# ❖UNIT I INTRODUCTION

**Introduction to Mechatronics**

- ❖ Systems
- ❖Concepts of Mechatronics approach – Need for Mechatronics
- ❖ Emerging areas of Mechatronics
- ❖ Classification of Mechatronics.
- ❖ Sensors and Transducers
- ❖ Static and dynamic Characteristics of Sensor Potentiometers
- ❖ LVDT
- ❖ Capacitance sensors
- ❖Strain gauges
- ❖Eddy current sensor
- ❖Hall effect sensor
- ❖Temperature sensors
- ❖Light sensors

# Mechatronics

Mechatronics is defined as a application of Electronics and computer technology to control the mechanical systems

**Examples of mechatronics system**

i) Auto focus camera

ii) Robotics

iii) Washing machine

iv) Engine management systems

v) Microwave ovens

vi) Camcorders

vii) Aircraft flight control and navigation systems

viii) Numerically controlled machine tools

ix) Photocopiers

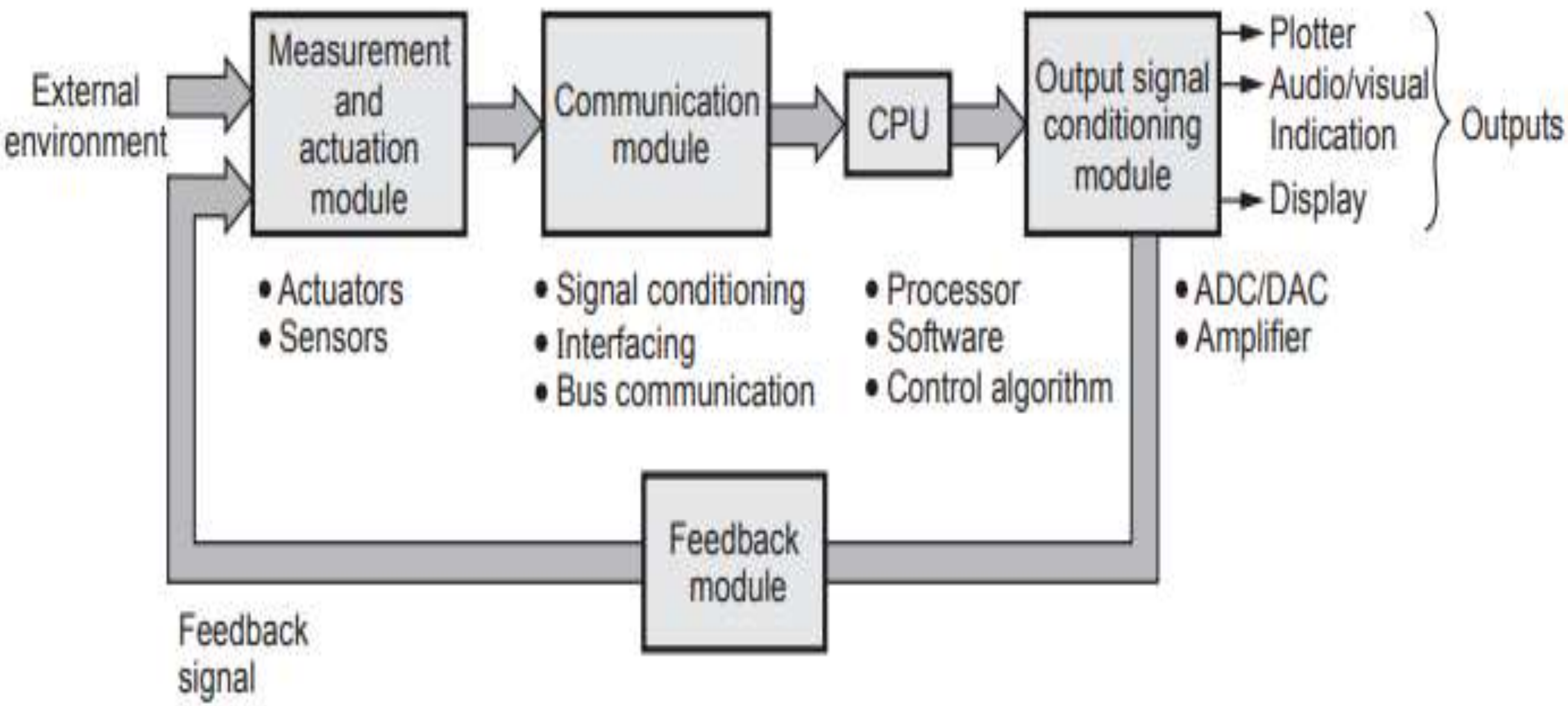
# System

- A system is defined as an orderly combination or arrangement of components connected to form a single unit for performing a defined function.
- System concerned only with the relationship between the input and output and not on the process going inside the box.


**Fig. 1.2.1 System**

- Here, the input is the electric power and the output after processed by the system is rotation. The system is motor.

# Buiding Block Mechatronics System



1. **Measurement and actuation module**
   - It receives signals from external environment and feedback signal. This module uses several actuators and sensors such as - solenoids, AC/DC and stepper motors, switches, strain gauge, temperature/pressure/photo sensors. These sensors can be adjusted manually.

2. **Communication module**
   - The position of sensors and the relative position of actuators are measured and corresponding signals are generated. These signals are feed to CPU through a communication module. The communication module includes signal conditioning circuits, interfacing circuits and bus communication.

3. **CPU**
   - CPU with a processor and necessary software performs the logical and arithmatic operations on the signal received, CPU then generates suitable control signal.

4. **Output signal conditioning module**
   - Output signal conditioning module consists of ADC/DACs, amplifiers to drive plotter, audio-visual indicators, displays etc. The output signal is given to feedback module.

5. **Feedback module**
   - The feedback module generates proportionate signal to the output signal which is given to the measurement and actuation module. The measurement and actuation module compares the external environment and feedback signal.

# Concepts of Mechatronics approach

The domestic washing machine that used cam operated switches in order to control the washing cycle is out of date.

Such mechanical switches are being replaced by microprocessor.

The microprocessor - controlled washing machine can be considered an example of a mechatronics approach in that a mechanical system has become integrated with electronic controls.

As a consequence, a bulky mechanical system is replaced by a much more compact microprocessor system which is readily adjustable to give a greater variety of programs.

Mechatronics brings together a number of technologies like, mechanical engineering, Electronic Engineering, electrical engineering, information technology, computer technology and control engineering.

- This can be considered as the application of Computer based digital control techniques, through electronic and electric interfaces to mechanical engineering problems.
- There are many applications of mechatronics in the mass produced products used in home.
- Microprocessor based controllers are to be found in domestic washing machines, dish washers, microwave ovens, cameras, camcorders, watches, hi-fi and video recorder systems, central heating controls, sewing machines, etc..
- They are to be found in cars in the active suspension, antiskid brakes, engine control, speedometer display, transmission etc.
- A large scale application of mechatronics is a Flexible Manufacturing engineering System (FMS) involving computer controlled machines, robots, automatic material conveying and overall supervisory control.

# Need for Mechatronics

- Industry is a plant structured to produce products and goods needed by people or industries.
- The need for mechatronics in industry can be described as follows

**1. Changing market conditions**

- Market situations are so volatile that often products become obsolete very fast because of the changing perceptions of consumers.
- Competition is so tough that the sellers' market is turning into buyers' market.
- To satisfy and attract customers the use of mechatronics in manufacturing industry and in products is predictability for entrepreneurs.

**2. Short production runs**

- Short product cycles, batch production, and job changeovers frequently influence the possibility of short production runs, market demand and obsoletion of features.
- Batch production in an industry producing products of diversified specification is not avoidable.

**3. Variety in product Range**

- Variation in size, shape, feature, facility, performance and aesthetics are governed by customer likes, dislikes and needs.
- Hence manufactures are compelled to produce a variety of products with a wide range.
- This is made easy by taking advantage of mechatronics.

# Emerging areas of Mechatronics

- Some of these Emerging areas of Mechatronics are as follows :

1. Control Systems (position, level, pressure and heat control systems...)
2. Robots (transport and welding robots)
3. Industrial Automation (barcode systems and production belts)
4. Building Automation (security systems, automatic air conditioning and automatic door systems)
5. Home appliances (washing machines and dish washers)
6. Automotive (air bag, antilock braking system)
7. Defence Industry (mine detection robots, automatically guided vehicles)
8. Medical Applications (magnetic resonance, arthroscopic devices, ultrasonic probes etc.)
9. Aeronautical Engineering (automatic pilots, unmanned aerial vehicles)
10. Image and Sound Processing (automatic focusing devices, sound-operated devices)
11. Production (Computerized Numerical Control - CNC, Numerical Control - NC)
12. Laser optical systems (barcode)
13. Intelligent measuring devices (calibration devices, testing and measuring sensors.

# Classification of Mechatronics

Mechatronics can be classified as follows

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.

   e.g. cassette tape player.

3. **Tertiary Level Mechatronics :** Incorporates advanced control strategy using microelectronics, microprocessors and other application specific integrated circuits

   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.

# Sensors

- A sensor is defined as an element which when subjected to some physical change experiences a relative change.
- Devices which respond directly to any physical phenomenon such as force, temperature, heat, light etc. are called sensors.

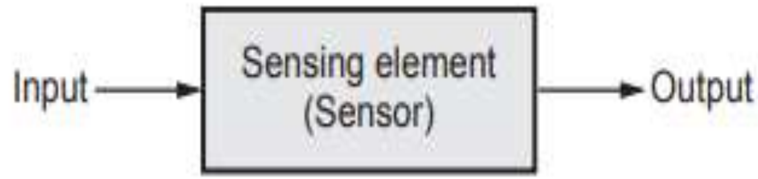



Fig. 1.7.1 Function of a sensor

- The sensor produces a proportional output signal mechanical, electrical or magnetic when exposed to physical phenomenon.

# Classification of sensor

Detail classification of sensors in view of their applications in manufacturing is as follows.

**A. Displacement, position and proximity sensors**

1. Potentiometer
2. Strain-gauged element
3. Capacitive element
4. Differential transformers
5. Eddy current proximity sensors
6. Inductive proximity switch
7. Optical encoders
8. Pneumatic sensors
9. Proximity switches (magnetic)
10. Hall effect sensors

**B. Velocity and motion sensors**

1. Incremental encoder
2. Tachogenerator
3. Pyroelectric sensors

**C. Force sensor**

1. Strain gauge load cell

**D. Fluid pressure sensors**

1. Diaphragm pressure gauge
2. Capsules, bellows, pressure tubes
3. Piezoelectric sensors
4. Tactile sensor

**E. Liquid flow sensor**

1. Orifice plate
2. Turbine meter

**F. Liquid level sensor**

1. Floats
2. Differential pressure

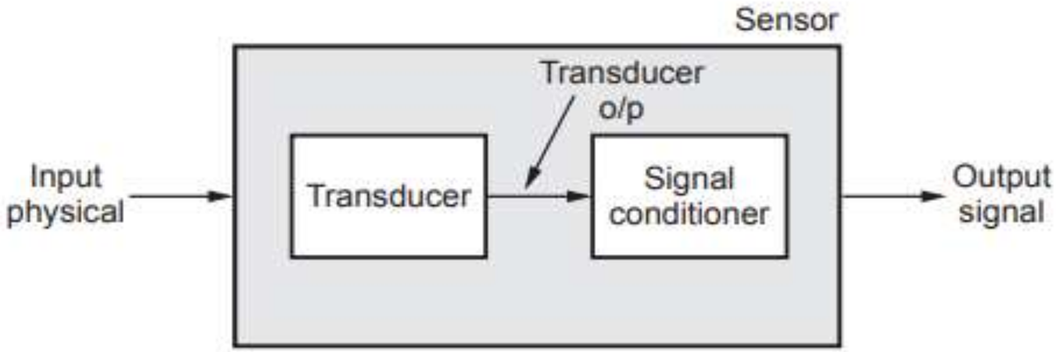
## G. Temperature sensors

1. Bimetallic strips
2. Resistance temperature detectors
3. Thermistors
4. Thermo-diodes and transistors
5. Thermocouples
6. Light sensors
7. Photo diodes
8. Photo resistors

# Transducer

Transducers are devices which converts one form of energy into other form of energy.

- For example, microphones, thermometers, position and pressure sensors and antenna ; LEDs etc.
- The term transducer is synonymously used with sensors although the principles are different.
- Transducers are physical element and is an essential part of sensor.
- The transducers refers to sensing element itself where as sensors refers to sensing element along with signal conditioning circuitry.
- Fig. 1.7.2 shows sensor with it's energy conversion function.



### 1.7.3.1 Classification of Transducers

- Transducers can be classified on many ways. Broadly they can be categorized as -
  1. Active and passive transducers.
  2. Analog and digital transducers.

#### 1. Active transducers

- The transducer which generates an electrical signal directly in response to the physical parameter being measured are called as **active transducers**.
- Active transducers are self generating devices i.e. they does not require an external power source for its operation. Active transducers operate under energy conversion principle that generates an equivalent output signal.

**Examples of active transducers -**

a) Photo voltaic cells

b) Thermocouples

c) Piezoelectric transducer

## 2. Passive transducers

- The transducer which requires external energy source for its operation is called as **passive transducer.**
- Passive transducer works under energy controlling principle, which makes it necessary to use an external electrical source for its operation.

**Examples of passive transducers -**

a) Thermistor

b) Strain gauge

c) Load cell

## 1.2.4 Characteristics of Measurement System

- In an industrial process, measuring device senses various parameters under observation. Therefore, it is necessary that the device must measure that parameter accurately. To obtain better performance from any measuring device, a number of its characteristics must be considered.
- The performance characteristics of any measuring device can be divided into two characteristics :

1. Static characteristics
2. Dynamic characteristics.

The overall performance of an instrument or measuring device is determined by its static and dynamic characteristics.

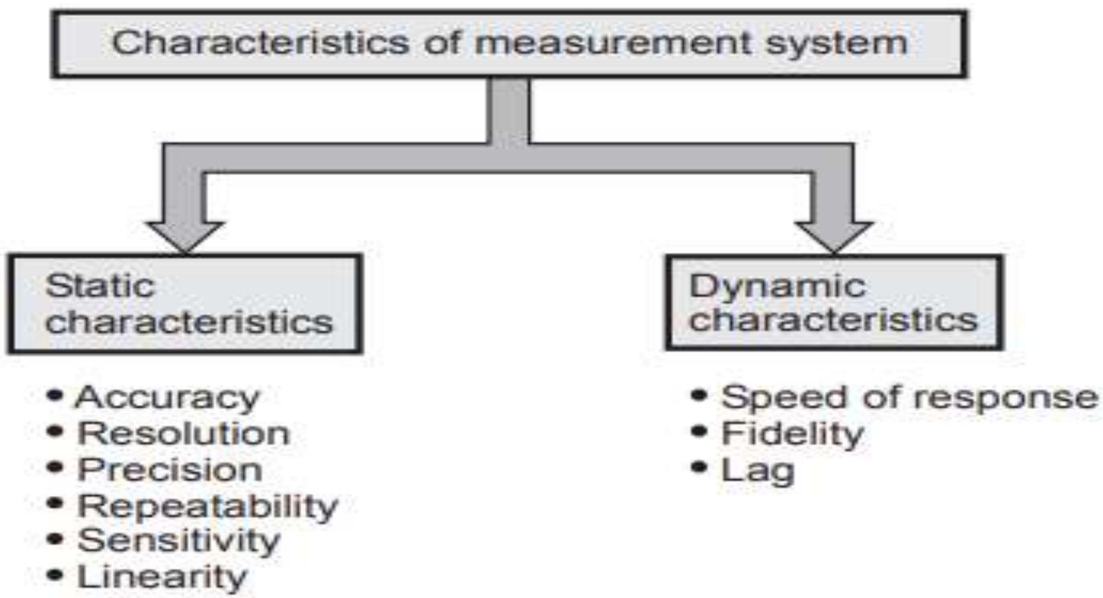



**Fig. 1.2.6 Characteristics of measurement system**

### 1.2.4.1 Static Characteristics of Sensors

☞ [ AU : Dec.-2016, 8 Marks ]

- Static characteristics describe performance at room temperature conditions, with very slow changes in measurement quantities.
- In some applications, measurement quantities are constant or varying quite slowly, the set of characteristics that defines the performance of device under such condition is known as **static characteristics** of device.
- Static characteristics of a device can be defined as the characteristics describing the relationship between specified points when system variable are not changing.
- Examples of static characteristics are - accuracy, precision, resolution, repeatability (reproducibility), zero drift, lag, sensitivity threshold and linearity.
- Accuracy is highly desirable and repeatability is certainly the most important static feature of any measuring device.

#### 1. Accuracy

- Accuracy is defined as the ability of the instrument to respond to the true value of the measure variable under the reference conditions.

## 2. Precision

- **Precision** is defined as the closeness with individual measurements are distributed about their mean value.

  Precision is the difference between a measured variable and best estimate of the true value of the measured variable.

- Precision is a measure of repeatability as it is the consistency of the instrument output for a given value of input.

- Accuracy and precision have totally distinct meanings.

- Precision consists of three characteristics :

  I. Conformity

  II. Number of significant figures

  III. Range of doubt.

### 3. Resolution

- Resolution is defined as the smallest increment in the measured value that can be detected.
- The resolution is the smallest change in the input value which will produce an observable change in the input.

### 4. Repeatability

- **Repeatability** is defined as the measure of the deviation of test results from the mean value.
- It is the closeness of a group of measurements of the same measured quantity made by the same observer, using the same conditions, methods and apparatus. Repeatability is affected by internal noise and drift.

  **For example,** if a displacement transducer is repeatedly subjected to an accurately known displacement, then its repeatability would be ± 1 percent if all the readings within these limits.
- Repeatability is also referred to as reproducibility. The perfect reproducibility indicates no drift in the instrument.

### 5. Stability

- Stability is defined as the ability of transducer to give same output for constant input over a period of time.

### 6. Drift

- **Drift** is a variation in the instrument output which is not caused by any change of input, it may be caused by internal temperature changes and component instability. The drift is a gradual shift of the instrument indication.

### 7. Hysteresis

- **Hysteresis** is the maximum difference in output, at any measurand value, within the specified range, when the value is approached first with increasing and then with decreasing value of parameter.
- Hysteresis can be defined as the maximum difference in any part of output readings so obtained during any one calibration cycle. Fig. 1.2.7 shows hysteresis curve.

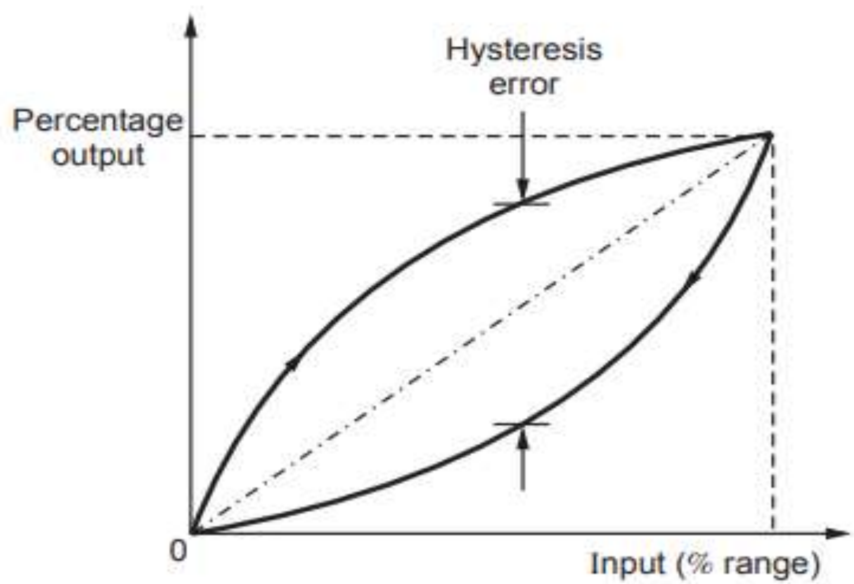



**Fig. 1.2.7 Hysteresis error**

## 8. Linearity

- **Linearity** describes the maximum deviation of the output of a device from a best fitting straight line through the calibration data. Most devices are designed such that the output is a linear function of input. i.e. sensitivity remains constant for all values of measurand.

## 9. Sensitivity

- **Sensitivity** is defined as the ratio of change in the magnitude of instrument output to the corresponding change in the magnitude of the measurand.

## 10. Threshold

- Threshold of a device is the minimum input for which there will be an output. Below this minimum input, the instrument will read zero.
- The resolution is the smallest measurable input change while threshlod is smallest measurable input.

## 11. Deadband

- Deadband is the largest change of measurand to which the instrument does not respond and is produced by friction, backlash or hysteresis in the device.
- It is defined as the largest change of input quantity for which there is no output from the instrument. It is produced by friction, backlash or hysteresis in the device.

## 12. Backlash

- Backlash is the 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.

### 13. Range and span

- The scale **range** of an instrument is the difference between the largest and smallest reading of the instrument. The selection of proper range is important in measurement.
- The difference between highest calibration point and lowest calibration point of an instrument is called **span** of instrument.

### 14. Output impedance

- The impedance across the sensor when it is giving electrical output is called output impedance of that sensor. This output impedance is either connected in series or parallel with the circuit to be interfaced. Therefore, the output impedance is an important parameter for any sensor or transducer.

### 15. Reproducibility

- The reproducibility of a transducer (instrument) is defined as the degree of closeness among the repeated measurements of the output for the same value of input under the same operating conditions at different times.
- Perfect reproducibility means that transducer has no drift i.e. transducer calibration does not gradually shift over a long period of time such as week, month or even a year.

## 1.2.5 Response of System

- The system does not respond instantaneously to any input to it. **Dynamic characteristics** determines the behavior of the system between the time when input value changes and time when output settles down to steady state.
- Dynamic characteristics of a control system are specified by rise time, response time and settling time as shown in Fig. 1.2.9.

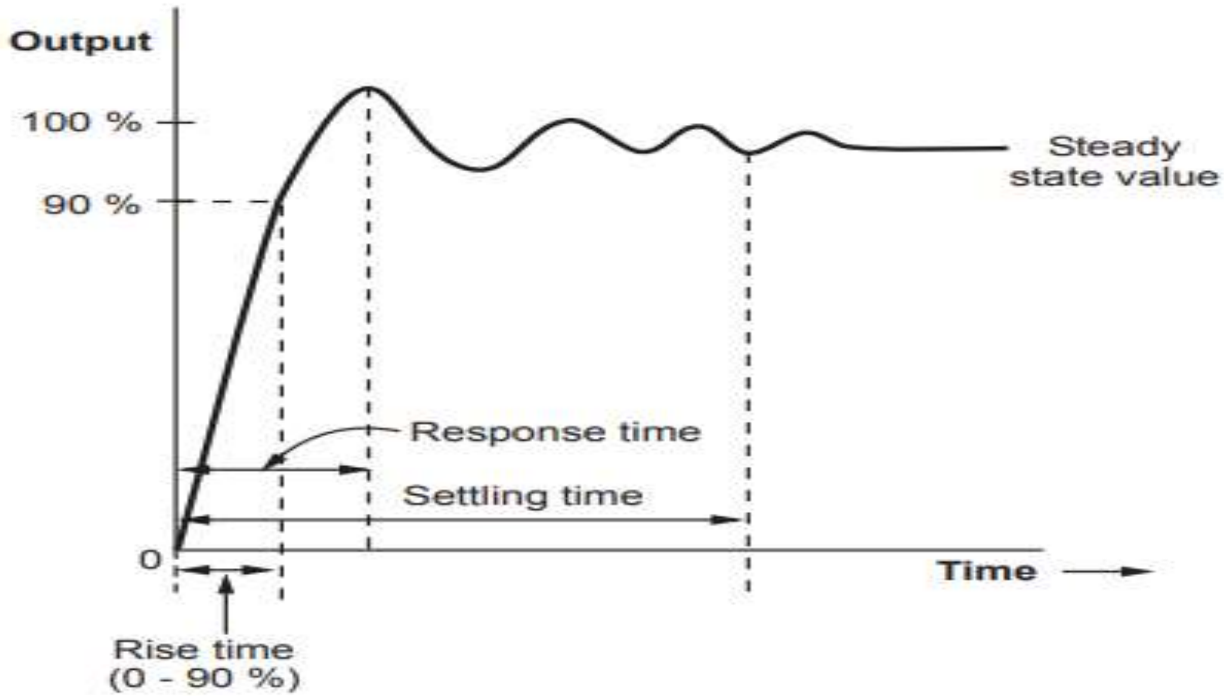



**Fig. 1.2.9 Rise, response and settling time**

### 1.2.5.1 Rise Time

- It is the time taken for the output to rise to some specified percentage of the steady state value, e.g. - in some system it is taken as time for 0 - 90 % of output also in some system rise time is taken as 10 % to 90 % of output.

### 1.2.5.2 Time Constant

- Response time is defined as time taken for the output to reach 63 % of its steady state value or time taken to reach its first peak of oscillation.

### 1.2.5.3 Settling Time

- Settling time is the time taken for the output to settle to within some percentage e.g. 2.5 % of steady state value.

## 1.9 Potentiometer

- A potentiometer [pot] can be used to convert rotary or linear displacement into a voltage.
- The potentiometers can be classified into following two types
  1. Linear potentiometer
  2. Rotary potentiometer

### 1.9.1 Linear Potentiometer

- A potentiometer is the most common position sensor.

- This type of sensor is basically a fixed resistor with a movable tap that allows the amount of resistance between the tap and either end of resistor to provide a portion of a total resistance [0 to 100 %].
- The linear potentiometer consist of resistance element with number of turns of wire wound around non-conducting bar together with a sliding contact.

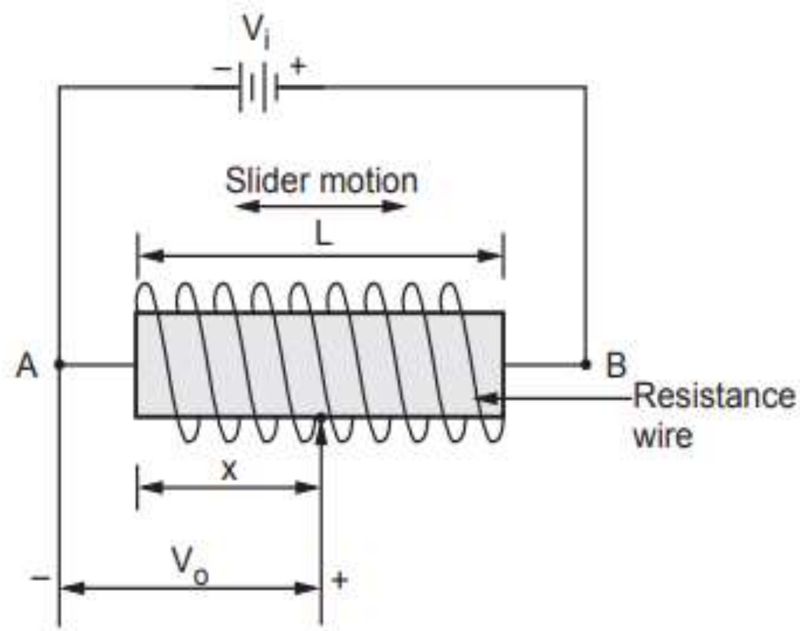


**Fig. 1.9.1 Linear potentiometer**

- Fig. 1.9.1 shows example of linear potentiometer.
- The relationship between the output voltage $V_o$ and position of a wiper x, as it moves along the length of the resistance wire L can be expressed as

$$V_o = \frac{x}{L} V_i \qquad \text{or} \qquad x = \frac{V_o}{V_i} \cdot L$$

- The linear displacement of the wiper contact is directly converted into proportional output voltage.
- There is linear relationship between the wiper position and the corresponding output voltage as shown in Fig. 1.9.2.
- The linear potentiometer is usable in applications where the amount of linear movement must be measured accurately e.g. pressure measurement using diaphragm.

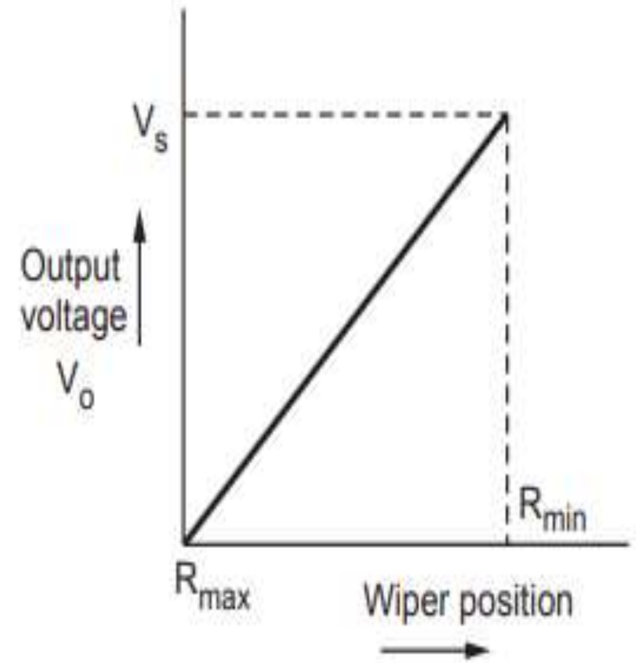
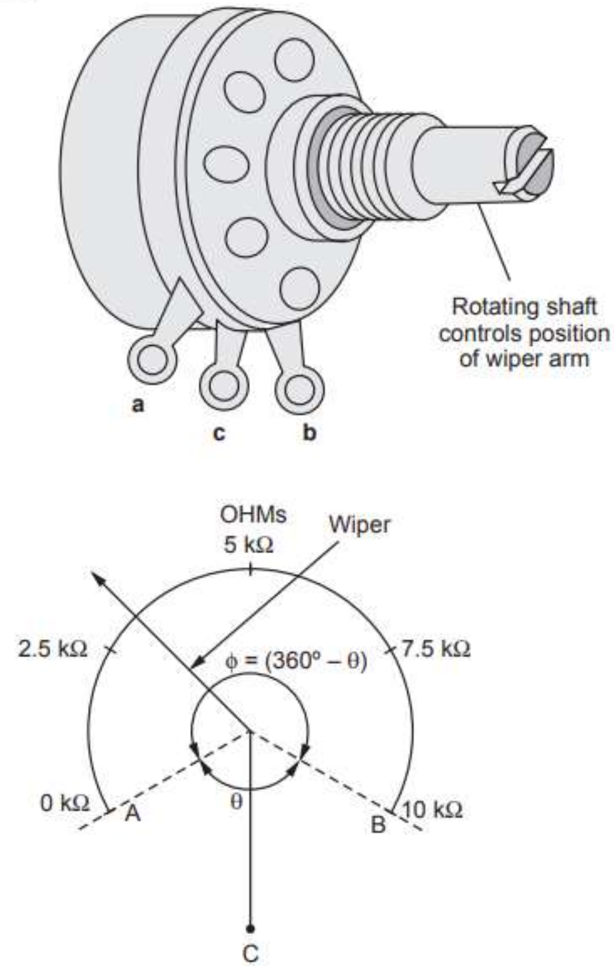



**Fig. 1.9.2 Linear potentiometer characteristics**

## 1.9.2 Rotary Potentiometer

- Electrically the operation of linear and rotary potentiometer operation is same. The main difference is that the shaft of the rotary potentiometer converts rotary motion into the change in resistance. Fig. 1.9.3 shows a rotary potentiometer with its electrical diagram.



- Rotary potentiometers are of two types -
  1. Single turn type potentiometer
  2. Multiturn type potentiometer.
- The single turn potentiometer allows the rotating shaft to move the wiper from one end of fixed resistor to the other in one shaft rotation. For example, if the total resistance of potentiometer is 1000 Ω, when shaft moves by 180°, the resistance of wiper to one end will be 500 Ω.
- The output voltage of rotary potentiometer is proportional to the angular movement of shaft.

**Applications of potentiometer**

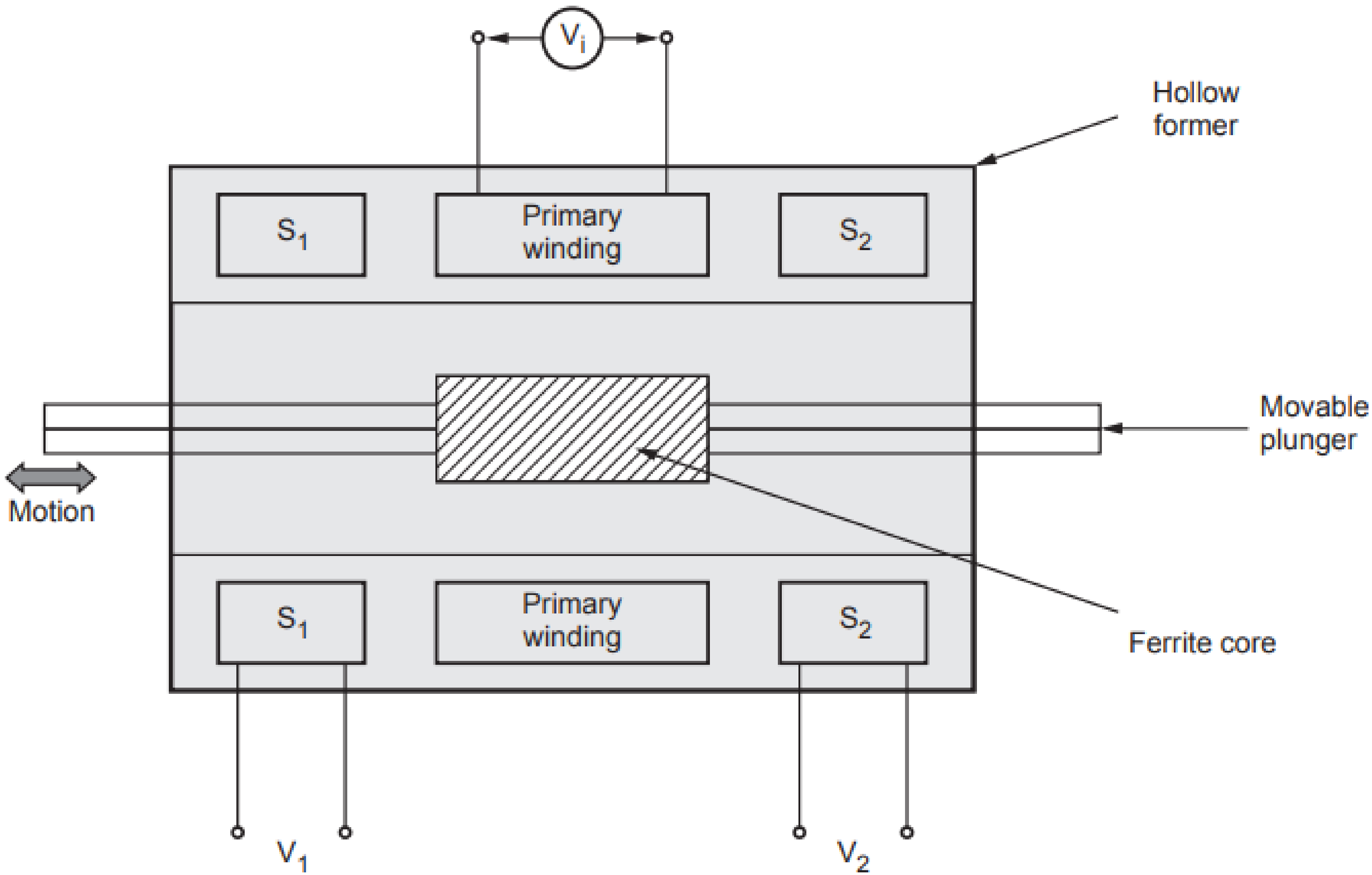
- These sensors are primarily used in the control systems with a feedback loop to ensure that the moving member or component reaches its commanded position.
- These are typically used on machine-tool controls, elevators, liquid-level assemblies, forklift trucks, automobile throttle controls.
- In manufacturing, these are used in control of injection moulding machines, woodworking machinery, printing, spraying, robotics, etc.
- These are also used in computer-controlled monitoring of sports equipment.

## 1.10 LVDT (Linear Variable Differential Transformer)

- LVDTs are mostly used transducer to translate linear displacements into electrical signals.
- LVDT find a number of applications in both measurement and control systems. Their high resolution, high accuracy and good reliability and stability make them an ideal device for applicatons involving short displacement measurement.

### Construction

- LVDT consists of one primary winding P and two secondary windings $S_1$ and $S_2$. The secondary windings are placed on either side of primary winding. All three windings are wound on the hollow cylindrical former. A cylindrical ferrite core is attached to the sensing shaft (plunger) and aligned axially so that it can slide freely in the former.



V_i
Hollow
former
S_1
Primary
winding
S_2
Movable
plunger
Motion
Ferrite core
S_1
Primary
winding
S_2
V_1
V_2

**Working**

- The secondaries $S_1$ and $S_2$ are connected in series opposition so that voltages induced in each coil opposes each other. The electrical equivalent connection shown in the Fig. 1.10.2.

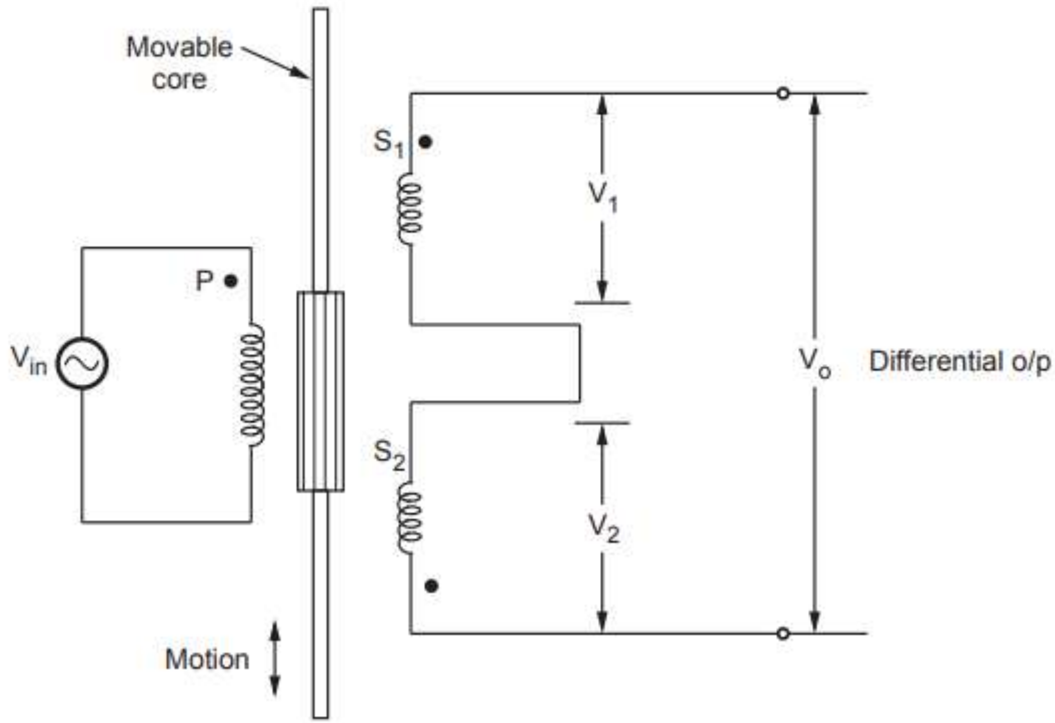



**Fig. 1.10.2 Electrical connection of LVDT**

- The position of movable core determines the flux linkage between the primary and each of two secondary windings.

Let $V_1$ = Output of secondary $S_1$

$V_2$ = Output of secondary $S_2$

Then $V_o = V_1 - V_2$

**Case I : When the core is at centre**

- With the core in the centre, the induced voltages $V_1$ and $V_2$ in the secondaries $S_1$ and $S_2$ are equal, since they oppose each other, the output will be zero volts. This is called as **Null** or **Reference position.**

**Case II : When the core is displaced**

- When the core is displaced from the null position the induced voltage in the secondary towards which the core has moved increases while that in other secondary decreases.
- Input voltage $V_i$ and output voltage $V_o$ waveform for various core position is shown in the Fig. 1.10.3.
- The phase difference between the output and input voltage changes by 180° when the core moves through the null position. Therefore in actual measurement to determine position uniquely, this phase change over is measured with phase sensitive detector.

## 1.10.1 Transfer Characteristics of LVDT

- In practice, due to imbalance a residual voltage remains with the core in null position.
- The output voltage versus core displacement charracteristic is shown in Fig. 1.10.4.

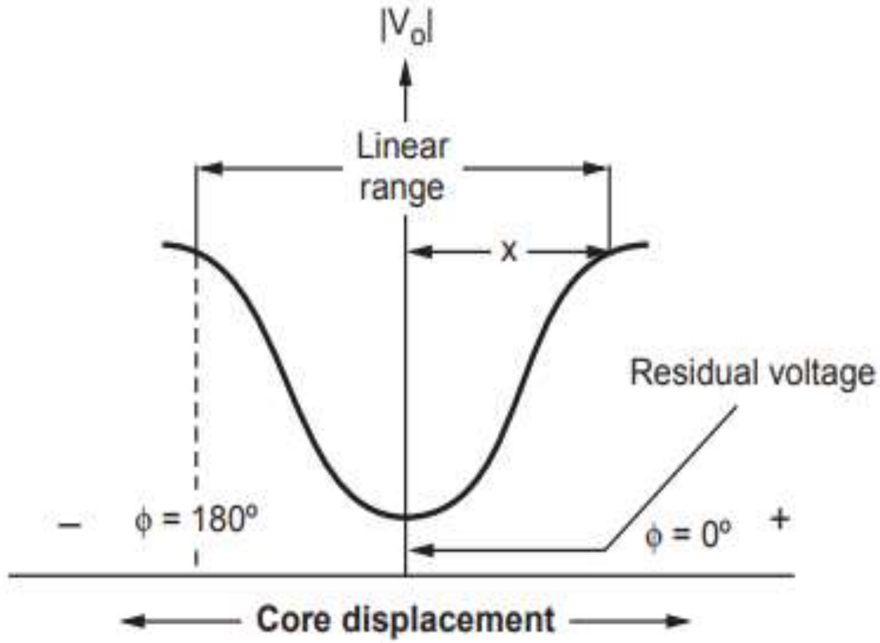



Fig. 1.10.4 Output voltage versus core displacement

### 1.10.3 Advantages and Disadvantages of LVDT

**Advantages of LVDT**

**A) Mechanical**

1. Wide range of displacement : ± 0.005 to ± 25 inch.
2. Frictionless operation : No physical contact exists between the core and coil structure.
3. Ruggedness : Good mechanical life.
4. Insensitive to temperature changes.
5. Highly repeatable response (performance).

**B) Electrical**

1. Linearity : Better (Output voltage is a linear function of mechanical displacement).
2. High sensitivity.
3. Resolution : Infinite.
4. Electrical isolation is better.

**Disadvantages of LVDT**

1. Physical size is large and it is bulky.
2. Inertia of core limits the speed of response, therefore not suitable for dynamic measurements.
3. Phase sensitive circuit is required.
4. Susceptibility to stray magnetic field, it can be reduced by shielding.

### 1.10.4 Applications of LVDT

There are some main applications of LVDT

- It is used to control the jet engine in aircraft.
- It is used for the measurement of the thickness and weight in the steel mills.
- It is used for the measurement of the weight on the highways.

## 1.12 Capacitive Sensor

- It is used for measuring, displacement, velocity, force etc.

**Principle :**

- It is passive type sensors in which *equal* and *opposite* charges are generated on the plates due to voltage applied across the plate which is *separated* by dielectric material.
- A combination of plates which can hold an electric charge is called a capacitor.
- The capacitor may be characterized by q, the magnitude of charge on either conductors, and by V, the positive potential difference between the conductors (Fig. 1.12.1 ).
- The ratio of charge to voltage is constant for each capacitor, and is called the capacitance (C) of the capacitor.

**Formula :**

The capacitance 'C' of a parallel plate capacitor is given by

$$C = \frac{\varepsilon_r \varepsilon_0 A}{d}$$

**...Ans.**

where $\varepsilon_r$ = Permittivity of the dielectric between the plates [= 1 for air]

$\varepsilon_0$ = Permittivity of free space [= $8.854 \times 10^{-12}$ F/m for air]

A = Area of overlap between two plates in $m^2$

d = Distance between two plates in m.

**By Changing the distance between two plates :**

- The displacement is measured due to the change in capacitance.

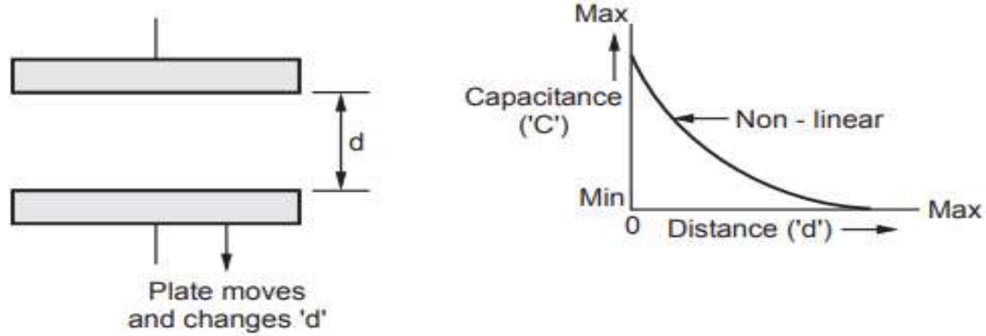



**Fig. 1.12.1**

**By varying the area of overlap :**

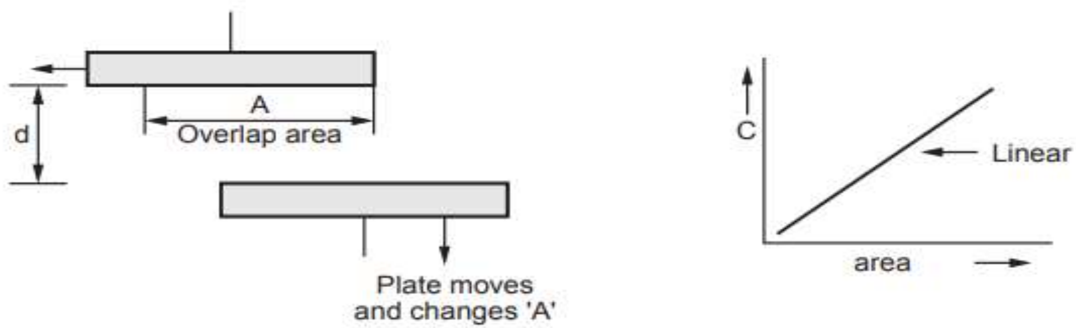



**Fig. 1.12.2**

- The displacement causes the area of overlap to vary.
- The capacitance is directly proportional to the area of the plates and varies linearly with changes in the displacement between the plates.

**By varying the dielectric constant :**

- The change in capacitance can be measured due to change in dielectric constant as a result of displacement.
- When the dielectric material is moved due to the displacement, the material causes the dielectric constant to vary in the region where the two electrodes are separated that results in a charge in capacitance.

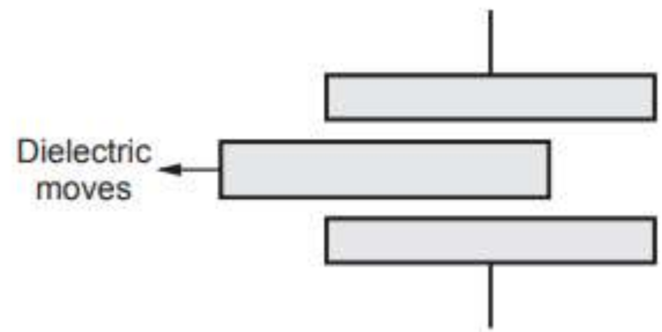



Fig. 1.12.3

### 1.12.1 Advantages of Capacitive Sensor

1. It is non contact type sensor and can be used with any material with resistivity less than $100\ \Omega/cm^2$.
2. The sensor is extremely rugged and be subjected to high shock loads.
3. Even at high temperature performance of the transducer is very good. (since $\varepsilon_r$ is constant for a wide temperature range).
4. Sensitivity is better in different environmental conditions.
5. Linearity is better.

### 1.12.2 Applications of Capacitive Sensor

i) Insulation layer measurement can be carried out by variable area capacitive transducers.

ii) Moisture measurement in wood is carried out by variable permittivity type capacitive transducer.

iii) Dynamic measurement of force can be carried out by variable distance capacitive transducer.

## 1.13 Strain Gauge

- Strain gauges are devices whose resistance changes under the application of force or strain.
- They can be used for measurement of force, strain, stress, pressure, displacement, acceleration etc.

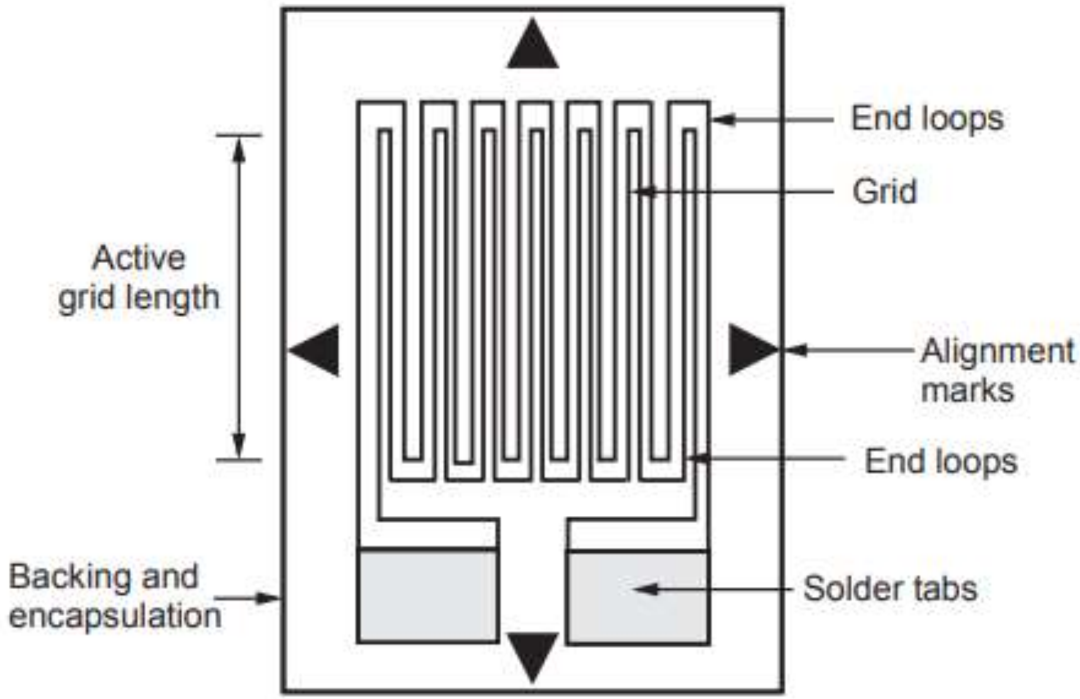



**Fig. 1.13.1 Strain gauge working**

## 1.13.1 Strain Gauge Working Principle

- A strain gauge consists of a foil of resistive characteristics, which is safely mounted on a backing material.
- When a known amount of stress in subjected on the resistive foil, the resistance of the foil changes accordingly.
- Thus, there is a relation between the change in the resistance and the strain applied.
- This relation is known by a quantity called gauge factor.

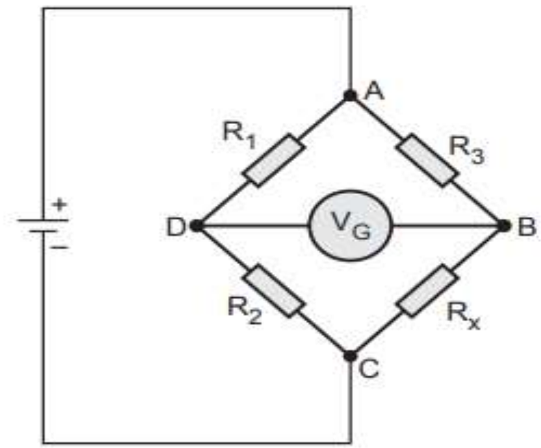


**Fig. 1.13.2 Wheatstone bridge**

- The change in the resistance can be calculated with the help of a Wheatstone bridge.
- As shown in the circuit diagram, there are four resistances connected as a bridge circuit.
- The three resistors R1, R2 and R3 will have known values.
- The value of the resistance RX will be unknown and has to be calculated.
- The value of resistance R2 is adjustable.
- A galvanometer has to be set between the points B and D.
- The property of the strain gauge not only depends on the electrical conductivity of the conductor, but also in the size and shape of the conductor used.

## 1.14 Eddy Current Sensor

- Eddy-Current sensors are noncontact devices capable of high-resolution measurement of the position and/or change of position of any conductive target.
- Eddy-Current sensors are also called inductive sensors, but generally "eddy current" refers to precision displacement instruments (or non-destructive testing probes) and "inductive" refers to inexpensive proximity switches.
- High resolution and tolerance of dirty environments make eddy-current sensors indispensable in today's modern industrial operations.

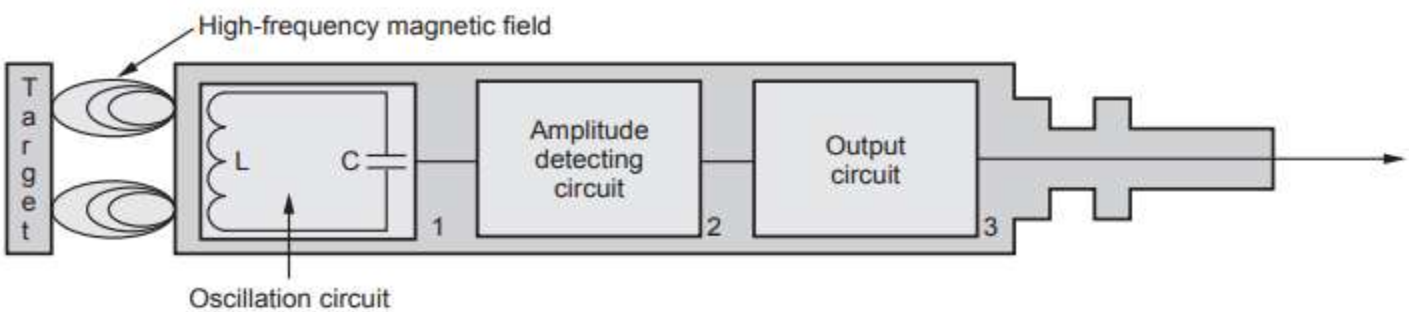



**Fig. 1.14.1 Schematic of eddy-current sensors**

- Eddy current sensors are used to detect non-magnetic but conductive materials.
- They comprise of a coil, an oscillator, a detector and a triggering circuit.
- Fig. shows the construction of eddy current sensor.
- When an alternating current is passed thru this coil, an alternative magnetic field is generated.
- If a metal object comes in the close with the coil, then eddy currents are induced in the object due to the magnetic field.

- These eddy currents create their own magnetic field which distorts the magnetic field responsible for their generation.
- As a result, impedance of the coil changes and so the amplitude of alternating current.
- This can be used to trigger a switch at some pre-determined level of change in current.
- Eddy current sensors are relatively inexpensive, available in small in size, highly reliable and have high sensitivity for small displacements.

### 1.14.1 Advantages of Eddy Current Sensor

1. Tolerance of dirty environments
2. Not sensitive to material in the gap between the probe and target
3. Less expensive and much smaller than laser interferometers
4. Less expensive than capacitive sensor

### 1.14.2 Disadvantages of Eddy Current Sensor

Eddy-Current sensors are not a good choice in these conditions :

1. Extremely high resolution (capacitive sensors are ideal)
2. Large gap between sensor and target is required (optical and laser are better)

### 1.14.3 Applications of Eddy Current Sensors

1. Automation requiring precise location
2. Machine tool monitoring
3. Final assembly of precision equipment such as disk drives
4. Drive shaft monitoring
5. Vibration measurements

## 1.15 Hall Effect Sensor

☞ [ AU : Dec.-2016, 8 Marks ]

- A device which converts magnetic or magnetically encoded information into electrical signals is called **Hall Effect Sensor.**
- A Hall Effect device/sensor is a solid state device that is becoming more and more popular because of its many uses in different types of applications.
- **Hall Effect Sensors** are devices which are activated by an external magnetic field.
- We know that a magnetic field has two important characteristics flux density, (B) and polarity (North and South Poles).
- The output signal from a Hall effect sensor is the function of magnetic field density around the device.
- When the magnetic flux density around the sensor exceeds a certain pre-set threshold, the sensor detects it and generates an output voltage called the Hall Voltage, $V_H$.
- Consider the diagram below,

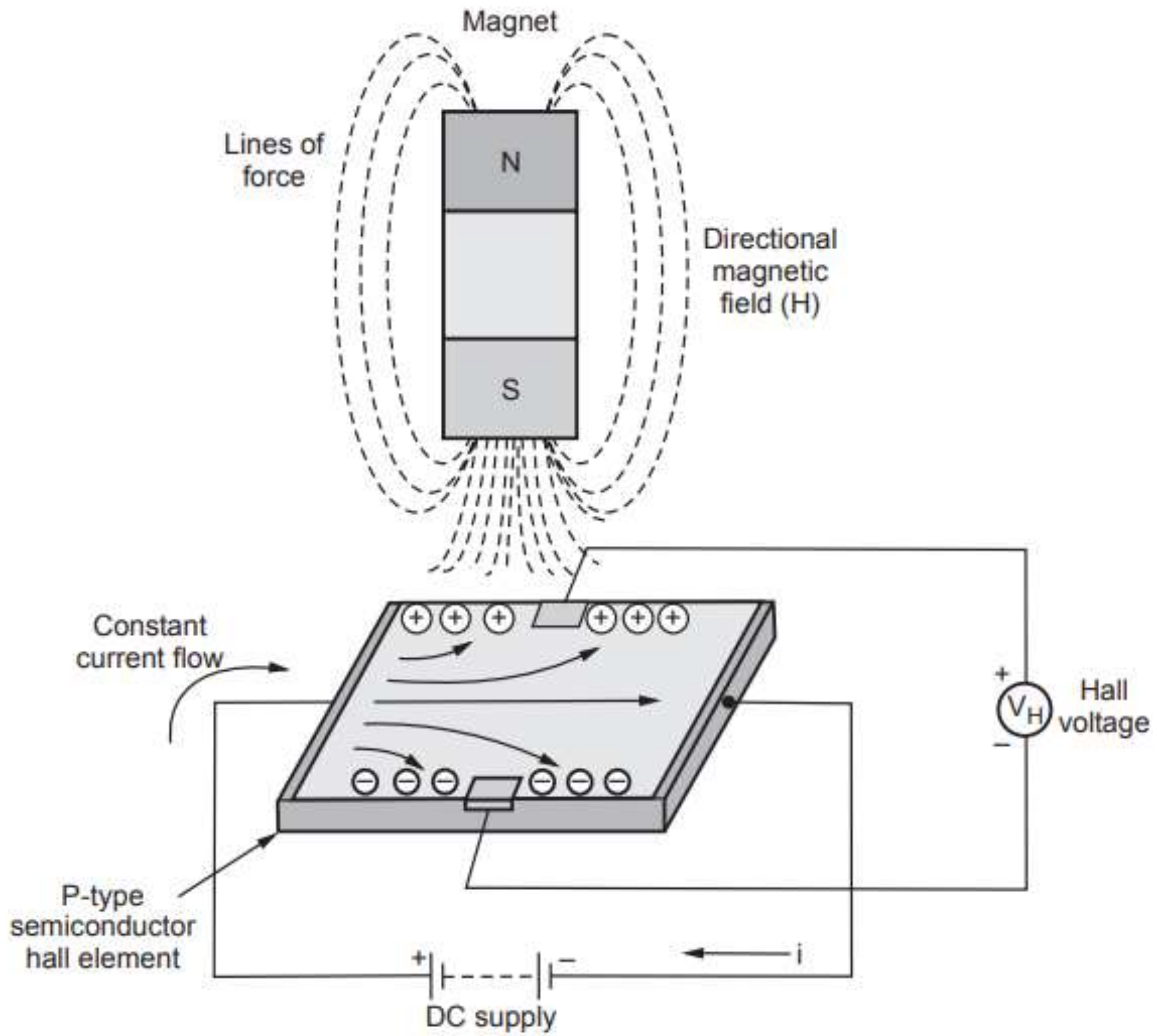



**Fig. 1.15.1 Hall effect sensor**

- **Hall Effect Sensors** consist basically of a thin piece of rectangular p-type semiconductor material such as gallium arsenide (GaAs), indium antimonide (InSb) or indium arsenide (InAs) passing a continuous current through itself.
- When the device is placed within a magnetic field, the magnetic flux lines exert a force on the semiconductor material which deflects the charge carriers, electrons and holes, to either side of the semiconductor slab.
  - This movement of charge carriers is a result of the magnetic force they experience passing through the semiconductor material.

## 1.15.1 Advantages of Hall Effect Sensors

The advantages of using Hall Effect sensors are as follows :

1. Production of an output voltage signal independent of the rate of the detected field.
2. Hall Effect sensors are built from semiconductor material that display low carrier density, hence conductivity is smaller and their voltage is larger.
3. A high speed operation is possible.
4. Hall sensors can measure zero speed.

### 1.15.2 Disadvantages of Hall Effect Sensors

The Hall Effect sensor does have its disadvantages :

1. The Hall Effect sensor is not capable of measuring a current flow at a distance greater than 10 cm; however, use of a magnet strong enough to generate a magnetic field wide enough may make this possible.
2. Hall Effect sensors work on the principle of a magnetic field, making it possible for external magnetic fields to interfere with this and bias the measurement of a current flow.
3. Temperature affects the electrical resistance of the element and the mobility of majority carriers and also the sensitivity of Hall Effect sensors.
4. Even with well-centered electrodes, the offset voltage still presents as an output voltage in the absence of a magnetic field.

### 1.15.3 Applications of Hall Effect Sensors

1. Analog output sensor applications include:
2. Current sensing
3. Variable speed drives
4. Motor control protection/indicators
5. Power supply sensing
6. Motion sensing
7. Diaphragm pressure gage
8. Flow meters

## 1.16 Temperature Sensors

### 1.16.1 Temperature

- Temperature is a condition of a body by virtue of which heat is transferred to or from other body. Temperature is a fundamental unit like mass, length and time. Temperature is measured in ° C or ° K or ° F.
- Three most widely used temperature detectors are -

  i) Thermocouples

  ii) Resistance Temperature Detectors (RTD)

  iii) Thermistors
- Four most widely used temperature detectors are

  i) Thermocouples

  ii) Resistance Temperature Detectors (RTD)

  iii) Thermistors

  iv) Bimetallic Strips

**Thermocouple construction**

- A thermocouple consists of a pair of dissimilar metal wires joined together at one end, forming the sensing, or hot junction; and terminated at the other end known as reference or cold junction, which is maintained at a known constant temperature (reference temperature). When a temperature difference exists between the sensing junction and the reference junction, an e.m.f. is produced. The magnitude of this voltage depends on the material used for the wires and the temperature difference between the two junctions.
- When the reference junction is terminated by a meter or recording instruments as in Fig. 1.16.2 the meter indication is proportional to the temperature difference between the hot junction and the reference junction. This thermoelectric effect, caused by contact potentials at the junctions, is known as the Seebeck effect.

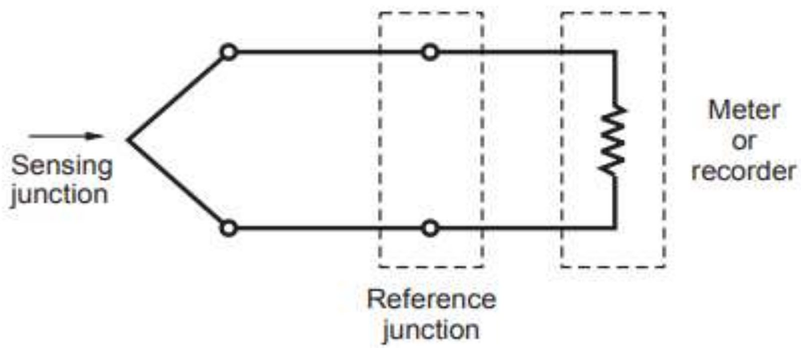



**Fig. 1.16.2 Thermocouple**

- Thermocouples are made from a number of different metals including copper-constantan, iron-constantan, chromel-constantan, chromel-Alumel, platinum-platinum/Rhodium. They cover wide range of temperature, going as high as 2700 °C.
- The Fig. 1.16.3 shows the thermal e.m.f.s for some common thermocouple materials. The values shown are based on a reference temperature of 32° F.

(See Fig. 1.16.3 on next page)

**Advantages of thermocouples :**

1) Rugged construction
2) Comparatively cheap
3) Temperature range – 250° C to 2500° C
4) Easy calibration
5) Good reproducibility
6) Good accuracy
7) Bridge circuit for sensing is not required because output is available directly in millivolts.

**Limitations of thermocouples**

1. For accurate measurement cold junction compensation is necessary.
2. E.M.F. versus temperature characteristic is non-linear.
3. Very small voltage is obtained as output.

### 1.16.3 Resistance Temperature Detectors (RTD)

- RTD stands for Resistance Temperature Detector.

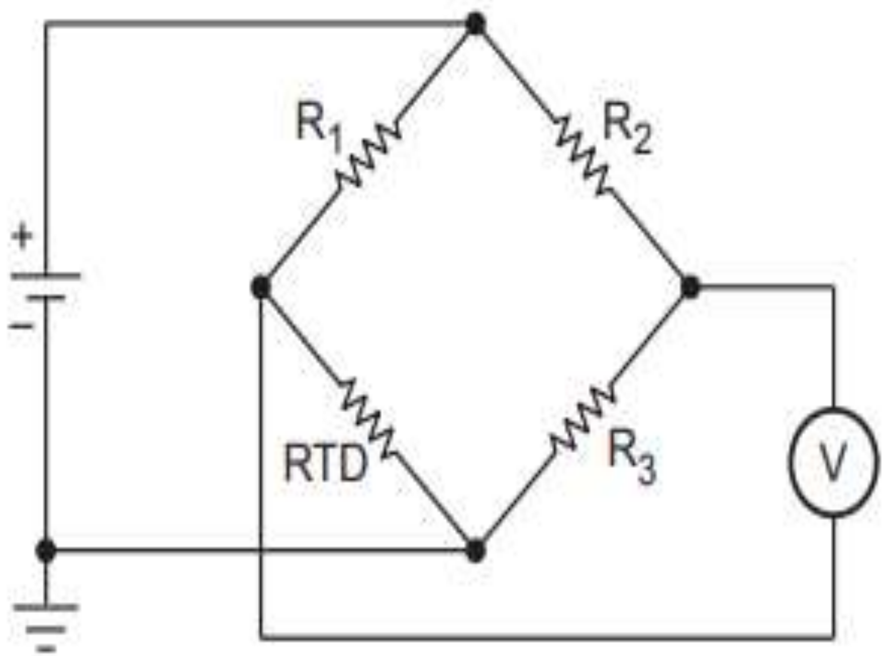



Fig. 1.16.4 Resistance Temperature Detectors (RTD)

- The change in temperature is detected by the change in resistance of the wire.
- There are two types of RTD, viz. having positive and negative thermal coefficients of resistivity (resistance increases or decreases with the increase in temperature respectively).
- RTDs are used for temperature measurements by using them in bridge circuits.
- The change in temperature causes considerable resistance change which gives a voltage drop in accordance with the thermal coefficient of resistance of the wire.
- This voltage is further amplified and the temperature is read thus.
- This is how the RTDs are used in circuits assisting in automatic control and measurement with high accuracy.

### 1.16.3.1 Advantages of RTD

1. Linearity over a wide operating range
2. Wide operating range
3. Higher temperature operation
4. Better stability at high temperature

### 1.16.3.2 Disadvantages of RTD

1. Low sensitivity
2. It can be affected by contact resistance, shock and vibration
3. Requires no point sensing
4. Higher cost than other temperature transducers

### 1.16.3.3 Applications of RTD

1. It is widely used in furnaces for automatic temperature measurement.
2. Used in medical and chemical laboratories to detect very low temperatures (like dry ice and liquid nitrogen).

**Bimetallic thermometer :**

**Basic Principle :**

- These thermometers use the following two principles :

1. All metals change in dimension, that is expand or contract when there is a change in temperature.

2. The rate at which this expansion or contraction takes place depend on the temperature co-efficient of expansion of the metal and this temperature coefficient of expansion is different for different metals.Hence the difference in thermal expansion rates is used to produce deflections which is proportional to temperature changes.

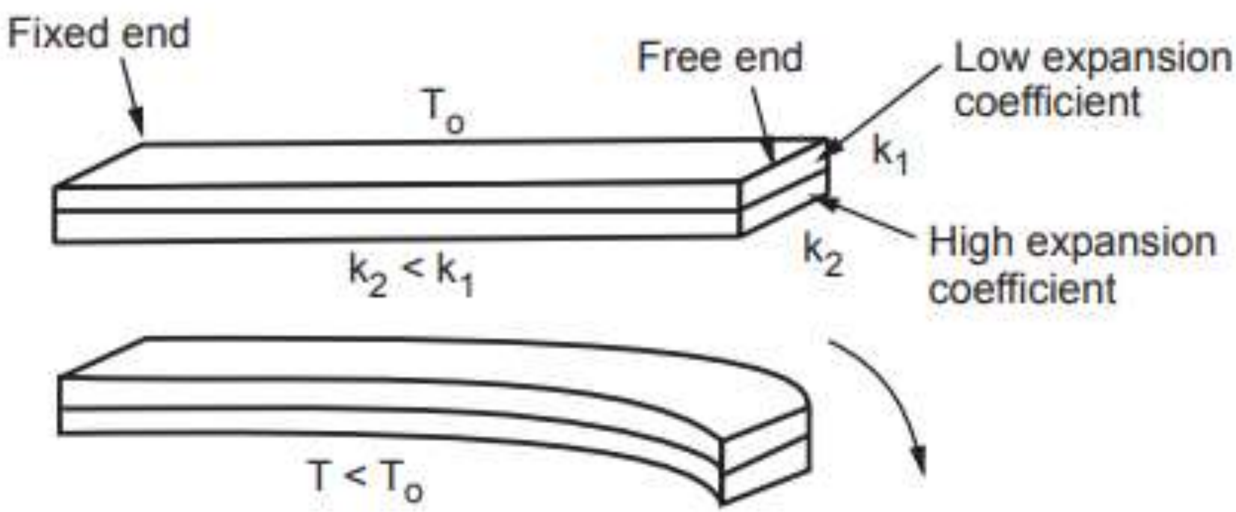



**Fig. 1.16.8 Bimetallic thermometer**

- The bimetallic thermometer consists of a bimetallic strip.
- A bimetallic strip is made of two thin strips of metals which have different coeffcients of expansion.
- The two metal strips are joined together by brazing, welding or riveting so that the relative motion between them is arrested.

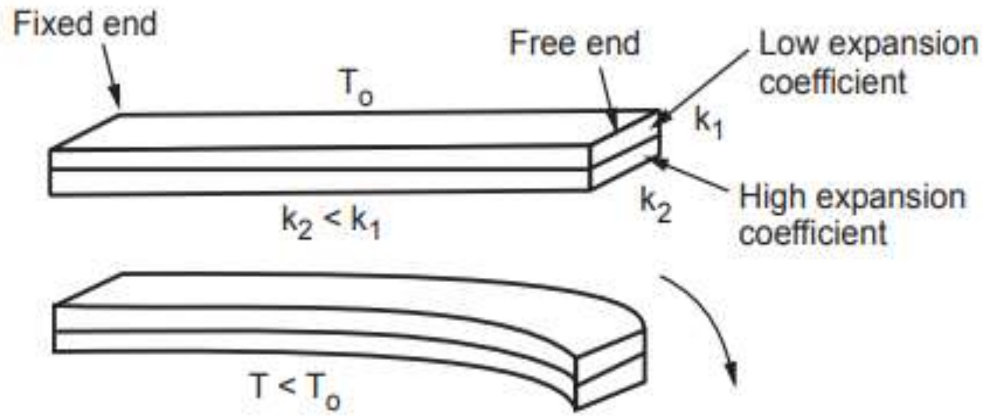



**Fig. 1.16.8 Bimetallic thermometer**

- The bimetallic strip is in the form of a cantilever beam.
- An increase in temperature will result in the deflection of the free end of the strip as shown in diagram.
- This deflection is linear and can be related to temperature changes.
- The radius of the curvature of the bimetallic strip which was initially flat is determined using the following relationship.

$$R = t\{3(1+m)^2 + (1+mn)[m^2 + 1/mn]\} / 6(\alpha_h - \alpha_l)(T_2 - T_1)(1+m)^2$$

## Advantages of bimetallic thermometers

1. They are simple, robust and inexpensive.
2. Their accuracy is between + or – 2 % to 5 % of the scale.
3. They can with stand 50 % over range in temperaures.
4. They can be used where evr a mecury -in-glass thermometer is used.

## Limitations of bimetallic thermometer :

1. They are not recommended for temperature above 400 °C.
2. When regularly used, the bimetallic may permanently deform, which inturn will introduce errors.

## Application of bimetallic strips and thermometers

1. The bimetallic strip is used in control devices.
2. The spiral strip is used in air conditioning thermostats.
3. The helix strip is used for process application such as refineries, oil burners, tyre vulcanisers etc.

# Thermister


- A thermistor is a type of resistor whose resistance strongly depends on temperature.
- The word thermistor is a combination of words "thermal" and "resistor".
- A thermistor is a temperature-sensing element composed of sintered semiconductor material and sometimes mixture of metallic oxides such as Mn, Ni, Co, Cu and Fe, which exhibits a large change in resistance proportional to a small change in temperature.
- Pure metals have positive temperature coefficient of resistance, alloys have nearly equal zero temperature coefficient of resistance and semiconductors have negative temperature coefficient of resistance.
- Thermistors can be classified into two types :
  - Positive Temperature Coefficient (PTC) thermistor : resistance increase with increase in temperature.
  - Negative Temperature Coefficient (NTC) thermistor : resistance decrease with increase in temperature.

### 1.16.4.1 Advantages of Thermistors

1. They are simple and easy to owing to their small sizes.
2. Their cost is low.
3. They are highly sensitive.
4. They can be adapted to various electrical readouts. With the help of computers thermistors can be easily used for accurate temperature measurement.

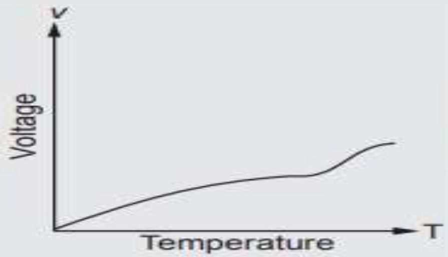
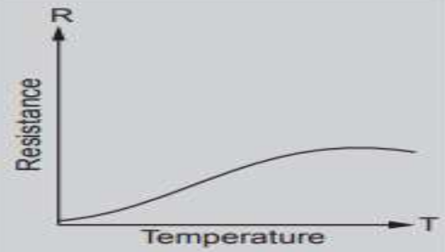
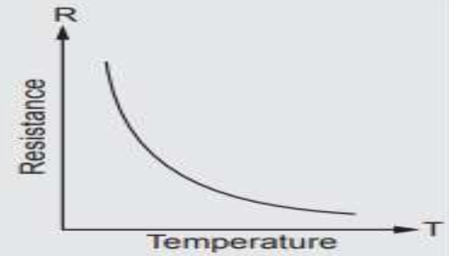
### 1.16.4.2 Disadvantages of Thermistors

1. The temperature vs resistance curves of thermistors are highly nonlinear.
2. It is not rugged and requires delicate handling which limits its application.
3. They are susceptible to self-heating errors.
4. Their range is limited to few hundred degrees Celsius.
5. Thermistors use semiconductors which are prone to permanent de-calibration

### 1.16.4.3 Applications of Thermistors

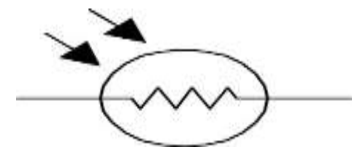
1. Thermistors are used in an automotive applications
2. Instrumentation and Communication
3. Consumer electronics
4. Food handling and processing
5. Military and aerospace

## 1.17 Comparision of Thermocouple, RTD and Thermistor

| | Thermocouple | RTD | Thermistor |
|---|---|---|---|
| Symbol |  |  |  |
| Characteristics |  |  |  |
| Advantages | • Self-powered<br>• Simple<br>• Rugged<br>• Inexpensive<br>• Wide variety<br>• Wide temperature range | • Most stable<br>• Most accurate<br>• More linear than thermocouple | • High output<br>• Fast<br>• Two-wire ohms measurement |
| Disadvantages | • Non-linear<br>• Low voltage<br>• Reference required<br>• Least stable<br>• Least sensitive | • Expensive<br>• Power supply required<br>• Small ΔR<br>• Low absolute resistance<br>• Self-heating | • Non-linear<br>• Limited temperature range<br>• Fragile<br>• Power supply required<br>• Self-heating |

## 1.18 Light Sensor

- A Light Sensor is something that a robot can use to detect the current ambient light level - i.e. how bright/dark it is.
- There are a range of different types of light sensors :
  i) Photoresistor ii) Photodiodes iii) Phototransistors.



### 1.18.1 Photoresistor

- A Photoresistor is a variable resistor that let current flow easy when it is exposed to light.
- It's most used as a sensor to detect changes in brightness.
- Streetlights often use a photoresistor to detect when it should turn on.
- Photoresistors, also known as Light Dependent Resistor (LDR), Cadmium Sulfide cells (CDS cells), Photoconductor and sometimes simply Photocells are a type of transducer which converts energy from one form to another where one of the known forms is electrical energy.
- To keep things simple, we will refer to it as Photoresistor.
- Resistance in a Photoresistor inversely varies with the amount of light it is exposed to.
- Bright light = Less resistance and Low light = more resistance.
- These sensors are used to make light sensitive devices and are more often found in street lights, cheap toys, outdoor clocks etc.
- If you have ever wondered how a street light turns on in the night and switches off in the day, you will be surprised to find a cheap photoresistor circuitry inside

## 1.18.2 Photodiode

- A photodiode is a semiconductor device that converts light into current.
- The current is generated when photons are absorbed in the photodiode.
- Photodiodes are used to detect light and feature wide, transparent junctions.
- Generally, these diodes operate in reverse bias, where in even small amounts of current flow, resulting from the light, can be detected with ease.

**Fig. 1.18.1 Symbol of a photo diode**

- Photodiodes can also be used to generate electricity, used as solar cells and even in photometry.
- The symbol of a photo diode is shown in Fig. 1.18.1.

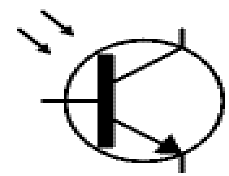
**Principle of operation**

- A photo diode is biased against its easy flow of direction of current, i.e. it is reverse biased so that a very low leakage current flows.
- If a photon of sufficient energy is incident on the diode at its junction, an electron is freed and if it possesses enough energy, it may pass over the energy barrier causing a small leakage current to flow.
- The amount of current is proportional to the amount of illumination of the junction.

## 1.18.3 Phototransistor

- The phototransistor is a semiconductor light sensor formed from a basic transistor with a transparent cover that provides much better sensitivity than a photodiode.

- A phototransistor is a light-sensitive transistor.



**Phototransistor operation :**

- Photo transistors are operated in their active regime, although the base connection is left open circuit or disconnected because it is not required.
- The base of the photo transistor would only be used to bias the transistor so that additional collector current was flowing and this would mask any current flowing as a result of the photo-action.
- For operation the bias conditions are quite simple.
- The collector of an n-p-n transistor is made positive with respect to the emitter or negative for a p-n-p transistor.
- The light enters the base region of the phototransistor where it causes hole electron pairs to be generated.
- This mainly occurs in the reverse biased base-collector junction. The hole-electron pairs move under the influence of the electric field and provide the base current, causing electrons to be injected into the emitter.

## 1.19 Selection Criteria for Sensor

**Factors Considered when selecting sensors for a particular application are**

1. **Accuracy** - How precise the measurement is, compared to real time value
2. **Repeatability** - How often does the data come out to be the same
3. **long- term stability** - How long the sensor would give an accurate output
4. Resistance to chemical and physical contaminants.
5. **Size** - Depends on the project. However it is important because, for example - you don't want a 200 feet sensor that senses water temperature, when you could find a centimeter chip that does the same function.
6. **Weight** - Also depends on the device.
7. **Cost** - The price should be truly considered especially when an issued budget is given.
8. **Effectiveness** - Capable of producing an intended result.
9. **Long term usage** - How long would the sensor give data.
10. **Response Time** - How fast the sensor would response to an issued command. For example - if a microprocessor is programmed to get information from a pressure sensor every 5 minute, but it takes the pressure sensor 2 hours to respond, obviously this would not be a good sensor.

$= 0.0125$ mm ...Ans.

**Example 1.10.5** *A steel cantilever is 300 mm long, 25 mm wide and 5 mm thick.*

*i) Calculate the value of deflection at the free end for the cantilever when a force of 30 N is applied at this end.The modulus of elasticity for steel is 200 Gpa.,*

*ii) An LVDT with a sensitivity of 0.6 V/mm is used. The voltage is read on a 20 V voltmeter having 100 divisions Two-tenths of division can be read. Calculate the resolution of the LVDT.*

*iii) Find the minimium and maximum value of force.* ☞ **[AU : Dec.-19, Marks 13]**

**Solution :** Moment of inertia for rectagular section, $I = \frac{bt^3}{12}$

$$= \frac{0.025 \times (0.005)^3}{12} = 2.6 \times 10^{-9} \text{ m}^4$$

a) Deflection, $\delta = \frac{FL^3}{3EI} = \frac{30\times(0.3)^3}{3\times 200\times 10^9 \times 2.6\times 10^{-9}}$

$$= 5.9\times 10^{-4} \text{ m} = 0.52 \text{ mm}$$

b) Deflection per unit force $= \frac{x}{F} = \frac{5.19\times 10^{-4}}{30} = 0.0173$ mm/N

Total sensitivity $= 0.0173\times 0.6 = 0.0104$ V/N

1 scale divsion $= \frac{20}{100} = 0.2$ V

Resolution $= \frac{2}{10}\times 0.2 = 0.04$ V

c) Minimum force $= \frac{0.04}{0.0104} = 3.85$ N

Maximum force $= \frac{20}{0.0104} = 1923.08$ N

**Q.51** *Consider a parallel rectangular plate air spaced capacitor of 30 cm × 20 cm and the distance between the plates is 1.2 mm. If the relative permittivity for air is 1.006. Calculate the displacement sensitivity of the device by neglecting the displacement of the central plate.*

*Assume permittivity of the plates as* $8.854 \times 10^{12}$ *F/m.* **[13]**

**Ans. : Given :** Area = $30 \text{ cm} \times 20 \text{ cm} = 0.06 \text{ m}^2$

$$\text{Distance, d} = 1.2 \text{ mm} = 1.2 \times 10^{-3} \text{ m}$$

$$\varepsilon_0 = 8.854 \times 10^{12} \text{ F/m}$$

$$\varepsilon_r = 1.006$$

$$C = \frac{\varepsilon_0 \varepsilon_r A}{d}$$

$$= \frac{8.854 \times 10^{12} \times 1.006 \times 0.06}{1.2 \times 10^{-3}}$$

$$C = 4.453 \times 10^{14}$$

$$S = \frac{\text{Change in capacitance}}{\text{Change in distance}}$$

$$S = \frac{c}{d} = \frac{4.453 \times 10^{14}}{1.2 \times 10^{-3}}$$

$$\boxed{S = 3.7108 \times 10^{9}}$$

...Ans.

**Thank you**