

Sensors

General introduction

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Mechatronics Engineering

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Sensor

- *It is defined as an element which produces signal relating to the quantity being measured.*
- *The output is usually an 'electrical quantity', and measured is a 'physical quantity'.*
- *Transducers or measurement systems are not perfect systems.*
- *Mechatronics design engineer must know the sensor specifications to properly assess its performance.*

Classification of sensors

- **Displacement, position and proximity sensors**
 - Potentiometer
 - Strain-gauged element
 - Capacitive element
 - Differential transformers
 - Eddy current proximity sensors
 - Inductive proximity switch
 - Optical encoders
 - Pneumatic sensors
 - Proximity switches (magnetic)
 - Hall effect sensors
- **Velocity and motion**
 - Incremental encoder
 - Tachogenerator
 - Pyroelectric sensors
- **Force**
 - Strain gauge load cell
- **Fluid pressure**
 - Diaphragm pressure gauge
 - Capsules, bellows, pressure tubes
 - Piezoelectric sensors
 - Tactile sensor
- **Liquid flow**
 - Orifice plate
 - Turbine meter
- **Liquid level**
 - Floats
- **Differential pressure**
- **Temperature**
 - Bimetallic strips
 - Resistance temperature detectors
 - Thermistors
 - Thermo-diodes and transistors
 - Thermocouples
 - Light sensors
 - Photo diodes
 - Photo resistors
 - Photo transistor

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.

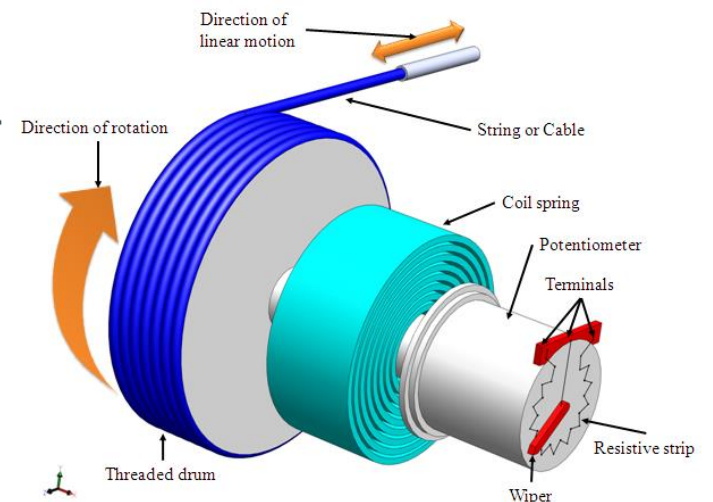
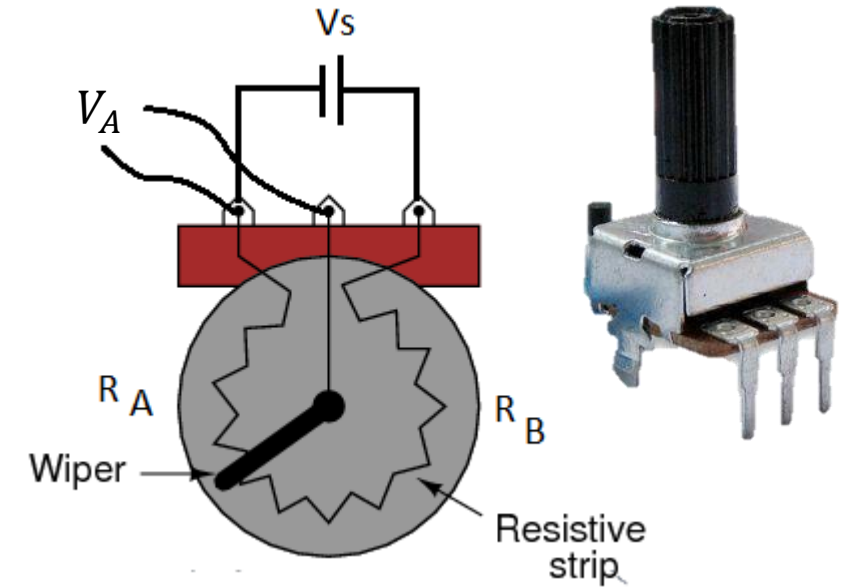
$$V_A = I R_A$$

$$\text{But } I = V_S / (R_A + R_B)$$

$$\text{Therefore } V_A = V_S R_A / (R_A + R_B)$$

As we know that $R = \rho L / A$, where ρ is electrical resistivity, L is length of resistor and A is area of cross section

$$V_A = V_S L_A / (L_A + L_B)$$



Displacement measurement by potentiometer

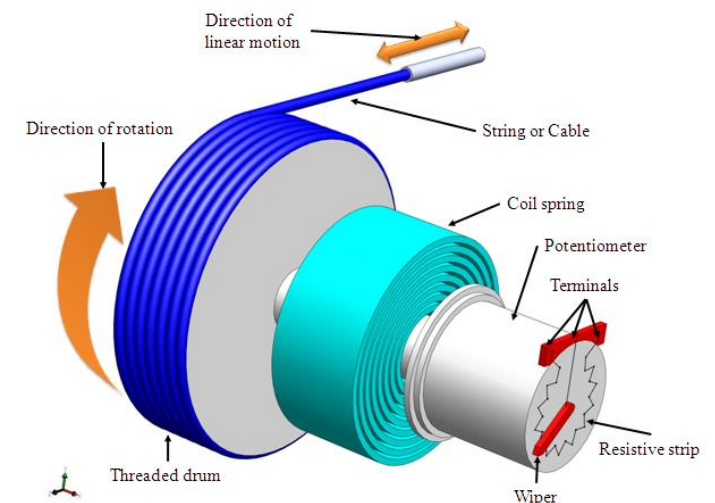
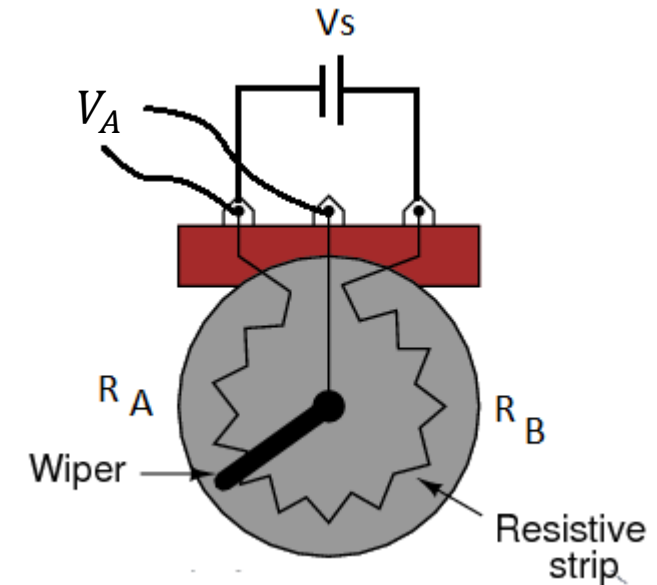
A potentiometer is used to measure a linear displacement of an elevator system as shown in the figure. The rotation range of the potentiometer is 340° and powered by 12 v source, calculate (a) the maximum displacement that can be measured if drum radius is 50 cm, (b) the measured voltage when the linear displacement is 1 m.

a) Maximum displacement

$$d = r_d \theta = 0.5 \left(340 \times \frac{\pi}{180} \right) = 2.967 \text{ m}$$

b) Measured voltage

$$V_A = V_S \frac{L_A}{L_A + L_B} = 12 \frac{1}{2.967} = 4.04 \text{ v}$$



Strain Gauges

- The strain in an element is a ratio of change in length in the direction of applied load to the original length of an element.

$$\Delta R/R \propto \epsilon;$$

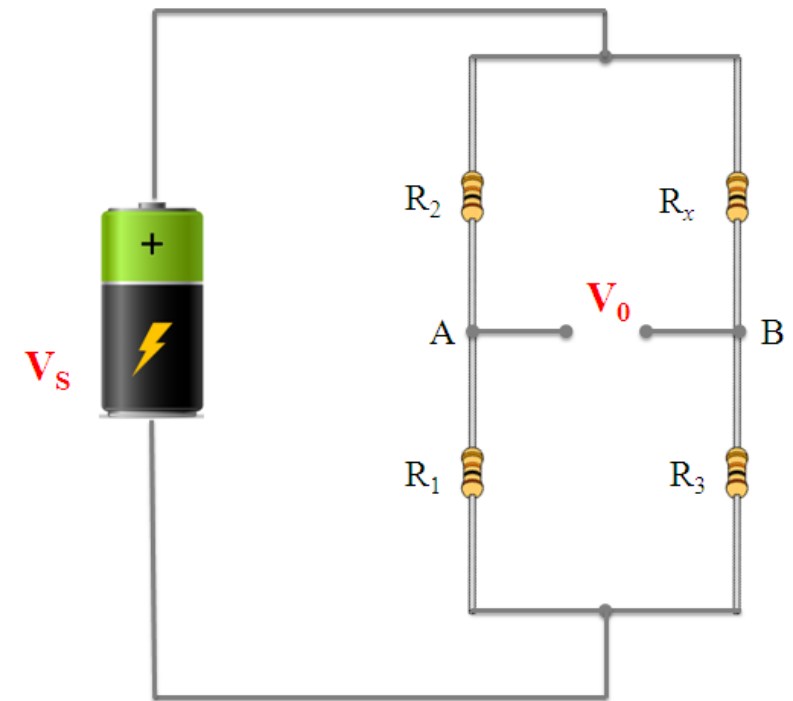
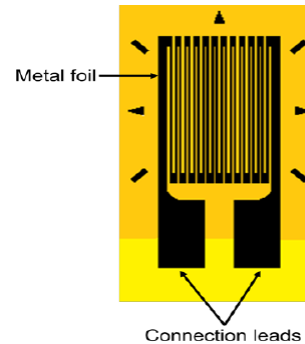
$$\Delta R/R = G \epsilon$$

where G is the constant of proportionality

$$R_2 / R_1 = R_x / R_3$$

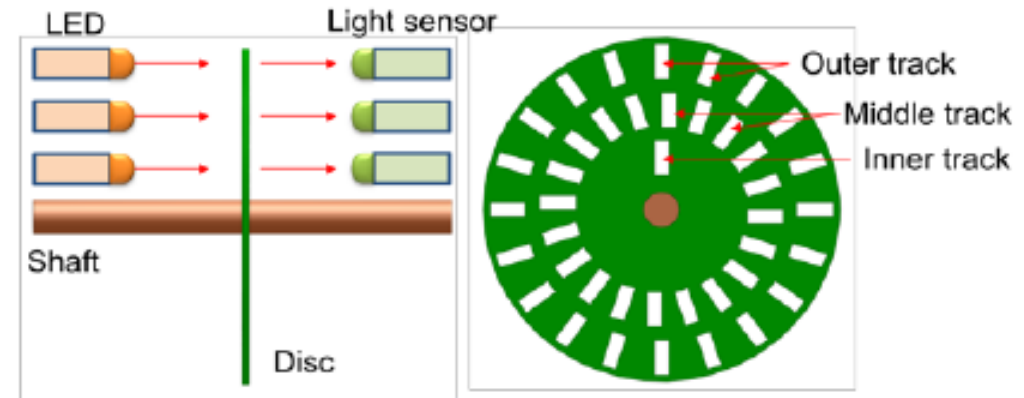
where R_x is resistance of strain gauge element.

R_2 is balancing/adjustable resistor, R_1 and R_3 are known constant value resistors. The measured deformation or displacement by the strain gauge is calibrated against change in resistance of adjustable resistor R_2 which makes the voltage across nodes A and B equal to zero.



Optical encoders

- Optical encoders provide digital output as a result of linear / angular displacement.
- These are widely used in the Servo motors to measure the rotation of shafts.
- Three light sensors are employed to detect the light passing thru the holes.
- These sensors produce electric pulses which give the angular displacement of the mechanical element
- The inner track has just one hole which is used to locate the 'home' position of the disc.
- The holes on the middle track offset from the holes of the outer track by one-half of the width of the hole. This arrangement provides the direction of rotation to be determined.
- When the disc rotates in clockwise direction, the pulses in the middle track lead those in the outer; in counter clockwise direction they lag behind.
- The resolution can be determined by the number of holes on disc.



Optical encoders example

This encoder has 20-holes inner and outer track.

1) If The encoder counts 10 pulses for the outer encoder, determine the rotation angle
20 pulses for 1 revolution
10 pulses for 0.5 revolution

2) Determine the resolution in angles of this encoder

The minimum angle of this encoder = $\frac{360^\circ}{20} = 18^\circ$

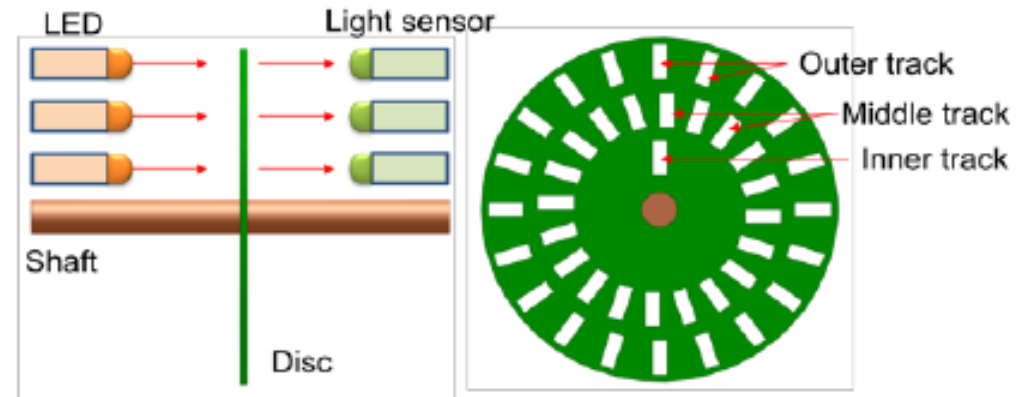
3) If the encoder counts 500 pulses in 1 min, calculate the angular speed.

calculate the number of revolutions

$$\frac{500}{20} = 25 \text{ rev}$$

calculate speed

$$\text{Speed} = \frac{25}{1} = 25 \text{ rev/min}$$

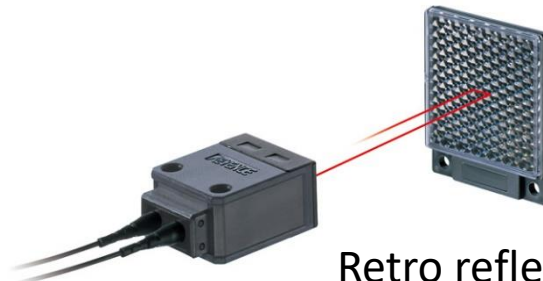


Proximity sensors

- Inductive
- Capacitive
- ***Proximity Switches***
- Optical sensors



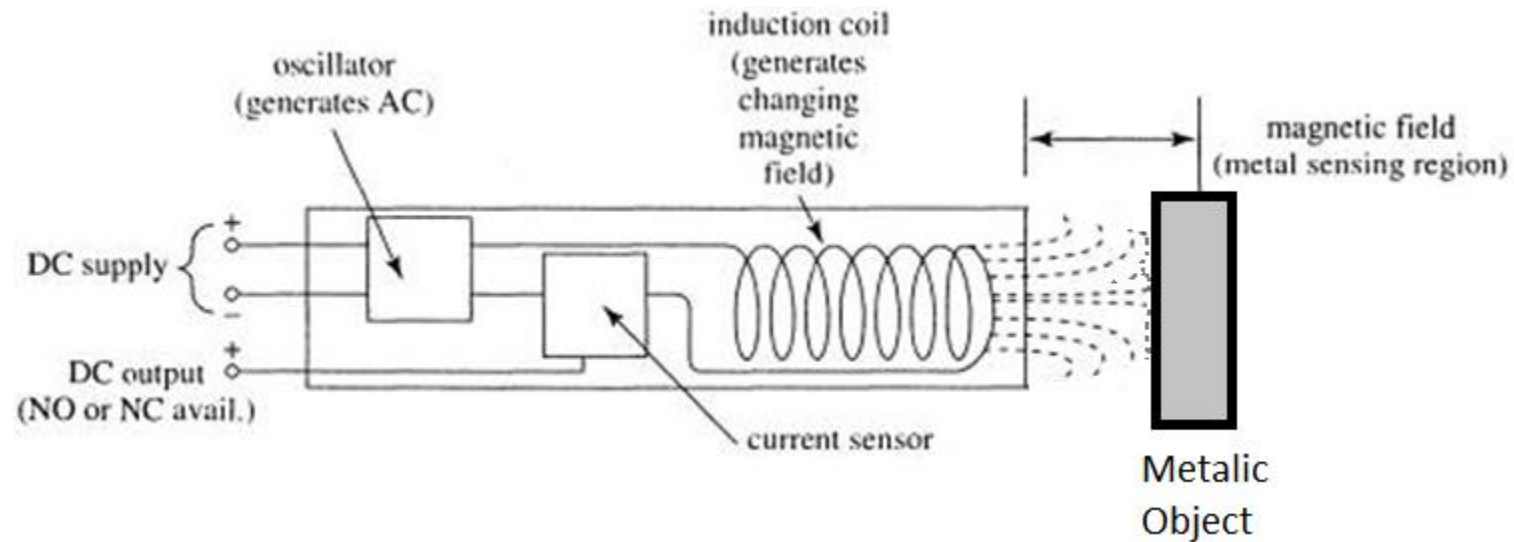
Through beam



Retro reflective

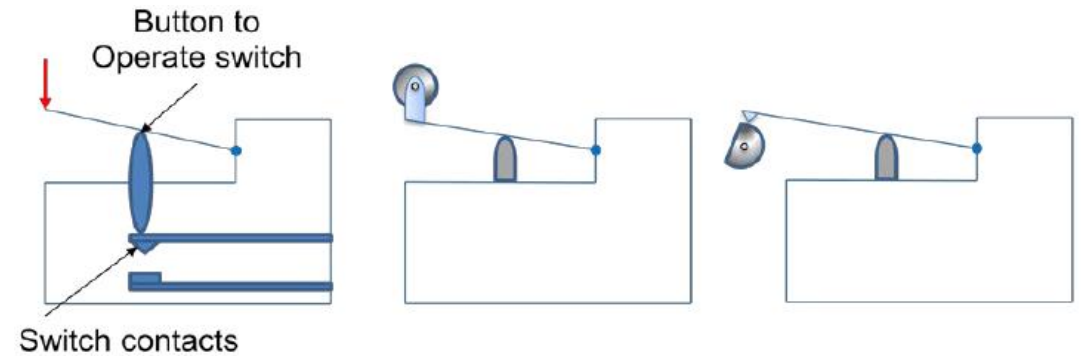
Inductive proximity sensor

- Inductive proximity sensors are basically used for detection of metallic objects.
- An inductive proximity sensor has four components; the coil, oscillator, detection circuit and output circuit.
- An alternating current is supplied to the coil which generates a magnetic field.
- When, a metal object comes closer to the end of the coil, inductance of the coil changes.



Proximity Switches

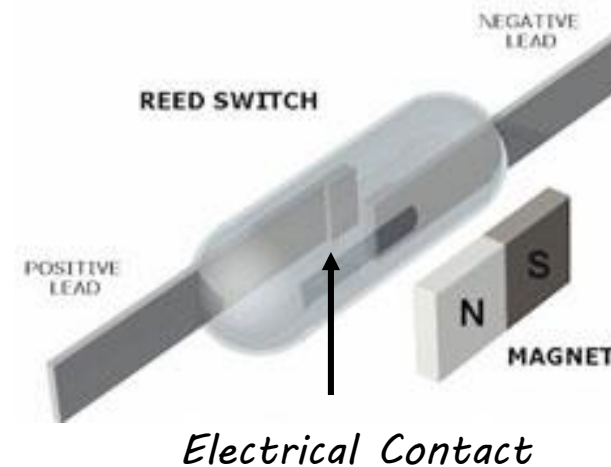
- They are basically employed on conveyor systems to detect the presence of an item on the conveyor belt.
- **Contact proximity switches** are small electrical switches which require physical contact and a small operating force to close the contacts.
- **Magnet based Reed switches** are used as proximity switches. When a magnet attached to an object brought close to the switch, the magnetic reeds attract to each other and close the switch contacts.



(a) Lever-operated

(b) Roller-operated

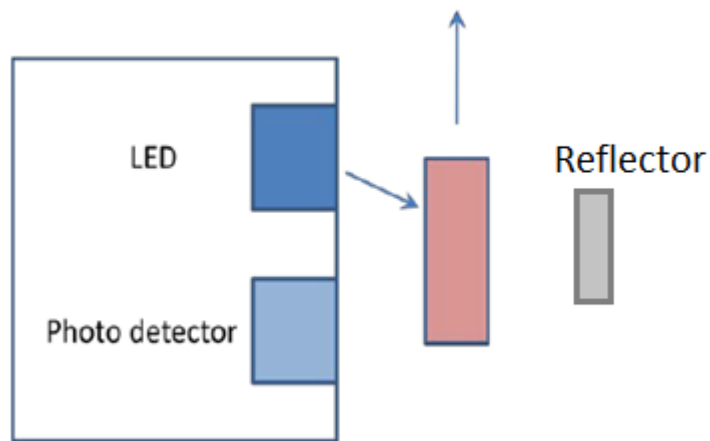
(c) Cam-operated



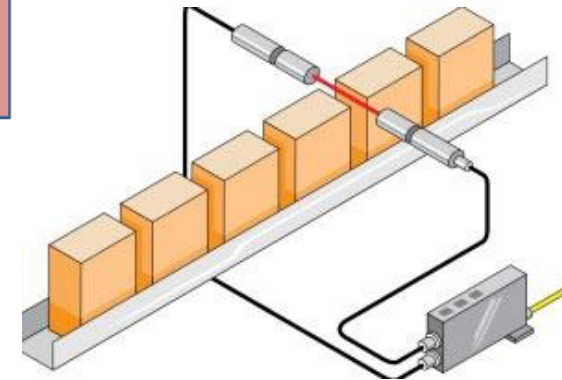
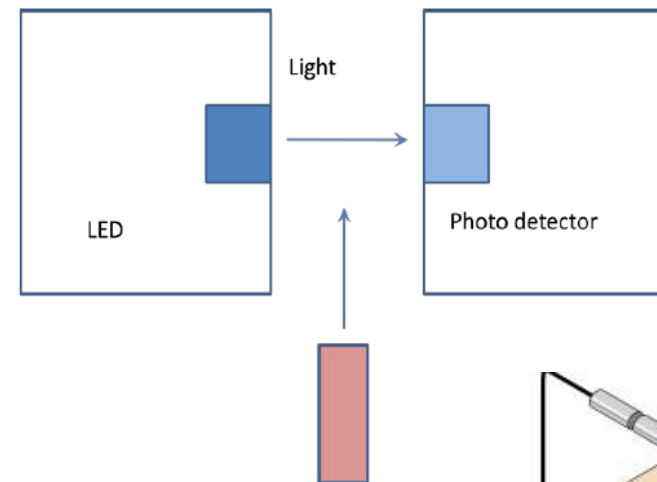
Optical sensors

- Photo emitting devices such as *Light emitting diodes (LEDs)* and photosensitive devices such as *photo diodes* and *photo transistors* are used in combination to work as proximity sensing devices.

Retro reflective



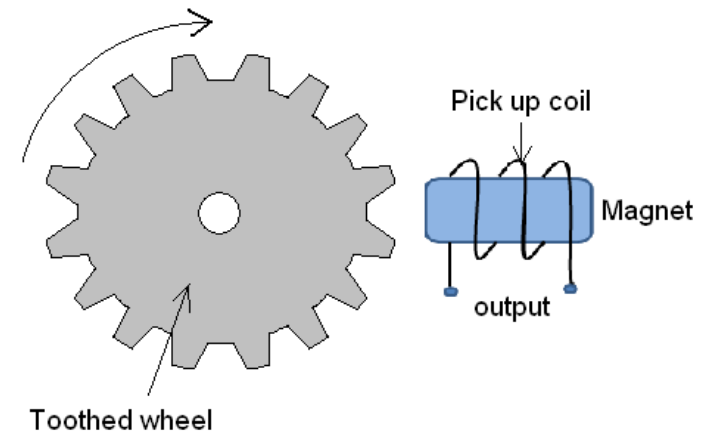
Through beam



Velocity, motion, force sensors

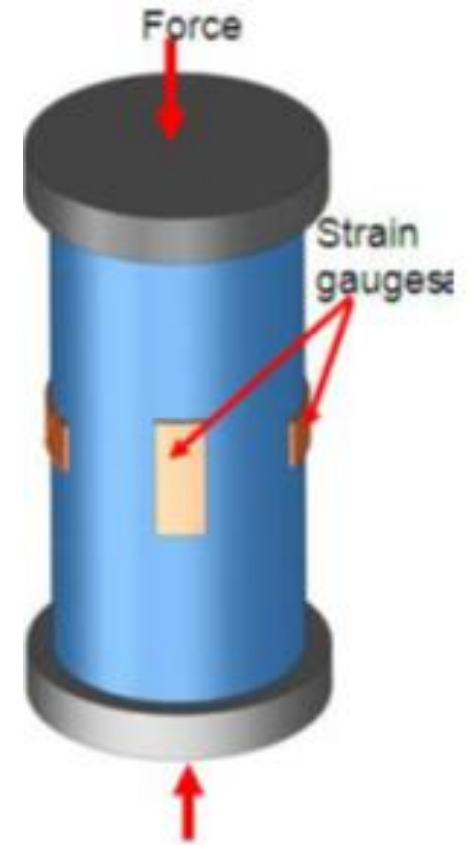
Tachogenerator

- It consists of an assembly of a **toothed wheel** and a **magnetic circuit**.
- As the wheel rotates, the air gap between wheel tooth and magnetic core changes which results in **cyclic change in flux** linked with the coil.
- The alternating emf generated is the measure of **angular motion**.
- A **pulse shaping signal conditioner** is used to transform the output into a number of pulses which can be counted by a counter.



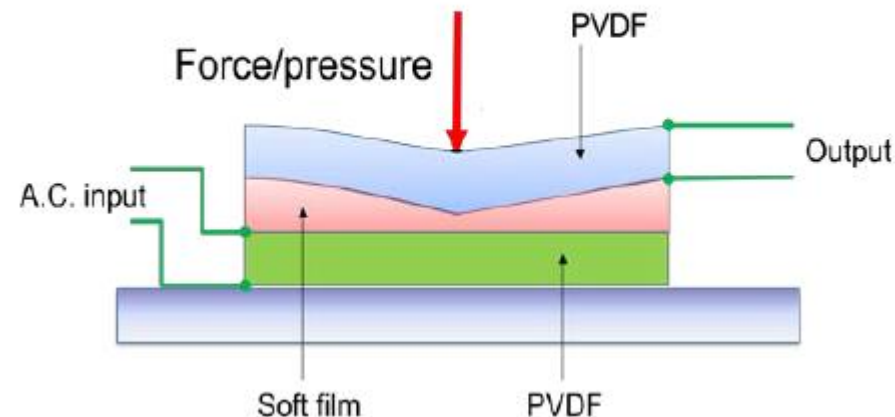
Strain Gauge as force Sensor

- *When, a mechanical element subjects to a tension or a compression the electric resistance of the material changes*
- *This is used to measure the force acted upon the element.*
- *Generally strain gauges are used to measure forces up to 10 MN.*
- *The non-linearity of this transducer is $\pm 0.03\%$.*
- *Repeatability errors is $\pm 0.02\%$.*



Tactile sensors

- In general, tactile sensors are used to sense the contact of fingertips of a robot with an object.
- piezo-electric polyvinylidene fluoride (PVDF) based tactile sensor. It has two PVDF layers separated by a soft film which transmits the vibrations.
- An alternating current is applied to lower layer which generates vibrations due to reverse piezoelectric effect. These vibrations are transmitted to the upper layer cause alternating voltage across
- When some pressure is applied on the upper layer the vibrations gets affected and the output voltage changes. This triggers a switch or an action in robots or touch displays.



Additional sensors

Thermistors

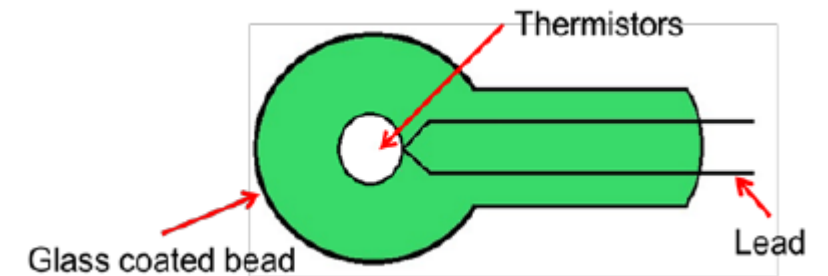
- Thermistors follow the principle of decrease in resistance with increasing temperature.
- The material used in thermistor is generally a **semiconductor material**.
- As the temperature of semiconductor material increases the number of electrons able to move about increases which results in more current in the material and reduced resistance.
- Individual thermistor curves are approximated by the following nonlinear equation:

$$\frac{1}{T} = A + B \ln R + C(\ln R)^3$$

T = temperature in kelvins

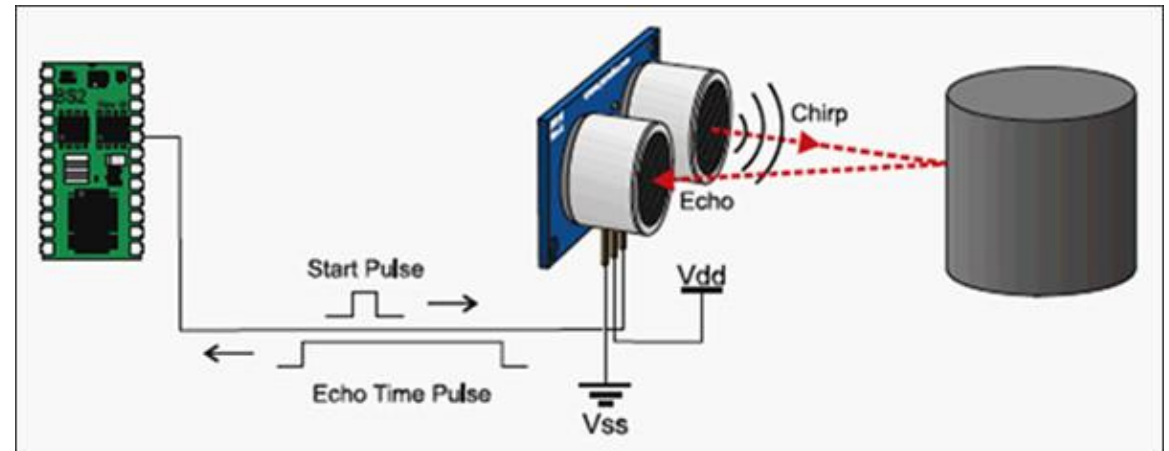
R = resistance of thermistor

A, B, C = curve fitting constants



Ultrasonic sensors

- Ultrasonic transducers are transducers that convert ultrasound waves to electrical signals or vice versa.
- Ultrasonic sensors can detect movement of targets and measure the distance to them in many automated factories and process plants.
- Ultrasonic sensors are useful in robotics applications to avoid obstacles.
- The quality of ultrasonic waves makes them useful for non-invasive measurements in environments (such as radioactive, explosive, and areas which are difficult to access).
- The ultrasonic transducer emits a pulse of an ultrasonic wave and then receives the echo from the object targeted.
- The ultrasonic transducer consists of a transmitter, a receiver, and a processing unit.



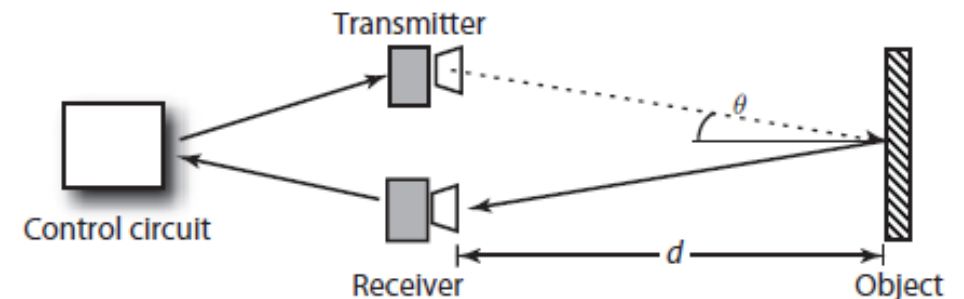
- The transducer produces ultrasonic waves normally in the frequency range of 30 to 100 kHz.
- Ultrasonic automotive vehicle detection systems are based on two techniques: *pulse technique* and *Doppler shift technique*.
- In the **pulse technique**, the detector measures the time, Δt , spent between transmission and reception of an ultrasonic signal to determine the distance between transmit/receiver and the object.
- Using the **Doppler technique**, the frequency of the received ultrasonic signal changes in relation to the emitted frequency depending on the velocity, v , of the object. If the object is approaching the detector, then the frequency of the signal received *increases* in relation to the emitted frequency. It is reduced when the object is moving away from the detector.
- The distance from the object can be given by the following formula.

$$\text{Distance: } d = \frac{vt \cos \theta}{2}$$

v : speed of the ultrasonic waves in the measured medium.

θ : incident angle.

t : is the time for the ultrasonic waves to travel to the object and back to the receiver.



PIR (Passive InfraRed) sensor

- All objects with a temperature above absolute zero emit heat energy in the form of radiation. Usually this radiation isn't visible to the human eye because it radiates at infrared wavelengths, but it can be detected by electronic devices designed for such a purpose.
- PIR sensor detects changes in the amount of infrared radiation imposing upon it, which varies depending on the temperature and surface characteristics of the objects in front of the sensor.
- When an object, such as a human, passes in front of the background, such as a wall, the temperature at that point in the sensor's field of view will rise from room temperature to body temperature, and then back again.
- The sensor converts the resulting change in the incoming infrared radiation into a change in the output voltage, and this triggers the detection. Objects of similar temperature but different surface characteristics may also have a different infrared **emission pattern**, and thus moving them with respect to the background may trigger the detector as well.

