Mechanical Engg. Department, School of Engg.
(Dronacharya Group of Institutions)

Measurement & Metrology
(Nme - 403)

Outlines of Presentation

- **Section-I (Lecture 1, 2 & 3)**
  Measurement & Measuring System
- **Section-II (Lecture 4 & 5)**
  Static & Dynamic Characteristics
- **Section-III (Lecture 6, 7 & 8)**
  Errors in Measurement
- **Lecture: 9 (Revision cum Activities/Numerical Version)**
- **Section-IV (Lecture 10, 11 & 12)**
  Sensors & Transducers
- **Lecture: 13 (Revision pertaining to Sessional-I)**
- **Section-V (Lectures 14, 15 &16)**
  Signal Conditioning, Transmission & Processing

Section–I

Measurement & Measuring System

Section–II

Static & Dynamic Characteristics

Section–III

Errors in Measurement

Lecture 1 to 9

(already covered)

Section-IV
Sensors & Transducers

Lecture 10 to 13

Open House Discussion (activity)

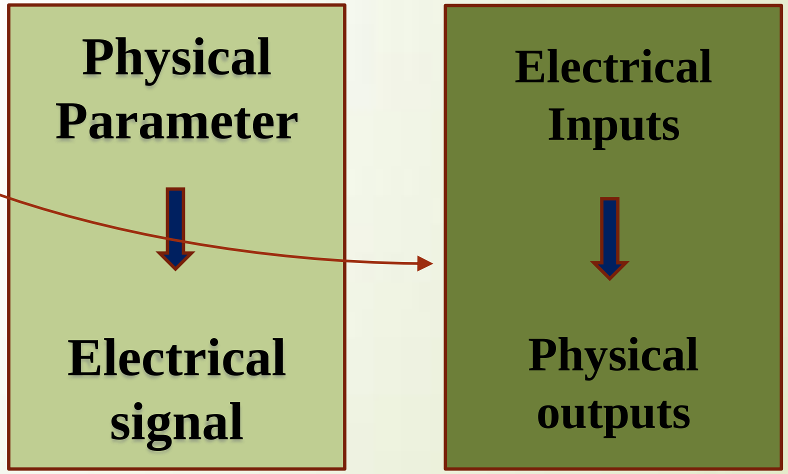
- What are Sensors?
- How a sensor work?
- What are the different kinds of sensors?
- What is the importance of learning different kind of sensors used in industries?
- What are the basic parameters required for using sensors?
- What are the principles behind various kinds of sensors used in laboratories/industries?

Sensors/Transducers

- A **sensor** converts the physical parameter to an electric outputs.

&

- An **actuator** converts an electrical signal to a physical outputs.
- Transducers are defined as elements that when subject to some change experience a related change.
- Thus we can say sensors are transducers, but a measurement system may use transducers in addition to the sensors.



What is Sensor..???

- A sensor is a converter, that measure a physical quantity and converts it into a signal which can be read (sensed) an observer or by an instruments.

OR

- A sensor is a device, which responds to an input quantity by generating a functionally related output usually in the form of an electrical or optical signals.
- Sensors are electronics devices that measure the physical quantity or produces a signal relating to the quantity being measured.
- Physical quantities can be temperature, pressure, light, current, weight etc.

Confused…???

1. Let's explain the example of temperature.
2. The mercury in the glass thermometer expands and contracts the liquid to convert the measured temperature which can be read by a viewer on the calibrated glass tube.

- Sensors are used in everyday objects such as touch sensitive elevator buttons and lamps which dim or brighten by touching and many more like in cars, machines, aerospace, robotics, manufacturing, industrial, airplanes, communications (cellular telephones, radios), electrical devices and many countless other applications.

Common Detectable Phenomenon

Stimulus	Quantity
Biological & Chemical	Fluid Concentrations (Gas or Liquid)
Electric	Charge, Voltage, Current, Electric Field (amplitude, phase, polarization), Conductivity, Permittivity
Magnetic	Magnetic Field (amplitude, phase, polarization), Flux, Permeability
Optical	Refractive Index, Reflectivity, Absorption
Thermal	Temperature, Flux, Specific Heat, Thermal Conductivity
Mechanical	Position, Velocity, Acceleration, Force, Strain, Stress, Pressure, Torque

Common types of sensors

- Temperature sensors
- Light sensors
- Magnetic sensors
- Ultra sonic sensors
- Pressure sensors
- Proximity & displacement sensors
- IR sensors
- Biosensors
- Displacement Sensors
- Position Sensors


Fig.: 4.1 Different types of sensors

Names are given in clockwise pattern for images shown

Temperature sensors

- Temperature sensors appear in building, chemical process plants, engines, appliances, computers, and many other devices that require temperature monitoring.
- e. g. - Resistance Temperature device(RTD),Thermocouple.

Fig.: 4.2 Temperature sensors

Light sensors

- Light sensors are used in cameras, infrared detectors, and ambient lighting applications.
- Sensor is composed of photoconductor such as a photoresistor (LDR), photodiode, or phototransistor.

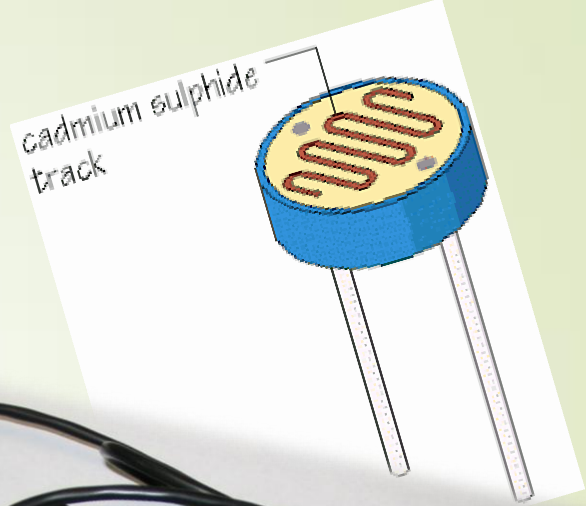


Fig: 4.3 Light sensors

Magnetic sensors & Displacement Sensors

- Magnetic Field sensors are used for power steering, security, and current measurements on transmission lines.
- **Displacement sensors** are concerned with the measurement of the amount by which some object has been moved.

Fig: 4.4 Magnetic sensors

Ultrasonic Sensor & Position Sensors

- **Ultrasonic** sensors are used for position measurements.
- **Ultrasonic** transducers are transducers that convert ultrasound waves to electrical signals or vice versa.
- Sound Navigation And Ranging (SONAR)
- Radio Detection And Ranging (RADAR)

Position sensors are concerned with the determination of the position of some object with reference to some reference point. (Hint: relate with direction finder)

Fig: 4.5 Ultrasonic Sensor

Proximity Sensor

- A proximity sensor detects the presence of objects that are nearly placed without any point of contact. Since there is no contact between the sensors and sensed object and lack of mechanical parts, these sensors have long functional life and high reliability.
- Used in automation engineering to define operating states in process engineering plants, production systems and automating plants **(Hint: TOM)**.
- Used in windows, and the alarm is activated when the window opens. Used in machine vibration monitoring to calculate the difference in distance between a shaft and its support bearing **(Room Acoustics)**.

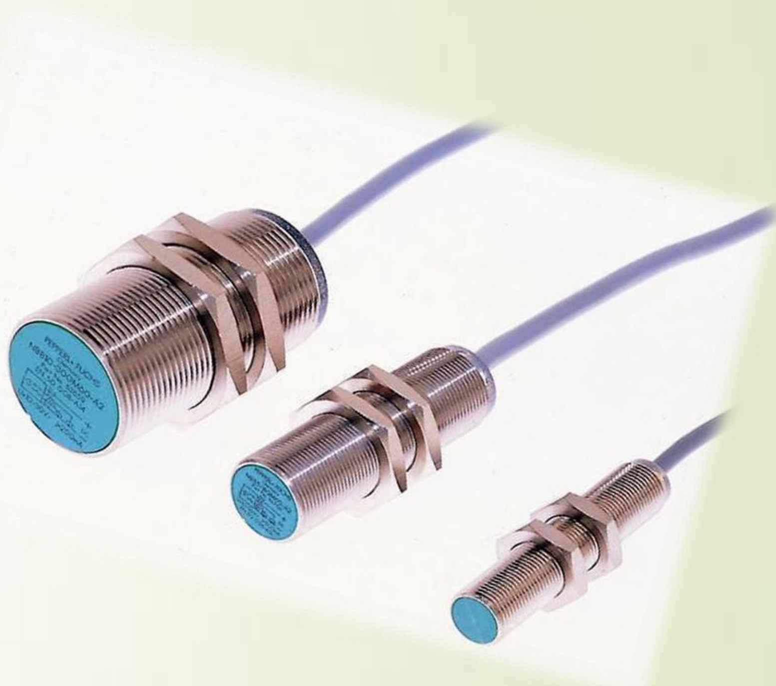


Fig.:4.6 Proximity Sensor

Bio-sensors

- Biosensors are based on the electrochemical technology. They are used for food testing, medical care device, water testing, and biological welfare agent detection.

And Many Other Types of sensors like;

- **Sound sensors:-** measure quantities such as velocity and acceleration.
- **Image sensors:-** They are used in consumer electronics, biometrics, traffic and security surveillance and PC imaging **(CID)**.
- **Sound sensors:- Microphones.**
- **Advanced Sensor Technology:-** for bar code identification. **(Super Beam)**

Displacement, Position & Proximity

Following points should be considered in mind while selecting a displacement, position or proximity sensor.

- Size of Displacement.
- Type of Displacement (linear/angular).
- Required Resolution.
- Accuracy Required.
- Material of the measured object.
- The Cost.

Potentiometer Sensor

- A Potentiometer consists of a resistance element with a sliding contact which can be moved over the length of the element.
- Such element can be used for linear or rotary displacements, the displacement being converted into potential difference.
- The rotary potentiometer consists of a circular wire wound track or a film of conductive plastic over which a rotatable sliding contact can be rotated. (**Explain with Gear system**)

Potentiometer Sensor

- With the constant input voltage V_s, between terminal 1 and 3, the output voltage V_o between terminal 2 and 3 is a fraction of the input voltage.
- This fraction depends upon the ratio of the resistance R_{23} between terminal 2 and 3 compared with the total resistance R_{13} between terminal 1 and 3. i.e.

  $Vo/Vs = R_{23}/R_{13}$ (use board for series/parellel)

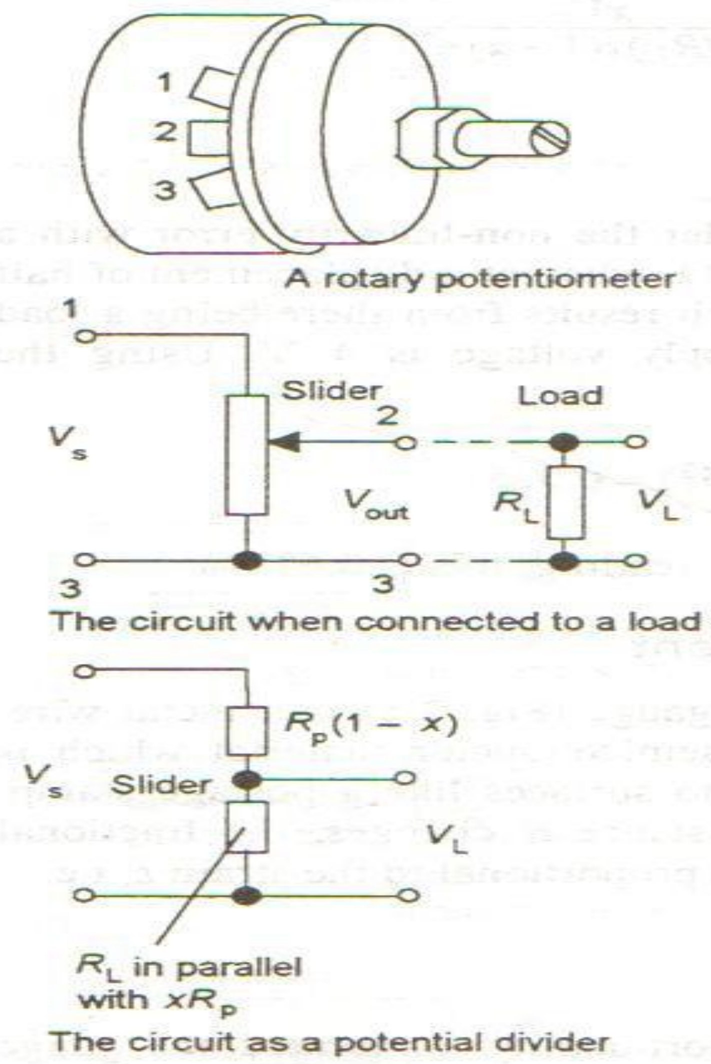


Fig. 2.5 Rotary potentiometer

Strain–gauged Element

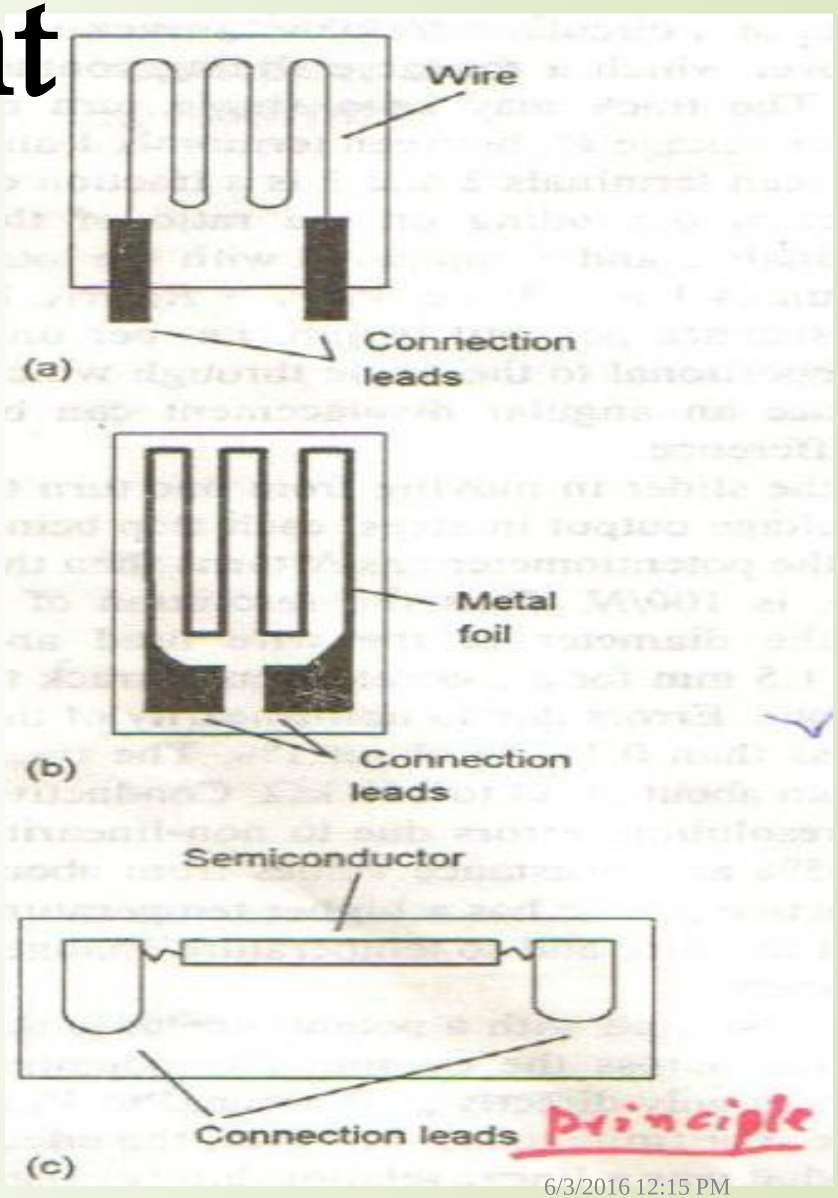
- The electrical resistance strain gauge is a metal wire, metal foil strip, or a strip of semiconductor material which is wafer like and can be struck in to surfaces like a postage stamp. (fringe/practical concept)
- When it is subjected to strain, its resistance R changes, the fractional change in resistance

$$\Delta R/R = G\varepsilon$$

- where G, is the constant of proportionality and it is termed as gauge factor.

Strain-gauged Element

- Since strain is the ratio (change is length/original length) then the resistance change of the strain gauge is a measurement of the change in length of the element to which the strain gauge is attached.
- A problem with all strain gauges is that their resistance not only changes with strain but also with temperature. So to get an accurate result various ways of temperature elimination are used. (**Explain whole experiment & applications**)



Capacitive Element

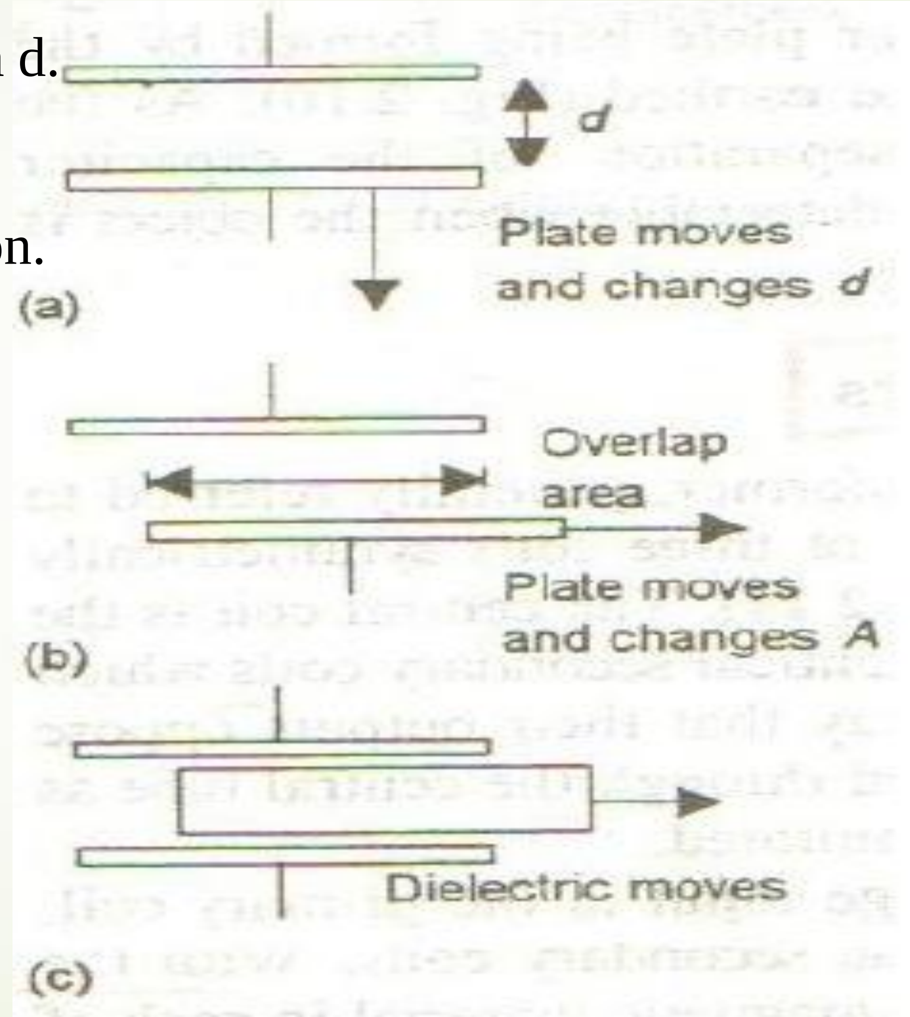
- The capacitance C of a parallel plate capacitor is given by;

$$\mathbf{C = (\varepsilon_r.\varepsilon_o.\ A)/d}$$

where, ε_r is the relative permittivity of the dielectric between the plates, ε_o is the permittivity of free space, A the area of overlap between the two plates and d the plate separation. Capacitive sensors used to measure linear displacements are shown in next slide.

Capacitive Element

- Capacitor a) is used to measure displacement by plate separation d.
- Capacitor b) is used to measure displacement by overlap area A.
- Capacitor c) is used to measure displacement by dielectric motion.



- For the displacement changing the plate separation, if the separation d is increased by displacement x then the capacitance becomes;

$$C-\Delta C = (\varepsilon_r.\varepsilon_o.\ A)/(d+x)$$

- Change in capacitance as a fraction of the initial capacitance is given by;

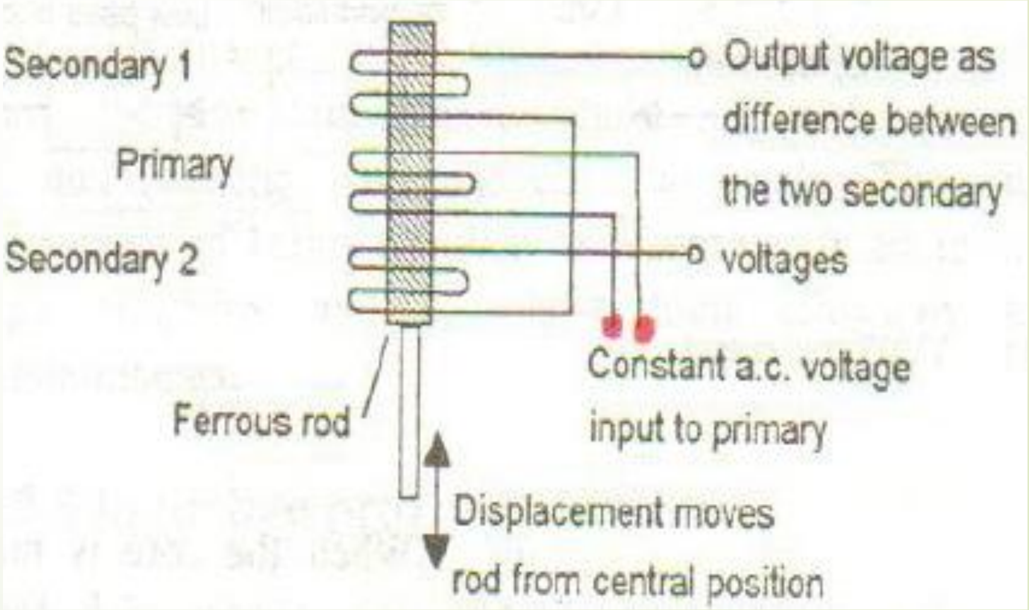
$$\Delta C/C = -\ (x/d)/[1+(x/d)]$$ **(prove it)**

Differential Transformers

- The Linear Variable Differential Transformer (LVDT) consists of three coils symmetrically spaced along an insulated tube.
- The central coil is the primary coil and the other two are identical secondary coils which are connected in series in such a way that their outputs oppose each other.
- A magnetic core is moved through the central tube as a result of the displacement being monitored.

Differential Transformers

- When there is an alternating voltage input to the primary coil, alternating e.m.f.s are induced in the secondary coil.
- With the magnetic core central, the amount of magnetic material in each of the secondary coils is the same.
- But when the core is displaced from the central position there is a greater amount of magnetic core in one coil than the other, e. g. more in secondary coil 2 than coil 1.



Differential Transformers

- The result is that a greater e.m.f. is induced in one coil than the other. There is then a net output from the two coils.
- Since a greater displacement means even more core in one coil than the other, the output, the difference between the two e.m.f.s increases the greater the displacement being monitored.
- LVDTs have operating ranges from about ±2mm to ±400mm with non-linearity errors of about ±0.25%.
- LVDTs are very widely used as primary transducers for monitoring displacements. The free end of the core may be **spring loaded** for contact with the surface being monitored, or threaded for mechanical connection.
- They are also used as secondary transducers in the measurement of force, weight and pressure; these variables are transformed in to displacements which can be monitored by LVDT's.

Eddy Current Proximity Sensor

- If a coil is supplied with an alternating current, an alternating magnetic field is produced. If there is a metal object in close proximity to this alternating magnetic field, then eddy currents are induced in it.
- The eddy currents themselves produce a magnetic field. This distorts the magnetic field responsible for their production.
- As a result, the impedance of the coil changes and so the amplitude of the alternating current. At some preset level, this change can be used to trigger a switch.
- This type of sensor is used for detection of non-magnetic but conductive materials.
- They are inexpensive, small in size, highly reliable and are very sensitive to small displacements.

Inductive proximity Switch

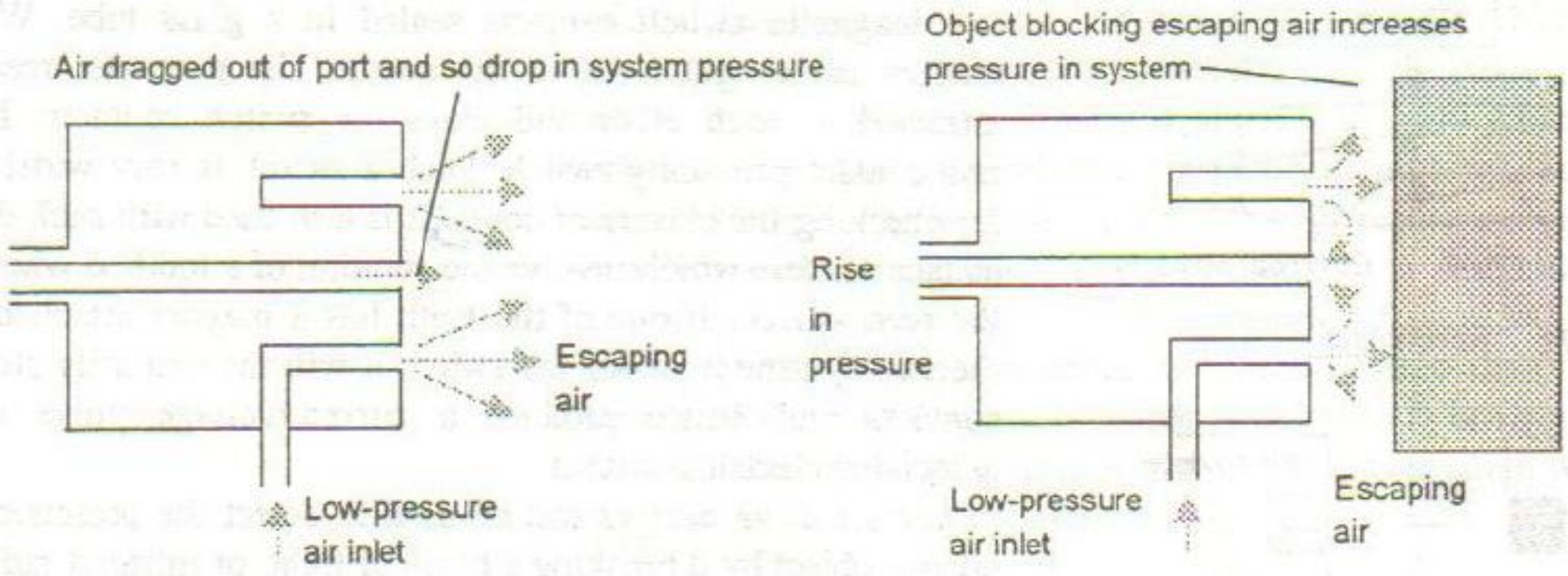
- This consists of a coil wound round a core. When the end of the coil is close to a metal object its inductance changes. This change can be used to trigger a switch.
- It is used for detection of metal objects and is best with ferrous metals.

Pneumatic Sensors

- Pneumatic sensors involve the use of compressed air, displacement or the proximity of an object being transformed in to a change in air pressure.
- Low pressure air is allowed to escape through a port in the front of the sensor. This escaping air in the absence of any close by object, escapes and in doing so also reduces the pressure in the nearby sensor output port.
- Typically 3-12 mm displacements can be measured by this sensor.

Pneumatic Sensors

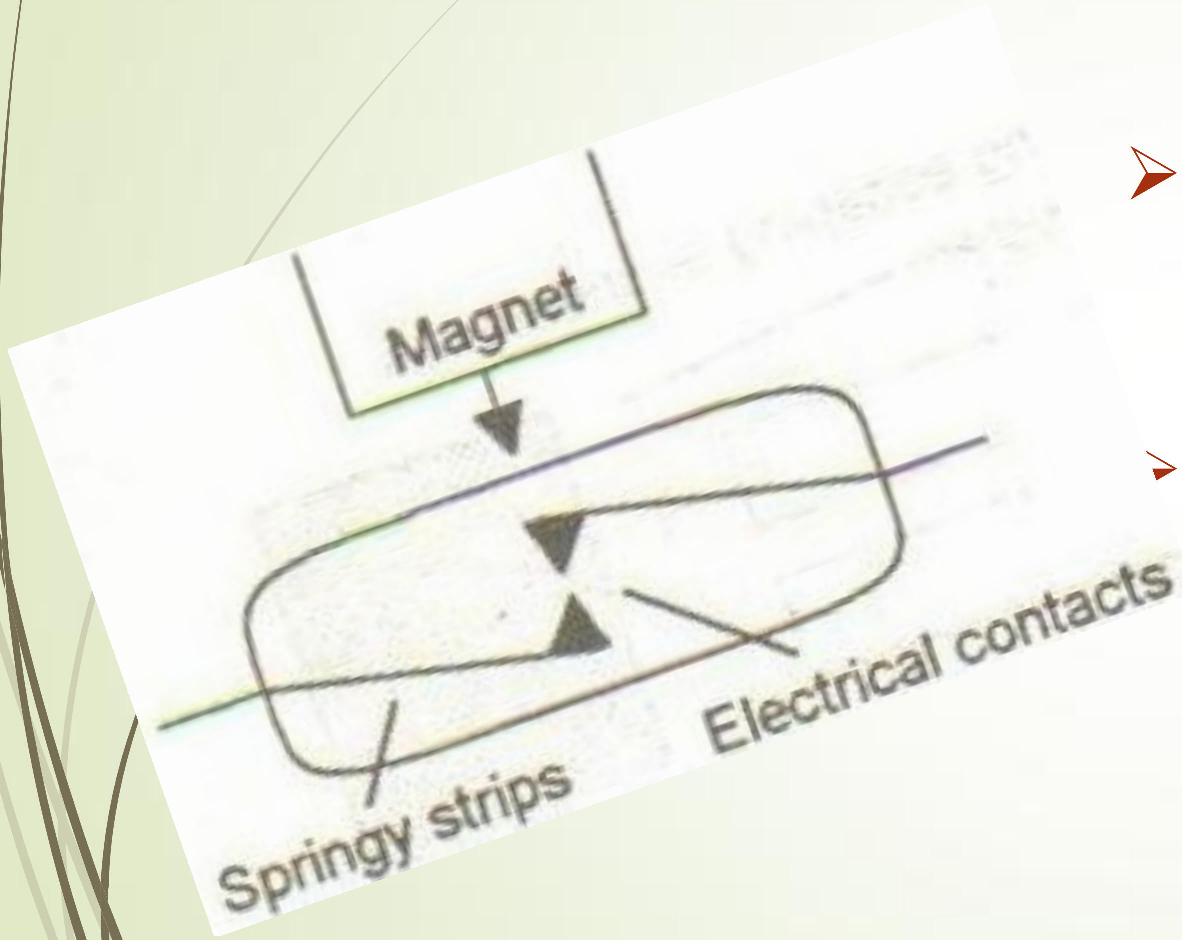
- But if there is a close by object, the air cannot so readily escape and the result is that the pressure increases in the sensor output port. The output pressure from the sensor thus depends on the proximity of objects.



Proximity Switches

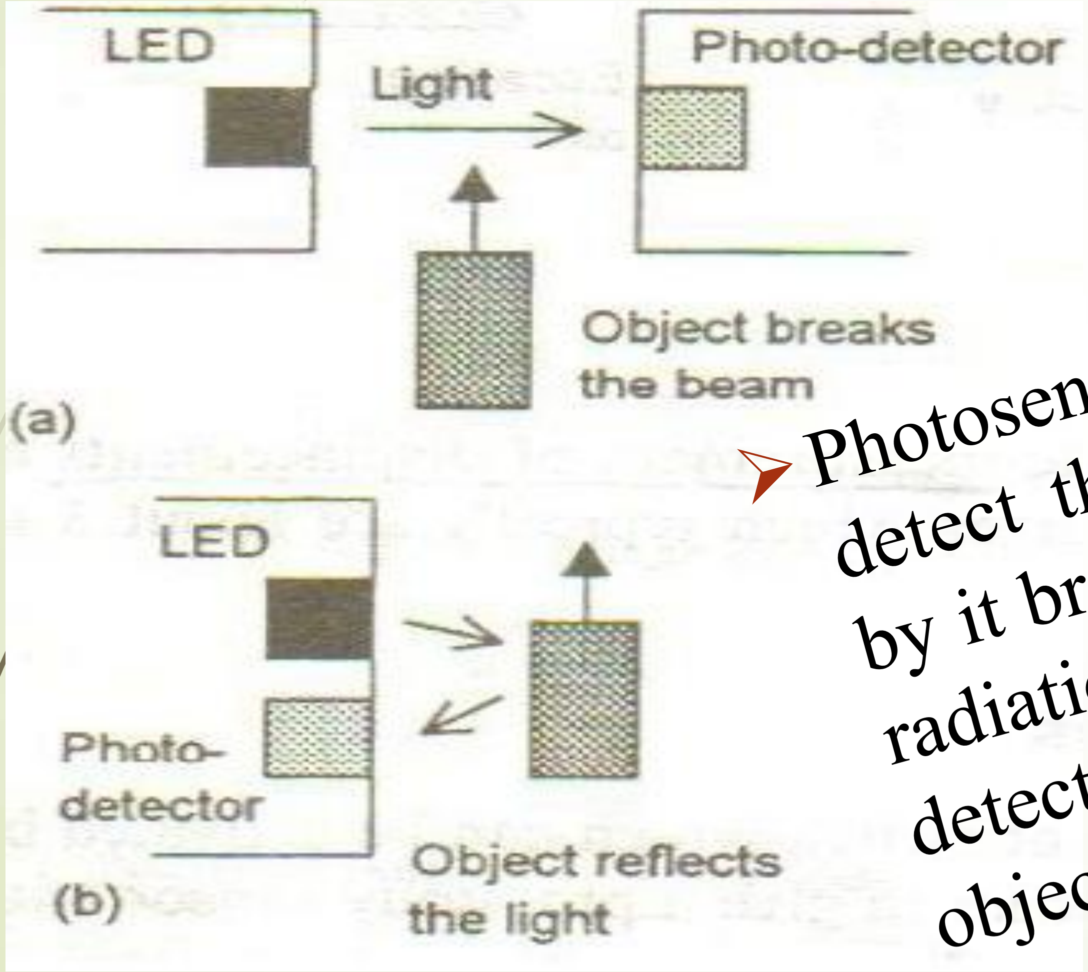
- There are many forms of switches which are activated by the presence of an object, to give an output to sensor which is either on or off.
- Microswitch is a small electrical switch which requires physical contact and a small operating force to close the contacts.
- On a conveyor belt presence of an item is determined by the weight on the belt.
- Lever operated, Roller Operated and Cam Operated switches are examples of Proximity Microswitches.

Proximity Switches



- Reed Switch consists of two magnetic switch contacts sealed in a glass tube.
- When a magnet is brought close to the switch, the magnetic reeds are attracted to each other and close the switch contacts.

Proximity Switches

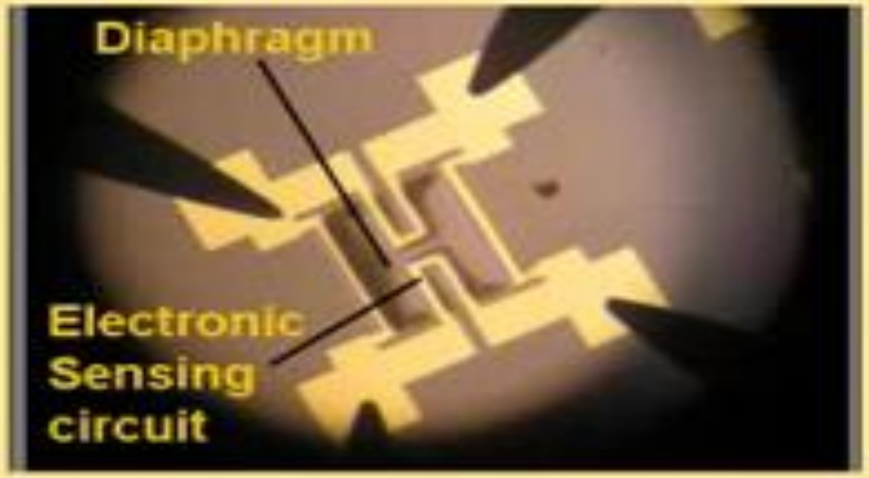


- Photosensitive devices can be used to detect the presence of an opaque object by it breaking a beam of light, or infrared radiation, falling on such a device or by detecting the light reflected back by the object. (SEM/TEM/XRD/SPM etc.)

Hall Effect Sensors

…..Self- Study

INTRODUCTION TO SENSORS



Micro-Pressure Sensor

Southwest Center for Microsystems Education

TRANSDUCERS

- Transducers are defined as elements that when subject to some change, experience a related change.
- Thus we can say sensors are transducers, but a measurement system may use transducers in addition to the sensors.

Classification of Transducers

Transducers can be classified on five basis:-

1. On the form of transduction used
2. As Primary & Secondary Transducers
3. As Passive & Active Transducers
4. As Analog & Digital Transducers
5. As Transducers & Inverse Transducers.

Classification of Transducers
(Acronyms/Abbreviations)

On the Basis of transduction used :-

Transducer can be classified in to resistive, inductive, capacitive etc. depending upon how they converts the input quantity in to Resistance, inductance, capacitance etc…

As Primary & Secondary Transducers:-

There are two stages of transduction, firstly the Pressure is Converted in to a displacement by bourdon tube then the Displacement is converted into analogous voltage by linear Variable differential transformer(L.V.D.T.), The Bourdon tube is Primary transducer & L.V.D.T. called secondary transducer.

As Passive & Active Transducer:-

Passive transducers uses the power from an external source & A part of it from the measurand quantity for the process of transduction e.g.- resistive, inductive, capacitive etc…

Active transducers self generate their own voltage or current output They do not require the external power source e.g.- photovoltaic cells, thermocouple etc……

Classification of Transducers

(Acronyms/Abbreviations)

Analog & Digital Transducers

Analog transducers converts the input quantity into an analog output which is continuous function of time.

e.g.- thermocouple, L.V.D.T.

Digital transducers converts the input quantity in to an electrical output which is in the form of pulses.

Transducers & Inverse Transducers

Transducers is the device which converts non electrical quantity in to electrical quantity.

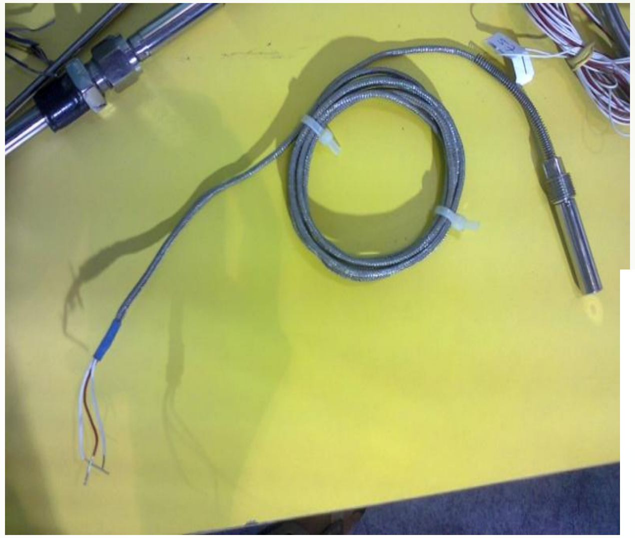
Inverse transducers is the device which converts electrical quantity in to non electrical quantity.

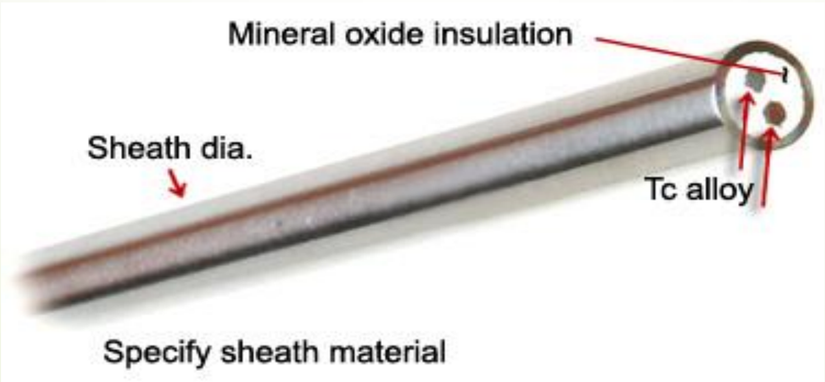
TRANSDUCERS

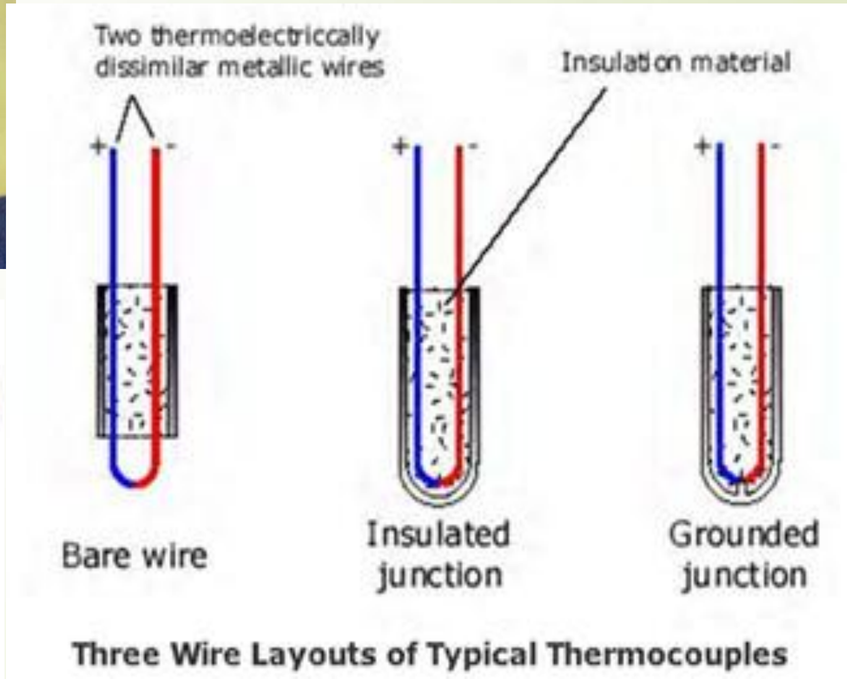
- In a process industry three basic and very important parameters to be measured and controlled are:
  - Flow measurement **(Self Study)**
  - Temperature measurement
  - Pressure measurement

Temperature Measurement

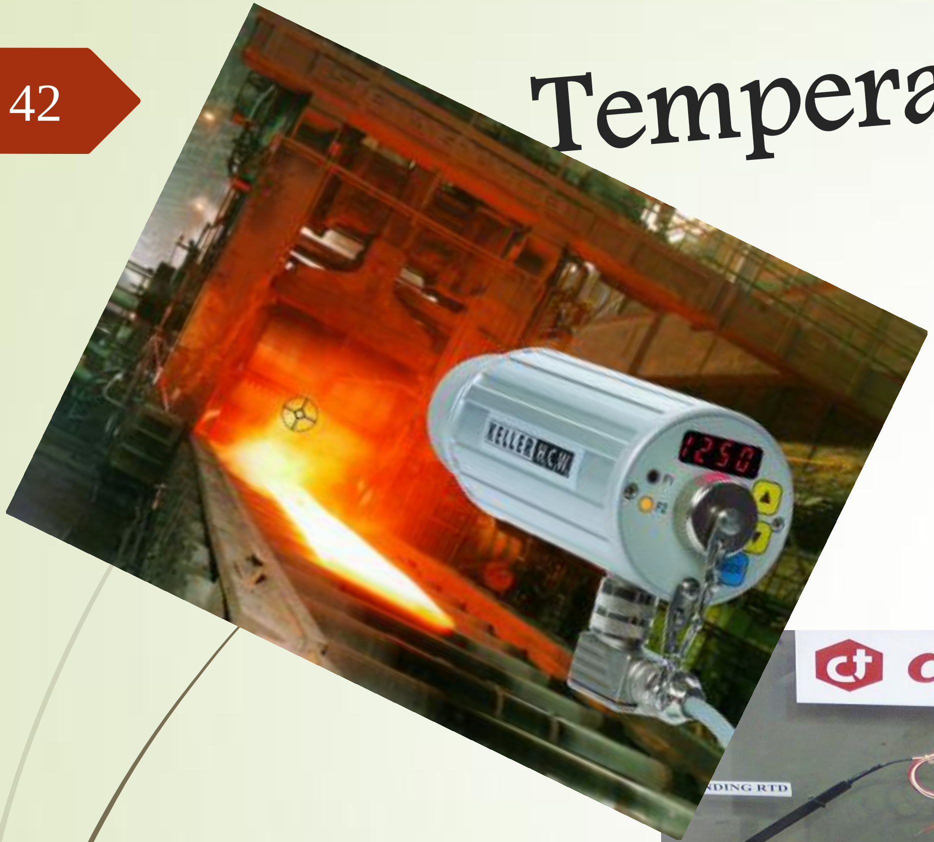
- Thermocouple
- Thermistor
- RTD
- Bimetallic Thermostat
- Pyrometers







Temperature Measurement

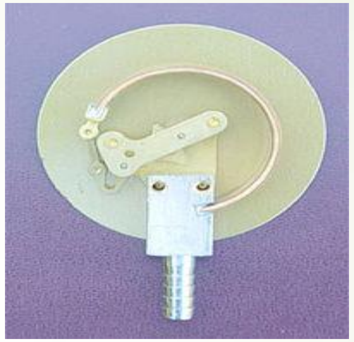


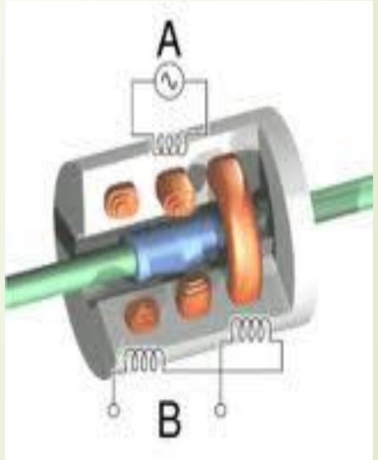
COMPARISION OF DIFFERENT TYPES OF TEMPERATURE SENSORS

Attribute	Thermocouple	RTD	Thermistor
Cost	Low	High	Low
Temperature Range	Very wide -350°F +3200°F	Wide -400°F +1200°F	Short to medium -100°F +500°F
Interchange ability	Good	Excellent	Poor to fair
Long-term Stability	Poor to fair	Good	Poor
Accuracy	Medium	High	Medium
Repeatability	Poor to fair	Excellent	Fair to good
Sensitivity (output)	Low	Medium	Very high
Response	Medium to fast	Medium	Medium to fast
Linearity	Fair	Good	Poor
Self Heating	No	Very low to low	High
Point (end) Sensitive	Excellent	Fair	Good
Lead Effect	High	Medium	Low
Size/Packaging	Small to large	Medium to small	Small to medium

Pressure Measurement

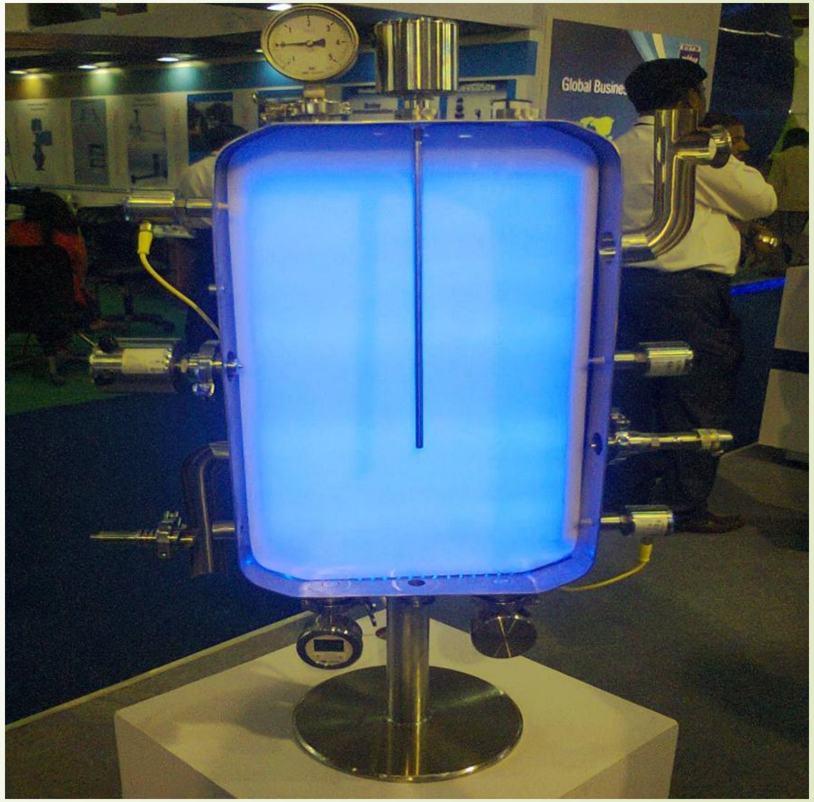
- Manometric Method
- Elastic Pressure Transducers
  1. Bourdon Tube
  2. Bellows
  3. Diaphragms
  4. Capsule
- Electric Pressure Transducers
  1. Capacitive
  2. Inductive e.g. LVDT





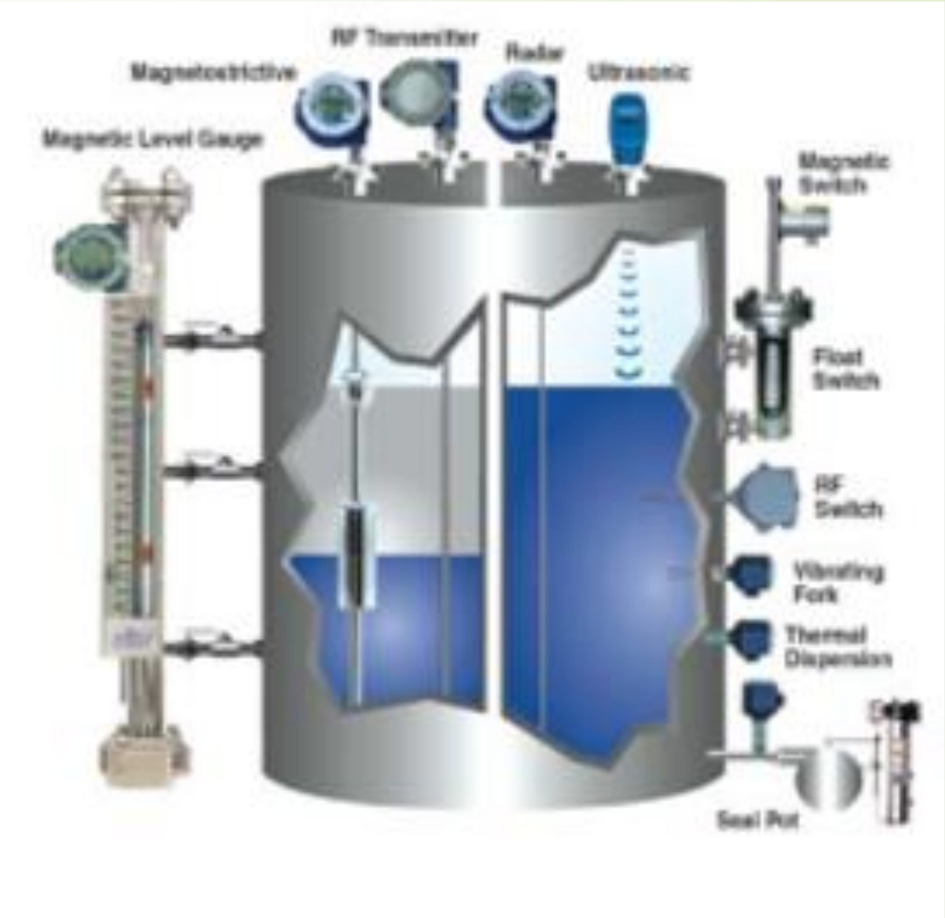
Pressure Gauge

- Generally named as Pressure gauges or Vacuum gauges.
- **Absolute pressure** is zero-referenced against a perfect vacuum, so it is equal to gauge pressure plus atmospheric pressure.
- **Gauge pressure** is zero-referenced against ambient air pressure, so it is equal to absolute pressure minus atmospheric pressure.
- **Differential pressure** is the difference in pressure between two points.



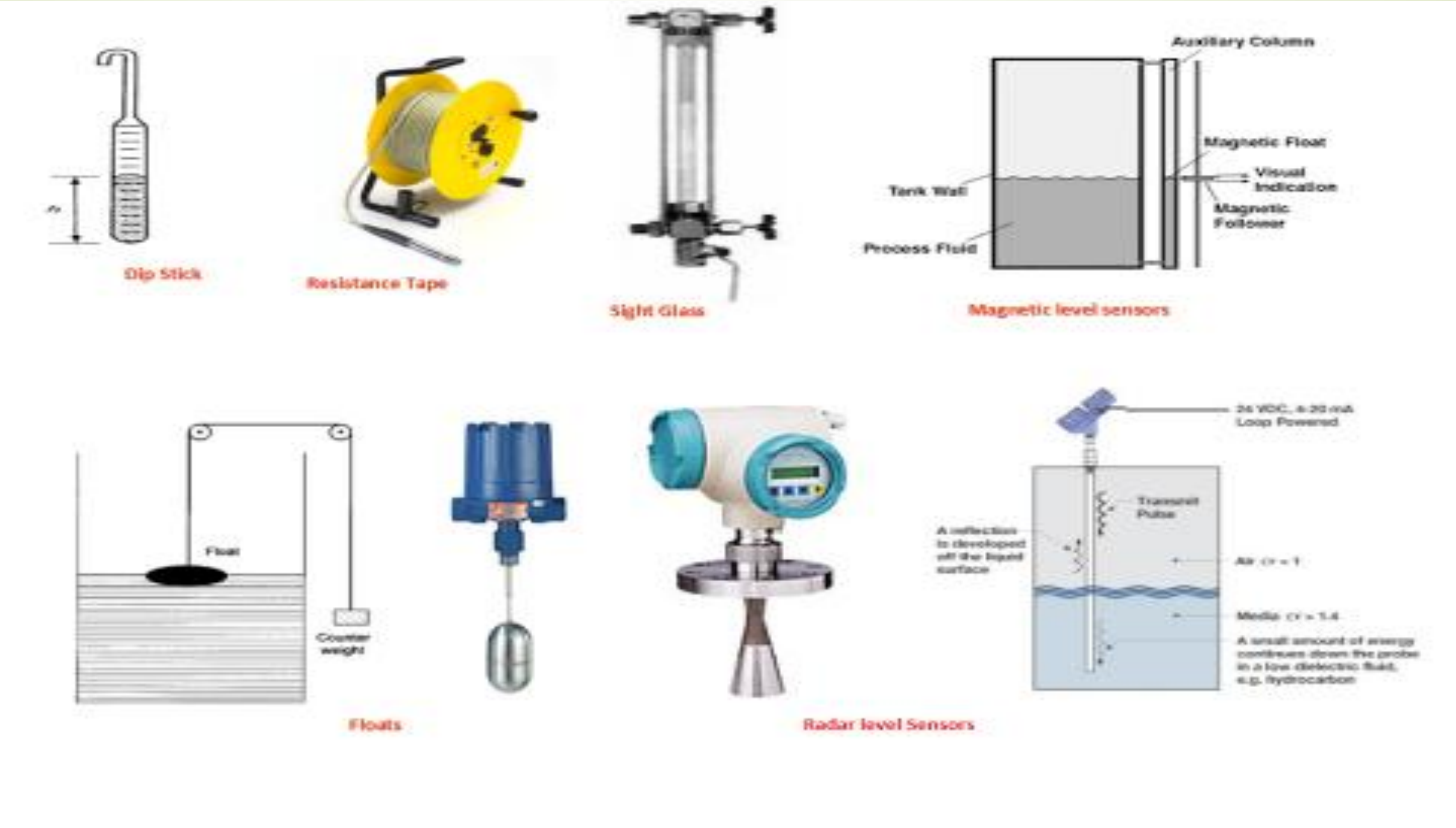
LEVEL MEASUREMENT

- Hydrostatic Head
- Float
- Load Cell
- Magnetic Level Gauge
- Capacitance Transmitters
- Magnetostrictive
- Ultrasonic
- Microwave
- Laser
- Radar
- Dip Stick
- Vibration



Source: AAI **No.s in lakhs**

LEVEL MEASUREMENT



LEVEL MEASUREMENT