- Life cycle

Advantages of the potentiometer are:

1. Easy to use
2. Low cost
3. High amplitude output
4. Proven technology
5. Easily available
6. Can be used for measuring even large displacements.
7. Can produce a high electrical efficiency

Disadvantages

1. Since the wiper is sliding across the resistive element there is a possibility of friction and wear. Hence the number of operating cycles are limited.
2. Limited bandwidth
3. Inertial loading

Applications-

Potentiometers are rarely used to directly control significant amounts of power (more than a watt or so). Instead they are used to adjust the level of analog signals (for example volume controls on audio equipment), and as control inputs for electronic circuits.

For example, a light dimmer uses a potentiometer to control the switching of a TRIAC and so indirectly to control the brightness of lamps.
2. **Linear Variable Differential Transformer**

LVDT works on the *principle of variation of mutual inductance*. It is one of the most popular types of displacement sensor. It has good linearity over a wide range of displacement. Moreover the mass of the moving body is small, and the moving body does not make any contact with the static part, thus minimizing the frictional resistance.

Commercial LVDTs are available with full scale displacement range of ±0.25mm to ±250mm. Due to the low inertia of the core, the LVDT has a good dynamic characteristics and can be used for time varying displacement measurement range.

*fig- Construction of LVDT.*

*fig- Characteristics of LVDT.*
The **construction** and principle of operation of LVDT can be explained with Fig. It consists of a primary winding and two identical secondary windings of a transformer, wound over a tubular former, and a ferromagnetic core of annealed nickel-iron alloy moves through the former. The two secondary windings are connected in series opposition, so that the net output voltage is the difference between the two.

**Working**

The primary winding is excited by 1-10V A.C. voltage source, the frequency of excitation may be anywhere in the range of 50 Hz to 50 KHz. The output voltage is zero when the core is at central position (voltage induced in both the secondary windings are same, so the difference is zero), but increasing as the core moves away from the central position, in either direction. Thus, from the measurement of the output voltage only, one cannot predict, the direction of the core movement. A phase sensitive detector (PSD) is a useful circuit to make the measurement direction sensitive. It is connected at the output of the LVDT and compares the phase of the secondary output with the primary signal to judge the direction of movement.

<table>
<thead>
<tr>
<th>1. If core is centered between S₁ and S₂</th>
<th><img src="null" alt="Diagram" /></th>
</tr>
</thead>
<tbody>
<tr>
<td>Equal flux from each secondary coil</td>
<td>Voltage $E₁ = E₂$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2. If core is closer to S₁</th>
<th><img src="max_left" alt="Diagram" /></th>
</tr>
</thead>
<tbody>
<tr>
<td>Greater flux at S₁,</td>
<td></td>
</tr>
<tr>
<td>Voltage $E₁$ increases, Voltage $E₂$ decreases,</td>
<td>$E_{out} = E₁ - E₂$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>3. If core is closer to S₂</th>
<th><img src="max_right" alt="Diagram" /></th>
</tr>
</thead>
<tbody>
<tr>
<td>Greater flux at S₂</td>
<td></td>
</tr>
<tr>
<td>Voltage $E₂$ increases, Voltage $E₁$ decreases</td>
<td>$E_{out} = E₂ - E₁$</td>
</tr>
</tbody>
</table>
**Advantages of LVDT**

1. **High Range** - The LVDTs have a very high range for measurement of displacement. They can be used for measurement of displacements ranging from 1.25 mm to 250 mm.

2. **No Frictional Losses** - As the core moves inside a hollow former so there is no loss of displacement input as frictional loss so it makes LVDT as very accurate device.

3. **High Input and High Sensitivity** - The output of LVDT is so high that it doesn't need any amplification. The transducer possesses a high sensitivity which is typically about 40V/mm.

4. **Low Hysteresis** - LVDTs show a low hysteresis and hence repeatability is excellent under all conditions.

5. **Low Power Consumption** - The power is about 1W which is very as compared to other transducers.

6. **Direct Conversion to Electrical Signals** - They convert the linear displacement to electrical voltage which are easy.

**Disadvantages of LVDT**

1. LVDT is sensitive to stray magnetic fields so they always require a setup to protect them from stray magnetic fields.

2. They are affected by vibrations and temperature.

**Applications of LVDT**

1. They are used in applications where displacements ranging from fraction of mm to few cm are to be measured.

2. The LVDT acting as a primary transducer converts the displacement to electrical signal directly.

3. Sensitive to stray(output) magnetic fields; hence shielding is essential.

4. They can also acts as the secondary transducers.

   E.g. the Bourbon tube which acts as a primary transducer and covert pressure into linear displacement. Then LVDT coverts this displacement into electrical signal which after calibration gives the ideas of the pressure of fluid.
3. Encoders

a. Digital optical encoder

A digital optical encoder is a device that converts motion into a sequence of digital pulses. By counting a single bit or by decoding a set of bits, the pulses can be converted to relative or absolute position measurements. Encoders have both linear and rotary configurations, but the most common type is rotary. Rotary encoders are manufactured in two basic forms: the absolute encoder where a unique digital word corresponds to each rotational position of the shaft, and the incremental encoder, which produces digital pulses as the shaft rotates, allowing measurement of relative position of shaft. Most rotary encoders are composed of a glass or plastic code disk with a photographically deposited radial pattern organized in tracks. As radial lines in each track interrupt the beam between a photo emitter-detector pair, digital pulses are produced.

**Digital Optical Encoders types**

1. Absolute Digital Optical Encoders
2. Incremental Digital Optical Encoders
1. Absolute Digital Optical Encoders

The optical disk of the absolute encoder is designed to produce a digital word that distinguishes N distinct positions of the shaft. For example, if there are 8 tracks, the encoder is capable of producing 256 distinct positions or an angular resolution of 1.406 (360/256) degrees. The most common types of numerical encoding used in the absolute encoder are **gray and binary codes**. To illustrate the action of an absolute encoder, the gray code and natural binary code disk track patterns for a simple 4-track (4-bit) encoder are illustrated in Fig.

The linear patterns and associated timing diagrams are what the photodetectors sense as the code disk circular tracks rotate with the shaft. The output bit codes for both coding schemes are listed in Table

---

**Table 1. 4-Bit gray and natural binary codes**

<table>
<thead>
<tr>
<th>Decimal code</th>
<th>Rotation range (deg.)</th>
<th>Binary code</th>
<th>Gray code</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0-22.5</td>
<td>0000</td>
<td>0000</td>
</tr>
<tr>
<td>1</td>
<td>22.5-45</td>
<td>0001</td>
<td>0001</td>
</tr>
<tr>
<td>2</td>
<td>45-67.5</td>
<td>0010</td>
<td>0011</td>
</tr>
<tr>
<td>3</td>
<td>67.5-90</td>
<td>0011</td>
<td>0010</td>
</tr>
<tr>
<td>4</td>
<td>90-112.5</td>
<td>0100</td>
<td>0110</td>
</tr>
<tr>
<td>5</td>
<td>112.5-135</td>
<td>0101</td>
<td>0111</td>
</tr>
<tr>
<td>6</td>
<td>135-157.5</td>
<td>0110</td>
<td>0101</td>
</tr>
<tr>
<td>7</td>
<td>157.5-180</td>
<td>0111</td>
<td>0100</td>
</tr>
<tr>
<td>8</td>
<td>180-202.5</td>
<td>1000</td>
<td>1100</td>
</tr>
<tr>
<td>9</td>
<td>202.5-225</td>
<td>1001</td>
<td>1101</td>
</tr>
<tr>
<td>10</td>
<td>225-247.5</td>
<td>1010</td>
<td>1111</td>
</tr>
<tr>
<td>11</td>
<td>247.5-270</td>
<td>1011</td>
<td>1110</td>
</tr>
<tr>
<td>12</td>
<td>270-292.5</td>
<td>1100</td>
<td>1010</td>
</tr>
<tr>
<td>13</td>
<td>292.5-315</td>
<td>1101</td>
<td>1011</td>
</tr>
<tr>
<td>14</td>
<td>315-337.5</td>
<td>1110</td>
<td>1001</td>
</tr>
<tr>
<td>15</td>
<td>337.5-360</td>
<td>1111</td>
<td>1000</td>
</tr>
</tbody>
</table>

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**Fig 2. 4-bit gray code absolute encoder disk track patterns**

**Fig 3. 4-bit binary code absolute encoder disk track patterns**
The gray code is designed so that only one track (one bit) will change state for each count transition, unlike the binary code where multiple tracks (bits) change at certain count transitions. This effect can be seen clearly in Table.

For the gray code, the uncertainty during a transition is only one count, unlike with the binary code, where the uncertainty could be multiple counts.

Since the gray code provides data with the least uncertainty but the natural binary code is the preferred choice for direct interface to computers and other digital devices, a circuit to convert from gray to binary code is desirable.

**Absolute Rotary Encoder Advantages**

1. Remembers an object’s position after a power outage
2. Continuous position monitoring
3. Speed, scaling, preset functions

**2. Incremental encoder**

The incremental encoder, sometimes called a relative encoder, is simpler in design than the absolute encoder. It consists of two tracks and two sensors whose outputs are called channels A and B. As the shaft rotates, pulse trains occur on these channels at a frequency proportional to the shaft speed, and the phase relationship between the signals yields the direction of rotation. The code disk pattern and output signals A and B are illustrated in Figure. By counting the number of pulses and knowing the resolution of the disk, the angular motion can be measured.

![Quadrature Encoder](image)

The A and B channels are used to determine the direction of rotation by assessing which channels "leads" the other. The signals from the two channels are a 1/4 cycle out of phase with each other and are known as quadrature signals. Often a third output channel, called INDEX, yields one pulse per revolution, which is
useful in counting full revolutions. It is also useful as a reference to define a home base or zero position.

![Fixed sensors diagram]

Figure illustrates two separate tracks for the A and B channels, but a more common configuration uses a single track with the A and B sensors offset a 1/4 cycle on the track to yield the same signal pattern. A single-track code disk is simpler and cheaper to manufacture.

The quadrature signals A and B can be decoded to yield the direction of rotation as shown in Figure. Decoding transitions of A and B by using sequential logic circuits in different ways can provide three different resolutions of the output pulses: 1X, 2X, 4X. 1X resolution only provides a single pulse for each cycle in one of the signals A or B, 4X resolution provides a pulse at every edge transition in the two signals A and B providing four times the 1X resolution. The direction of rotation (clockwise or counter-clockwise) is determined by the level of one signal during an edge transition of the second signal.
Quadrature signals A and B can be decoded to yield the direction of rotation.

**Incremental Rotary Encoder Advantages**

1. Good for simple pulse counting or frequency monitoring applications
2. Good for speed, direction, and position monitoring
3. More cost effective than an absolute encoder
4. Less complex than an absolute encoder

**Incremental Encoder Applications**

The three broad categories of applications based on environment are:

- **Heavy Duty:** demanding environment with a high probability of contaminants and moisture, higher temperature, shock, and vibration requirements as seen in pulp, paper, steel, and wood mills.
- **Industrial Duty:** general factory operating environment which requires standard IP ratings, moderate shock, vibration, and temperature specs as seen in food and beverage, textile, generally factory automation plants.
- **Light Duty/Servo:** controlled environment with high accuracy and temperature requirements such as robotics, electronics, and semiconductors.

<table>
<thead>
<tr>
<th></th>
<th>Incremental</th>
<th>Absolute</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complexity</td>
<td>Single-channel</td>
<td>Quadrature</td>
</tr>
<tr>
<td>Output</td>
<td>Speed, displacement</td>
<td>Velocity and direction</td>
</tr>
<tr>
<td>Needs homing on startup?</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Resolution</td>
<td>Up to 10k PPR (direct read)</td>
<td>Up to 22-bit (ST) / 12-bit (MT)</td>
</tr>
<tr>
<td>Communication via protocol?</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Cost</td>
<td>Generally lower</td>
<td>Generally higher</td>
</tr>
</tbody>
</table>
B. Proximity sensors

A proximity sensor is a sensor able to detect the presence of nearby objects without any physical contact.

A proximity sensor often emits an electromagnetic field or a beam of electromagnetic radiation (infrared, for instance), and looks for changes in the field or return signal. The object being sensed is often referred to as the proximity sensor's target. Different proximity sensor targets demand different sensors.

For example, a capacitive or photoelectric sensor might be suitable for a plastic target; an inductive proximity sensor always requires a metal target.

The maximum distance that this sensor can detect is defined "nominal range".

Proximity sensors are commonly used on smartphones to detect (and skip) accidental touchscreen taps when held to the ear during a call. They are also used in machine vibration monitoring to measure the variation in distance between a shaft and its support bearing. This is common in large steam turbines, compressors, and motors that use sleeve-type bearings.

**Proximity sensors types:** 1. Optical 2. Inductive 3. Capacitive

1. **Optical Proximity Sensors**

Optical proximity sensors generally cost more than inductive proximity sensors, and about the same as capacitive sensors. They are widely used in automated systems because they have been available longer and because some can fit into small locations. These sensors are more commonly known as light beam sensors of the thru-beam type or of the retro reflective type. Both sensor types are shown below.
A complete optical proximity sensor includes a light source, and a sensor that detects the light. The light source is supplied because it is usually critical that the light be "tailored" for the light sensor system. The light source generates light of a frequency that the light sensor is best able to detect, and that is not likely to be generated by other nearby sources. Infra-red light is used in most optical sensors. To make the light sensing system more foolproof, most optical proximity sensor light sources pulse the infra-red light on and off at a fixed frequency. The light sensor circuit is designed so that light that is not pulsing at this frequency is rejected.

The light sensor in the optical proximity sensor is typically a semiconductor device such as a photodiode, which generates a small current when light energy strikes it, or more commonly a phototransistor that allows current to flow if light strikes it. Early light sensors used photoconductive materials that became better conductors, and thus allowed current to pass, when light energy struck them. Sensor control circuitry is also required. The control circuitry may have to match the pulsing frequency of the transmitter with the light sensor. Control circuitry is also often used to switch the output circuit at a certain light level. Light beam sensors that output voltage or current proportional to the received light level are also available.

Through beam type sensors are usually used to signal the presence of an object that blocks light. If they have adjustable switching levels, they can be used, for example, to detect whether or not bottles are filled by the amount of light that
2. Inductive Proximity sensors

An inductive proximity sensor is a type of non-contact electronic proximity sensor that is used to detect the position of metal objects. The sensing range of an inductive switch is dependent on the type of metal being detected.

Ferrous metals, such as iron and steel, allow for a longer sensing range, while nonferrous metals, such as aluminum and copper, can reduce the sensing range by up to 60 percent. Since the output of an inductive sensor has two possible states, an inductive sensor is sometimes referred to as an inductive proximity switch.

**Working** - Electrical energy is fed into the circuit to initiate and sustain the oscillation. Without sustaining energy, the oscillation would collapse due to the small power losses from the electrical resistance of the thin copper wire in the coil and other parasitic losses.

The oscillation produces an electromagnetic field in front of the sensor, because the coil is located right behind the “face” of the sensor. The technical name of the sensor face is “active surface”.

When a piece of conductive metal enters the zone defined by the boundaries of the electromagnetic field, some of the energy of oscillation is transferred into the metal of the target. This transferred energy appears as tiny circulating electrical currents called eddy currents. This is why inductive proxes are sometimes called eddy current sensors.

The flowing eddy currents encounter electrical resistance as they try to circulate. This creates a small amount of power loss in the form of heat (just like a little electric heater).
The power loss is not entirely replaced by the sensor’s internal energy source, so the amplitude (the level or intensity) of the sensor’s oscillation decreases. Eventually, the oscillation diminishes to the point that another internal circuit called a Schmitt Trigger detects that the level has fallen below a pre-determined threshold. This threshold is the level where the presence of a metal target is definitely confirmed. Upon detection of the target by the Schmitt Trigger, the sensor’s output is switched on.

**Advantages**

1. They are very accurate compared to other technologies.
2. Have high switching rate.
3. Can work in harsh environmental conditions.

**Disadvantages**

1. It can detect only metallic target.
2. Operating range may be limited.

**Applications**

Common applications of inductive sensors include metal detectors, traffic lights, car washes, and a host of automated industrial processes. Because the sensor does not require physical contact it is particularly useful for applications where access presents challenges or where dirt is prevalent.
3. **Capacitive Proximity sensors**-

Capacitive sensing is a noncontact technology suitable for detecting metals, nonmetals, solids, and liquids, although it is best suited for nonmetallic targets because of its characteristics and cost relative to inductive proximity sensors. In most applications with metallic targets, inductive sensing is preferred because it is both a reliable and a more affordable technology.

The sensor consists of four basic components:
- A capacitive probe or plate
  - An oscillator
  - A signal level detector
  - A solid-state output switching device
  - An adjustment potentiometer
Working:

- Capacitive proximity sensors are similar in size, shape, and concept to inductive proximity sensors. However, unlike inductive sensors which use induced magnetic fields to sense objects, capacitive proximity generate an electrostatic field and reacts to changes in capacitance caused when a target enters the electrostatic field.

- When the target is outside the electrostatic field, the oscillator is inactive. As the target approaches, a capacitive coupling develops between the target and the capacitive probe.

- When the capacitance reaches a specified threshold, the oscillator is activated, triggering the output circuit to switch states between ON and OFF

- The ability of the sensor to detect the target is determined by the target’s size, dielectric constant and distance from the sensor.

- The larger the target’s size, the stronger the capacitive coupling between the probe and the target.

- Materials with higher dielectric constants are easier to detect than those with lower values.

- The shorter the distance between target and probe, the stronger the capacitive coupling between the probe and the target.

The advantages of capacitive proximity sensors:

1. Detects metal and nonmetal, liquids and solids
2. Can see through certain materials (product boxes)
3. Solid-state, long life

4. Many mounting configurations

**The disadvantages of capacitive proximity sensors:**

1. Short (1 inch or less) sensing distance varies widely according to material being sensed

2. Very sensitive to environmental factors — humidity in coastal/ water climates can affect sensing output

3. Not at all selective for its target — control of what comes close to the sensor is essential

**Typical Applications:**

1. Liquid level sensing- Sensing through a sight glass to watch liquid level, such as batter for food processing or ink for printing applications. Insertion through sealed tubes into drums or holding tanks for chemicals or aqueous solutions

2. Product filling lines- Bottling applications, such as shampoo Full-case detection to ensure that a container has the required number of products. Checking material levels, such as cereal in boxes

3. Plastic parts detection- Plastics on product packages, such as spouts on laundry detergent boxes. Plastic materials within a hopper

4. Pallet detection for materials handling

5. Irregularly shaped products- Objects randomly oriented on conveyor belt. Highly textured objects
Variable Reluctance speed sensors can sense a ferrous metal target and is ideal for use in all types of environments and user specifications.

Variable Reluctance (VR) sensors offer a unique solution to many system measurement problems by providing an uncomplicated, accurate, reliable, versatile counting device.

Reluctance- the ability of a material to pass a magnetic field, and is often likened to resistance in an electrical circuit.

Ferrous materials possess a low reluctance as they help concentrate magnetic fields that easily pass through them.

Mathematically, the equation for reluctance looks much like Ohm’s Law:

\[ R = \frac{mmf}{\Phi} \]

where  

\( R \) = value of reluctance,  

\( mmf \) = magnetomotive force in ampere-turns, and  

\( \Phi \) = intensity of the magnetic field in Webers.

The frequency of the output is controlled by the speed of rotation and the number of teeth in the target.

For example, a 100-tooth gear turning at 1,800 rpm generates an output frequency of 3,000 Hz.

A variable reluctance sensor is composed of a winding wound around a cylindrical magnetic material, typically made of some type of ferrous material that is referred to as a pole piece. A magnet is attached behind the pole piece, creating a magnetic field through the pole piece and winding. This magnetic field projects out from the pole piece front, also known as the sensor tip. When ferrous material passes through and disrupts this magnetic field, electricity (a sine wave) is generated.
They are passive devices and do not require any external source of power to generate a signal.

Therefore, when the tip of the sensor is placed near a moving or rotating device made of ferrous metal such as a gear or rotor, a simple technique for measuring rotational speed is created. The frequency of the signal is directly proportional to the speed of rotation. The amplitude of the signal is affected by the speed of rotation, the material being sensed and the distance, known as the "air gap", between the sensor tip and the rotating object.

A common method of converting this signal into a useful signal for interfacing with other digital circuit is by using a Schmitt trigger circuit.

• Another method is by using a quenched oscillator circuit as shown in the figure. This circuit has good resistance to interference

**Advantages and disadvantages**

The first is low cost - coils of wire and magnets are relatively inexpensive. Unfortunately, the low cost of the transducer is partially offset by the cost of the additional signal-processing circuitry needed to recover a useful signal. And because the magnitude of the signal developed by the VR sensor is proportional to target speed, it is difficult to design circuitry to accommodate very-low-speed signals. A given VR-sensing system has a definite limit as to how slow the target can move and still develop a usable signal

**Uses and Applications**

A VR sensor used as a simple proximity sensor can determine the position of a mechanical link in a piece of industrial equipment.

A Crankshaft position sensor (in an automobile engine) is used to provide the angular position of the crankshaft to the Engine control unit. The Engine control unit can then calculate engine speed (angular velocity).

Speed sensors used in automobile transmissions, are used to measure the rotational speed (angular velocity) of shafts within the transmission. The Engine control unit or Transmission control unit (depending on the particular automobile) uses these sensors to determine when to shift from one gear to the next.
E. Temperature measurement Sensors

1. EMF based

   eg- Thermocouple

2. Resistance based

   eg- Resistance Temperature Detectors (RTD)

**Thermocouples**

- Based on the Seebeck effect – a phenomenon whereby a voltage that is almost proportional to temperature can be produced from a circuit consisting of two dissimilar metal wires

- The junctions at each end of the dissimilar metal wires produce a voltage

- One junction is called the hot junction (the junction on the probe) and the other junction is the cold junction (kept at some known reference temperature)

- The actual difference between the junction voltages is known as Vnet, which is essentially the output voltage of this system.

\[
V_{net} = V_{hot} - V_{cold}
\]

- A thermocouple made from iron and constantan (an alloy) generates a voltage of approximately 35µV/°F
The following criteria are used in selecting a thermocouple:

- Temperature range
- Chemical resistance of the thermocouple or sheath material
- Abrasion and vibration resistance
- Installation requirements (may need to be compatible with existing equipment; existing holes may determine probe diameter)

### Types of Thermocouple

1. Type B – very poor below 50ºC; reference junction temperature not important since voltage output is about the same from 0 to 42 ºC
2. Type E – good for low temperatures since dV/dT is high for low Temperatures
3. Type J – cheap because one wire is iron; high sensitivity but also high uncertainty (iron impurities cause inaccuracy)
4. Type T – good accuracy but low max temperature (400 ºC); one lead is copper, making connections easier; watch for heat being conducted along the copper wire, changing your surface temp
5. Type K – popular type since it has decent accuracy and a wide temperature range; some instability (drift) over time
6. Type N – most stable over time when exposed to elevated temperatures for long periods
Properties of Thermocouple:

1. The temp and e.m.f relation should be linear and reproducible
2. It should be strong for withstand high temp.
3. It should maintain its calibration without drift for long period of time.
4. Cost should be reasonable
5. It should have long life

Advantages of Thermocouple:

1. Better response
2. Higher range of temp. measurements
3. Sensing element can be easily installed
4. Cheap
5. Very convenient for measuring the temp. at one particular point in a piece of apparatus.

Disadvantages of Thermocouple:

1. Low accuracy
2. Circuit is very complex
3. For long life they need to be amply protected.
**Resistance Temperature Detectors (RTD)**

- The RTDs use the phenomenon that the resistance of a metal changes with temperature. They are, however, linear over a wide range and most stable. Typically, a wire (usually a platinum wire) is wrapped around a ceramic or glass rod.

**Construction of Resistance Temperature Detector or RTD**

- The construction is typically such that the wire is wound on a form (in a coil) on notched mica cross frame to achieve small size, improving the thermal conductivity to decrease the response time and a high rate of heat transfer is obtained.

  In the industrial RTD’s, the coil is protected by a stainless steel sheath or a protective tube. So that, the physical strain is negligible as the wire expands and increase the length of wire with the temperature change.

**Working**

- If the strain on the wire is increasing, then the tension increases. Due to that, the resistance of the wire will change which is undesirable. So, we don’t want to change the resistance of wire by any other unwanted changes except the temperature changes. This is also useful to RTD maintenance while the plant is in operation.

- Mica is placed in between the steel sheath and resistance wire for better electrical insulation. Due less strain in resistance wire, it should be carefully wound over mica sheet.

- The relationship between temperature and resistance of conductors in the temperature range near 0oC can be calculated from the equation:
\[ R_t = R_0 (1 + \alpha \Delta t) \]

- \( R_t \) = the resistance of the conductor at temperature \( t \) (°C)
- \( R_0 \) = the resistance at the reference temperature, usually 20°C
- \( \alpha \) = the temperature coefficient of resistance
- \( \Delta T \) = the difference between the operating and the reference temperature

Platinum wire has a temperature coefficient of 0.0039 Ω/°C, which means that the resistance goes up 0.0039 Ω for each ohm of wire for each Celsius degree of temperature rise. Therefore, a 100-platinum RTD has a resistance of 100 Ω at 0°C, and it has a positive temperature coefficient of 0.39 Ω/°C

**Advantages of platinum as RTD**

- The temperature-resistance characteristics of pure platinum are stable over a wide range of temperatures.
- It has high resistance to chemical attack and contamination
- It forms the most easily reproducible type of temperature transducer with a high degree of accuracy.
- It can have accuracy ± 0.01 °C up to 500 °C and ± 0.1 °C up to 1200 °C.
- Linearity over a wide operating range

**Limitations of RTD**

- These are resistive devices, and accordingly they function by passing a current through a sensor.
- Even though only a very small current is generally employed, it creates a certain amount of heat and thus can throw off the temperature reading.
- This self heating in resistive sensors can be significant when dealing with a still fluid (i.e., one that is neither flowing nor agitated), because there is less carry-off of the heat generated.
- This problem does not arise with thermocouples, which are essentially zero-current devices.
- Low sensitivity
- It can be affected by contact resistance, shock and vibration
✓ No point sensing
✓ Higher cost than other temperature transducers
✓ Requires 3 or 4 wire for its operation and associated instrumentation to eliminate errors due to lead resistance

**Applications of Resistance Temperature Detectors**

1. Air conditioning and refrigeration servicing
2. Food Processing
3. Stoves and grills
4. Textile production
5. Plastics processing
6. Petrochemical processing
7. Micro electronics
8. Air, gas and liquid temperature measurement
9. Exhaust gas temperature measurement

**F. Force/Pressure Sensor**

✓ Stress measurement *using strain*

✓ Strain is change in length (dl) per unit length (l)

✓ Strain gauge is primary sensing element used in pressure, force and position sensors

![Diagram of strain measurement](image)
Young's Modulus or Modulus of Elasticity

**Hooke's Law**: states that when a material is loaded within elastic limit, the stress is directly proportional to strain,

\[ \sigma \propto \varepsilon \quad \text{or} \quad \sigma = E \times \varepsilon \]

\[ E = \frac{\sigma}{\varepsilon} = \frac{P \times l}{A \times \Delta l} \]

Based on the **variation of resistance of a conductor or semiconductor when subjected to a mechanical stress**.

The electric resistance of a wire is having length \( l \), cross section \( A \), and resistivity \( \rho \) is:

\[ R = \rho \frac{l}{A} \]

When the wire is stressed longitudinally, \( R \) undergoes a change.

✓ **Passing small amount of current** through such wire will, thus, **help measure voltage change**.

✓ The sensing element of the strain gauge is **made of copper-nickel alloy foil**. The alloy foil has a rate of resistance change proportional to strain with a certain constant.

**Derivation of Strain Gauge Factor**

Let us consider a long straight metallic wire of length \( l \) circular cross section with diameter \( d \). When this wire is subjected to a force applied at the two ends, a strain will be generated and as a result, the dimension will change (\( l \) changing to \( l + \Delta l \), \( d \) changing to \( d + \Delta d \), \( A \) changing to \( A + \Delta A \)). For the time being, we are considering that all the changes are in positive direction. Now the resistance of the wire:

![Fig. 5 Change of resistance with strain](image)
From the above expression, the change in resistance due to strain:

\[
\Delta R = \left( \frac{\partial R}{\partial l} \right) \Delta l + \left( \frac{\partial R}{\partial A} \right) \Delta A + \left( \frac{\partial R}{\partial \rho} \right) \Delta \rho
\]

\[
= \frac{\rho}{A} \Delta l - \frac{\rho}{A^2} \Delta A + \frac{l}{A} \Delta \rho
\]

\[
= R \frac{\Delta l}{l} - R \frac{\Delta A}{A} + R \frac{\Delta \rho}{\rho}
\]

or,

\[
\frac{\Delta R}{R} = \frac{\Delta l}{l} - \frac{\Delta A}{A} + \frac{\Delta \rho}{\rho} \quad (6)
\]

Now, for a circular cross section, \( A = \frac{\pi d^2}{4} \); from which, \( \Delta A = \frac{\pi d}{2} \Delta d \). Alternatively,

\[
\frac{\Delta A}{A} = 2 \frac{\Delta d}{d}
\]

Hence,

\[
\frac{\Delta R}{R} = \frac{\Delta l}{l} - 2 \frac{\Delta d}{d} + \frac{\Delta \rho}{\rho} \quad (7)
\]

Now, the Poisson’s Ratio is defined as:

\[
\nu = -\frac{\text{lateral strain}}{\text{longitudinal strain}} = -\frac{\Delta d}{\Delta l}
\]

The Poisson’s Ratio is the property of the material, and does not depend on the dimension. So, (6) can be rewritten as:

\[
\frac{\Delta R}{R} = (1 + 2\nu) \frac{\Delta l}{l} + \frac{\Delta \rho}{\rho}
\]

Hence,

\[
\frac{\Delta R}{\Delta l} = 1 + 2\nu + \frac{\Delta \rho}{\Delta l}
\]

The last term in the right hand side of the above expression, represents the change in resistivity of the material due to applied strain that occurs due to the piezo-resistance property of the material. In fact, all the elements in the right hand side of the above equation are independent of the geometry of the wire, subjected to strain, but rather depend on the material property of the wire. Due to this reason, a term Gage Factor is used to characterize the performance of a strain gage. The Gage Factor is defined as:

\[
G := \frac{\Delta R/R}{\Delta l/l} = 1 + 2\nu + \frac{\Delta \rho/\rho}{\Delta l/l} \quad (8)
\]

For normal metals the Poisson’s ratio \( \nu \) varies in the range:

\[0.3 \leq \nu \leq 0.6\]

while the piezo-resistance coefficient varies in the range:

\[0.2 \leq \frac{\Delta \rho/\rho}{\Delta l/l} \leq 0.6\]
Thus, the Gage Factor of metallic strain gages varies in the range 1.8 to 2.6. However, the semiconductor type strain gages have a very large Gage Factor, in the range of 100-150. This is attained due to dominant piezo-resistance property of semiconductors. The commercially available strain gages have certain fixed resistance values, such as, 120Ω, 350 Ω, 1000 Ω, etc. The manufacturer also specifies the Gage Factor and the maximum gage current to avoid self-heating (normally in the range 15 mA to 100 mA).

Types of Strain Gauges

1. Bonded Wire Strain Gauge :

- Consists of a **strain sensitive conductor** (wire) mounted on a small piece of paper or plastic backing.
- This gauge is cemented to the surface of the structural member to be tested. The wire grid may be & flat type or wrap-around.
- In the **flat type** after attaching the lead wires to the ends of the grids, a second piece of paper is cemented over the wire as cover.
- In the **wrap-around type**, the wire is wound around a cylindrical core in the form of a close wound helix. This core is then flattened & cemented between layers of paper for the purpose of protection and insulation.
- Formerly only wrap-around gauges were available, but generally **flat grid gauges are preferred as they are superior to wrap-around gauge** in terms of hysteresis, creep, elevated temperature, performance, stability & current carrying capacity.
2. Un-bonded wire strain gauge:

The principal is based on the change in electrical resistance of a metallic wire due to the change in the tension of the wire.

- Fine wire loops are wounded around the insulated pins with pretension. Relative motion between the platform and the frame increases the tension in two loops, while decreasing tension in the other two loops.
- These four elements are connected approximately to a four arm Wheat stone bridge.
- These type strain gauges are used for measurement of acceleration, pressure, force etc.

3. Foil Strain Gauges:

- The foil type of strain gauges has a foil grid made up of thin strain sensitive foil.
- The width of the foil is very large as compared to the thickness (microns) so that larger area of the gauge is for cementing.
- High heat dissipation capability, Better bonding properties
The Wheatstone bridge is an electric circuit for detection of minute resistance changes. It is therefore used to measure resistance changes of a strain gauge.

Strain gauge is connected in place of R4 in the circuit. When the gauge bears strain and initiates a resistance change, \( \Delta R \), the bridge outputs a corresponding voltage.

- **Quarter Bridge**: \( \frac{V_{\text{output}}}{V_{\text{input}}} = \frac{1}{4} \times GF \times \varepsilon \)

- **Half Bridge**: \( \frac{V_{\text{output}}}{V_{\text{input}}} = \frac{1}{2} \times GF \times \varepsilon \)

- **Full Bridge**: \( \frac{V_{\text{output}}}{V_{\text{input}}} = GF \times \varepsilon \)
Effect of Temperature on Output of Gauge

✓ Ideally, we would like the resistance of the strain gauge to change only in response to applied strain.

✓ However, strain gauge material, as well as the specimen material to which the gauge is applied, will also respond to changes in temperature.

✓ Strain gauge manufacturers attempt to minimize sensitivity to temperature by processing the gauge material to compensate for the thermal expansion of the specimen material; compensated gauges reduce the thermal sensitivity, they do not totally remove it.

✓ By using two gauges.

✓ One gauge is active, and a second gauge is placed transverse to the applied strain.

✓ The strain has little effect on the second gauge, called the dummy gauge.

✓ Because the temperature changes are identical in the two gauges, the ratio of their resistance does not change, the voltage does not change, and the effects of the temperature change are minimized.
H. Electromagnetic Flow sensor

It works on the principle of basic electromagnetic induction; i.e. when a conductor moves along a magnetic field perpendicular to the direction of flow, a voltage would be induced perpendicular to the direction of movement as also to the magnetic field. The flowing liquid acts like a conductor. External magnetic field is applied perpendicular to the direction of the flow and two electrodes are flushed on the wall of the pipeline as

- Magnetic flow meters operate based upon Faraday’s Law of electromagnetic induction, which states that a voltage will be induced in a conductor moving through a magnetic field.
- Faraday’s Law: \( E = k B D V \)

The magnitude of the induced voltage \( E \) is directly proportional to the velocity of the conductor \( V \), conductor width \( D \), and the strength of the magnetic field \( B \).

- Magnetic field coils are placed on opposite sides a pipe to generate a magnetic field.

![Figure 2.21 - The Magnetic Head Flow Meter](image)

- As the liquid moves through the field with average velocity \( V \), electrodes sense the induced voltage.
- An insulating liner prevents the signal from shorting to the pipe wall.
- The output voltage \( E \) is directly proportional to liquid velocity, resulting in the linear output of a magnetic flow meter.
Advantages of Electromagnetic Flow Meter

(i) The obstruction to the flow is almost nil and therefore this type of meters can be used for measuring heavy suspensions, including mud, sewage and wood pulp.

(ii) There is no pressure head loss in this type of flow meter other than that of the length of straight pipe which the meter occupies.

(iii) They are not very much affected by upstream flow disturbances.

(iv) They are practically unaffected by variation in density, viscosity, pressure and temperature.

(v) Electric power requirements can be low (15 or 20 W), particularly with pulsed DC types.

(vi) These meters can be used as bidirectional meters.

(vii) The meters are suitable for most acids, bases, water and aqueous solutions because the lining materials selected are not only good electrical insulators but also are corrosion resistant.

(viii) The meters are widely used for slurry services not only because they are obstruction less but also because some of the liners such as polyurethane, neoprene and rubber have good abrasion or erosion resistance.

(ix) They are capable of handling extremely low flows.

Disadvantages-

1. Operating cost is high particularly if heavy slurries are handled
2. Must be full at all times because velocity as analogues to volume flow rate
3. Limited to fluid having conductivity at least of order of 0.05μmho/cm

Applications

Fluids like sand water slurry, coal powder, slurry, sewage, wood pulp, chemicals, water other than distilled water in large pipe lines, hot fluids, high viscous fluids specially in food processing industries, cryogenic fluids can be metered by the electromagnetic flow meter.
Actuator

converts an information signal from the control, into energy acting on the basic system.

\textit{a. Stepper Motor}

- Discrete Positioning device
- Moves one step at a time for each input
- Appropriate excitation in winding/s, makes the rotor attract towards the stator

\textit{Advantages}

1. The rotation angle of the motor is proportional to the input pulse.
2. The motor has full torque at standstill (if the windings are energized)
3. Precise positioning and repeatability of movement since good stepper motors have an accuracy of 3 – 5% of a step and this error is non cumulative from one step to the next.

4. Excellent response to starting/stopping/reversing.

5. Very reliable since there are no contact brushes in the motor. Therefore the life of the motor is simply dependant on the life of the bearing.

6. The motors response to digital input pulses provides open-loop control, making the motor simpler and less costly to control.

7. It is possible to achieve very low speed synchronous rotation with a load that is directly coupled to the shaft.

8. A wide range of rotational speeds can be realized as the speed is proportional to the frequency of the input pulses.

Disadvantages

1. Resonances can occur if not properly controlled.

2. Not easy to operate at extremely high speeds.

Applications

1. Industrial Machines – Stepper motors are used in automotive gauges and machine tooling automated production equipments.


3. Medical – Stepper motors are used inside medical scanners, samplers, and also found inside digital dental photography, fluid pumps, respirators and blood analysis machinery.


b. Servo Motor

✓ Precise control of angular position, velocity and acceleration

✓ Electric (DC/AC) motor driven using Pulse Width Modulation (PWM)

✓ Closed looped control system

✓ Basically DC motor (in some special cases it is AC motor)
Servo unit consists - small DC motor, potentiometer, gear arrangement, an intelligent circuitry

Servo mechanism consists of position sensor (potentiometer/encoder), gear mechanism and intelligent circuitry

Advantages:
1. If a heavy load is placed on the motor, the driver will increase the current to the motor coil as it attempts to rotate the motor. Basically, there is no out-of-step condition.
2. High-speed operation is possible.
3. Work well for velocity control
4. Available in all sizes
5. Quiet in operation
6. Smoother rotation at lower speeds

Disadvantages:
1. Since the servomotor tries to rotate according to the command pulses, but lags behind, it is not suitable for precision control of rotation.
2. Higher cost.
3. When stopped, the motor’s rotor continues to move back and forth one pulse, so that it is not suitable if you need to prevent vibration

Applications of Servo Motors
In Industries they are used in machine tools, packaging, factory automation, material handling, printing converting, assembly lines, and many other demanding applications robotics, CNC machinery or automated manufacturing.
They are also used in radio controlled airplanes to control the positioning and movement of elevators.

They are used in robots because of their smooth switching on and off and accurate positioning.

They are also used by aerospace industry to maintain hydraulic fluid in their hydraulic systems.

They are used in many radio controlled toys.

They are used in electronic devices such as DVDs or Blue ray Disc players to extend or replay the disc trays.

They are also being used in automobiles to maintain the speed of vehicles.

c. **Solenoid Actuator**

- Electromagnetic actuator
- Consist of a movable ferrite core that is activated by current flow
  - When the coil is energized, a magnetic field is established that provides the force to push or pull the core
  - Provide large force over a short duration
- Normally used as linear actuator
- Application in- Room heating, gas flow, water flow etc
A solenoid is defined as a coil of wire commonly in the form of a long cylinder that when carrying a current resembles a bar magnet so that a moveable core (armature) is drawn into (pulled-in) the coil when a current flows.

A more simple definition is that a solenoid is a coil and a moveable iron core used to convert electrical energy into mechanical energy.

Normally, the movement of the core compresses a spring.

On power-off, the armature returns back to its normal

The stroke of the armature varies from fraction of a mm to several mm depending on application.

There are two main categories of solenoids:

- Rotary – rotary motion of the armature
- Linear – linear motion of the armature