BITS Pilani
Pilani Campus

Mechatronics

(Merged - DEZG516/DMZG511/ESZG511)

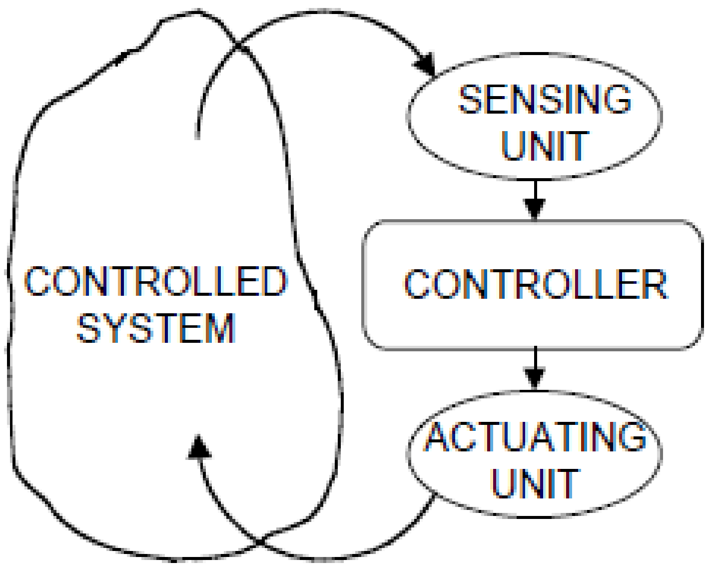
Session 2

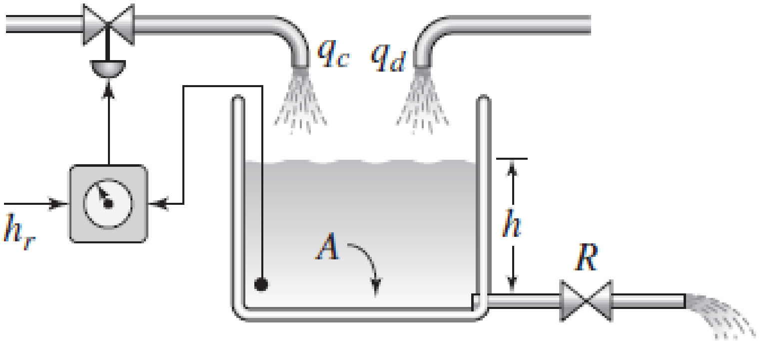
Session 2

Type	Content Ref.	Topic Title	Study/HW Resource Reference
Pre CH			
During CH	T1, T2	Sensor and Transducers: Definition and performance terminology, Static and dynamic characteristics Sensing physical quantities: Displacement, position and proximity	T1: Chapter 2, T2: Chapter 9
Post CH			Chapter end problems

Sensors and Transducer

Typical Mechatronic System





Measurement system

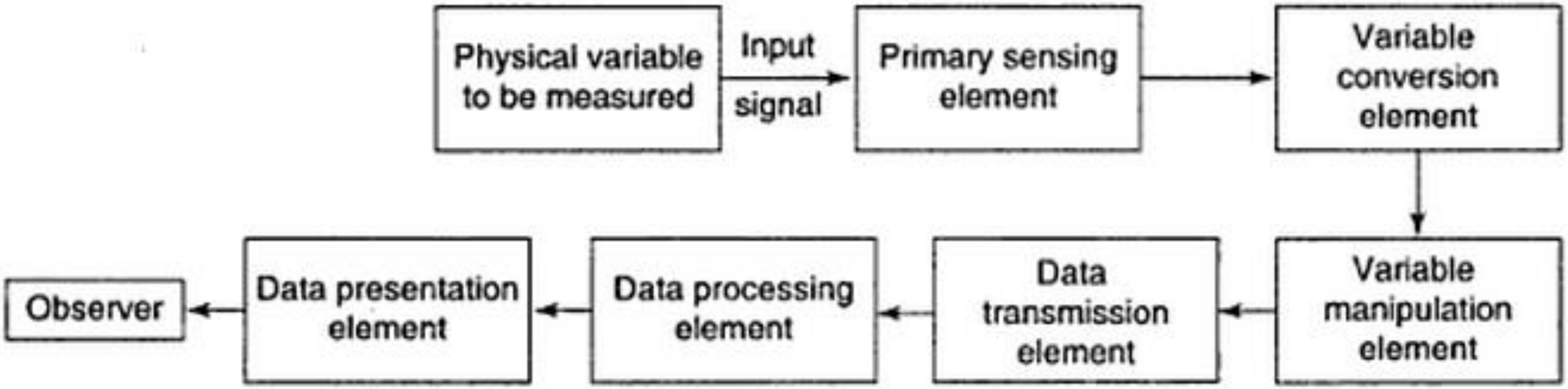
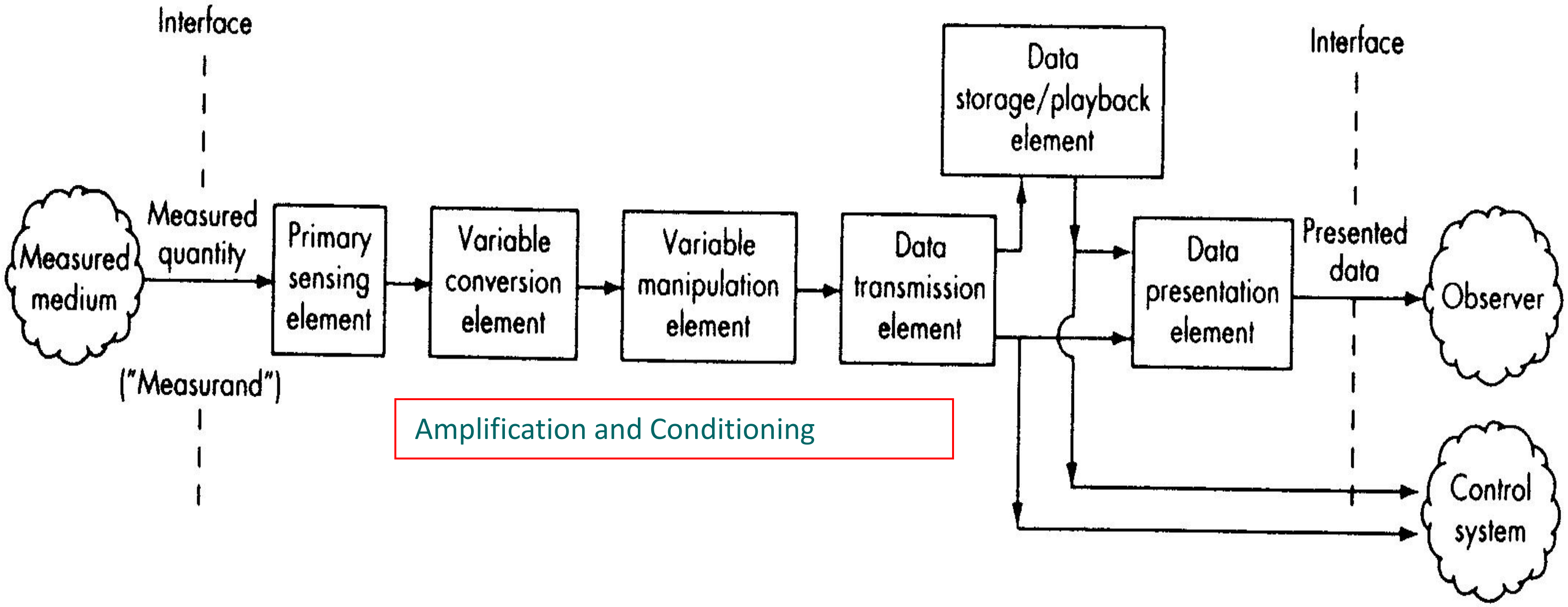


Figure 1.12 | Functional elements of a measurement system.

Basic components in a measurement system

Basic components in a measurement system are shown below:



It is also important to mention that a power supply is an important element for the entire system.

Sensor Characteristics

Static Characteristics

The static characteristics are the values given when steady-state conditions occur, i.e. the values given when the transducer has settled down after having received some input.

Dynamic Characteristics

Refer to the behaviour between the time that the input value changes and the time that the value given by the transducer settles down to the steady-state value.

Static characteristics

Range

It defines the maximum and minimum values of the inputs or the outputs for which the instrument is recommended to use.

Span

The span is the maximum value of the input minus the minimum value.

For example, for a temperature measuring instrument the input range may be 100-500 ^{o}C and the output range may be 4-20 mA.
(Example – Range – 100°C to 500°C, Span – 400°C)

Static characteristics

Error

- Error is the difference between the result of the measurement and the true value of the quantity being measured.
- Error = M.V. – T.V. (actual measured)

Static characteristics

Sensitivity

It can be defined as the ratio of the *incremental output* and the *incremental input* .
sensitivity of a thermocouple is denoted as 100µ*V*/°*C*.

Again sensitivity of an instrument may also vary with temperature or other external factors. This is known **as** ***sensitivity drift***.

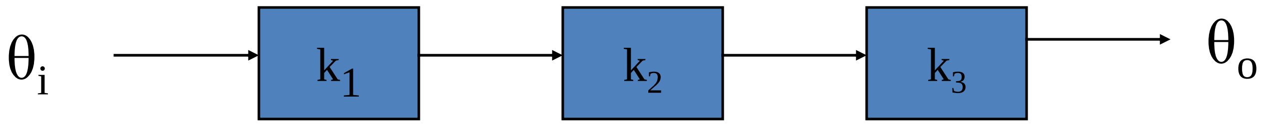
Suppose the sensitivity of the spring balance mentioned is 25 mm/kg at 20 ^{o}C and 27 mm/kg at 30^{o}C. Then the sensitivity drift/^{o}C is 0.2 (mm/kg)/^{o}C.

Static characteristics - Sensitivity

Example 2:

Pressure sensor A with a value of 2 bar caused a deviation of 10 degrees. Therefore, the sensitivity of the equipment is 5 degrees/bar.

- Sensitivity of the whole system is (k) = $k_1 \times k_2 \times k_3 \times .. \times k_n$



Static characteristics - Sensitivity

Example:

Consider a measuring system consisting of a transducer, amplifier and a recorder, with sensitivity for each equipment given below:

Transducer sensitivity	0.2 mV/°C
Amplifier gain	2.0 V/mV
Recorder sensitivity	5.0 mV/V

Therefore,

Sensitivity of the whole system:

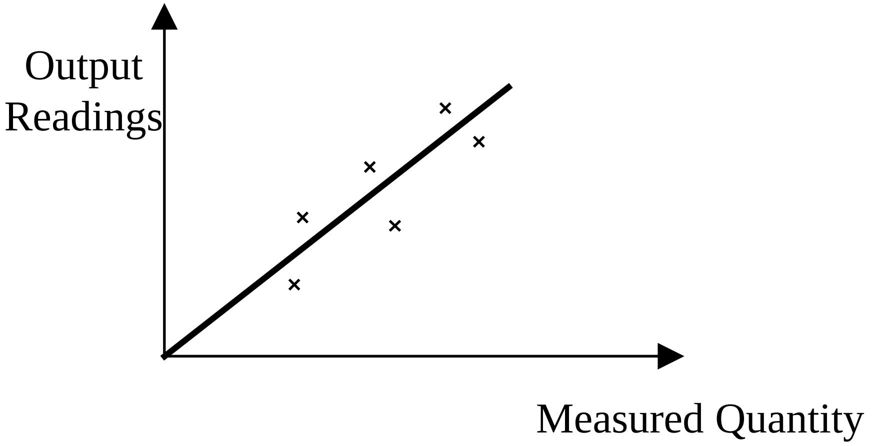
$$(k) = k_1 \times k_2 \times k_3$$

$$k = 0.2 \frac{\text{mV}}{°\text{C}} \times 2.0 \frac{\text{V}}{\text{mV}} \times 5.0 \frac{\text{mV}}{\text{V}}$$

$$k = 2.0 \text{ mV/°C}$$

Linearity

- Maximum deviation from linear relation between input and output.
- The output of an instrument has to be linearly proportionate to the measured quantity.
- Normally shown in the form of full scale percentage (% fs).
- The graph shows the output reading of an instrument when a few input readings are entered.
- *Linearity* = maximum deviation from the reading of x and the straight line.



Linearity

$$Linearity = \frac{\Delta O}{O_{\max} - O_{\min}}$$

where, $\Delta O = \max(\Delta O_1, \Delta O_2)$.

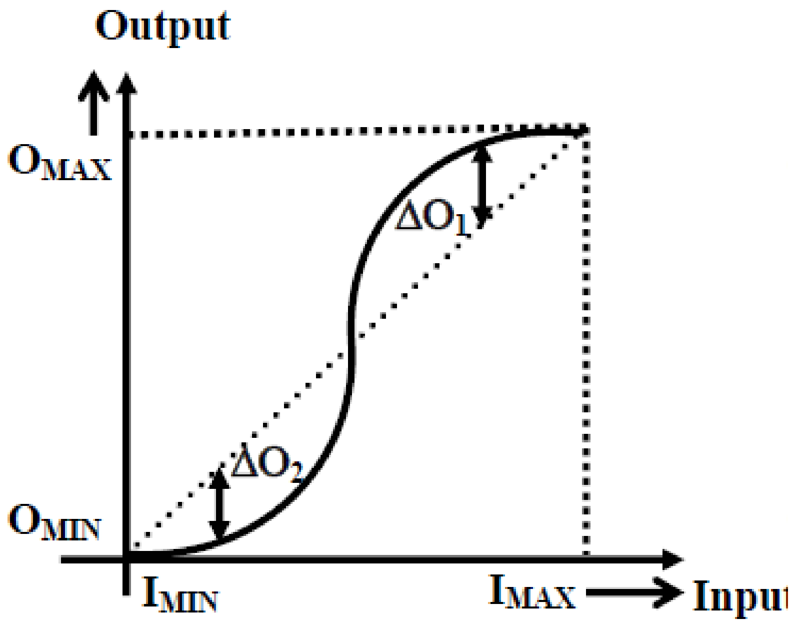


Fig. 1 Linearity

Hysteresis

- The phenomenon in which the value of a physical property lags behind changes in the effect causing it.

- Transducers can give different outputs from the same value of quantity being measured according to whether that value has been reached by a continuously increasing change or a continuously decreasing change. This effect is called hysteresis.

Static characteristics

$$Linearity = \frac{\Delta O}{O_{\max} - O_{\min}} \qquad (1)$$

where, $\Delta O = \max(\Delta O_1, \Delta O_2)$.

$$Hysteresis = \frac{H}{O_{\max} - O_{\min}} X100.$$

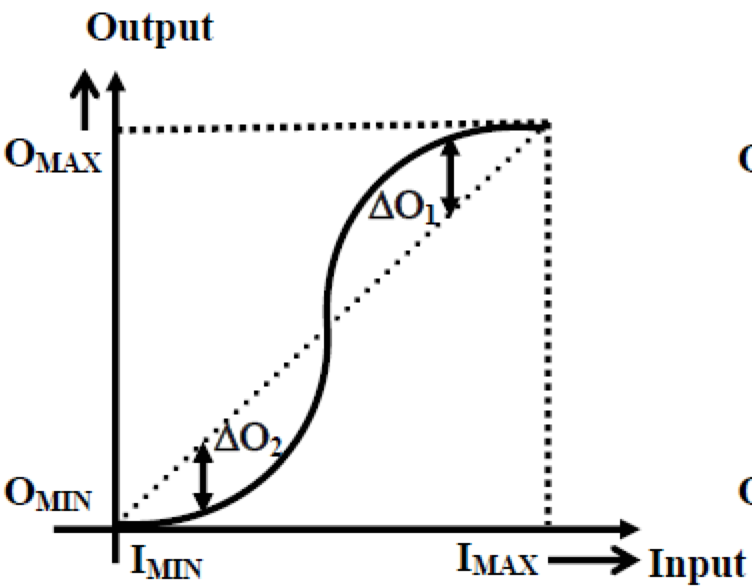


Fig. 1 Linearity

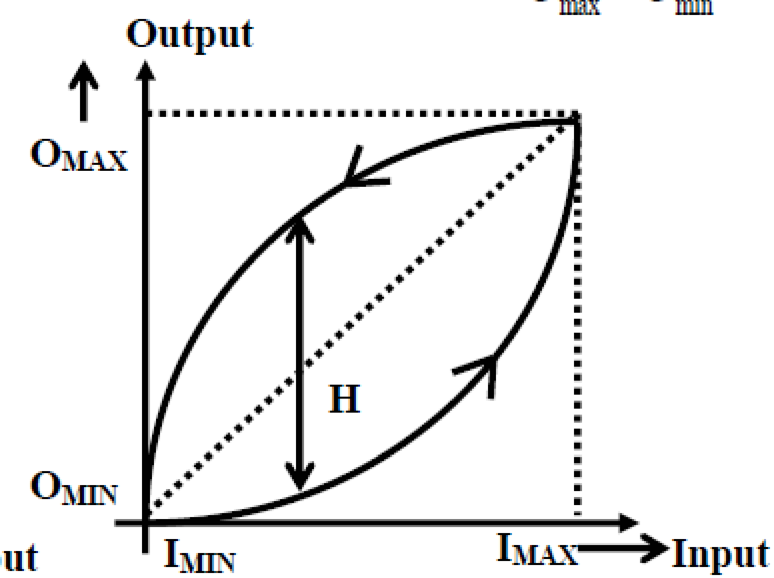


Fig. 2 Hysteresis

Static characteristics - Resolution

The resolution is the smallest change in the input value that will produce an observable change in the output.

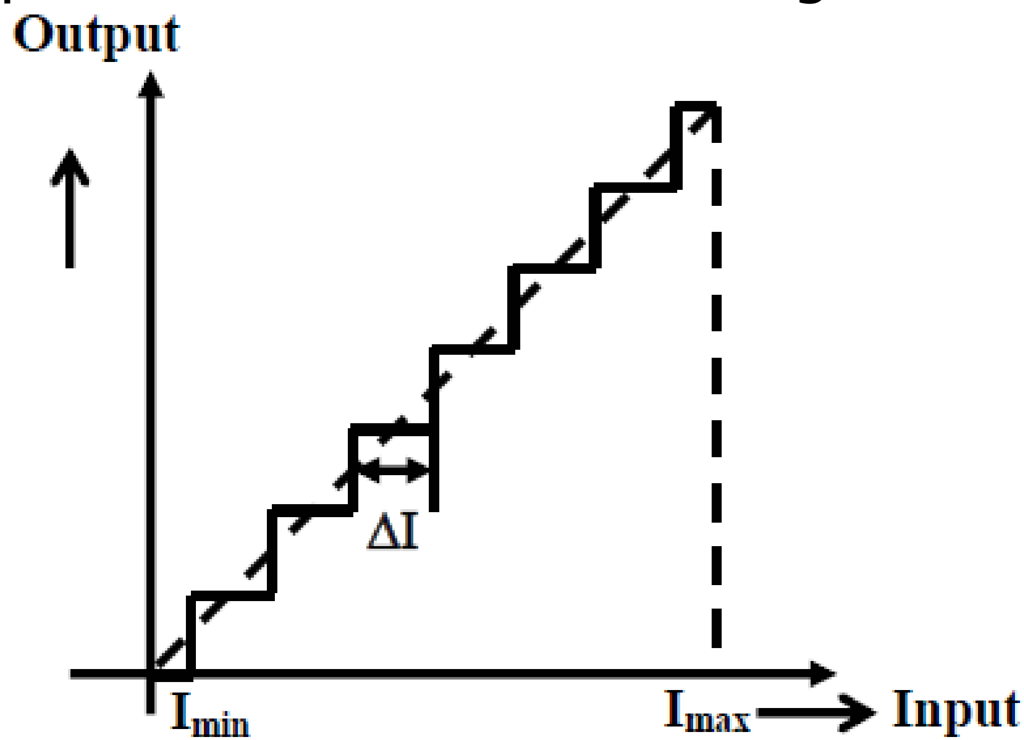


Fig. 3 Resolution

- The smallest change in input reading that can be traced accurately.
- Given in the form '% of full scale (% fs)'.
- Available in digital instrumentation.

Static characteristics - Accuracy

Accuracy indicates the closeness of the measured value with the actual or true value, and is expressed in the form of the *maximum error (= measured value – true value)* as a percentage of **<u>full scale reading.</u>**

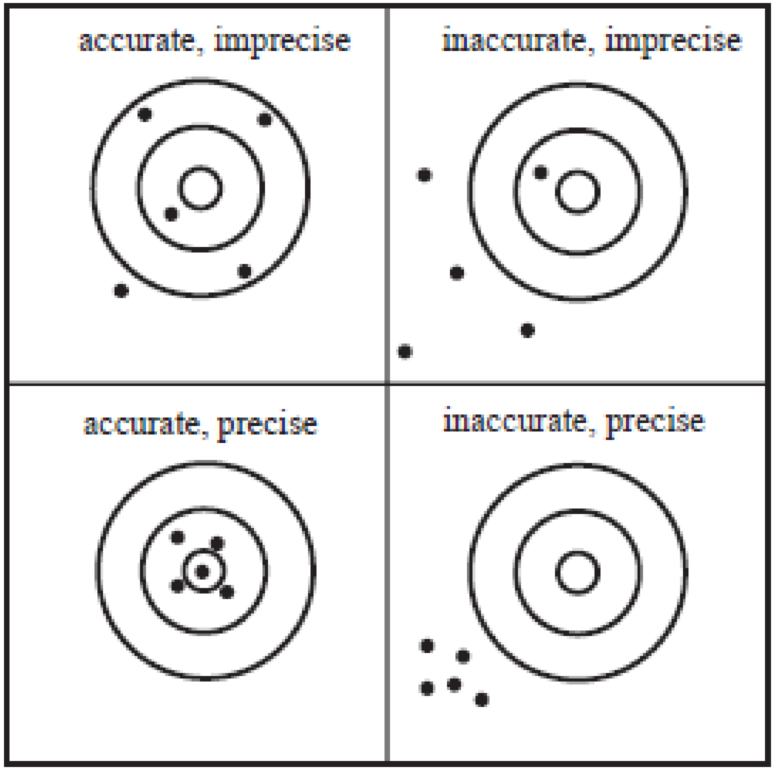
- Accuracy is the extent to which the value indicated by a measurement system might be wrong.
- Thus, if the accuracy of a temperature indicator, with a full scale range of 0-500 ^{o}C is specified as ±0.5%, it indicates that the measured value will always be within ±2.5 ^{o}C of the true value, if measured through a standard instrument during the process of calibration.

Question:
Can we use above instrument to measure say 25°C with ±0.5 ^{o}C *tolerence?*

Static characteristics - Precision

Precision indicates the repeatability or reproducibility of an instrument (but does not indicate accuracy).

$$Precision = \frac{measured\ range}{\sigma_e}$$



Repeatability and Reproducibility

- The terms repeatability and reproducibility of a transducer are used to describe its ability to give the same output for repeated applications of the same input value.

$$\text{repeatability} = \frac{\text{max.} - \text{min. values given}}{\text{full range}} \times 100$$

Repeatability and Reproducibility

Reproducibility may be defined as the closeness of agreement among the repeated measurements of the output for the same value of the input under the same operating conditions over a period of time. Perfect reproducibility means that the instrument calibration does not gradually shift over a long period of time.

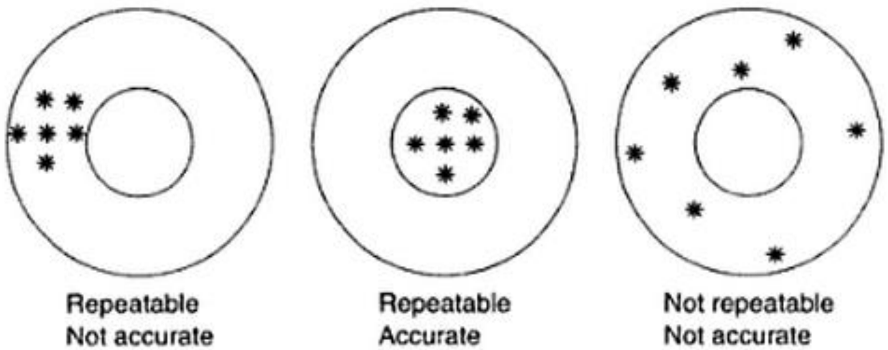


Figure 2.6 | Difference between repeatability and accuracy.

Tolerance

- Closely related to accuracy of an equipment where the accuracy of an equipment is sometimes referred to in the form of tolerance limit.
- Defined as the maximum error expected in an instrument.
- Explains the maximum deviation of an output component at a certain value.

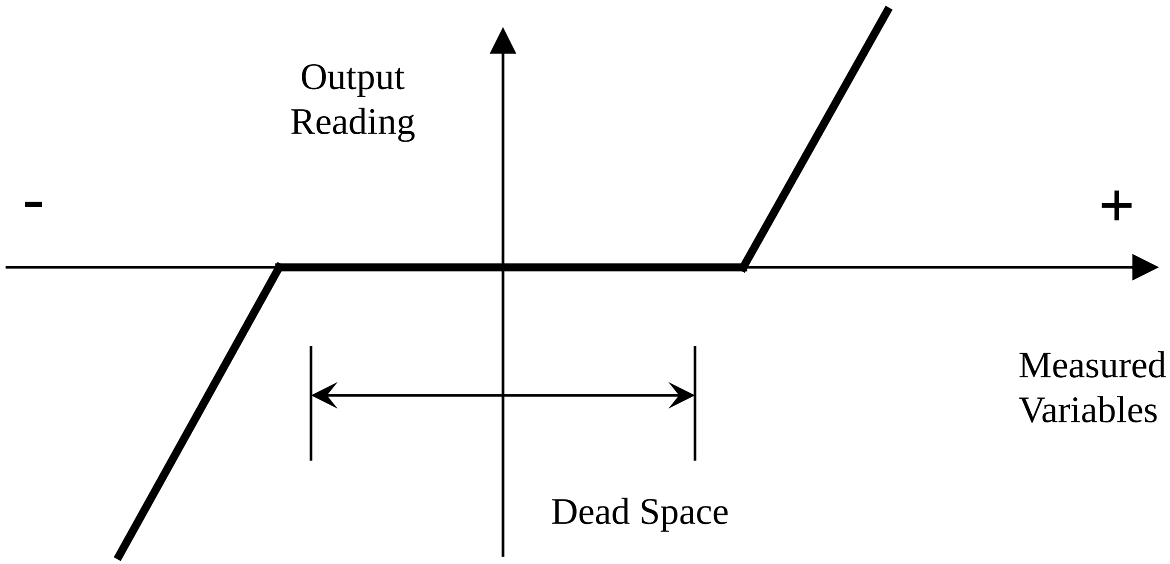
Bias

- Constant error which occurs during the measurement of an instrument.
- This error is usually rectified through calibration.

<u>Example :</u>

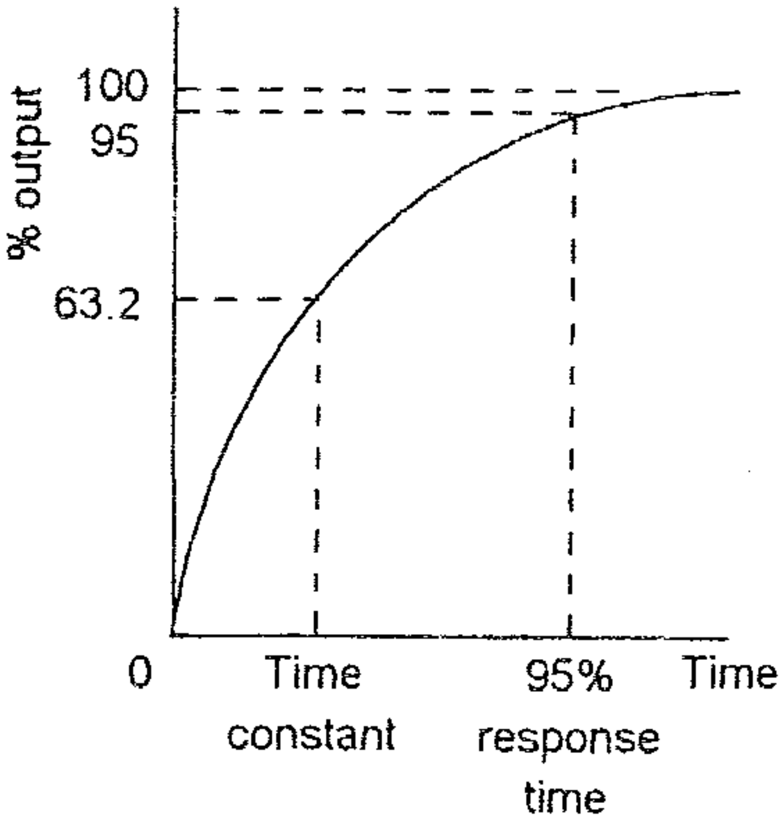
A weighing scale always gives a bias reading. This equipment always gives a reading of 1 kg even without any load applied. Therefore, if A with a weight of 70 kg weighs himself, the given reading would be 71 kg. This would indicate that there is a constant bias of 1 kg to be corrected.

Dead space / dead band



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

Dynamic Characteristics



Response Time:
- Time for transducer to reach output (95%) of the input value

Time constant:
- 63.2 % of Response time

Rise time:
Output to reach 10% of input to 95% of input

Settling time:
Time required for the output to settle down at 2% of the steady state value of the input.

The above are due to inertia of sensors

Definitions - Sensors

- Also called: transducer, probe, gauge, detector, pick-up etc.
- A device that responds to a physical stimulus and transmits a resulting impulse.
- A device, such as a photoelectric cell, that receives and responds to a signal or stimulus.

- A device that responds to a physical stimulus (as heat, light, sound, pressure, magnetism, or a particular motion) and transmits a resulting impulse (as for measurement or operating a control) .

Definitions - Transducer

- A device that is actuated by power from one system and supplies power usually in another form to a second system.
- A substance or device, such as a piezoelectric crystal, that converts input energy of one form into output energy of another. (from: Trans-ducere – to transfer, to lead)
- a loudspeaker is a transducer that transforms electrical signals to sound energy.

Definitions - Actuator

- A mechanism for moving or controlling something indirectly instead of by hand.
- One that activates, especially a device responsible for actuating a mechanical device such as one connected to a computer by a sensor link
- One that actuates; a mechanical device for moving or controlling something.
  - Electical actuators
  - Hydraulic actuators
  - Pneumatic actuators

1. Active and passive sensors

Active sensor: a sensor that requires external power to operate. Examples: the carbon microphone, thermistors, strain gauges, capacitive and inductive sensors, etc.

Other name: parametric sensors (output is a function of a parameter - like resistance)

Passive sensor: generates its own electric signal and does not require a power source. Examples: magnetic microphones, piezoelectric sensors.

Other name: self-generating sensors

2. Contact and noncontact sensors

Contact sensor: a sensor that requires physical contact with the stimulus. Examples: strain gauges, most temperature sensors

Non-contact sensor: requires no physical contact. Examples: most optical and magnetic sensors, infrared thermometers, etc.

3. Absolute and relative sensors

Absolute sensor: a sensor that reacts to a stimulus on an absolute scale: Thermistors, strain gauges, etc., (thermistor will always read the absolute temperature)

Relative scale: The stimulus is sensed relative to a fixed or variable reference. Thermocouple measures the temperature difference, pressure is often measured relative to atmospheric pressure.

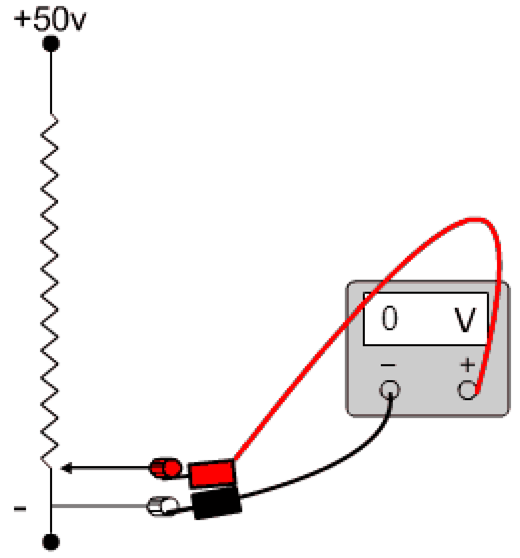
Displacement, Position, Proximity

Displacement, Position, Proximity Sensors

- **Displacement sensors** are concerned with the measurement of the amount by which some object has been moved; (Linear/ Angular)
- **Position sensors** are concerned with the determination of the position of some object in relation to some reference point.
- **Proximity sensors** are a form of position sensor and are used to determine when an object has moved to within some particular critical distance of the sensor. (On/OFF)

Displacement Sensors - Potentiometer

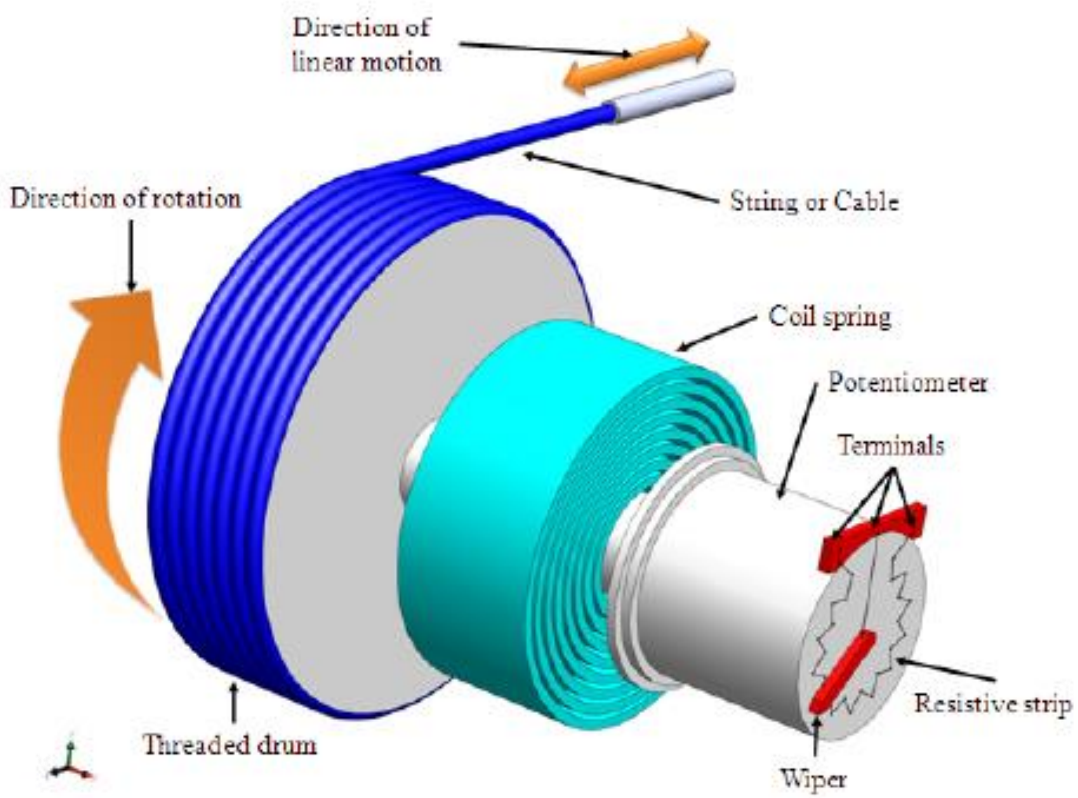
- Linear position
- Angular position



Potentiometers are used as sensors with the electronic systems in cars, being used for such things as the accelerator pedal position and throttle position.

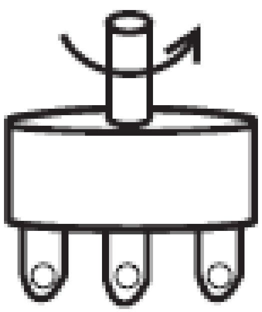
Displacement Sensors

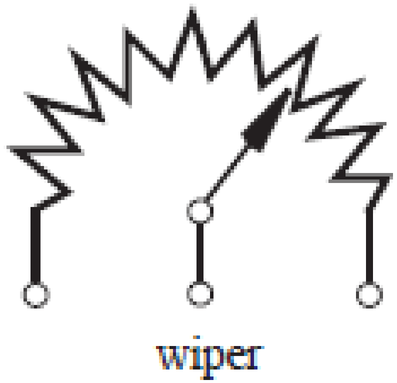
Linear position measurement using Potentiometers

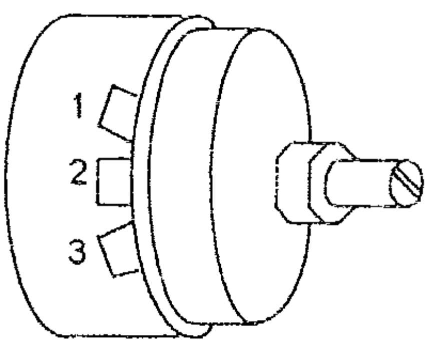


Displacement Sensors

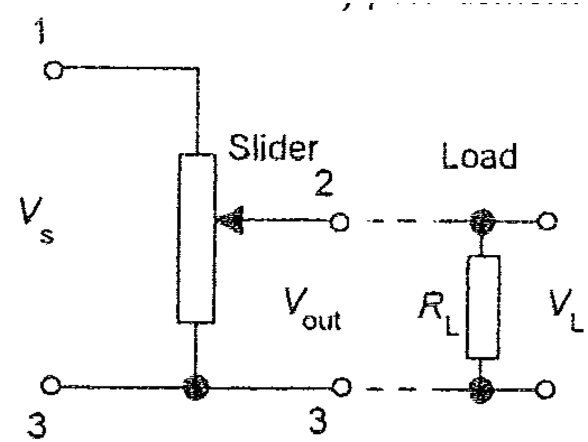
Angular position measurement using Potentiometers





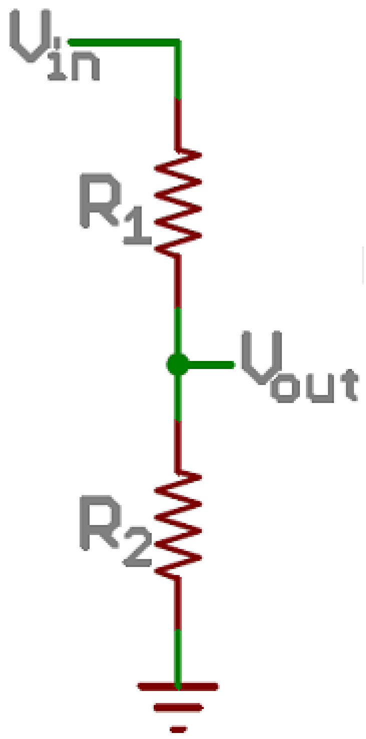


A rotary potentiometer



Used to sense accelerator position in cars

Displacement Sensors



$$V_{out} = V_{in} \cdot \frac{R_2}{R_1 + R_2}$$

$$R = \rho\, L \,/\, A,$$

ρ – resistivity ; A – Area are constants

R is Proportional to Length (L)

Vout is proportional to Resistance

LVDT Linear variable differential transformer

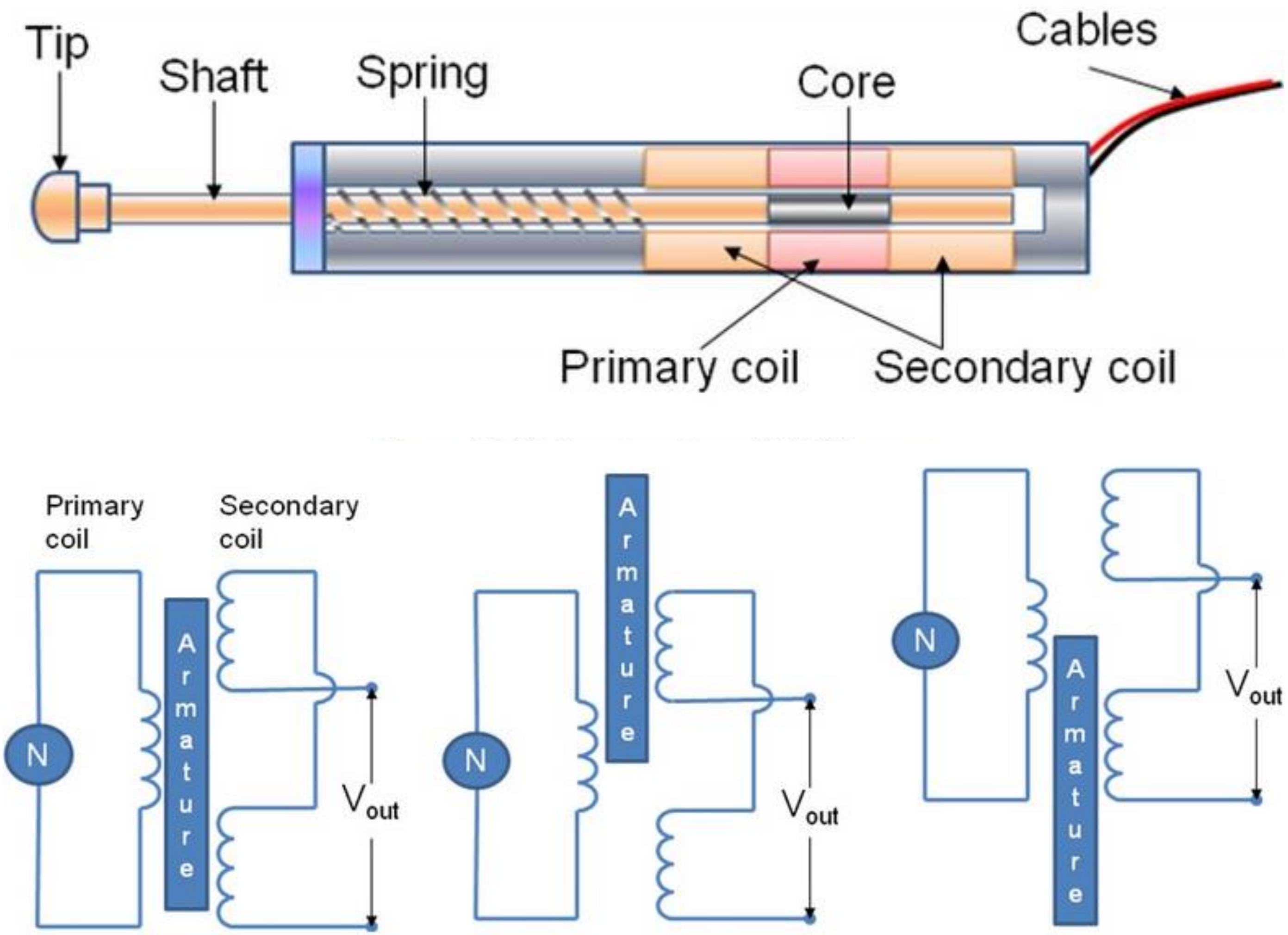
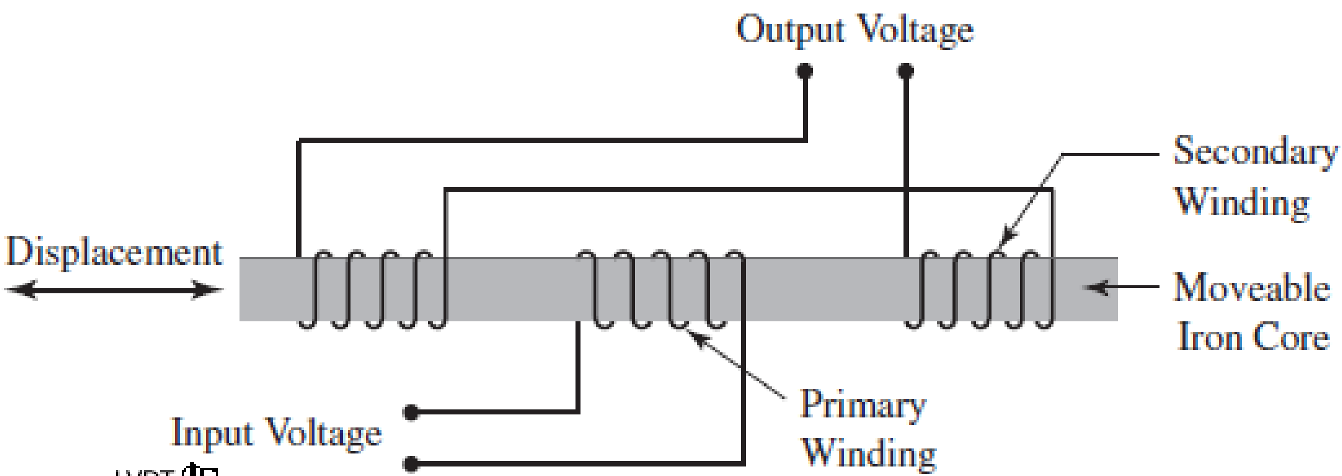
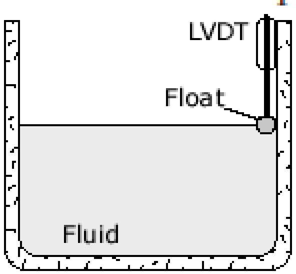
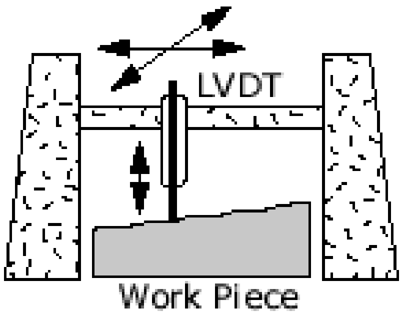


Figure 2.2.7 Working of LVDT sensor

Linear Variable Differential transformer(LVDT)







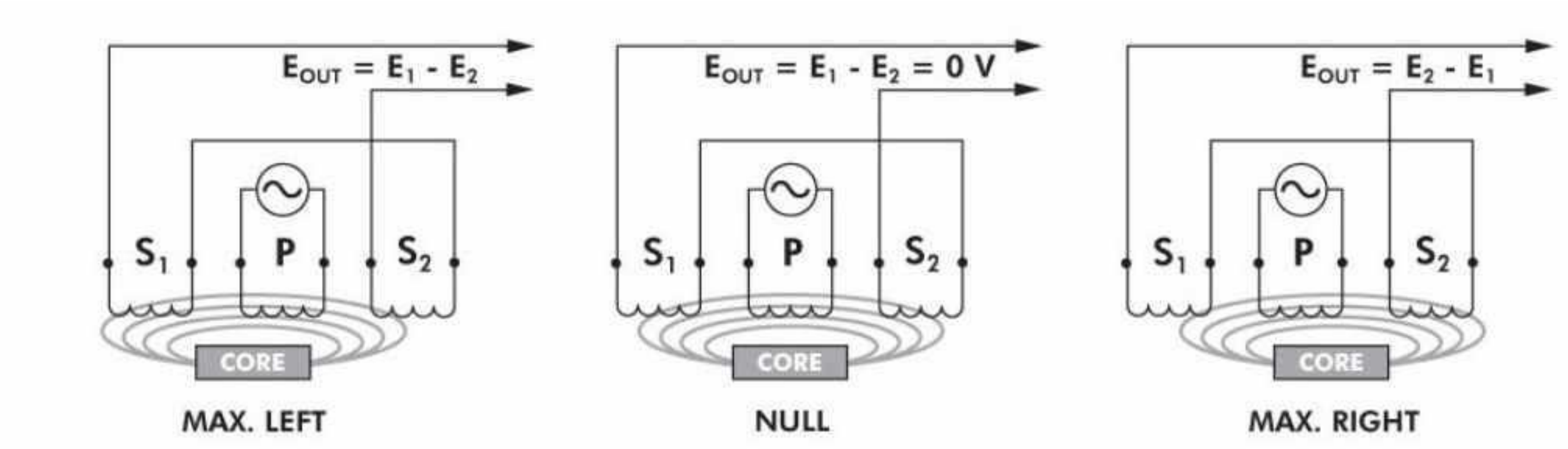
Profile Gauge

An external AC voltage is applied to the center (primary) coil, and the output signal is obtained from the two end (secondary) coils which are connected in opposite phase

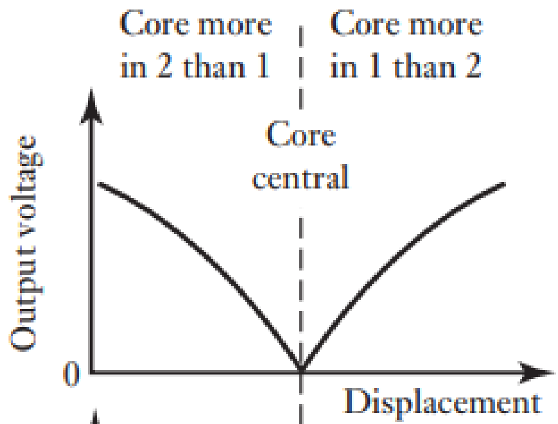
Range : +/- 2 mm to +/- 400 mm

non-linearity errors of about +/-0.25%

Linear Variable Differential transformer(LVDT)



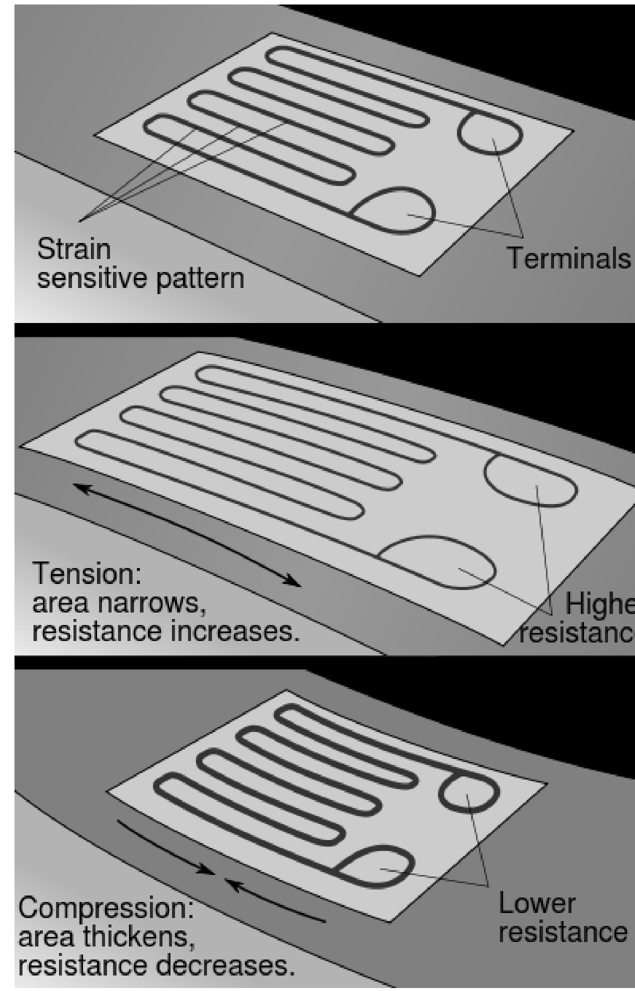
non-linearity errors of about +/- 0.25%



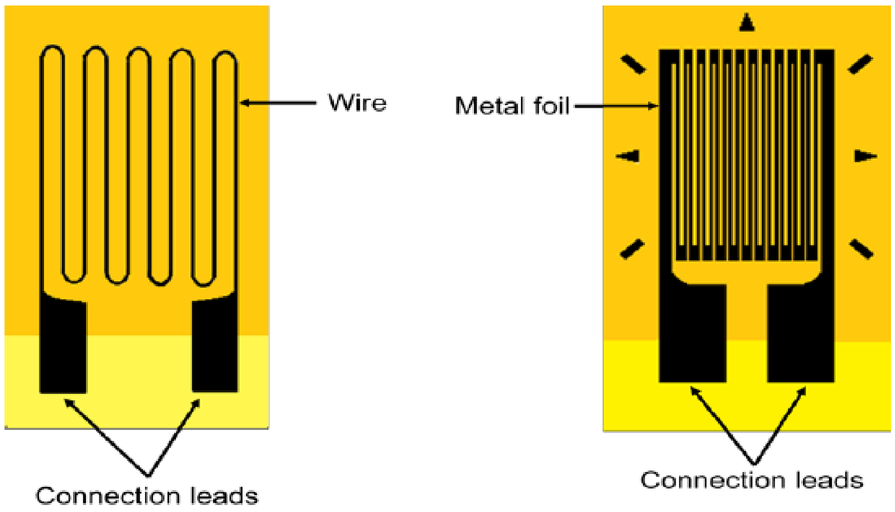
Strain Gauge

A strain gauge (also strain gage) is a device used to measure the strain of an object. Invented by Edward E. Simmons and Arthur C. Ruge in 1938, the most common type of strain gauge consists of an insulating flexible backing which supports a metallic foil pattern.

The gauge is attached to the object by a suitable adhesive. As the object is deformed, the foil is deformed, causing its electrical resistance to change.



Strain Gauges



These foils are made of Constantan alloy (copper-nickel 55-45% alloy) and are bonded to a backing material plastic (polyimide), epoxy or glass fibre reinforced epoxy. The strain gauges are secured to the workpiece by using epoxy

When subject to strain, resistance R changes

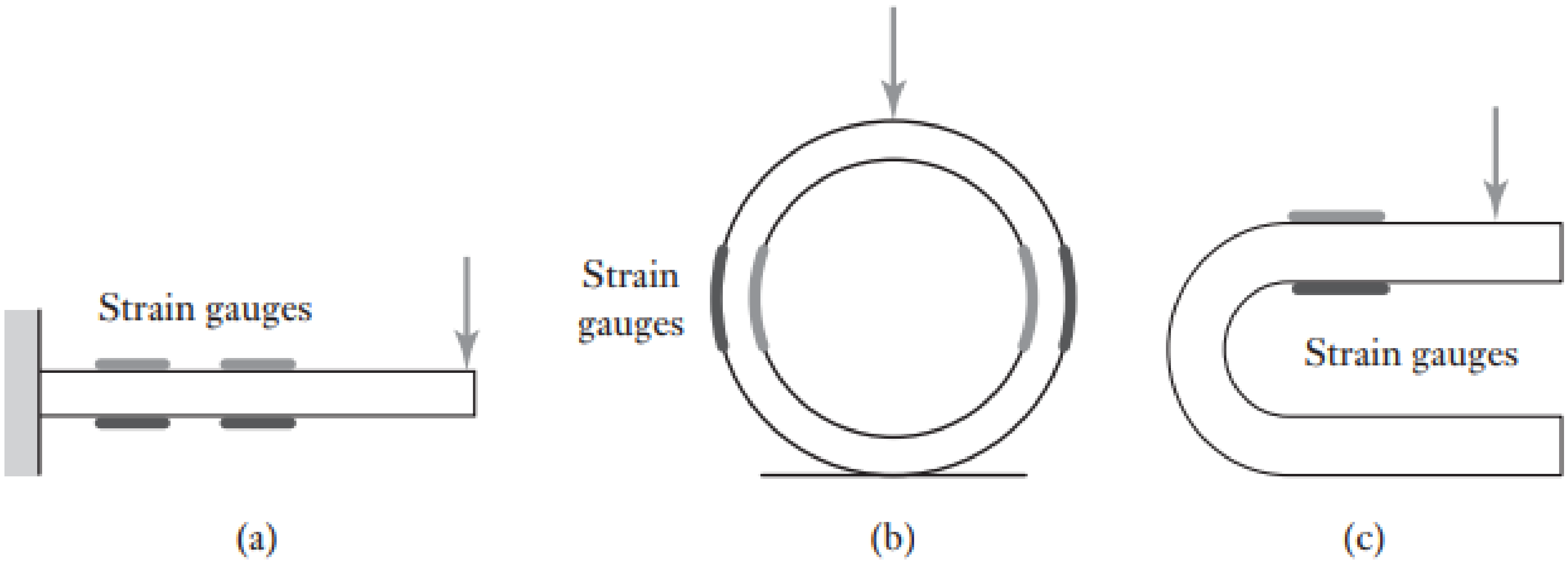
$\Delta R/R = G\varepsilon$

G- Constant of proportionality = Gauge Factor

ε – Strain

It should be noted that changes in resistance to temperature needs to be taken into account.

Strain Gauges



Capacitive Sensor

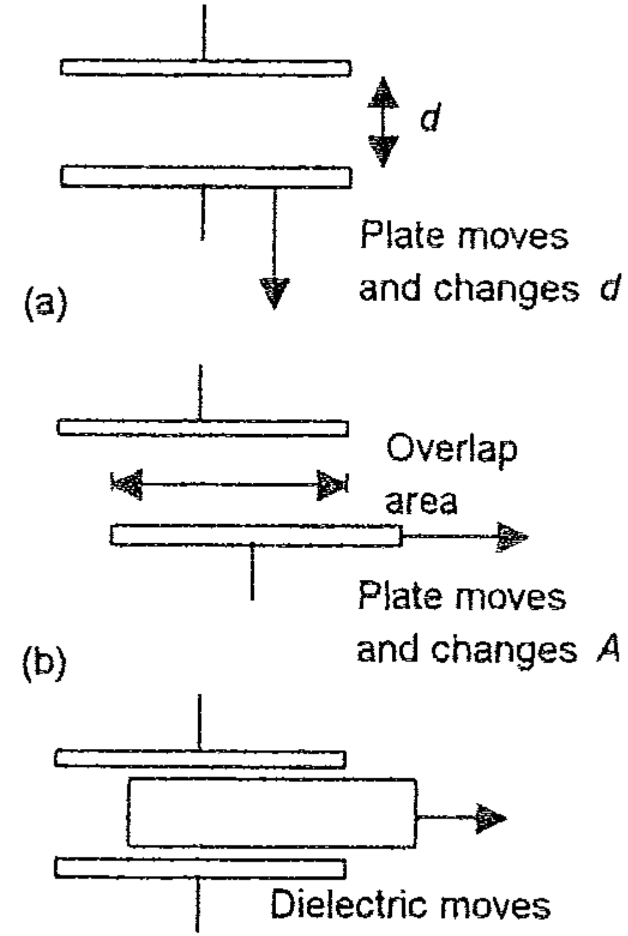
The capacitance C of a parallel plate capacitor is given by

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

where ε_r is the relative permittivity of the dielectric between the plates, ε_0 a constant called the permittivity of free space, A the area of overlap between the two plates and d the plate separation. Capacitive sensors for the monitoring

Modification of capacitance is possible by,

- Changing the distance between the two parallel electrodes.
- Changing the dielectric constant, permittivity, of dielectric medium .
- Changing the area of the electrodes, *A.*



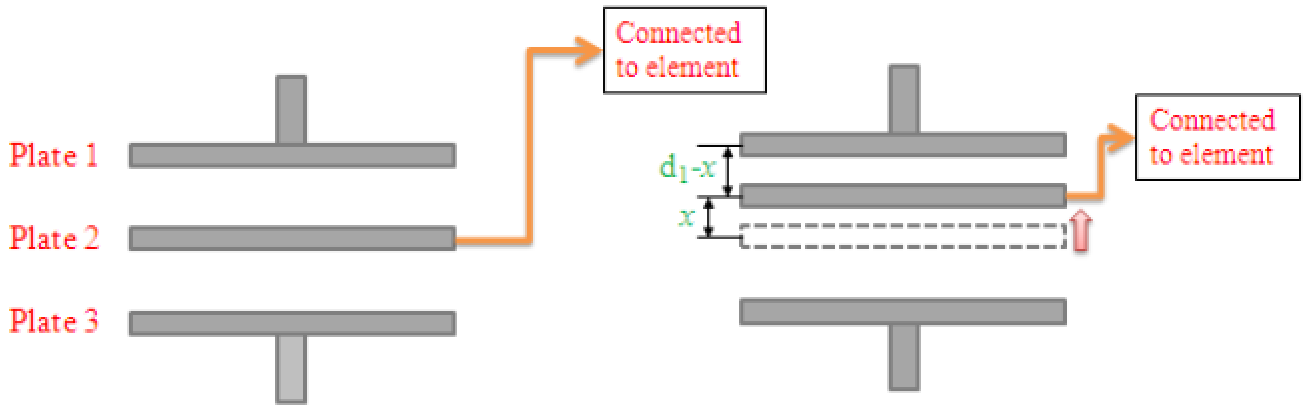
Capacitive Sensor

$$C - \Delta C = \frac{\varepsilon_0 \varepsilon_r A}{d + x}$$

$$\frac{\Delta C}{C} = -\frac{d}{d + x} - 1 = -\frac{x/d}{1 + (x/d)}$$

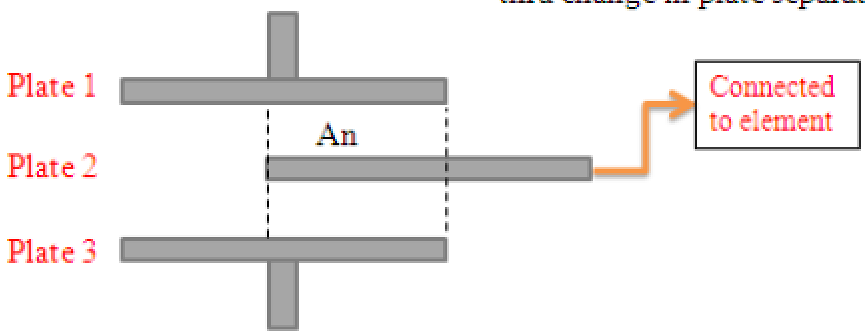
Change in capacitance is with respect to distance is non linear

Capacitive Sensor



(a) Three-plates capacitive element sensor

(b) Displacement measurement thru change in plate separation



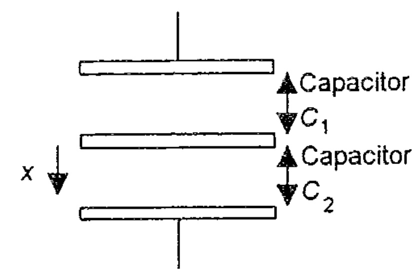


Fig. 2.9 Push-pull sensor

Sensors

Capacitive Proximity Sensor (Dielectric materials – Constants >1.2)

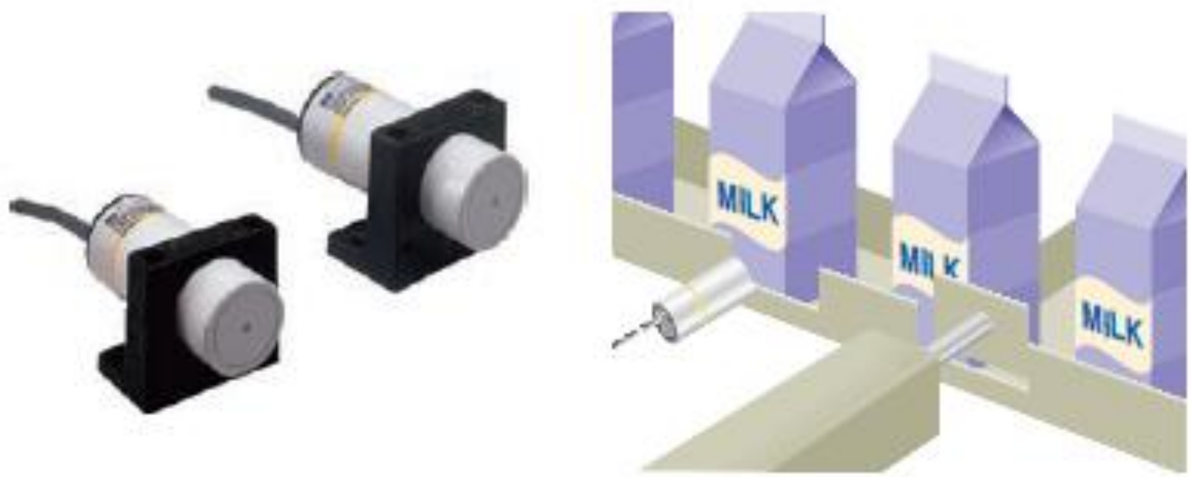
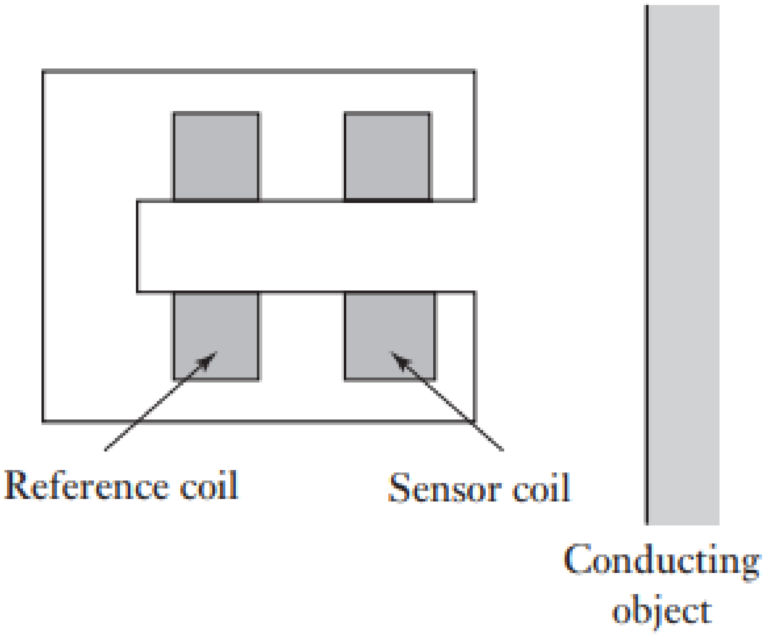


Figure 6-24 Capacitive proximity sensor liquid detection.
Source: Photo courtesy Omron Industrial Automation, **www.ia.omron.com**.

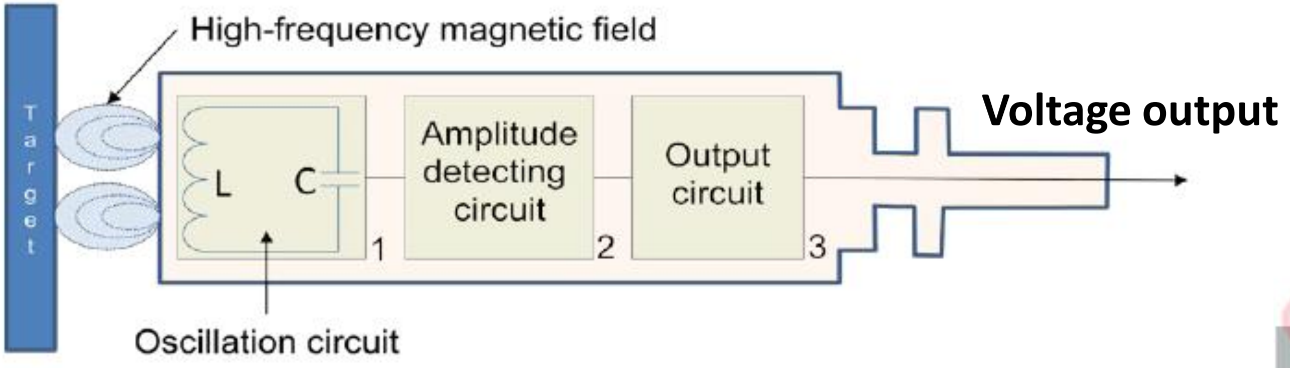
Eddy current Sensors

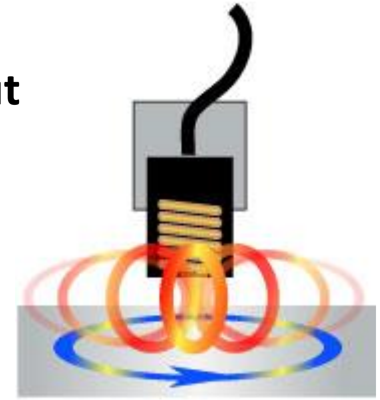


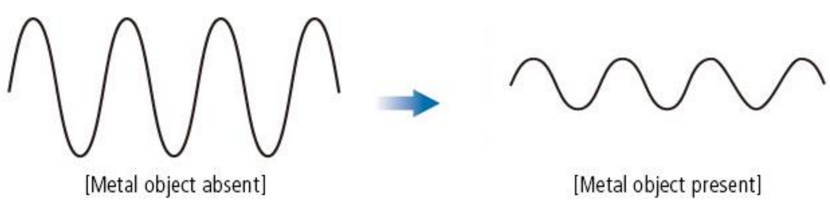
$$e = M\frac{di}{dt}$$

M is the inductance

Eddy current Sensors





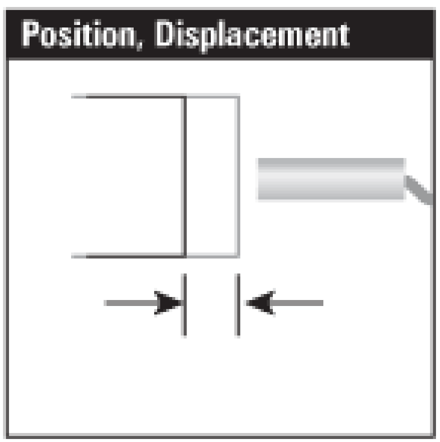


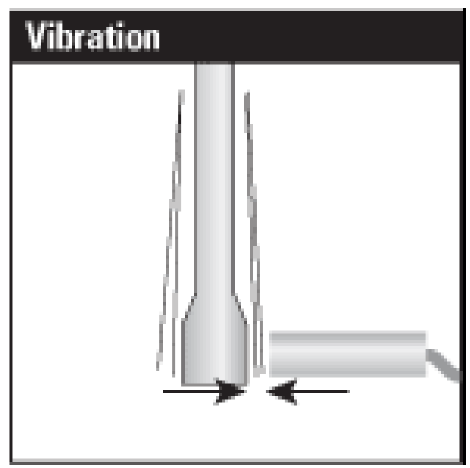
For very high accuracy
- Uses Air core coil

When an alternating current is passed thru this coil, an alternative magnetic field is generated. If a metal object comes in the close proximity of 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.

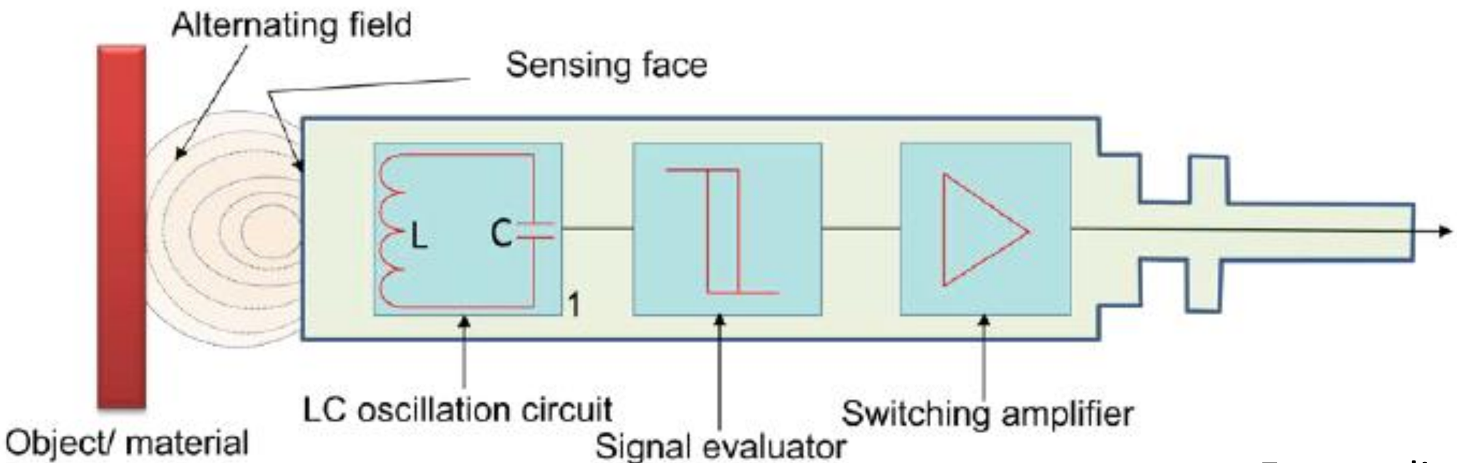
Eddy current Sensors

- Tolerance to dirty environments
- Less expensive than capacitive sensors





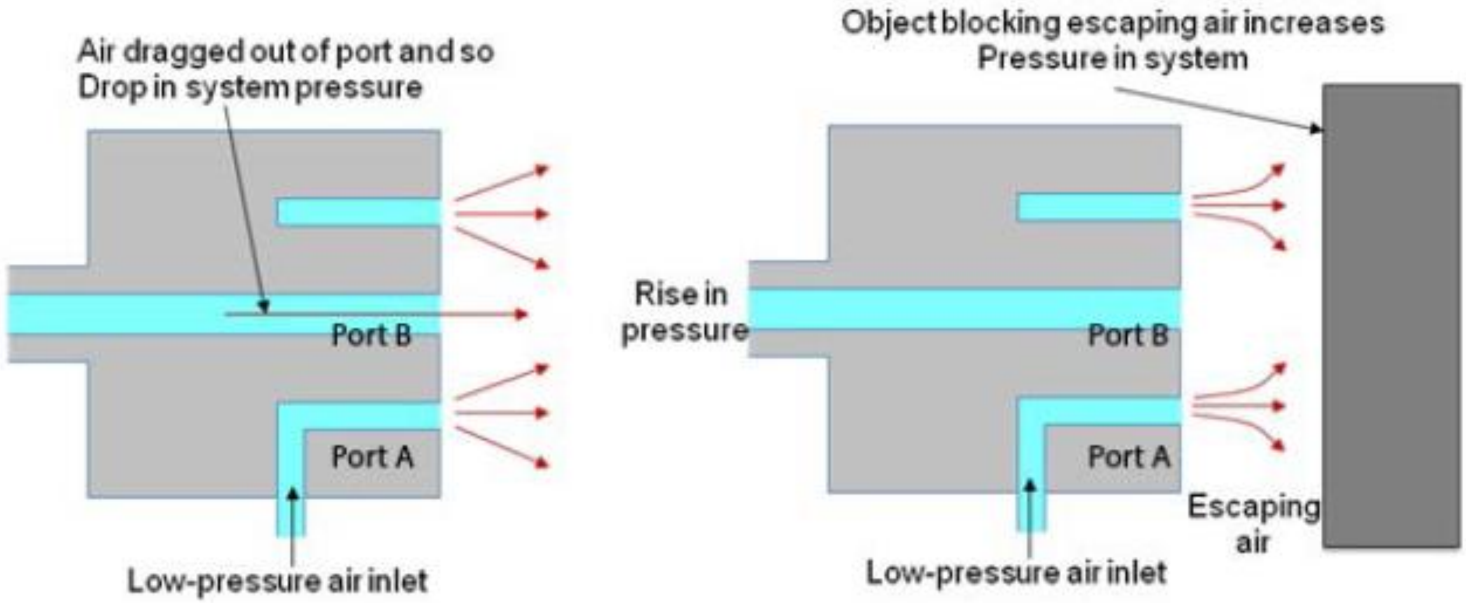
Inductive Proximity Sensors



For medium accuracy
- Uses Ferromagnetic coil

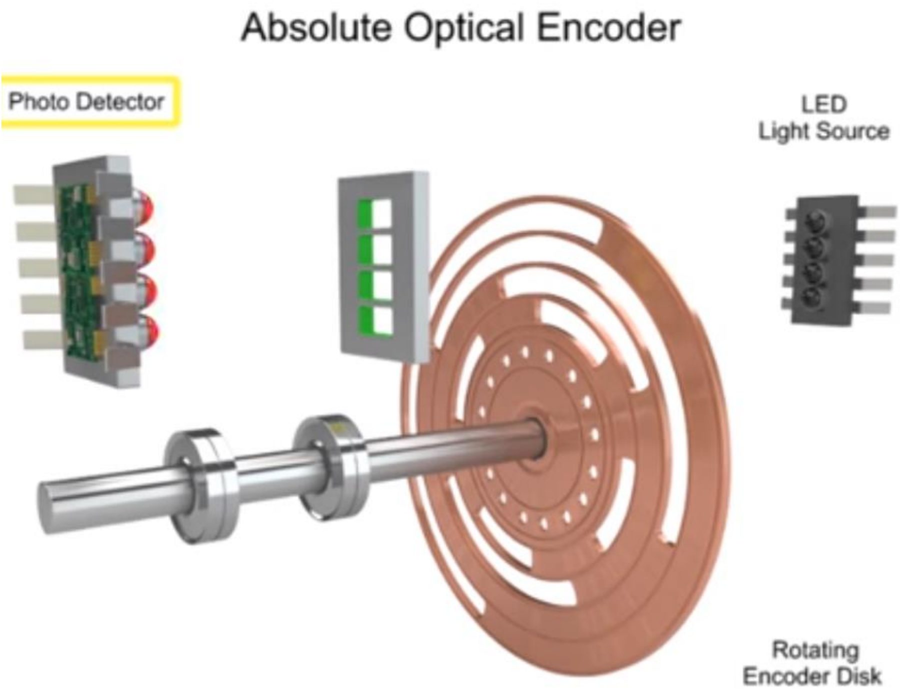
An alternating current is supplied to the coil which generates a magnetic field. When, **a metal** object comes closer to the end of the coil, inductance of the coil changes. This is continuously monitored by a circuit which triggers a switch when a preset value of inductance change is occurred.

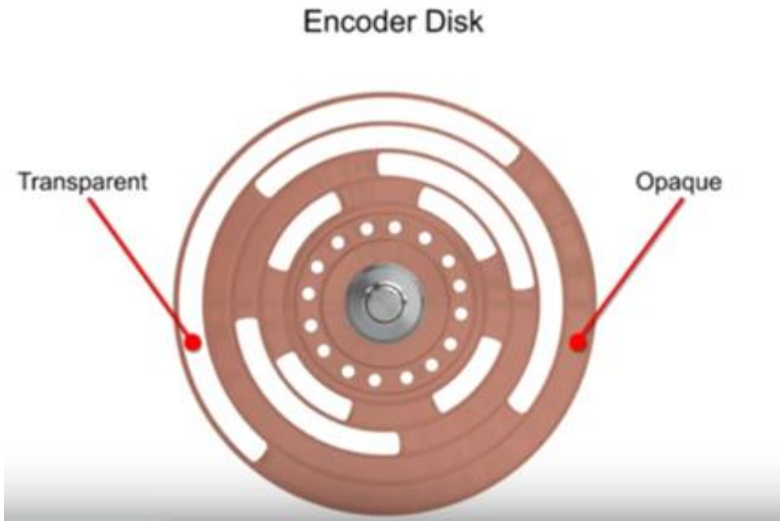
Pneumatic Proximity Sensors



Low pressure air is allowed to escape through port A. In the absence of any obstacle / object, this low pressure air escapes and in doing so, reduces the pressure in the port B. However when an object obstructs the low pressure air (Port A), there is rise in pressure in output port B. This rise in pressure is calibrated to measure the displacement or to trigger a switch.

Absolute Optical Encoders





Absolute Optical Encoders

Number of tracks = Number of LEDs

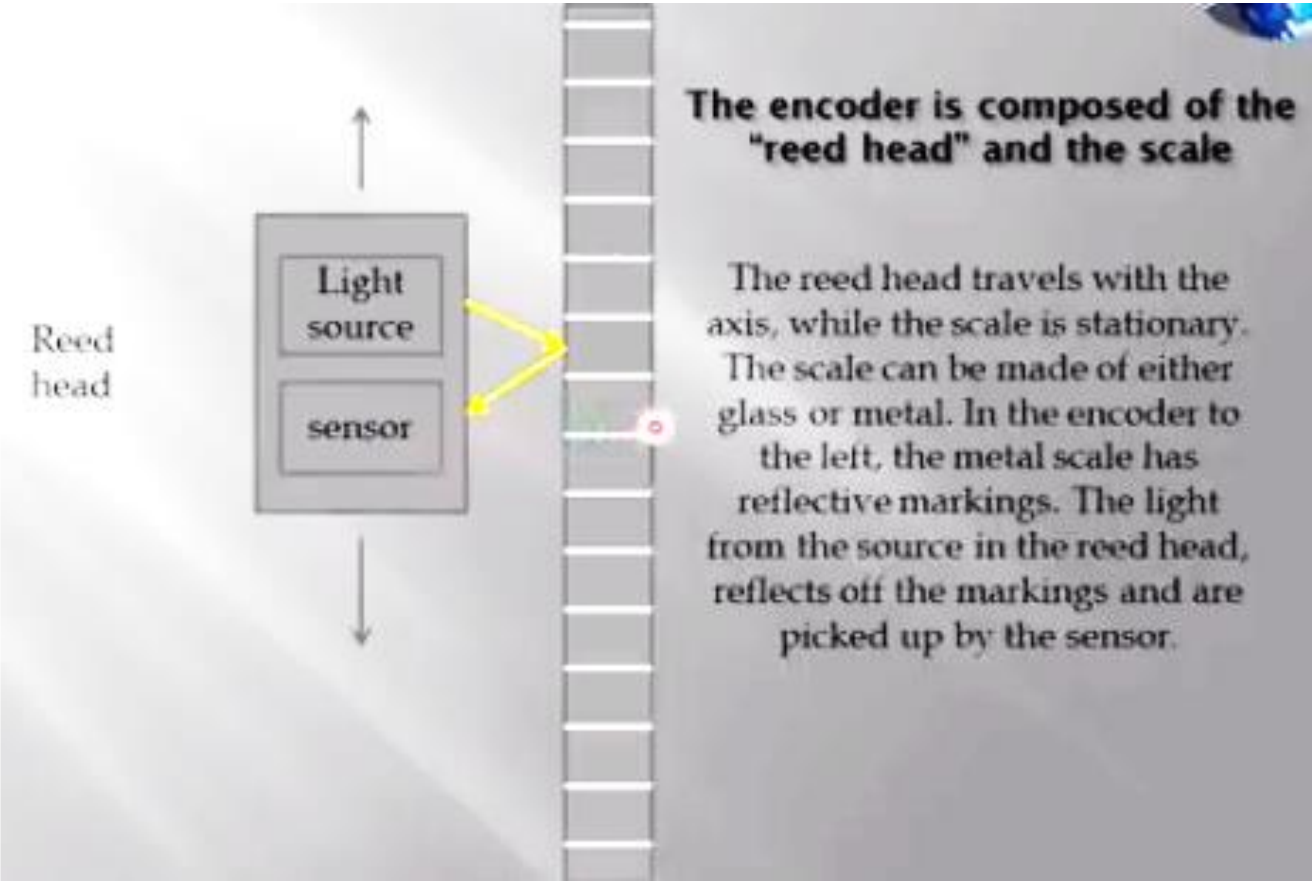
4 tracks means 2^4 = 16 bits

360° / 16 = 22.5°

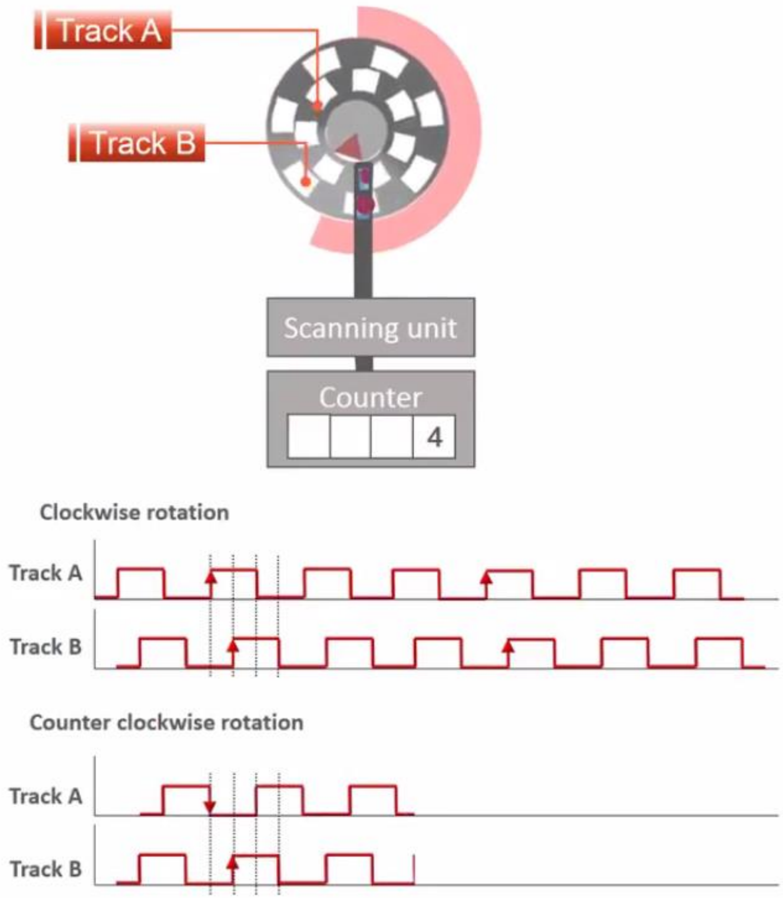
Resolution is 22.5°

	Normal binary	Gray code
0	0000	0000
1	0001	0001
2	0010	0011
3	0011	0010
4	0100	0110
5	0101	0111
6	0110	0101
7	0111	0100
8	1000	1100
9	1001	1101
10	1010	1111

Linear Encoder



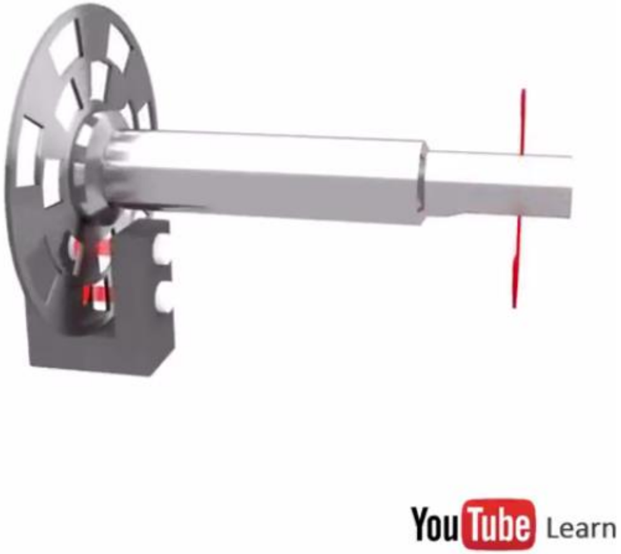
Incremental Optical Encoders



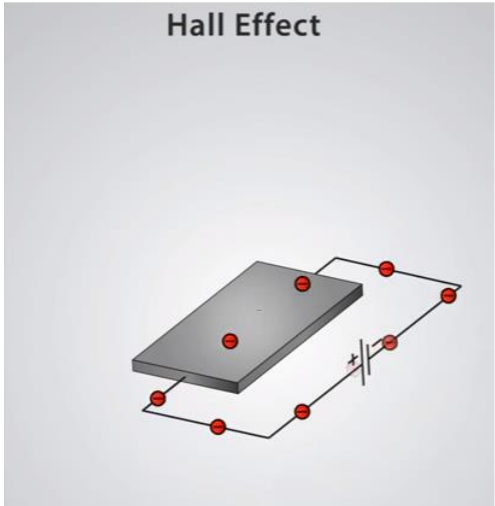
Measurement signals are added up from a reference point

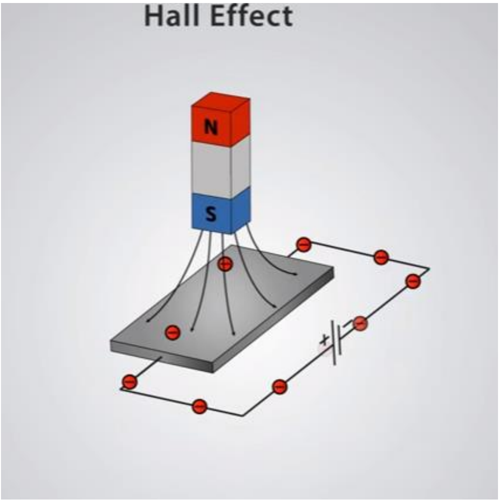
Advantage: simple structure, cheap

Disadvantage: reference drive necessary after power failure



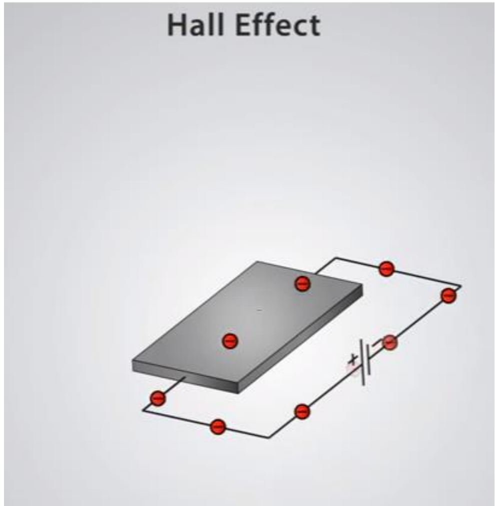
Hall effect

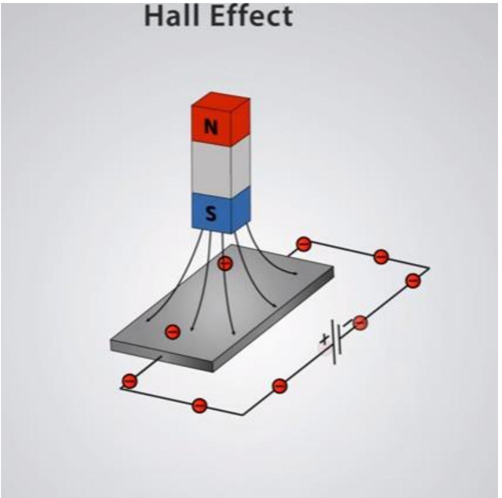


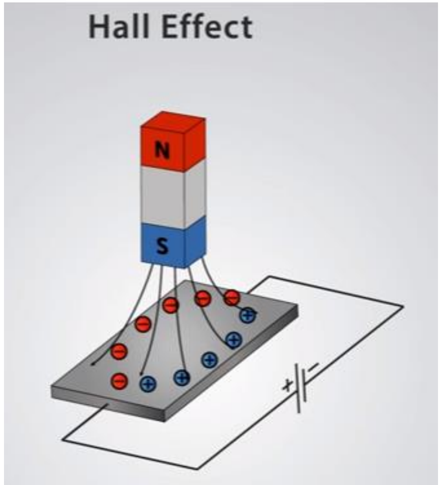


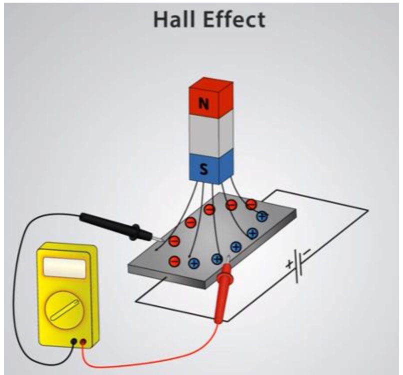
The production of a potential difference across an electrical conductor when a magnetic field is applied in a direction perpendicular to that of the flow of current.

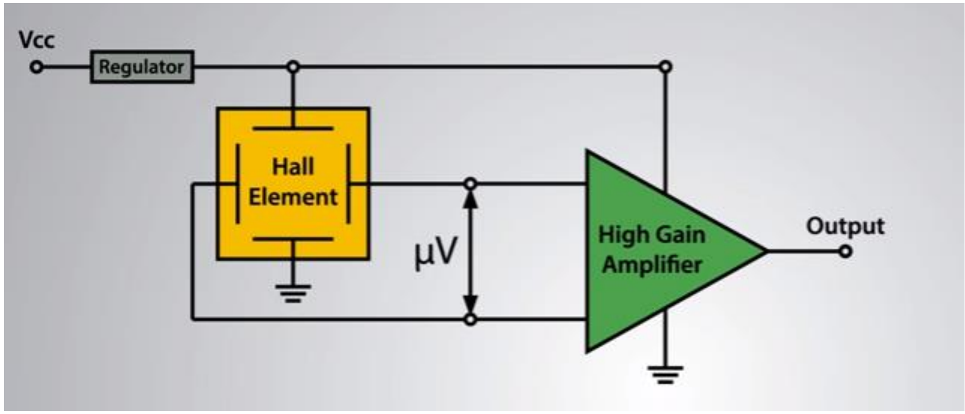
Hall effect sensors











Factors for selecting sensor

- The nature of the measurement required,
  - e.g. the variable to be measured, its nominal value,
  - the range of values,
  - the accuracy required,
  - the required speed of measurement,
  - the reliability required,
  - the environmental conditions under which the measurement is to be made.
- The nature of the output required from the sensor,
- Then possible sensors can be identified, taking into account such factors as their range, accuracy, linearity, speed of response, reliability, maintainability, life, power supply requirements, ruggedness, availability, cost.

Numerical

- What will be the change in resistance of an electrical resistance strain gauge with a gauge factor of 2.1 and resistance 50 V if it is subject to a strain of 0.001?
- Suggest a sensor that could be used, as part of a control system, to determine the difference in levels between liquids in two containers. The output is to provide an electrical signal for the control system.
- Suggest a sensor that could be used as part of a system to control the thickness of rolled sheet by monitoring its thickness as it emerges from rollers. The sheet metal is in continuous motion and the measurement needs to be made quickly to enable corrective action to be taken quickly. The measurement system has to supply an electrical signal.

Session 3… Next week

Type	Content Ref.	Topic Title	Study/HW Resource Reference
Pre CH			
During CH	T1, T2	Sensing physical quantities: Force, strain, velocity and motion Sensing physical quantities: Temperature measurement with Thermocouples, Thermistors, RTDs, AD590, LM35	T1: Chapter 2, T2: Chapter 9
Post CH			Chapter end problems

Thank you