Mechatronic Systems and Applications
Unit 1

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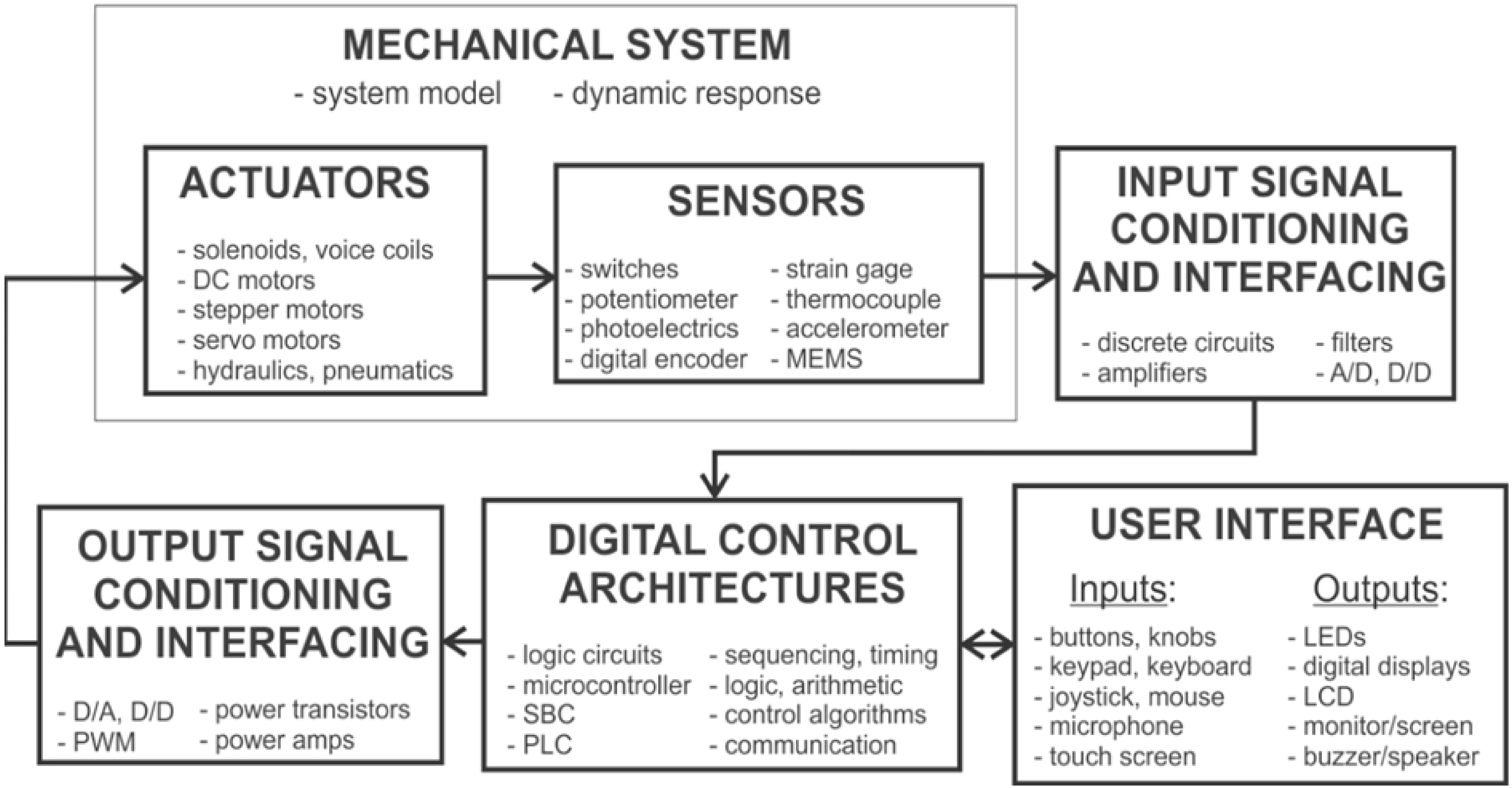
Mechatronics

- Mechatronics is an interdisciplinary field of engineering that combines mechanical engineering, electrical engineering, telecommunications engineering, control engineering and computer engineering to create intelligent systems that can interact with their environment in order to achieve a desired result.
- It is a combination of mechanical, electrical, and computer engineering that is used to design and develop automated systems and products. It is used in a wide range of industries including automotive, aerospace, medical, consumer electronics and robotics.

- Mechatronics is a field that integrates multiple disciplines of engineering to create intelligent and automated systems that can perform complex tasks. The integration of mechanical, electrical, and computer engineering enables the creation of systems that are more efficient, reliable, and versatile than those developed using a single discipline.
- Mechatronics is used in a variety of industries where automation and intelligent systems are required, such as in manufacturing, transportation, healthcare, and entertainment. Mechatronics engineers apply their knowledge and skills to design, develop, test, and maintain complex systems that can sense, analyze, and respond to their environment.


MECHANICAL SYSTEM
- system model
- dynamic response
ACTUATORS
- solenoids, voice coils
- DC motors
- stepper motors
- servo motors
- hydraulics, pneumatics
SENSORS
- switches
- potentiometer
- photoelectrics
- digital encoder
- strain gage
- thermocouple
- accelerometer
- MEMS
INPUT SIGNAL CONDITIONING AND INTERFACING
- discrete circuits
- amplifiers
- filters
- A/D, D/D
OUTPUT SIGNAL CONDITIONING AND INTERFACING
- D/A, D/D
- PWM
- power transistors
- power amps
DIGITAL CONTROL ARCHITECTURES
- logic circuits
- microcontroller
- SBC
- PLC
- sequencing, timing
- logic, arithmetic
- control algorithms
- communication
USER INTERFACE
Inputs:
- buttons, knobs
- keypad, keyboard
- joystick, mouse
- microphone
- touch screen
Outputs:
- LEDs
- digital displays
- LCD
- monitor/screen
- buzzer/speaker

Elements of mechatronics system

1. **Sensors:** Sensors are used to measure physical quantities such as temperature, pressure, force, position, velocity, and acceleration.
2. **Actuators:** Actuators convert electrical or mechanical energy into motion and are used to move parts of the mechatronic system.
3. **Control systems:** Control systems are used to process the inputs from the sensors, determine the desired output and control the actuators to achieve the desired output.
4. **Electronics:** Electronic components such as microprocessors, amplifiers, and other electronic components are used to implement the control algorithms.
5. **Mechanical components:** Mechanical components such as motors, gears, and linkages are used to transfer energy from one component to another.
6. **Software:** Software is used to design, implement, and debug the control algorithms for the mechatronic system.

Mechatronics in manufacturing systems

Mechatronics is an integration of mechanical engineering, electronics and computer science to create smart devices, products and systems.

This technology has been used extensively in the manufacturing sector to allow for more efficient, automated and cost-effective production processes.

Mechatronics can be used to automate the production of components, optimize assembly lines, and reduce human error in the manufacturing process. It can also be used to increase efficiency and accuracy in the production of parts and products, and to reduce downtime.

Additionally, it can be used to monitor the performance of machines, provide predictive maintenance and even enable self-diagnosis.

Mechatronics in product and design

Mechatronics is a multidisciplinary field that combines mechanical, electrical, and computer engineering in the design and manufacture of products and systems.

It is used to create products that are controlled by a combination of electrical and mechanical systems, with the objective of making them smarter, faster, and more efficient.

In product design, mechatronics is used to create products that are easier to use and navigate, while reducing the complexity of the user interface. It can also be used to create products that are more reliable and durable, with fewer maintenance requirements.

In design, mechatronics is used to create products that are more visually appealing, with better ergonomics and aesthetics, as well as products that are easier to manufacture.

Mechatronics in measurement systems

- Mechatronics is the integration of mechanical, electrical, and software engineering in the design of complex systems. It is used in a variety of industries such as aerospace, automotive, medical, and energy.
- In the field of measurement systems, mechatronics is used to create specialized tools and sensors that are able to accurately measure a variety of parameters. Examples include pressure, temperature, flow, and acceleration. These tools and sensors are used in a variety of applications such as industrial automation, medical diagnostics, and materials testing.
- Mechatronics provides the capability to integrate multiple sensing and control systems into a single device for more precise measurements. Additionally, mechatronics can be used to develop more efficient and reliable systems that are able to perform complex tasks with greater accuracy.

Use of Mechatronics in Control system

- It is applied in the design and operation of control systems for machines, robotics, and other automated processes.
- Mechatronics is used to control the movement of mechanical elements, such as motors, actuators, and sensors, and to analyze the data they collect. Control systems can be used to regulate the speed, position, and torque of a motor, or to adjust the temperature, pressure, or composition of a process.
- Mechatronics systems can also be used to automate the operation of a machine, such as an automated assembly line or a robotic arm. Mechatronics is also used in the design and implementation of medical devices, such as prosthetic limbs and artificial organs.

SENSORS AND TRANSDUCERS

Measurement is an important subsystem of a mechatronics system. Its main function is to collect the information on system status and to feed it to the micro-processors for controlling the whole system.

Measurement system comprises of sensors, transducers and signal processing devices.

Sensors in manufacturing are basically employed to automatically carry out the

production operations as well as process monitoring activities.

Sensor technology has the following important advantages in transforming a conventional manufacturing unit into a modern one.

1. Sensors alarm the system operators about the failure of any of the sub units of manufacturing system. It helps operators to reduce the downtime of complete manufacturing system by carrying out the preventative measures.
2. Reduces requirement of skilled and experienced labours.
3. Ultra-precision in product quality can be achieved.

Sensor

- It is defined as an element which produces signal relating to the quantity being measured.
- According to the Instrument Society of America, sensor can be defined as "A device which provides a usable output in response to a specified measurand."
- Here, the output is usually an "electrical quantity" and measurand is a "physical quantity", property or condition which is to be measured. Thus in the case of, say, a variable inductance displacement element, the quantity being measured is displacement and the sensor transforms an input of displacement into a change in inductance.

Transducer

- It is defined as an element when subjected to some physical change experiences a related change or an element which converts a specified measured into a usable output by using a transduction principle.
- It can also be defined as a device that converts a signal from one form of energy to another form.
- A wire of Constantan alloy (copper-nickel 55-45% alloy) can be called as a sensor because variation in mechanical displacement (tension or compression) can be sensed as change in electric resistance. This wire becomes a transducer with appropriate electrodes and input-output mechanism attached to it. Thus we can say that “sensors are transducers”.

No.	Differential Matters	Sensor	Transducer
01.	Definition	A sensor is a device which detects one form of energy and converts the data to electrical energy	A transducer is a device which converts one form of energy into another. So sensors are, in fact, a type of transducer
02.	Function	A sensor is a device which detects a physical quantity and produces an electric signal based on the strength of the quantity measured.	A transducer is a device which converts one form of energy into anther form.
03.	Sensing Element	Sensing element itself	Sensing element plus any associated circuitry
04.	Feedback	A sensor merely measures a quantity and cannot, by itself, give feedback to the system.	A transducers can convert between any forms of energy, they can be used to provide feedback to the system.

PERFORMANCE TERMINOLOGY

- Transducers or measurement systems are not perfect systems. Mechatronics design engineer must know the capability and shortcoming of a transducer or measurement system to properly assess its performance.
- There are a number of performance related parameters of a transducer or measurement system. The parameters are called as sensor specifications.
- Sensor specifications inform the user to the about deviations from the ideal behaviour of the sensors.

Following are the various specifications of a sensor/transducer system.

1. Range

The range of a sensor indicates the limits between which the input can vary. For example, a thermocouple for the measurement of temperature might have a range of 25- 225°C.

2. Span

The span is difference between the maximum and minimum values of the input. Thus, the above-mentioned thermocouple will have a span of 200 °C.

3. Error

Error is the difference between the result of the measurement and the true value of the quantity being measured. A sensor might give a displacement reading of 29.8 mm, when the actual displacement had been 30 mm, then the error is –0.2mm.

4. Accuracy

The accuracy defines the closeness of the agreement between the actual measurement result and a true value of the measurand. It is often expressed as a percentage of the full range output or full–scale deflection.

A piezoelectric transducer used to evaluate dynamic pressure phenomena associated with explosions, pulsations, or dynamic pressure conditions in motors, rocket engines, compressors, and other pressurized devices is capable to detect pressures between 0.1 and 10,000 psi (0.7 KPa to 70 MPa). If it is specified with the accuracy of about ±1% full scale, then the reading given can be expected to be within ±0.7 MPa.

5. Sensitivity

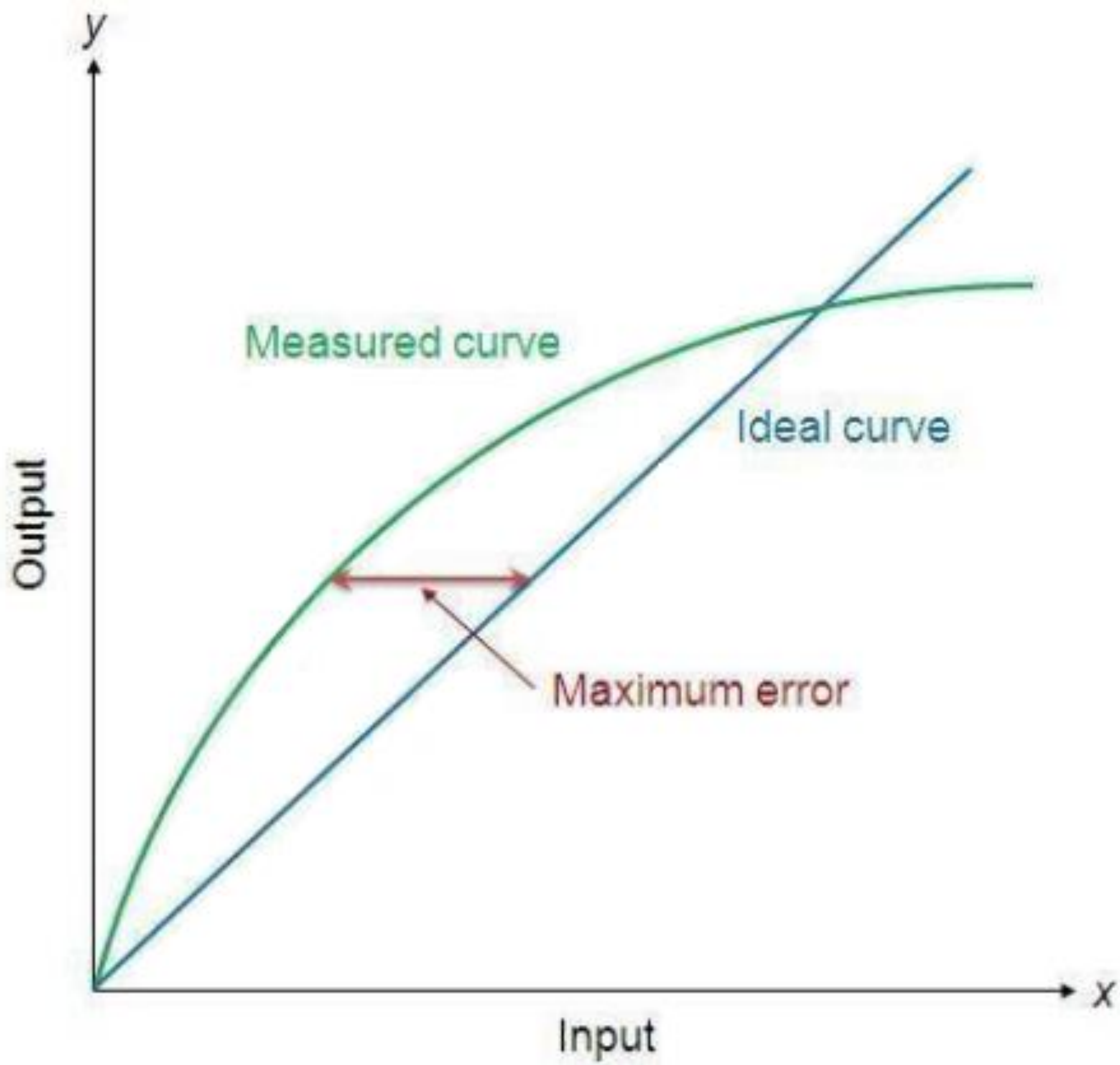
Sensitivity of a sensor is defined as the ratio of change in output value of a sensor to the per unit change in input value that causes the output change. For example, a general purpose thermocouple may have a sensitivity of 41µV/°C.

6. Nonlinearity

The nonlinearity indicates the maximum deviation of the actual measured curve of a sensor from the ideal curve. Figure shows a somewhat exaggerated relationship between the ideal, or least squares fit, line and the actual measured or calibration line. Linearity is often specified in terms of percentage of nonlinearity, which is defined as:

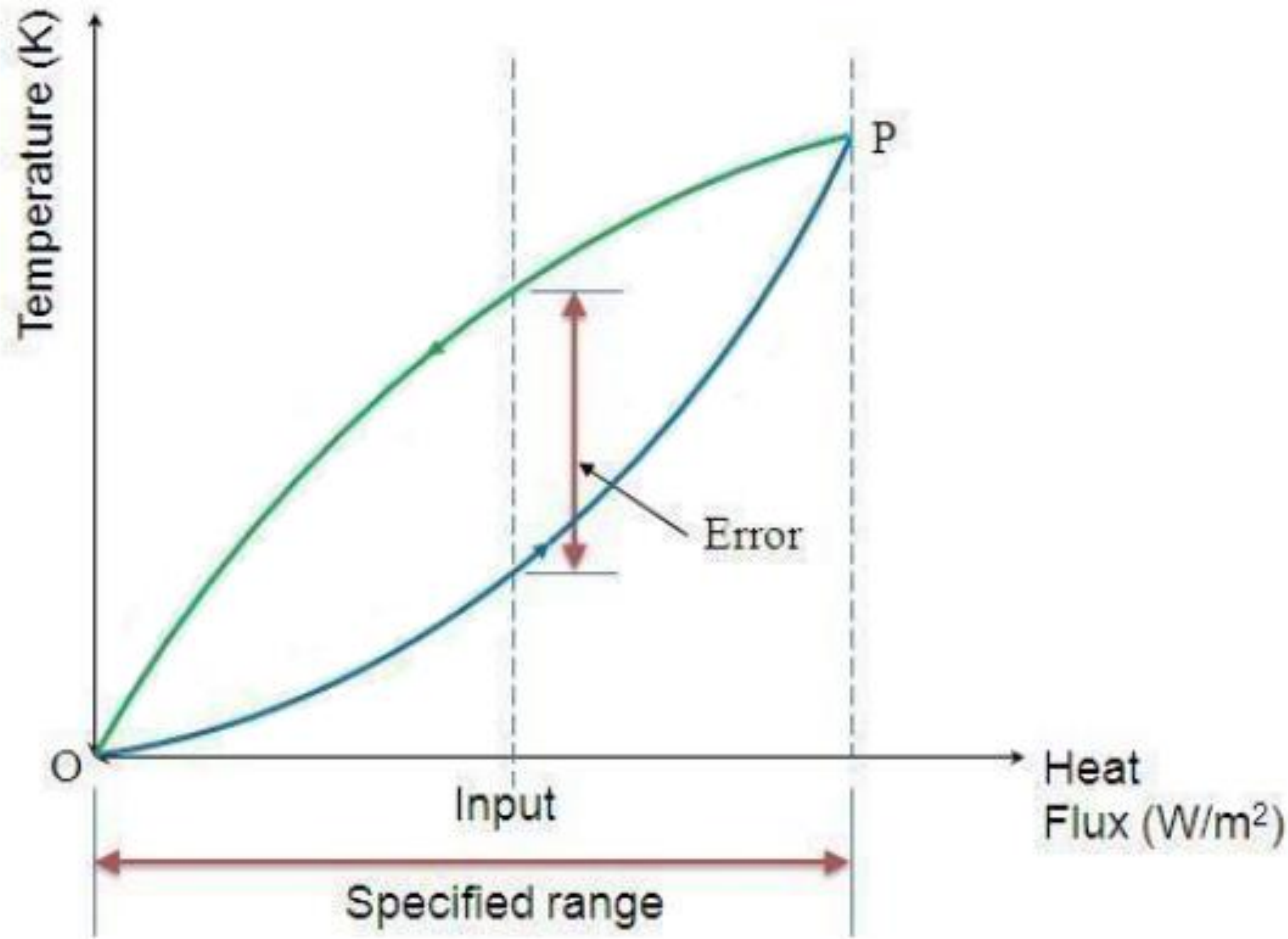
Nonlinearity (%) = Maximum deviation in input / Maximum full scale input

The static nonlinearity defined by Equation is dependent upon environmental factors, including temperature, vibration, acoustic noise level, and humidity. Therefore it is important to know under what conditions the specification is valid.


y
Measured curve
Ideal curve
Output
Maximum error
x
Input

7. Hysteresis

The hysteresis is an error of a sensor, which is defined as the maximum difference in output at any measurement value within the sensor's specified range when approaching the point first with increasing and then with decreasing the input parameter. Figure shows the hysteresis error might have occurred during measurement of temperature using a thermocouple. The hysteresis error value is normally specified as a positive or negative percentage of the specified input range.


Temperature (K)
P
Error
O
Input
Heat
Flux (W/m2)
Specified range

8. Resolution

Resolution is the smallest detectable incremental change of input parameter that can be detected in the output signal. Resolution can be expressed either as a proportion of the full scale reading or in absolute terms. For example, if a LVDT sensor measures a displacement up to 20 mm and it provides an output as a number between 1 and 100 then the resolution of the sensor device is 0.2mm.

9. Stability

Stability is the ability of a sensor device to give same output when used to measure a constant input over a period of time.The term “drift” is used to indicate the change in output that occurs over a period of time. It is expressed as the percentage of full range output.

10. Dead band time

The dead band or dead space of a transducer is the range of input values for which there is no output. The dead time of a sensor device is the time duration from the application of an input until the output begins to respond or change.

11. Repeatability

It specifies the ability of a sensor to give same output for repeated applications of same input value. It is usually expressed as a percentage of the full range output:

Repeatability = (maximum – minimum values given) X 100 ⁄ full range

12. Response time

Response time describes the speed of change in the output on a step-wise change of the measurand. It is always specified with an indication of input step and the output range for which the response time is defined.

Static and dynamic characteristics of transducers

Static Characteristics: -

- The sensitivity of a transducer, which is the ratio of output signal to the input signal.
- The accuracy of the transducer, which is the degree of agreement between the measured value of a physical quantity and its true value.
- The linearity of the transducer, which is a measure of how well the input signal is related to the output signal.
- The hysteresis of the transducer, which is the difference in output for a given input at different times.
- The frequency response of the transducer, which is a measure of how much the output signal of the transducer changes when the frequency of the input signal is varied.
- The temperature coefficient of the transducer, which is the change in output signal due to a change in temperature.

Dynamic Characteristics: -

- The response time of a transducer, which is the time required for the transducer to respond to a given input.
- The settling time of a transducer, which is the time required for the transducer to reach its steady-state output.
- The frequency response of the transducer, which is a measure of how much the output signal of the transducer changes when the frequency of the input signal is varied.
- The distortion of the transducer, which is a measure of the magnitude of the changes in the output signal from the ideal response.
- The noise of the transducer, which is a measure of the unwanted signal that is generated due to random processes within the transducer.

CLASSIFICATION OF SENSORS

- Sensors can be classified into various groups according to the factors such as measurand, application fields, conversion principle, energy domain of the measurand and thermodynamic considerations. These general classifications of sensors are well described.
- Detail classification of sensors in view of their applications in manufacturing is as follows.

A. 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

B. Velocity and motion

- Incremental encoder
- Tacho-generator
- Pyro-electric sensors

C. Force

- Strain gauge load cell

D. Fluidpressure

- Diaphragm pressure gauge
- Capsules, bellows, pressure tubes
- Piezoelectric sensors
- Tactile sensor

E. Liquidflow

- Orifice plate
- Turbine meter

F. Liquid level

- Floats
- Differential pressure

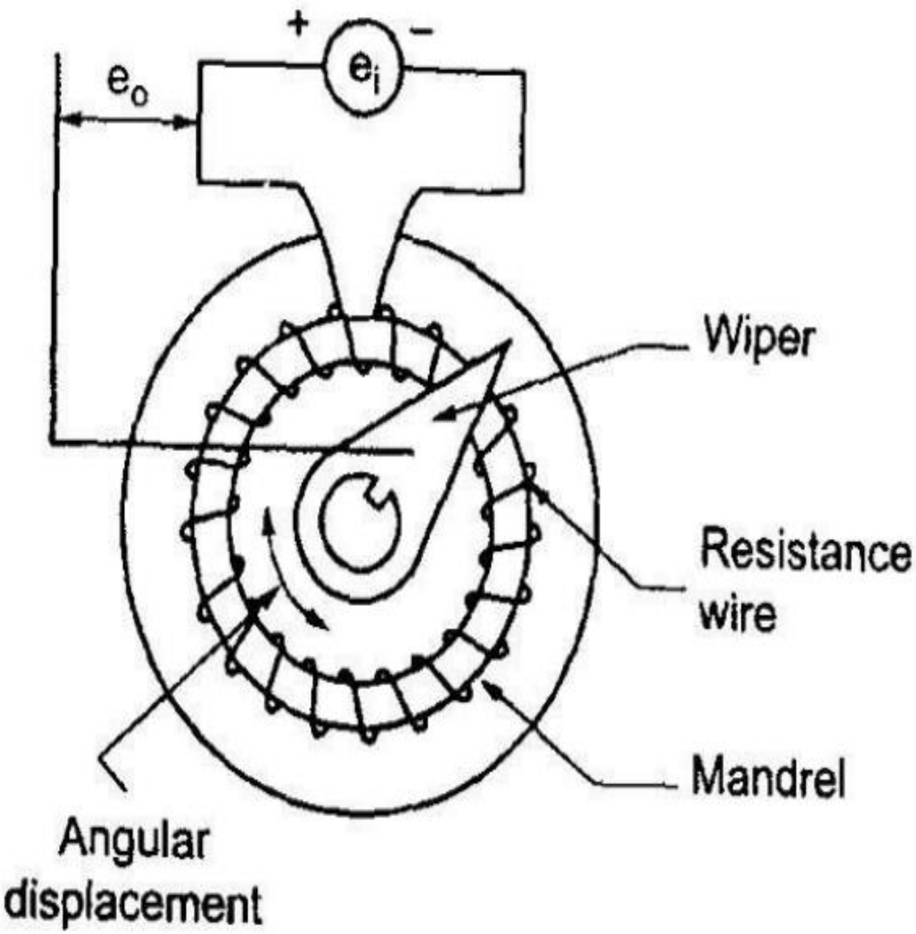
G. Temperature

- Bimetallic strips
- Resistance temperature detectors
- Thermistors
- Thermo-diodes and transistors
- Thermocouples
- Light sensors
- Photodiodes
- Photo resistors

DISPLACEMENT AND POSITION SENSORS

- Displacement sensors are basically used for the measurement of movement of an object.
- Position sensors are employed to determine the position of an object in relation to some reference point.
- Proximity sensors are a type of position sensor and are used to trace when an object has moved with in particular critical distance of a transducer.

Potentiometer Sensors



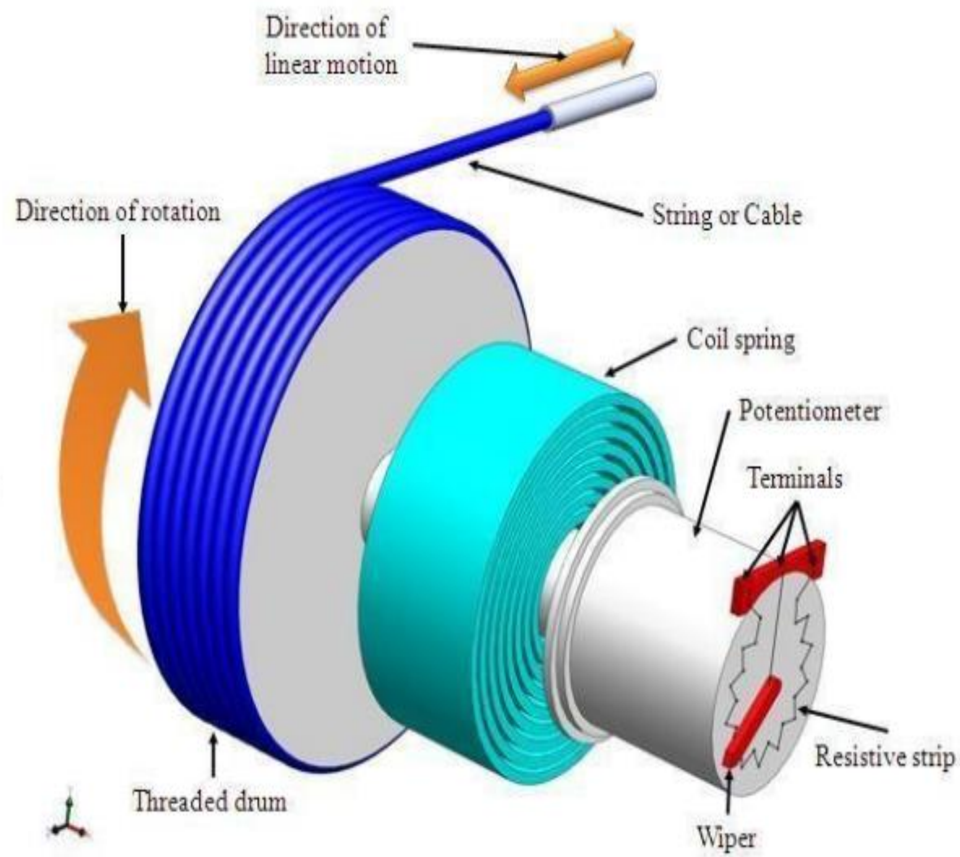


Figure : Schematic of a potentiometer sensor for measurement of linear displacement

The object of whose displacement is to be measured is connected to the slider by

using

- a rotating shaft (for angular displacement)
- a moving rod (for linear displacement)
- a cable that is kept stretched during operation

- The resistive element is a wire wound track or conductive plastic. The track comprises of large number of closely packed turns of a resistive wire.
- Conductive plastic is made up of plastic resin embedded with the carbon powder. Wire wound track has a resolution of the order of ± 0.01 % while the conductive plastic may have the resolution of about 0.1μm.
- During the sensing operation, a voltage Vs is applied across the resistive element. A voltage divider circuit is formed when slider comes into contact with the wire.
- The output voltage (VA) is measured as shown in the figure. The output voltage is proportional to the displacement of the slider over the wire. Then the output parameter displacement is calibrated against the output voltage (VA).

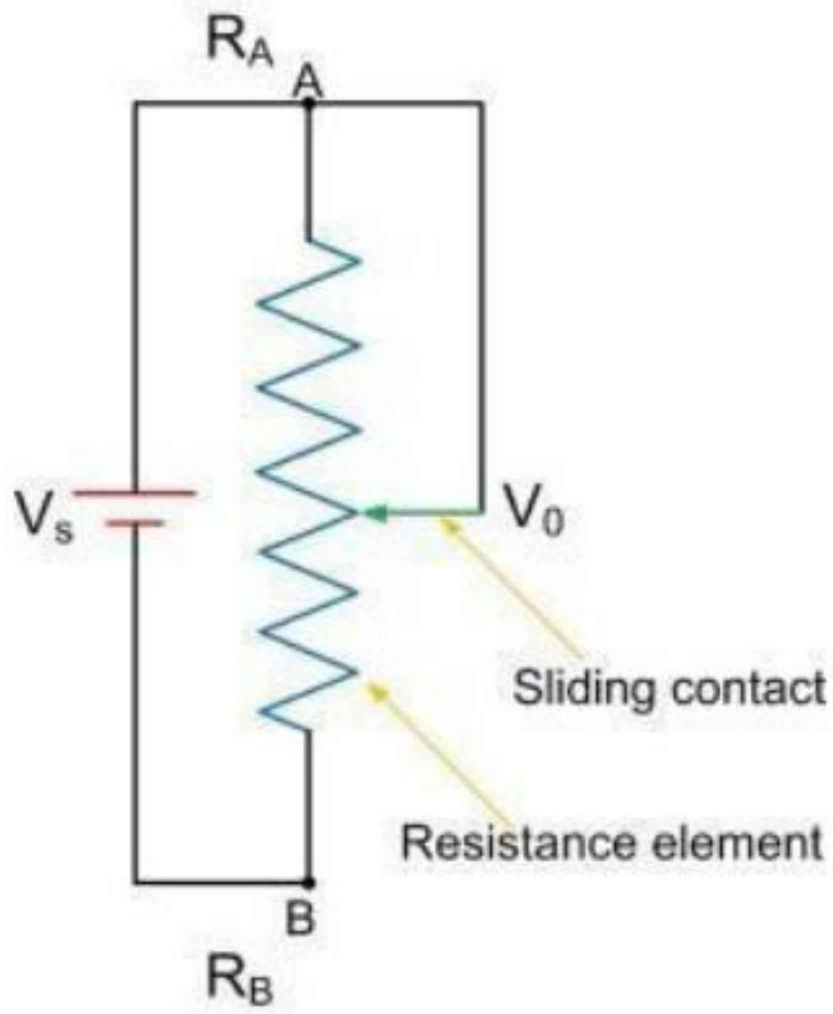


Figure : Potentiometer,Electric circuit

$V_A = I\, R_A$

But $I = V_S / (R_A + R_B)$

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

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

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 molding machines, wood working machinery,printing,spraying,robotics, etc.

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. The strain changes the resistance R of the element.
- Therefore, we can say,
- $\Delta R/R \propto \varepsilon$;
- $\Delta R/R = G\,\varepsilon$
- where G is the constant of proportionality and is called as gauge factor. In general, the value of G is considered in between 2 to 4 and the resistances are taken of the order of 100 Ω.

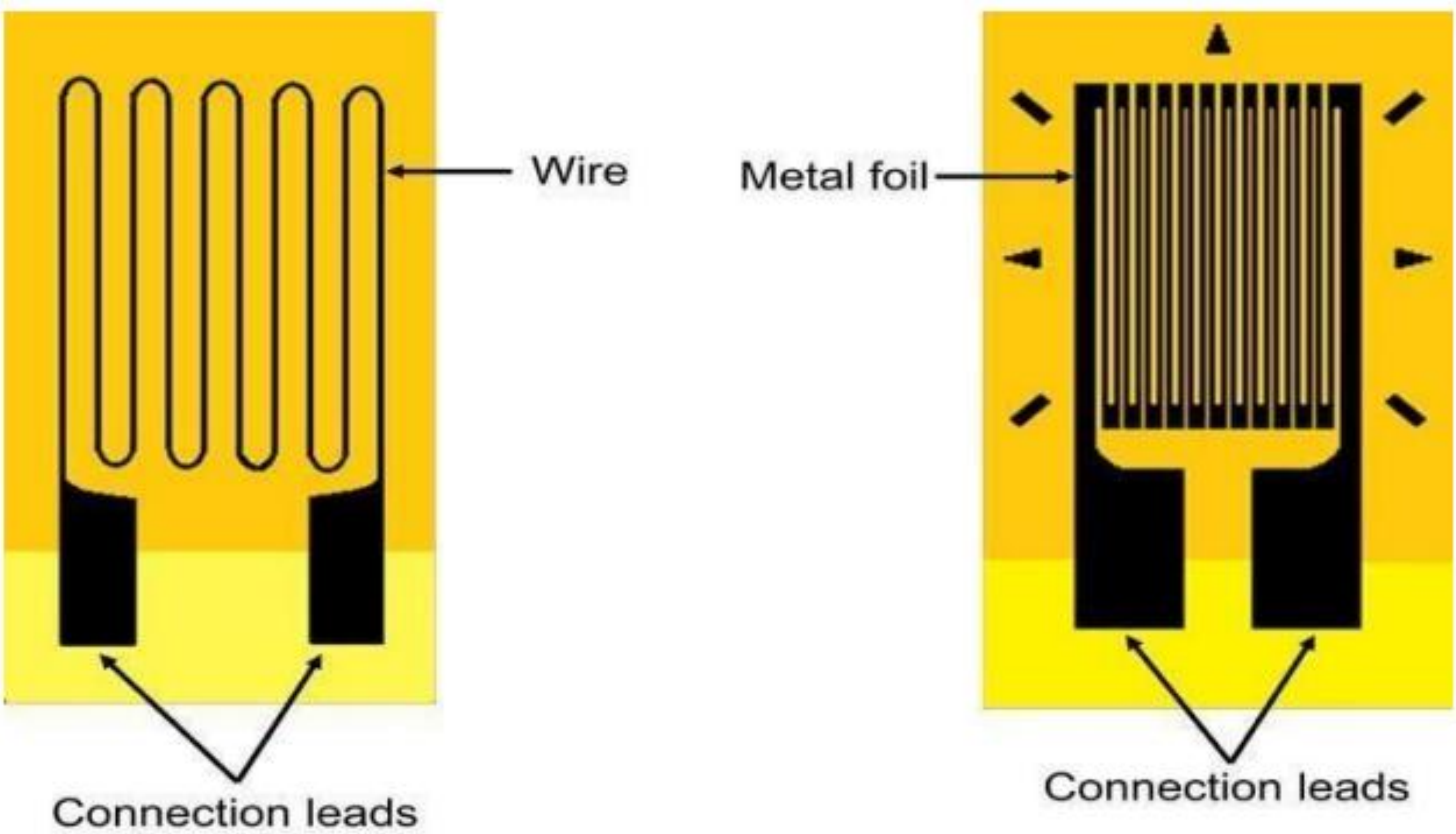


Figure : A pattern of resistive foils

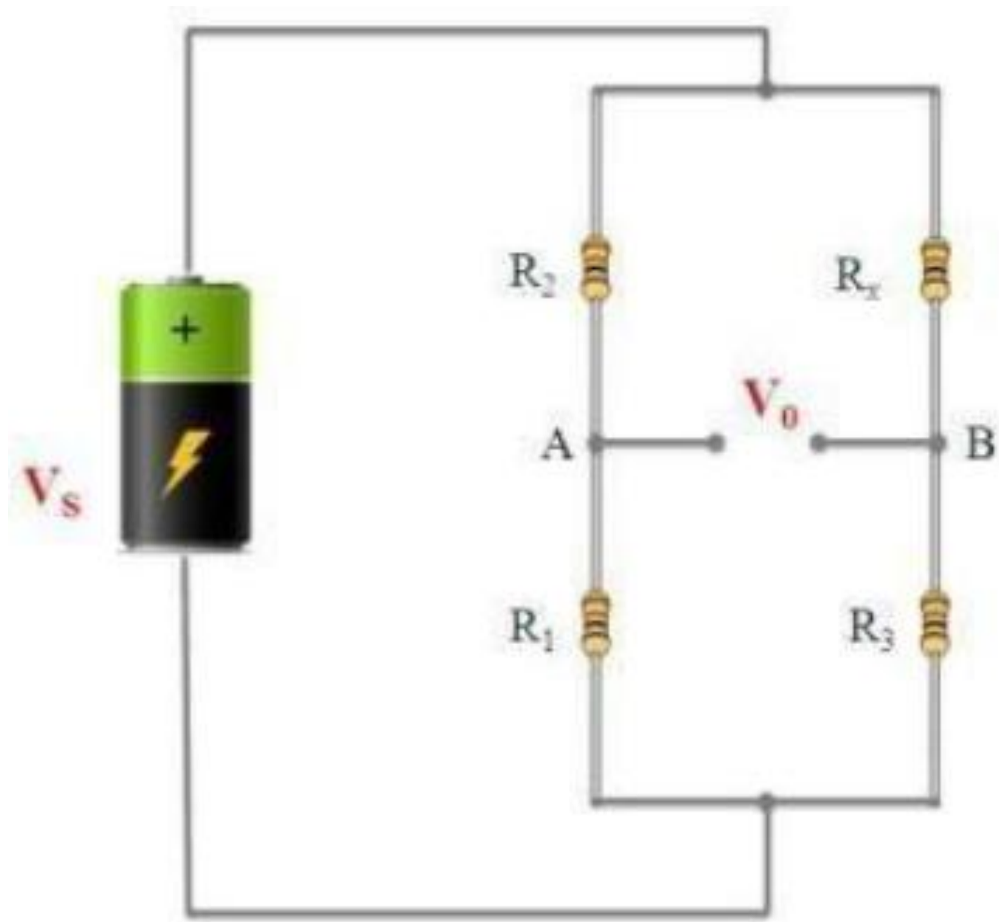


Figure: Wheatstone's bridge

- Resistance strain gauge follows the principle of change in resistance as per the equation. It comprises of a pattern of resistive foil arranged as shown in Figure.
- These foils are made of Constant an alloy(copper-nickel55-45%alloy)and are bonded to a backing material plastic (polyimide), epoxy or glass fiber reinforced epoxy. The strain gauges are secured to the workpiece by using epoxy.
- As the workpiece undergoes change in its shape due to external loading, the resistance of strain gauge element changes. This change in resistance can be detected by a using a Wheatstones resistance bridge as shown in Figure. In the balanced bridge we can have a relation,
- $R2/ R1 = Rx / R3$

- Where Rx is resistance of strain gauge element, R2 is balancing/adjustable resistor, R1 and R3 are known constant value resistors.
- The measured deformation or displacement by the stain gauge is calibrated against change in resistance of adjustable resistor R2 which makes the voltage across nodes A and B equal to zero.

Applications of strain gauges

Strain gauges are widely used in experimental stress analysis and diagnosis on machines and failure analysis.

They are basically used for multi-axial stress fatigue testing, proof testing, residual stress and vibration measurement, torque measurement, bending and deflection measurement, compression and tension measurement and strain measurement.

Strain gauges are primarily used as sensors for machine tools and safety in automotives.

In particular, they are employed for force measurement in machine tools, hydraulic or pneumatic press and as impact sensors in aerospace vehicles.

Capacitive element based sensor

- Capacitive sensor is of non-contact type sensor and is primarily used to measure the linear displacements from few millimeters to hundreds of millimeters.
- It comprises of three plates, with the upper pair forming one capacitor and the lower pair another. The linear displacement might take in two forms:

a. One of the plates is moved by the displacement so that the plate separation changes.

b. Area of overlap changes due to the displacement.

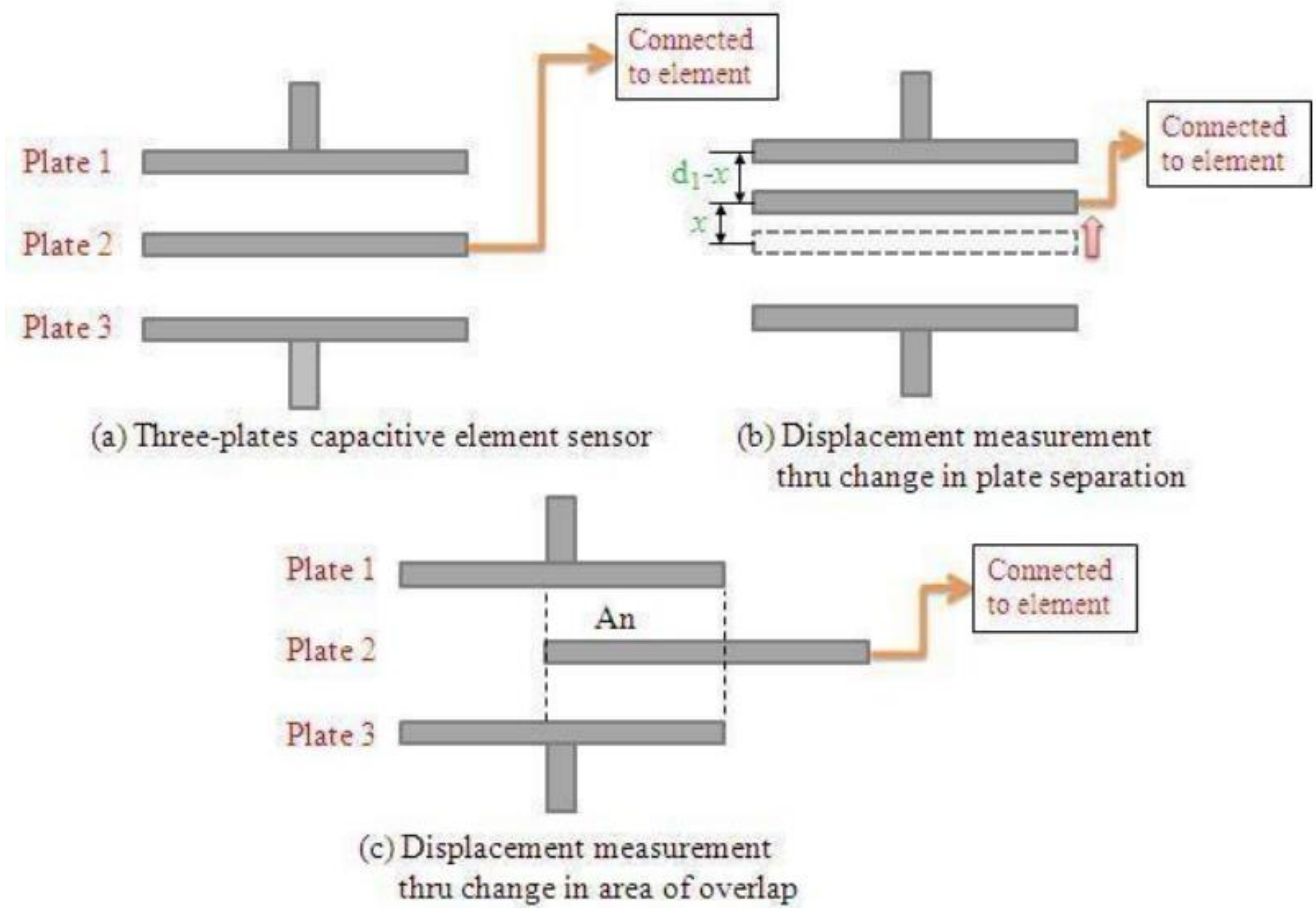


Figure: Shows the schematic of three-plate capacitive element sensor and displacement measurement of a mechanical element connected to the plate 2.

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

$C = \varepsilon r \varepsilon o\ A / d$

Where εr is the relative permittivity of the dielectric between the plates, εo permittivity of free space, A area of overlap between two plates and d the plate separation.

As the central plate moves near to top plate or bottom one due to the movement of the element/workpiece of which displacement is to be measured, separation in between the plate

changes. This can be given as,

$C1 = (\varepsilon r \varepsilon o\ A) / (d + x)$

$C2 = (\varepsilon r \varepsilon o\ A) / (d - x)$

When C1 and C2 are connected to a Wheatsone’s bridge, then the resulting out-of balance voltage would be in proportional to displacement x. Capacitive elements can also be used as proximity sensor. The approach of the object towards the sensor plate is used for induction of change in plate separation. This changes the capacitance which is used to detect the object.

Applications of capacitive element sensors

- Feed hopper level monitoring
- Small vessel pump control
- Grease level monitoring
- Level control of liquids
- Metrology applications
- to measure shape errors in the part being produced
- to analyze and optimize the rotation of spindles in various machine tools such as surface grinders, lathes, milling machines, and air bearing spindles by measuring errors in the machine tools themselves
- Assembly line testing:
- to test assembled parts for uniformity, thickness or other design features
- to detect the presence or absence of a certain component, such as glue etc.

Linear variable differential transformer(LVDT)

- Linear variable differential transformer (LVDT) is a primary transducer used for measurement of linear displacement with an input range of about ±2 to ±400mm in general. It has nonlinearity error ± 0.25% of full range. Figure shows the construction of a LVDT sensor.
- It has three coils symmetrically spaced along an insulated tube. The central coil is primary coil and the other two are secondary coils.
- Secondary coils are connected in series in such a way that their outputs oppose each other. A magnetic core attached to the element of which displacement is to be monitored is placed inside the insulated tube.

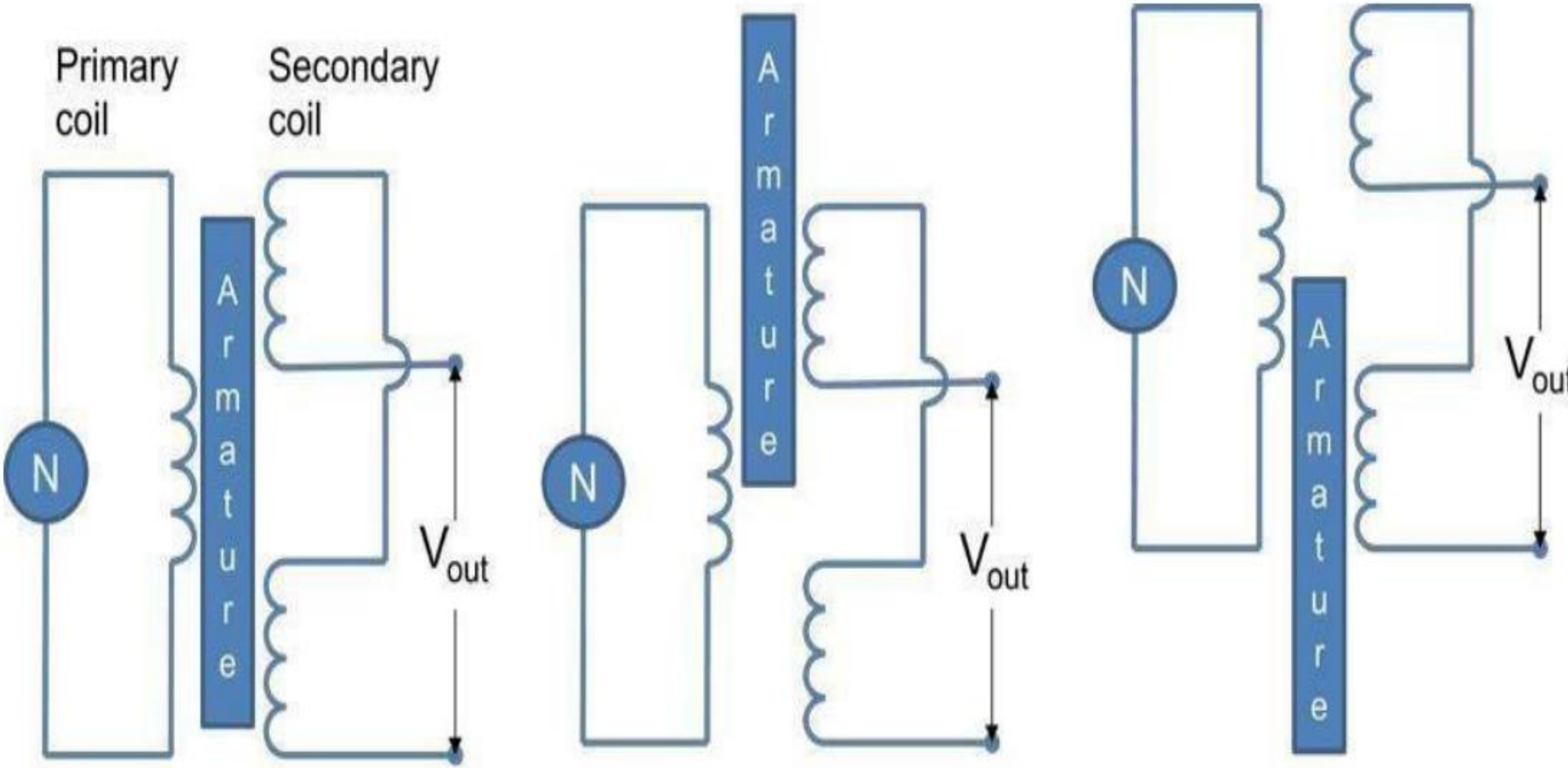


Figure: Working of LVDT sensor

- Due to an alternating voltage input to the primary coil, alternating electro-magnetic forces (emfs) are generated in secondary coils.
- When the magnetic core is centrally placed with its half portion in each of the secondary coil regions then the resultant voltage is zero.
- If the core is displaced from the central position as shown in Figure, say, more in secondary coil 1 than in coil 2, then more emf is generated in one coil i.e. coil 1 than the other, and there is a resultant voltage from the coils. If the magnetic core is further displaced, then the value of resultant voltage increases in proportion with the displacement.
- With the help of signal processing devices such as low pass filters and demodulators, precise displacement can be measured by using LVDT sensors.

- LVDT exhibits good repeatability and reproducibility.
- It is generally used as an absolute position sensor.
- Since there is no contact or sliding between the constituent elements of the sensor, it is highly reliable.
- These sensors are completely sealed and are widely used in Servomechanisms, automated measurement in machine tools.
- A rotary variable differential transformer (RVDT) can be used for the measurement of rotation.

Applications of LVDT sensors

- Measurement of spool position in a wide range of servo valve applications.
- To provide displacement feedback for hydraulic cylinders.
- To control weight and thickness of medicinal products viz. tablets or pills.
- For automatic inspection of final dimensions of products being packed for dispatch.
- To measure distance between the approaching metals during Friction welding process.
- To continuously monitor fluid level as part of leak detection system.
- To detect the number of currency bills dispensed by an ATM.

Eddy current proximity sensors

- Eddy current proximity sensors are used to detect non-magnetic but conductive materials. They comprise of a coil, an oscillator, a detector and a triggering circuit.
- Figure shows the construction of eddy current proximity switch.
- 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.
- 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.

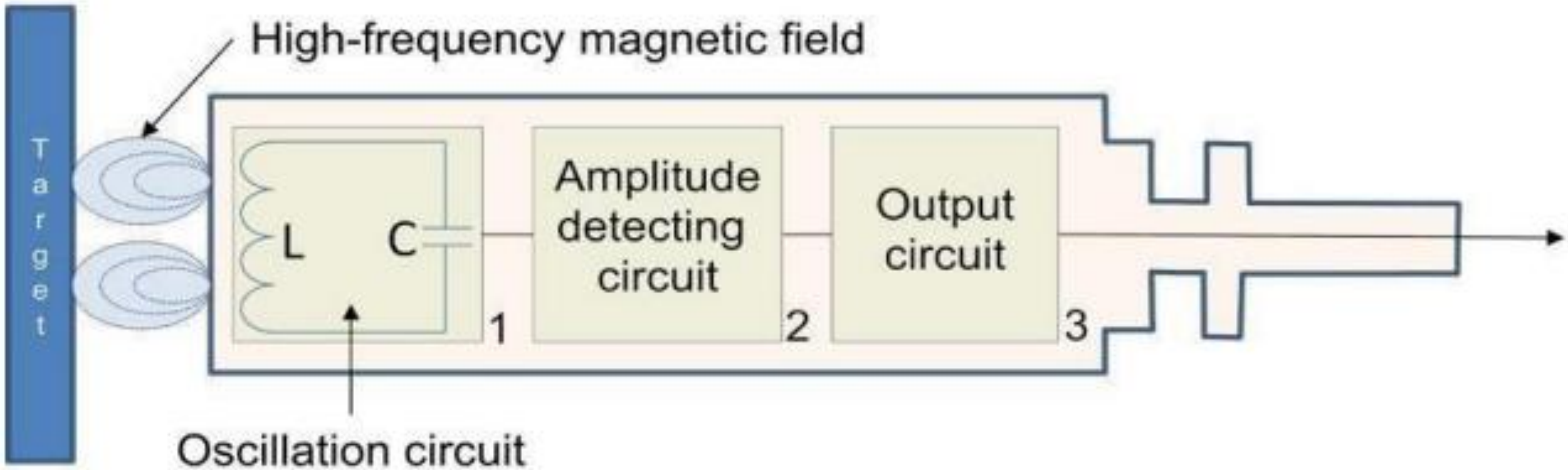


Figure: Eddy current proximity sensors

Applications of eddy current proximity sensors

- Automation requiring precise location.
- Machine tool monitoring.
- Final assembly of precision equipment such as disk drives.
- Measuring the dynamics of a continuously moving target, such as a vibrating element.
- Drive shaft monitoring.
- Vibration measurements.

Inductive proximity switch

- Inductive proximity switches are basically used for detection of metallic objects.
- Figure shows the construction of inductive proximity switch.
- 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.
- This is continuously monitored by a circuit which triggers a switch when a preset value of inductance change is occurred.

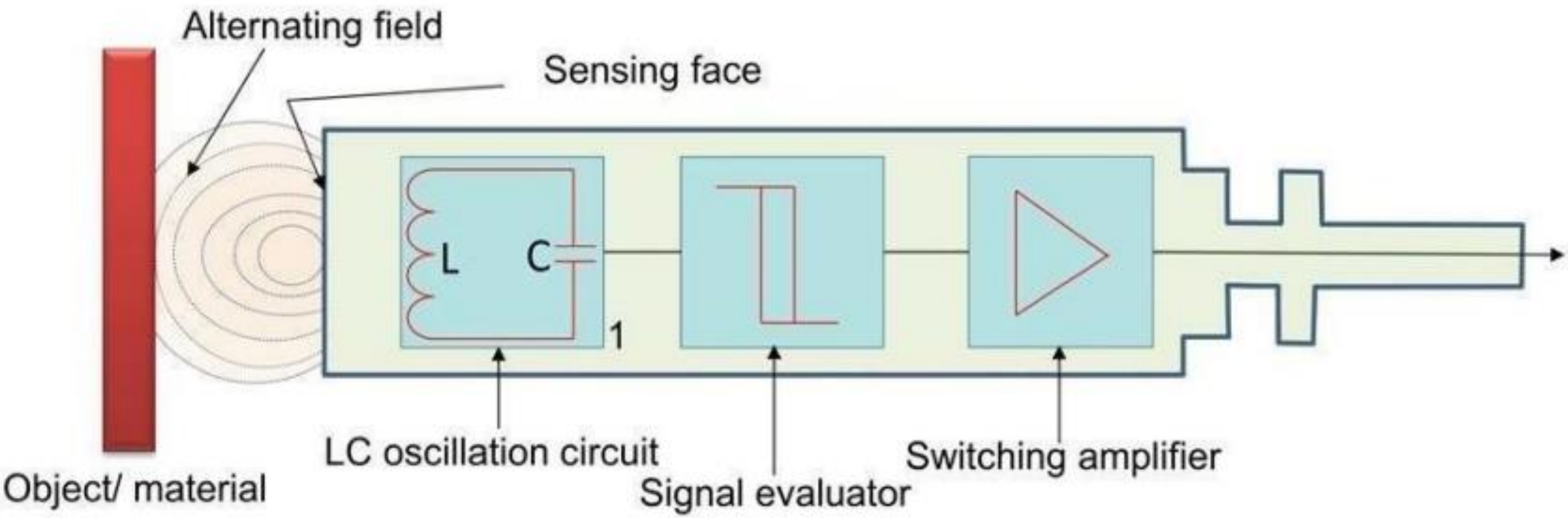


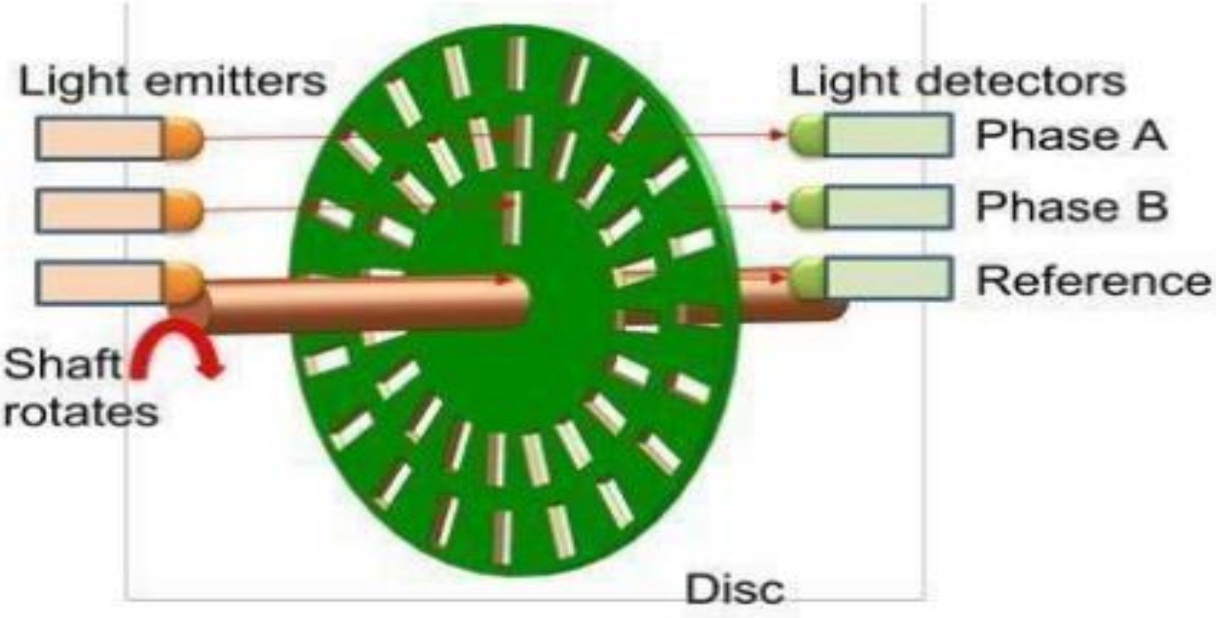
Figure: Schematic of Inductive Proximity Switch

Applications of inductive proximity switches

- Industrial automation: counting of products during production or transfer.
- Security: detection of metal objects, arms, landmines.

Optical encoders

- Optical encoders provide digital output as a result of linear / angular displacement.
- These are widely used in the Servomotors to measure the rotation of shafts.
- Figure shows the construction of an optical encoder. It comprises of a disc with three concentric tracks of equally spaced holes.
- 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 e.g. shaft on which the Optical encoder is mounted.
- The inner track has just one hole which is used locate the home position of the disc.



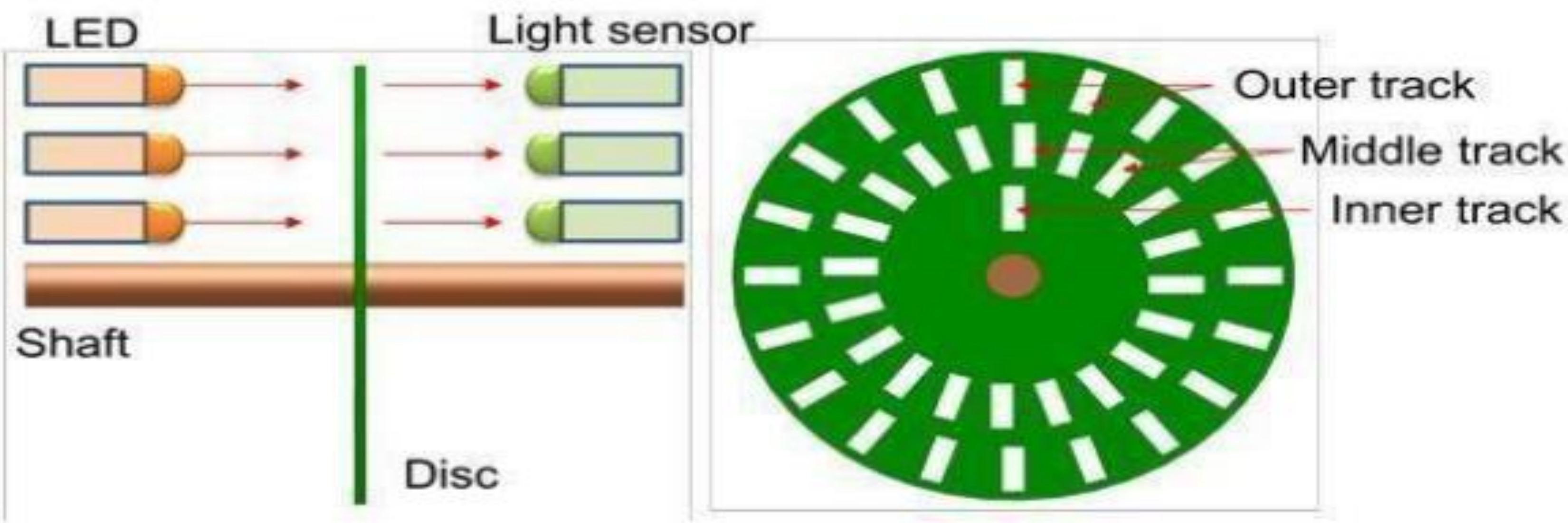


Figure: Optical encoders

- 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 outer track lead those in the inner; in counter clockwise direction they lag behind. The resolution can be determined by the number of holes on disc. With 100 holes in one revolution, the resolution would be,
- $360^o /100 = 3.6^o$

Pneumatic Sensors

- Pneumatic sensors are used to measure the displacement as well as to sense the proximity of an object close to it. The displacement and proximity are transformed into change in air pressure.
- Figure shows a schematic of construction and working of such a sensor. It comprises of three ports. 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.
- These sensors are used in robotics, pneumatics and for tooling in CNC machine tools.

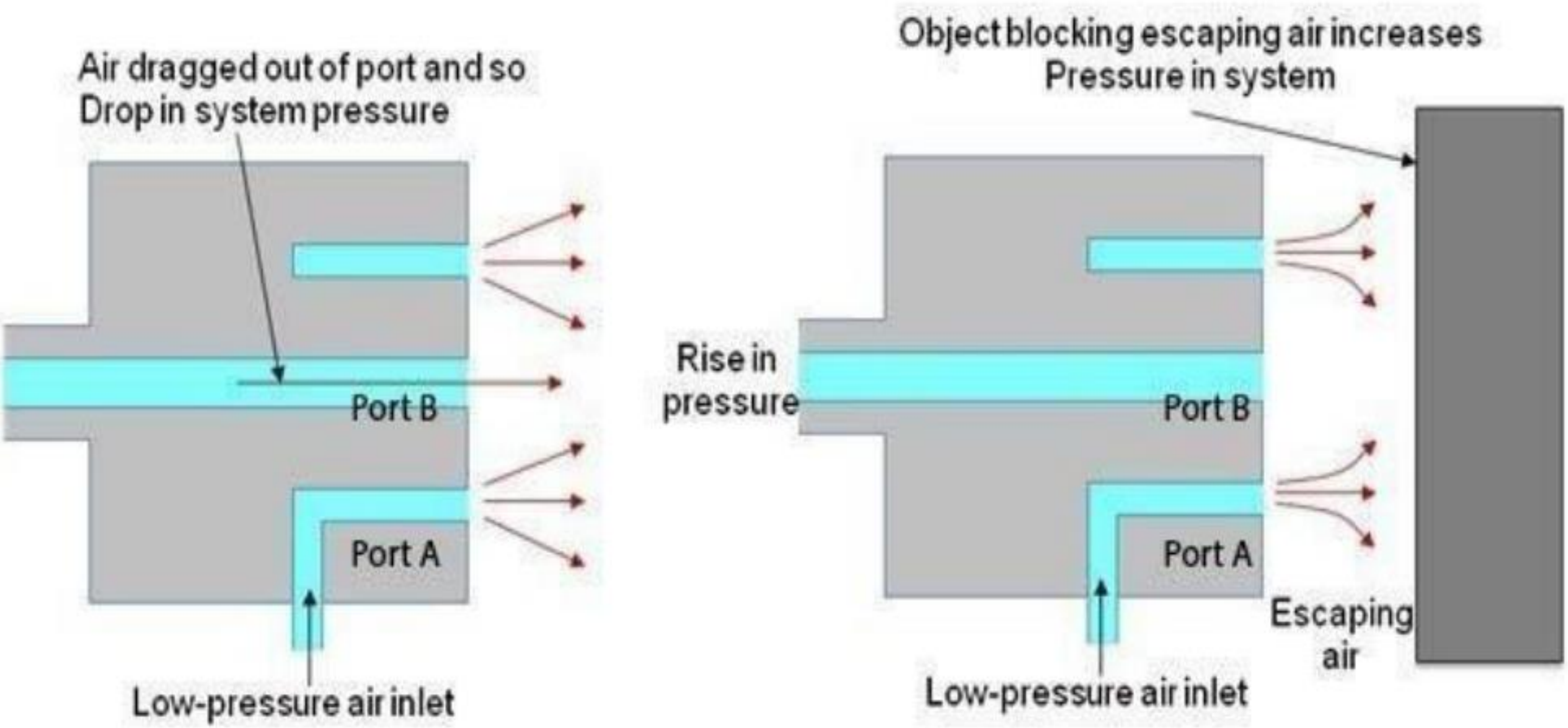


Figure: Working of Pneumatic Sensors

PROXIMITY SWITCHES

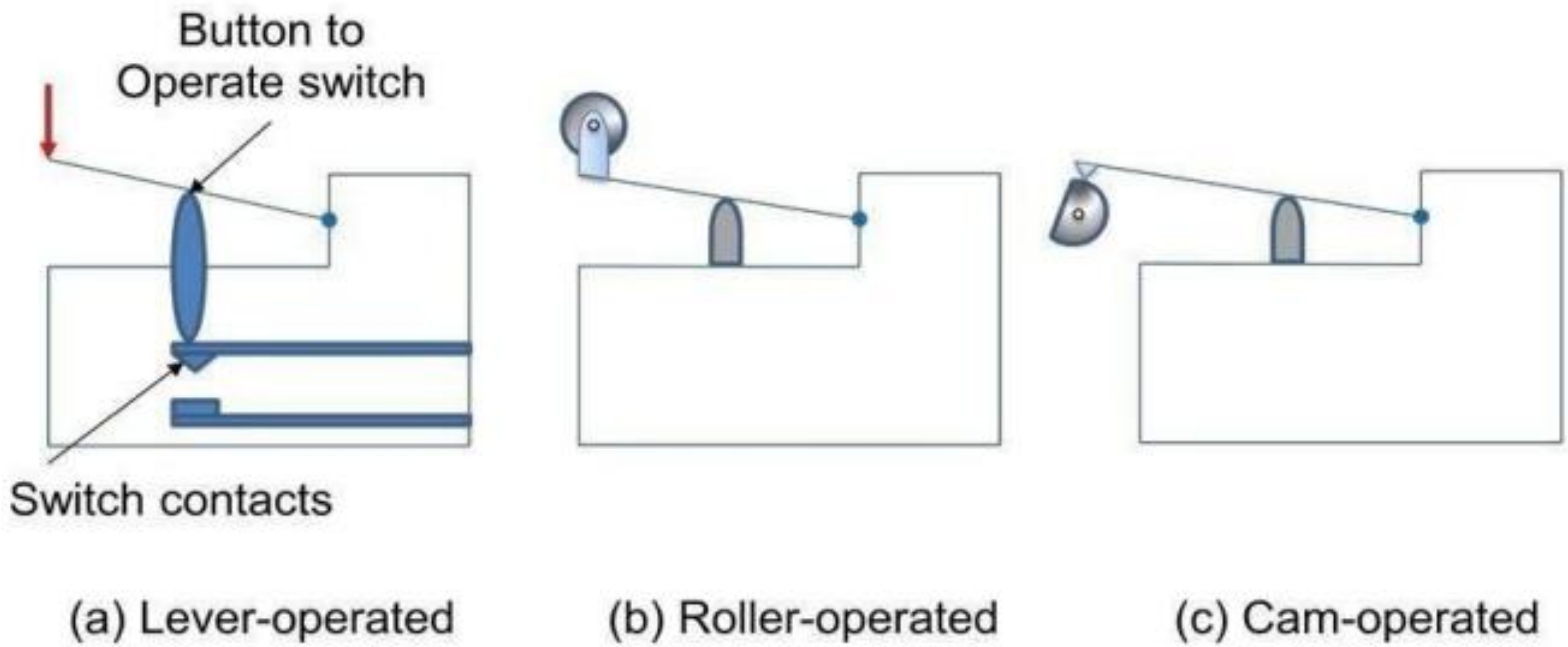


Figure: Configurations of contact type proximity switch

- Contact-type proximity switches being used in manufacturing automation. These are small electrical switches which require physical contact and a small operating force to close the contacts.
- They are basically employed on conveyor systems to detect the presence of an item on the conveyor belt.

Reed Switch

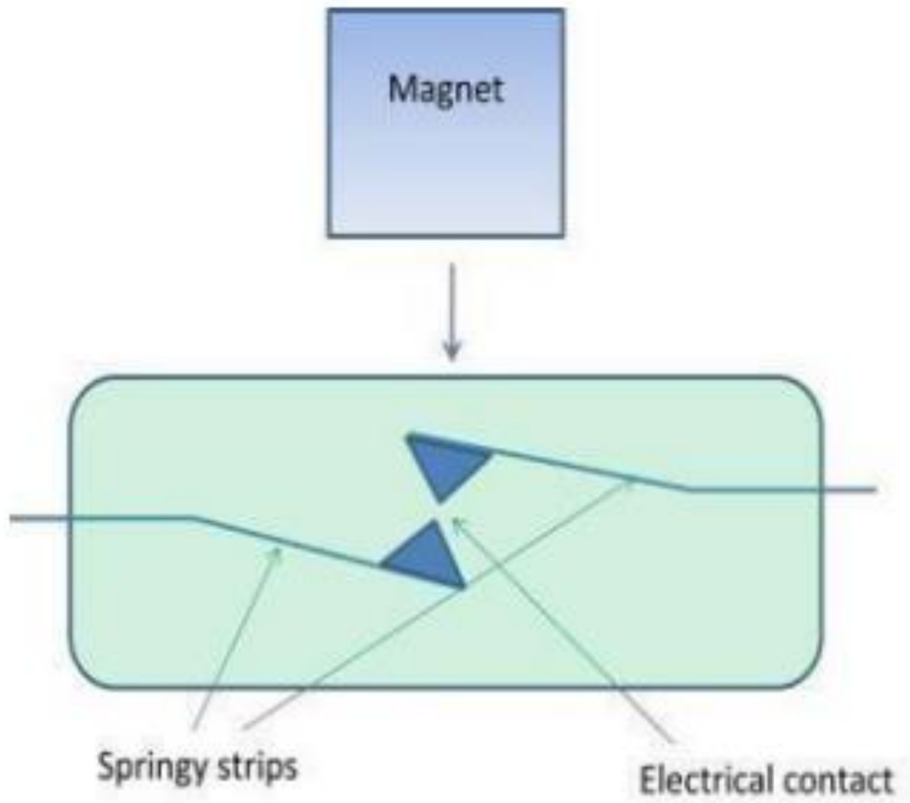


Figure: Reed Switch

- 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 schematic is shown in Figure.

LED based proximity 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.
- Figure shows two typical arrangements of LEDs and photo diodes to detect the objects breaking the beam and reflecting light.

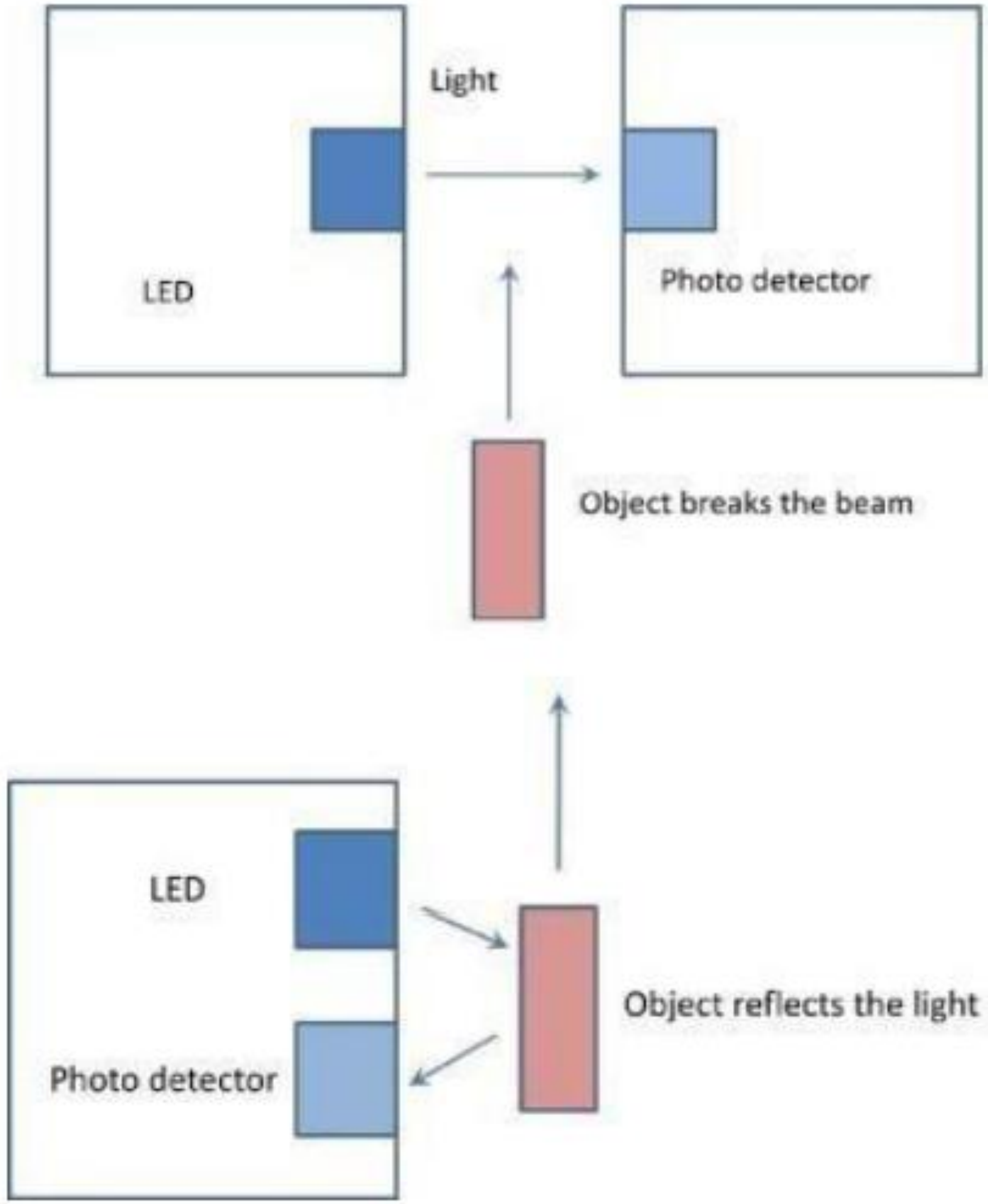
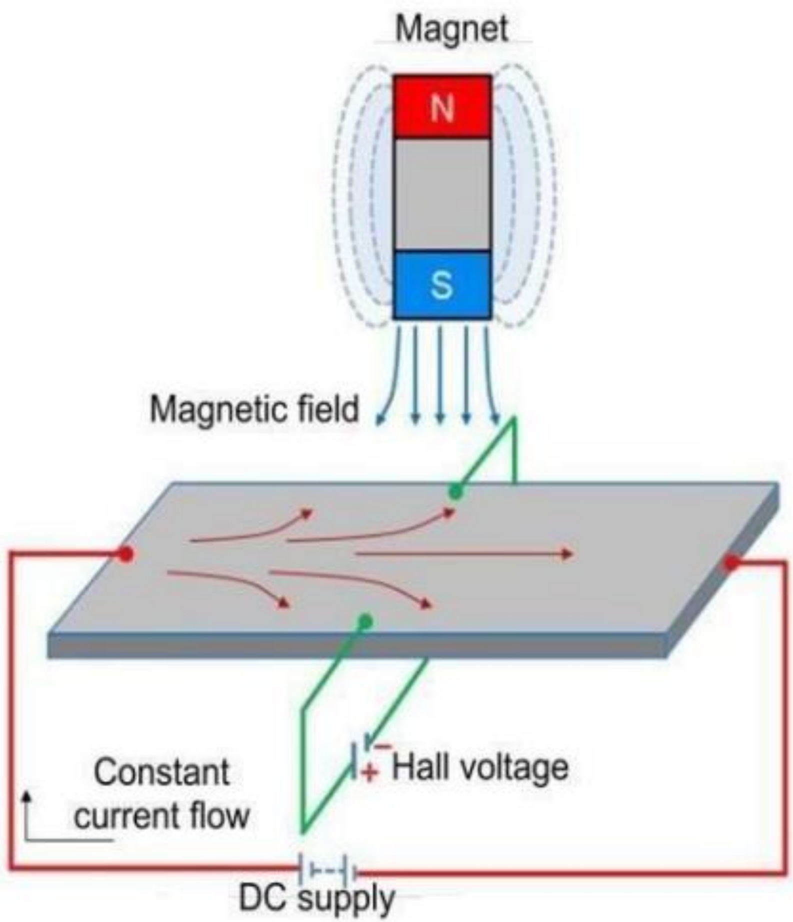


Figure: LED based proximity sensors

Hall effect sensor



Principle of working of Hall effect sensor

- Hall effect sensors work on the principle that when a beam of charge particles passes through a magnetic field, forces act on the particles and the current beam is deflected from its straight line path.
- Thus one side of the disc will become negatively charged and the other side will be of positive charge. This charge separation generates a potential difference which is the measure of distance of magnetic field from the disc carrying current.
- The typical application of Hall effect sensor is the measurement of fluid level in a container. The container comprises of a float with a permanent magnet attached at it stop.
- An electric circuit with a current carrying disc is mounted in the casing. When the fluid level increases, the magnet will come close to the disc and a potential difference generates. This voltage triggers a switch to stop the fluid to come inside the container.
- These sensors are used for the measurement of displacement and the detection of position of an object. Hall effect sensors need necessary signal conditioning circuitry. They can be operated at 100 kHz. Their non-contact nature of operation, good immunity to environment contaminants and ability to sustain in severe conditions make them quite popular in industrial automation.

Variable reluctance tachometer

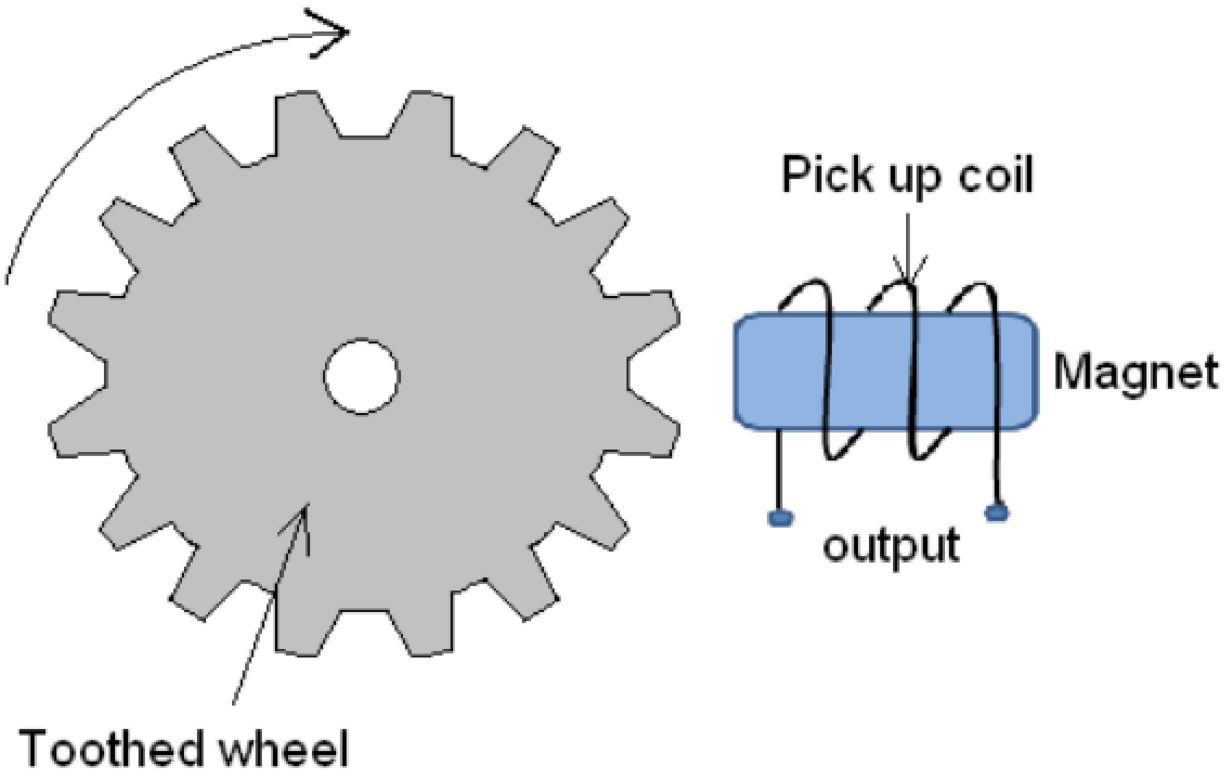


Figure: Variable reluctance tachometer

- Tacho-generator works on the principle of variable reluctance. It consists of an assembly of a toothed wheel and a magnetic circuit as shown in figure.
- Toothed wheel is mounted on the shaft or the element of which angular motion is to be measured. Magnetic circuit comprising of a coil wound on a ferromagnetic material core.
- 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.

Electromagnetic Tachometer

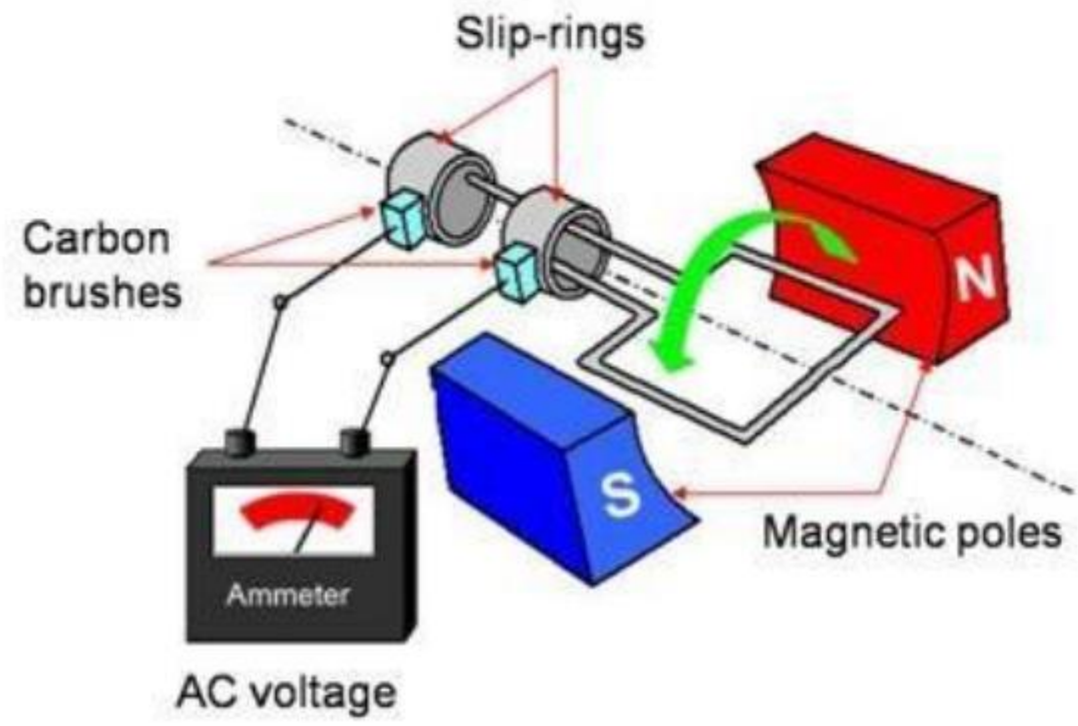


Figure: Electromagnetic Tachometer

- An alternating current (AC) generator can also be used as a techo-generator. It comprises of rotor coil which rotates with the shaft. Figure shows the schematic of AC generator.
- The rotor rotates in the magnetic field produced by a stationary permanent magnet or electromagnet. During this process, an alternating emf is produced which is the measure of the angular velocity of the rotor.
- In general, these sensors exhibit nonlinearity error of about ± 0.15% and are employed for the rotations up to about 10000rev/min.

Photoelectric Tachometer

- The tachometer which uses the light for measuring the speed of rotation of shaft or disc of machines is known as the photoelectric tachometer. The opaque disc with holes on its periphery, light source and laser are the essential parts of the photoelectric tachometer.

- The tachometer consists the opaque disc which is mounted on the shaft whose speed needs to be measured. The disc consists the equivalent holes around the periphery.
- The light source is placed on one side of the disc and the light sensor on the other side. They are in line with each other.

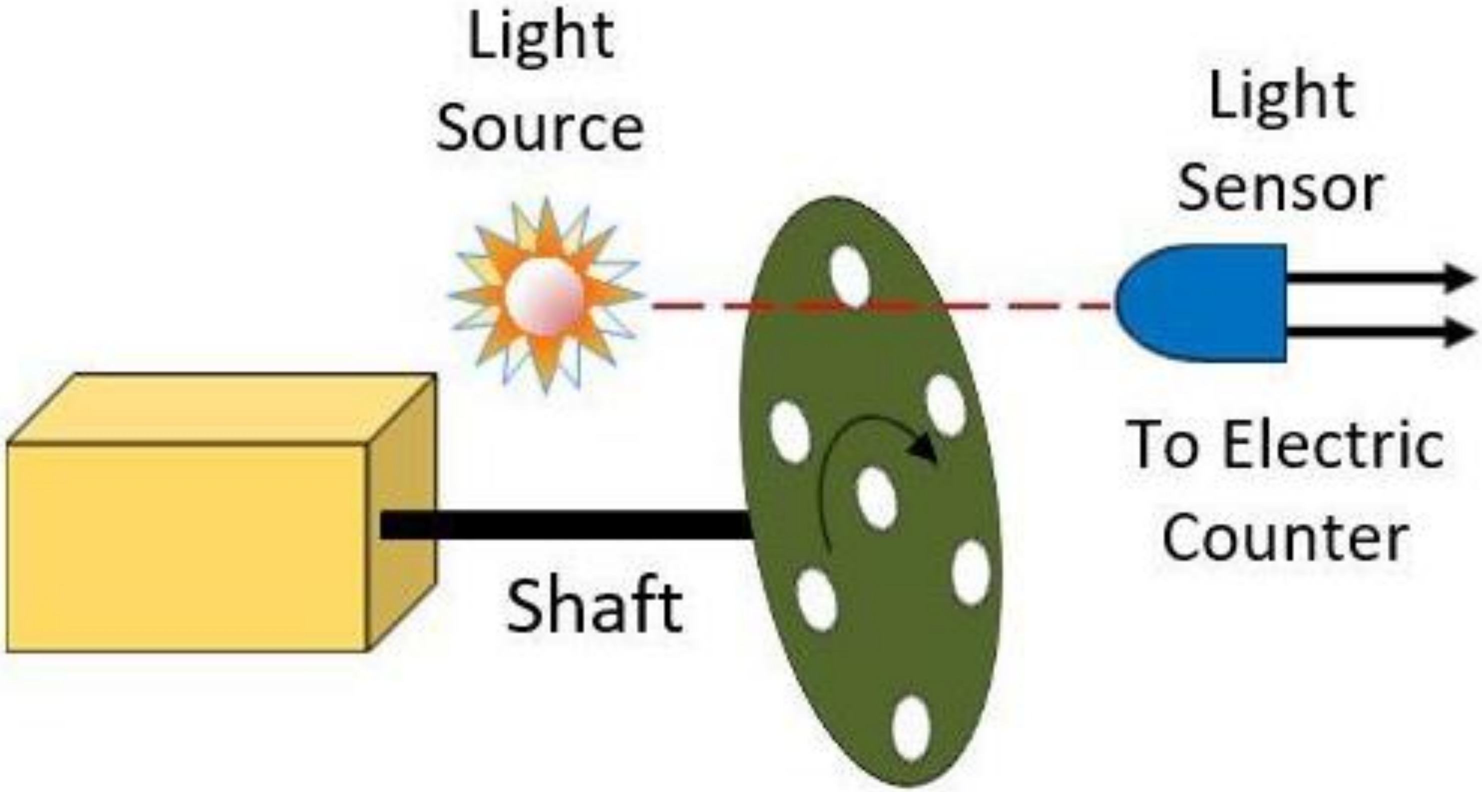


Figure: Photoelectric Tachometer

- When the disc rotates their holes, and the opaque portion comes alternatively between the light source and light sensor. When the holes come in the line of the light source and the light sensor, then the light passes through the holes and collapse to the sensor. Hence the pulse is generated. These pulses are measured through the electric counter.
- When the opaque portion comes in the line of light source and sensor, then the disc blocked the light source, and the output becomes zero. The production of pulses depends on the following factor.

1. The number of holes on the disc.
2. The speed of rotation of the disc.

- The holes are fixed, and hence the pulse generation depends on the speed of the rotation of the disc. The electronic counter is used for measuring the pulse rate.

Advantages of Photoelectric Tachometer

- The digital output voltage is obtained, and hence there is no need of analogue to digital conversion.
- The pulses of constant amplitude are obtained which simplify the electronic circuitry.

Disadvantages of Photoelectric Tachometer

- The life of the light source is approximately 50,000 hours. Hence the light source needs to be replaced timely.
- The accuracy of this method depends on the error which is represented by the unit pulse. These errors can be minimized by using the gating period. The gating period means the meter measures the frequency by counting the input pulses.

The total number of pulses generated at one revolution is also used for minimizing the error.

Piezoelectric Materials

- A piezoelectric material is one in which electric potential is generated across the surface ends, when the material undergoes deformation by the application of external force.
- This is called as Piezoelectric Effect.

Inverse Piezoelectric Effect

- Conversely, if a time varying electric potential is applied across the two ends of the piezoelectric material, the material undergoes deformation and vibrates with a certain frequency.
- This is called Inverse Piezoelectric Effect.

Types of Piezoelectric Crystal materials

- Piezoelectric Crystals are of two types:

1. Natural Crystals - Quartz, Tourmaline etc.
2. Synthetic Crystals - Rochelle Salt, Lithium Sulphate, Dipotassium Tartarate etc.

Piezoelectric sensor

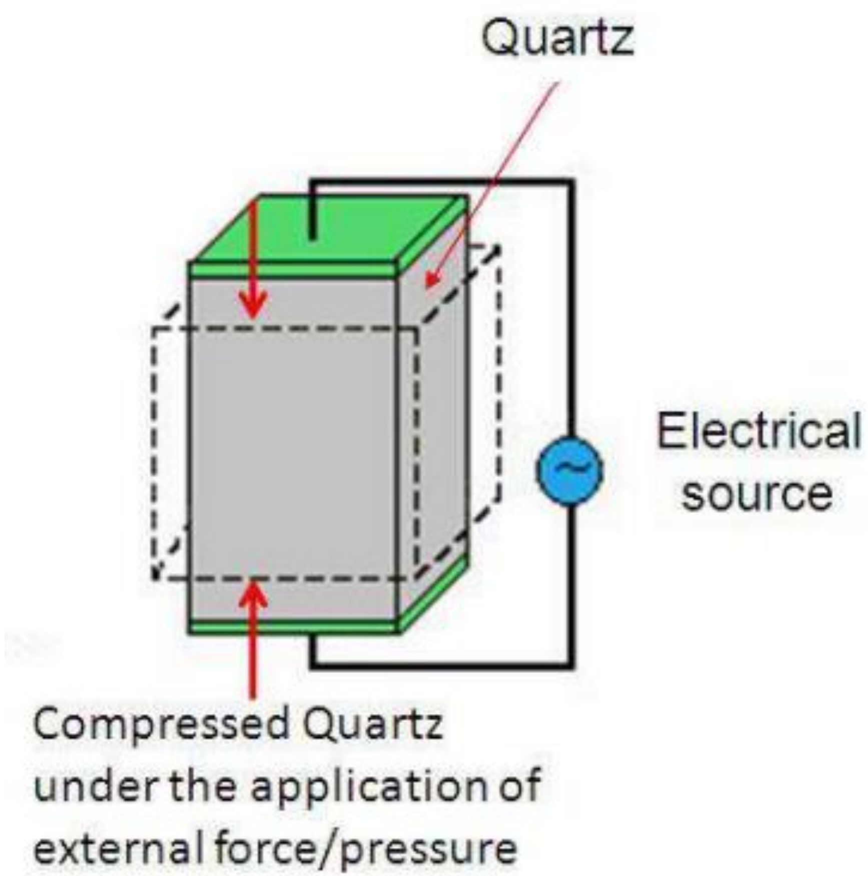


Figure: Principle of working of Piezoelectric sensor

- Piezoelectric sensor is used for the measurement of pressure, acceleration and dynamic-forces such as oscillation, impact, or high speed compression or tension.
- It contains piezoelectric ionic crystal materials such as Quartz (Figure). On application of force or pressure these materials get stretched or compressed.
- During this process, the charge over the material changes and redistributes. One face of the material becomes positively charged and the other negatively charged.
- The net charge q on the surface is proportional to the amount x by which the charges have been displaced. The displacement is proportion to force.
- Therefore we can write, $q = kx = SF$ where k is constant and S is a constant termed the charge sensitivity.

Tactile sensors

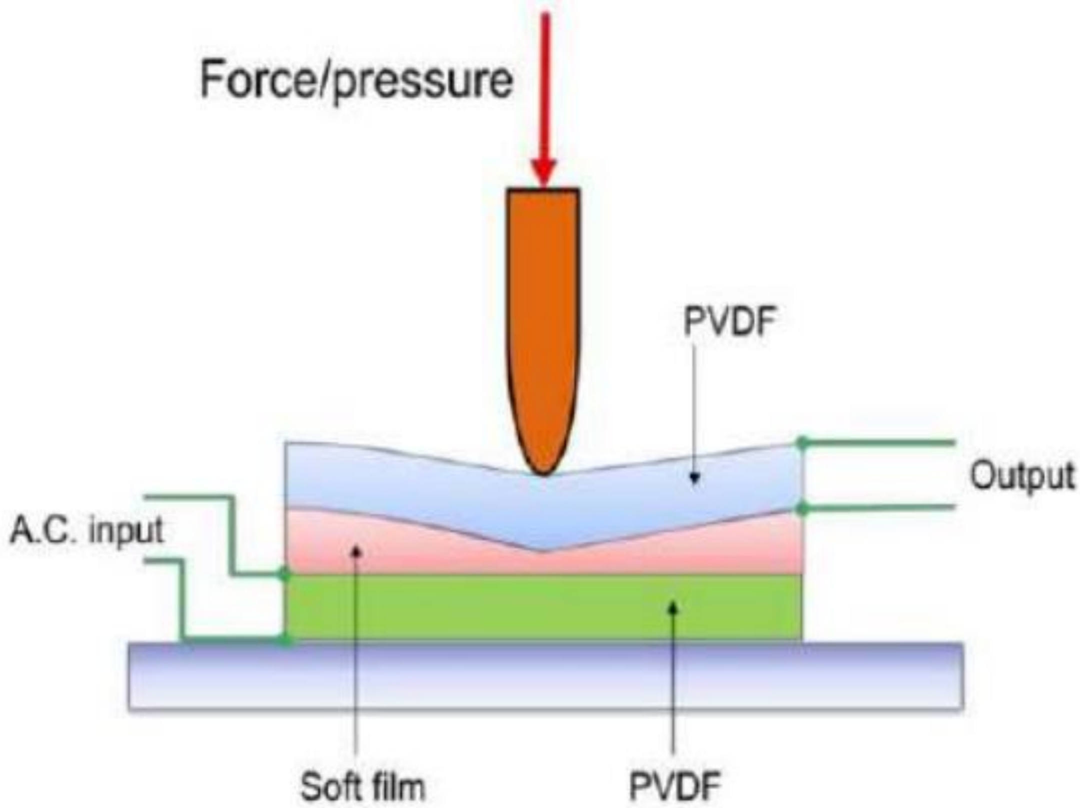


Figure: Schematic of a tactile sensor

- In general, tactile sensors are used to sense the contact of fingertips of a robot with an object. They are also used in manufacturing of ‘touch display’ screens of visual display units (VDUs) of CNC machine tools.
- Figure shows the construction of piezo-electric poly vinylidene 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 PVDF layer which generates vibrations due to reverse piezoelectric effect. These vibrations are transmitted to the upper PVDF layer via soft film. These vibrations cause alternating voltage across the upper PVDF layer.
- When some pressure is applied on the upper PVDF layer the vibrations gets affected and the output voltage changes. This triggers a switch or an action in robots or touch displays.

Liquid flow

- Liquid flow is generally measured by applying the Bernoulli’s principle of fluid flow through a constriction. The quantity of fluid flow is computed by using the pressure drop measured.
- The fluid flow volume is proportional to square root of pressure difference at the two ends of the constriction. There are various types of fluid flow measurement devices being used in manufacturing automation such as Orifice plate, Turbine meter etc.

Orifice Plate

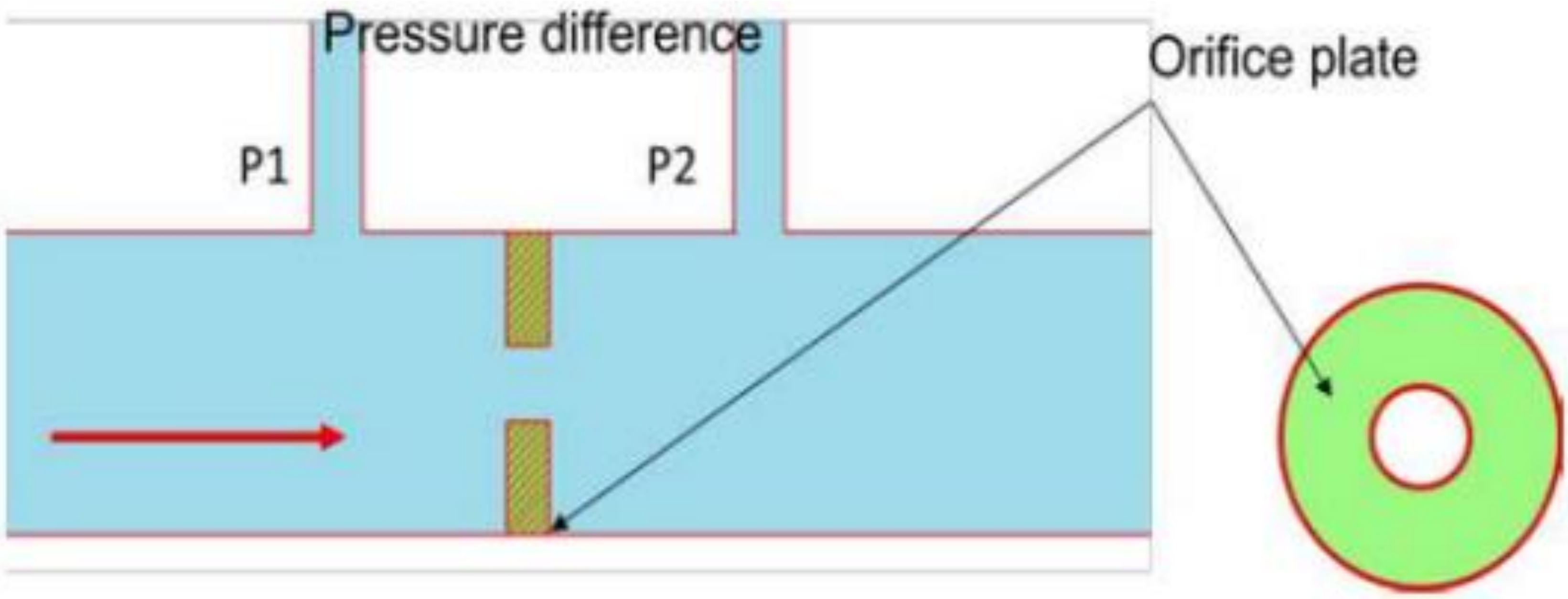


Figure: Orifice Plate

Figure above shows a schematic of Orifice plate device.

- It has a disc with a hole at its center, through which the fluid flows.
- The pressure difference is measured between a point equal to the diameter of the tube upstream and a point equal to the half the diameter downstream.
- Orifice plate is inexpensive and simple in construction with no moving parts. It exhibits nonlinear behavior and does not work with slurries. It has accuracy of ± 1.5%.

Types of Sensors used in Vibration Measurement

DIFFERENT SENSOR TYPES USED FOR VIBRATION MEASUREMENTS

- *Accelerometers (piezoelectric)*
- *Velocity Sensor*
- *Proximity Probes (capacitance or eddy current)*
- *Laser displacement sensors*

1. VELOCITY SENSORS

- **Electromagnetic linear velocity transducers :**

Typically used to measure oscillatory velocity. A permanent magnet moving back and forth within a coil winding induces an *emf* in the winding. This *emf* is proportional to the velocity of oscillation of the magnet. This permanent magnet may be attached to the vibrating object to measure its velocity.

Electromagnetic tachometer generators :

- Used to measure the angular velocity of vibrating objects. They provide an output voltage/frequency that is proportional to the angular velocity. *DC tachometers* use a permanent magnet or magneto, while the *AC tachometers* operate as a variable coupling transformer, with the coupling coefficient proportional to the rotary speed.

2. ACCELERATION SENSORS

- **Capacitive accelerometers :**

Used generally in those that have diaphragm supported seismic mass as a moving electrode and one/two fixed electrodes. The signal generated due to change in capacitance is post-processed using LC circuits etc., to output a measurable entity.

- **Piezoelectric accelerometers :**

Acceleration acting on a seismic mass exerts a force on the piezoelectric crystals, which then produce a proportional electric charge. The piezoelectric crystals are usually preloaded so that either an increase or decrease in acceleration causes a change in the charge produced by them. But they are not reliable at very low frequencies.

Potentiometric accelerometers :

- Relatively cheap and used where slowly varying acceleration is to be measured with a fair amount of accuracy.
- In these, the displacement of a spring mass system is mechanically linked to a viper arm, which moves along a potentiometric resistive element. Various designs may have either viscous, magnetic or gas damping.

Reluctive accelerometers :

They compose accelerometers of the differential transformer type or the inductance bridge type. The AC outputs of these vary in phase as well as amplitude. They are converted into DC by means of a phase-sensitive demodulator.

Servo accelerometers :

- These use the closed loop servo systems of force-balance, torque-balance or null-balance to provide close accuracy. Acceleration causes a seismic mass to move. The motion is detected by one of the motion-detection devices, which generate a signal that acts as an error signal in the servo-loop.
- The demodulated and amplified signal is then passed through a passive damping network and then applied to the torquing coil located at the axis of rotation of the mass. The torque is proportional to the coil current, which is in turn proportional to the acceleration.

Strain Gage accelerators :

These can be made very small in size and mass. The displacement of the spring-mass system is converted into a change in resistance, due to strain, in four arms of a Wheatstone bridge. The signal is then post-processed to read the acceleration.

3. PROXIMITY SENSORS

Eddy Current Sensor Probe :

- Eddy currents are formed when a moving (or changing) magnetic field intersects a conductor, or vice-versa. The relative motion causes a circulating flow of electrons, or currents, within the conductor. These circulating eddies of current create electromagnets with magnetic fields that oppose the effect of the applied magnetic field.
- The stronger the applied magnetic field, or greater the electrical conductivity of the conductor, or greater the relative velocity of motion, the greater the currents developed and the greater the opposing field Eddy current probes sense this formation of secondary fields to find out the distance between the probe and the target material.

Capacitance Proximity Sensors :

- Capacitive sensors use the electrical property of “capacitance” to make measurements. Capacitance is a property that exists between any two conductive surfaces within some reasonable proximity.
- Changes in the distance between the surfaces change the capacitance. It is this change of capacitance that capacitive sensors use to indicate changes in position of a target. High-performance displacement sensors use small sensing surfaces and as result are positioned close to the targets .

What are Transducers?

Transducers are the mechanical, electronic, electrical, or electrochemical devices that convert one form of energy to the property that cannot be measured directly into the other form of energy or property that can be measured easily. The signal given to the transducer is called as input this is the parameter that is to be measured but cannot be measured directly. The signal obtained from the transducer is called as output, which can be measured easily.

Types of Pressure Transducers

- Mechanical transducers
- Electrical transducers

Note : Elastic pressure transducers are mechanical transducers.

Elastic Pressure Transducers

The elastic pressure transducers are the mechanical elements that are used for converting one form of energy into the other form of energy that can be measured easily.

Types of Elastic Pressure Transducers

There are number of mechanical transducers, some of the commonly used ones are described below:

- Bourdon tube pressure transducers
- Diaphragm pressure transducers
- Bellows pressure transducers

Bourdon tube Pressure Transducers

Bourdon tubes

How they work

- A Bourdon tube can be either c-shaped or helical, with an oval cross section. When the pressure media enters the tube, the pressure acts to change the oval towards a circular cross section. The effect of this distortion causes the tube to move – opening the c-shape, or extending the helix. The closed end of the tube is attached to a movement, so that displacement causes an indicator needle to deflect. The deflection can be measured on a scale, calibrated to represent the pressure exerted by the media.
- The diagrams below illustrate the operating principle of the c-shaped and helical Bourdon tube, respectively. Alternatively, the movement mechanism can be attached to a potentiometer to provide an electrical representation of the pressure.
- Depending on application requirements, such as corrosion resistance, cost, size, measurement range, proof pressure, and burst pressure, the tube may be made from a metal such as copper, brass, aluminium, or a nickel alloy such as monel.

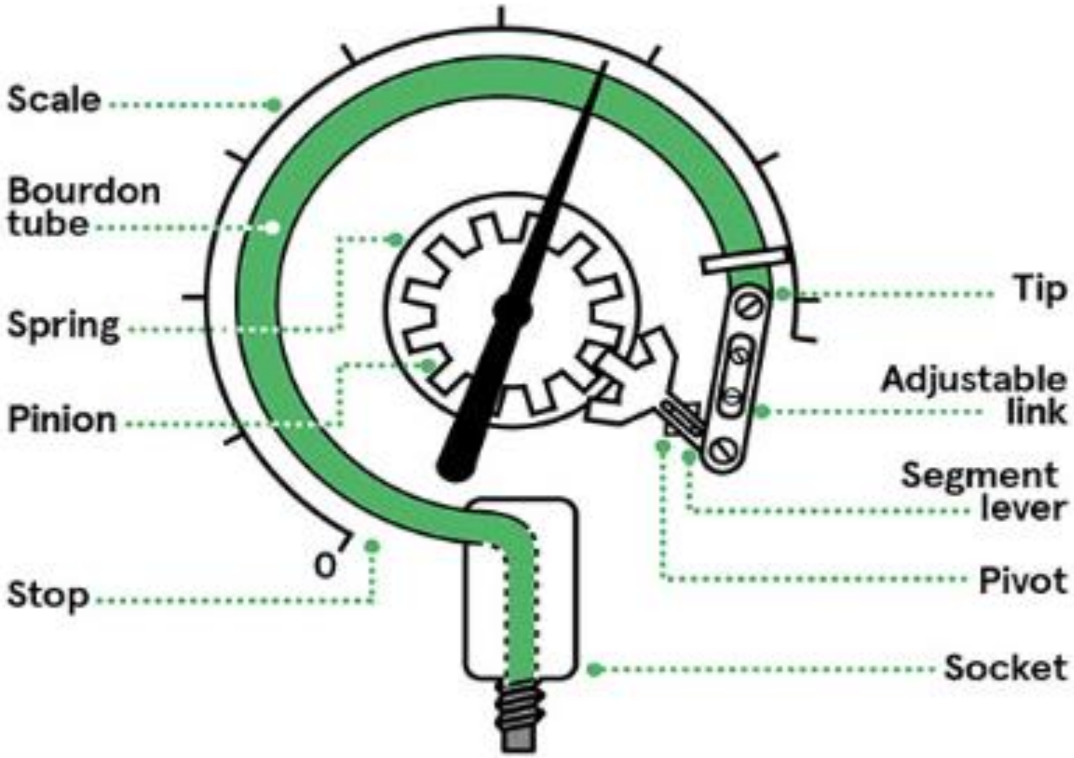


Figure: *A cross-section of a C-shaped Bourdon tube*

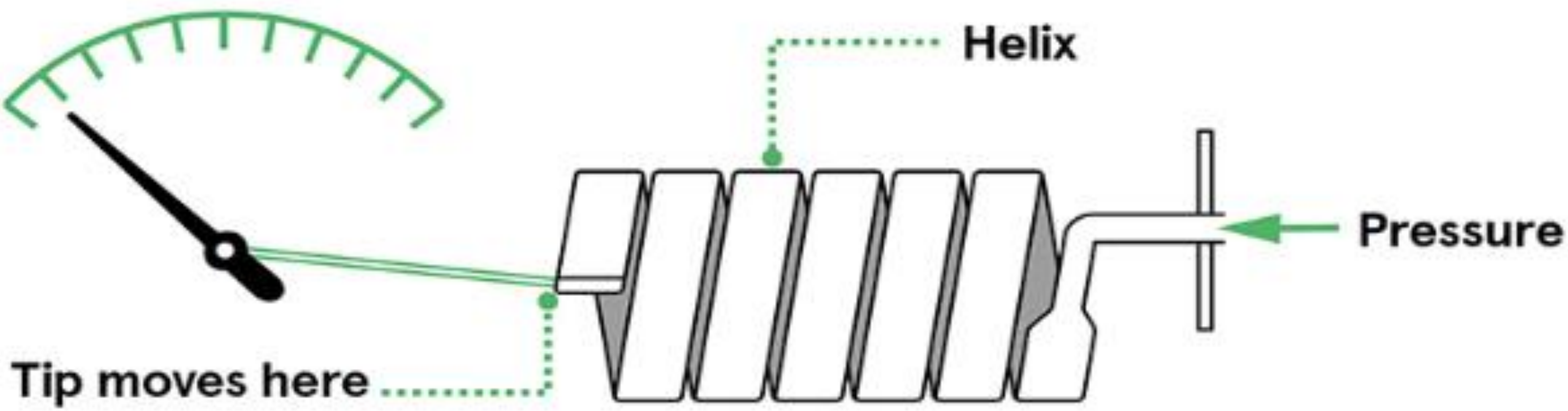


Figure: *A helical Bourdon tube*

Advantages

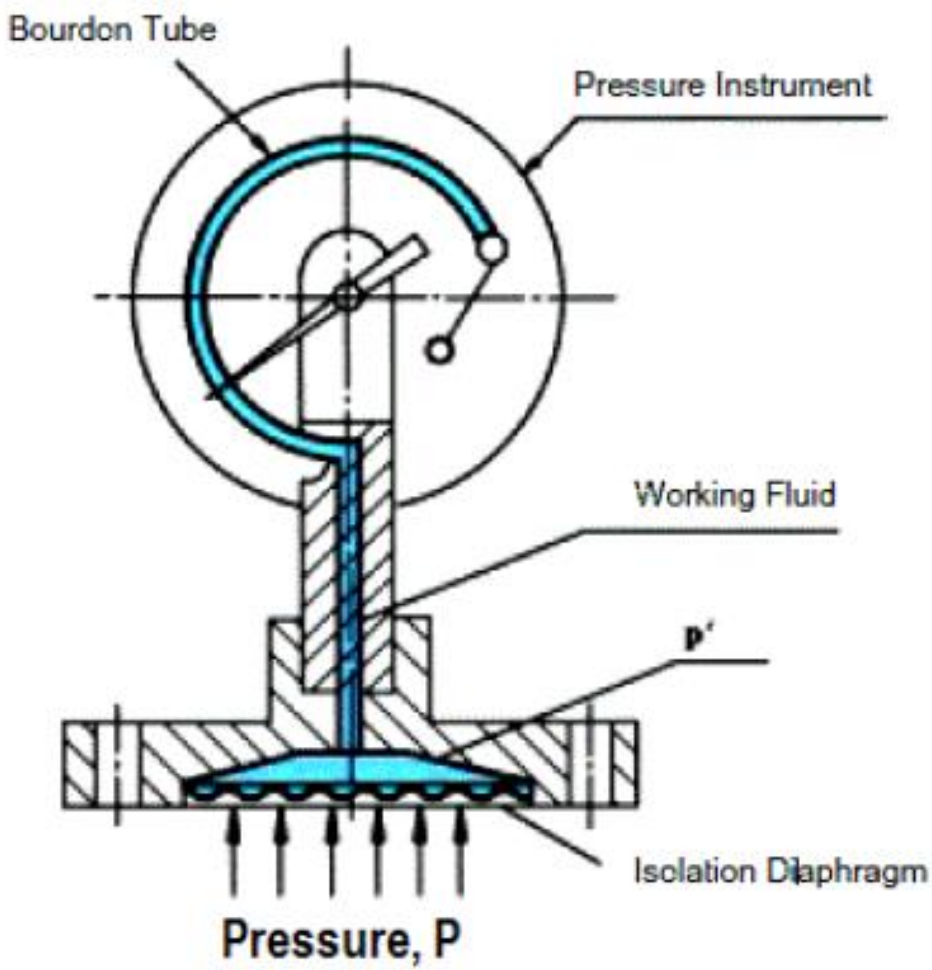
- Low cost Simple construction.
- Time-tested in applications.
- Availability in a wide variety of ranges, including very high ranges.
- Adaptability to transducer designs for electronic instruments.
- High accuracy, especially in relation to cost.

Disadvantages

- Low spring gradient
- Susceptibility to shock and vibrations
- Susceptibility to hysteresis

Diaphragm Pressure Transducers

Figure: Elastic Diaphragm Gauge



- Diaphragm pressure transducers use a flexible diaphragm, which is a thin membrane that is applied to a pressure port to measure changes in pressure.
- The diaphragm is connected to a pressure sensor which converts the pressure change into an electrical signal.
- This signal can then be used to measure the pressure of a liquid or gas within a system.
- Diaphragm pressure transducers are often used in applications such as water pressure monitoring, air conditioning systems, and automotive fuel systems.

Advantages

- Diaphragm Pressure Transducer cost is moderate.
- Diaphragm Pressure Transducer possesses high over range characteristics.
- Diaphragm Pressure Transducers are adaptable to absolute and differential pressure measurement.
- Diaphragm Pressure Transducer has good linearity.
- Diaphragm Pressure Transducer is small in size.

Disadvantages:

- Diaphragm Pressure Transducer lack good vibration and shock resistance.
- Diaphragm Pressure Transducers are difficult to repair.
- Diaphragm Pressure Transducer is limited to relatively low pressures.

Bellows pressure transducers

- Bellows pressure transducers are pressure sensors that measure pressure by converting pressure changes into an electrical signal.
- They are commonly used in industrial and automotive applications, such as gas and liquid pressure measurement, flow rate measurement, and temperature measurement.
- Bellows pressure transducers rely on a thin metal diaphragm that flexes and bends when subjected to pressure changes, resulting in a change in the electrical resistance of the diaphragm.
- This change is read by a Wheatstone bridge circuit, which then produces an output voltage that indicates the pressure change. Bellows pressure transducers are also known for their high accuracy and reliability.

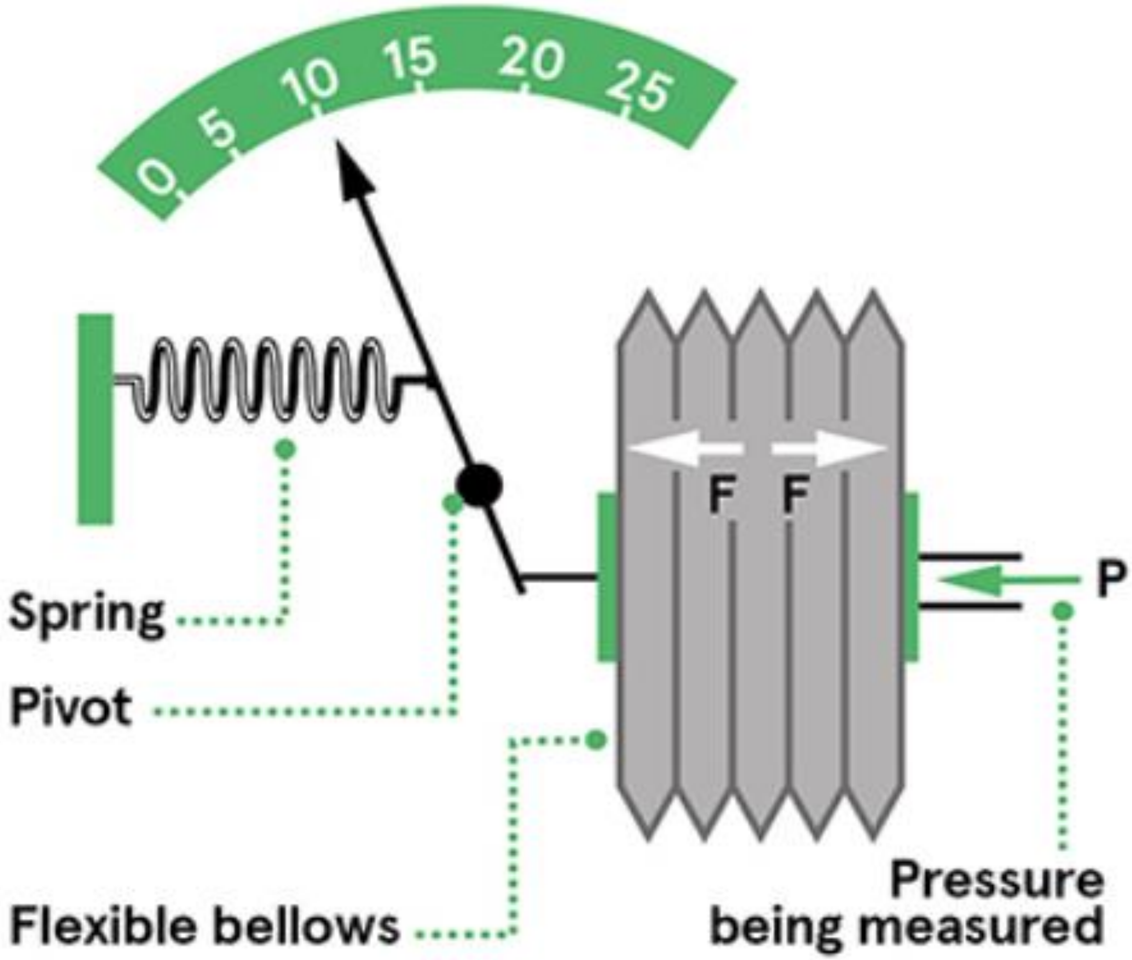


Figure: *The Bellows operating principle*

Advantages

- Moderate cost Delivery of high force.
- Adaptability for absolute and differential pressure.
- Good in the low to moderate pressure range.

Disadvantages

- Ambient temperature compensation needed.
- Unsuitable for high pressure.
- Limited availability of metals and work hardening of some of them.
- Unsuitability of its zero and the stiffness (therefore it is used in conjunction with (in parallel with) a reliable spring of appreciably higher stiffness for accurate characterization.

Piezoelectric pressure sensors

- Piezoelectric pressure sensors are devices which measure pressure using the piezoelectric effect. When pressure is applied to a piezoelectric element, it produces an electric charge proportional to the applied pressure.
- This charge can then be amplified and measured to determine the pressure. Piezoelectric pressure sensors are used in a variety of applications, including medical monitoring, process control, and aerospace applications.

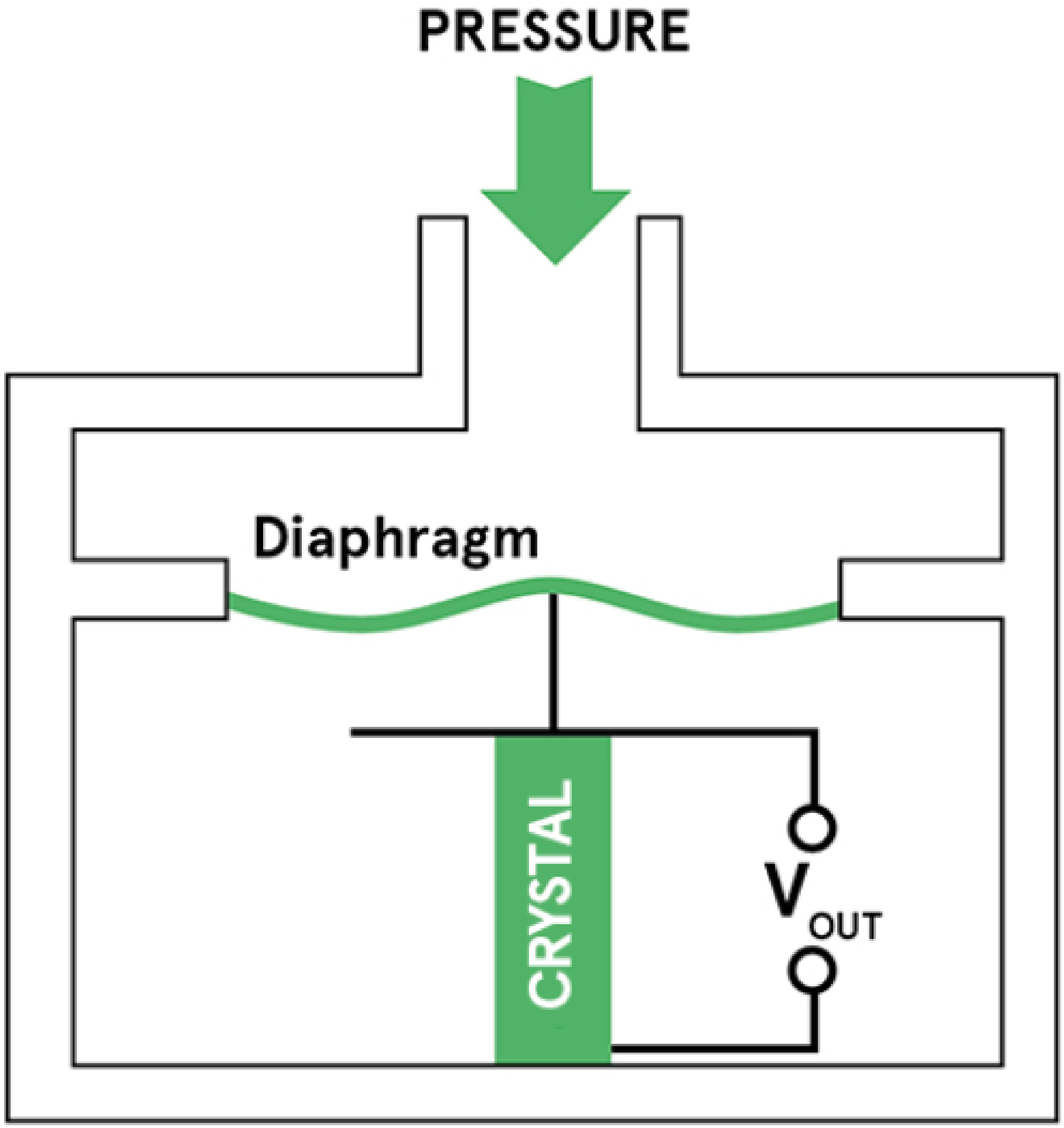


Figure : Piezoelectric pressure sensors

Working principle

- When a force is applied to a piezoelectric material, an electric charge is generated across the faces of the crystal. This can be measured as a voltage proportional to the pressure.

- There is also an inverse piezoelectric effect where applying a voltage to the material will cause it to change shape.

- A given static force results in a corresponding charge across the sensor. However, this will leak away over time due to imperfect insulation, the internal sensor resistance, the attached electronics, etc.

- As a result, piezoelectric sensors are not normally suitable for measuring static pressure. The output signal will gradually drop to zero, even in the presence of constant pressure. They are, however, sensitive to dynamic changes in pressure across a wide range of frequencies and pressures.

- This dynamic sensitivity means they are good at measuring small changes in pressure, even in a very high-pressure environment.

Advantages of Piezoelectric pressure sensors

1. High accuracy: Piezoelectric sensors offer a high level of accuracy in measuring pressure, in some cases with an accuracy of up to 0.005%.

2. Fast response time: Piezoelectric sensors have a very fast response time, allowing for quick and accurate readings.

3. Low cost: Piezoelectric pressure sensors are usually more cost effective than other types of sensors.

4. Versatility: Piezoelectric sensors can be used to measure pressure in almost any environment, from very high to very low pressure.

5. Easy to install: Piezoelectric pressure sensors are usually simple to install and do not require much maintenance once installed.

Disadvantages of Piezoelectric pressure sensors

1. High cost.
2. Limited temperature range.
3. Limited pressure range.
4. Can be affected by noise and other external factors.
5. Relatively low resolution compared to other pressure measurement devices.

Strain Gauge as force Sensor

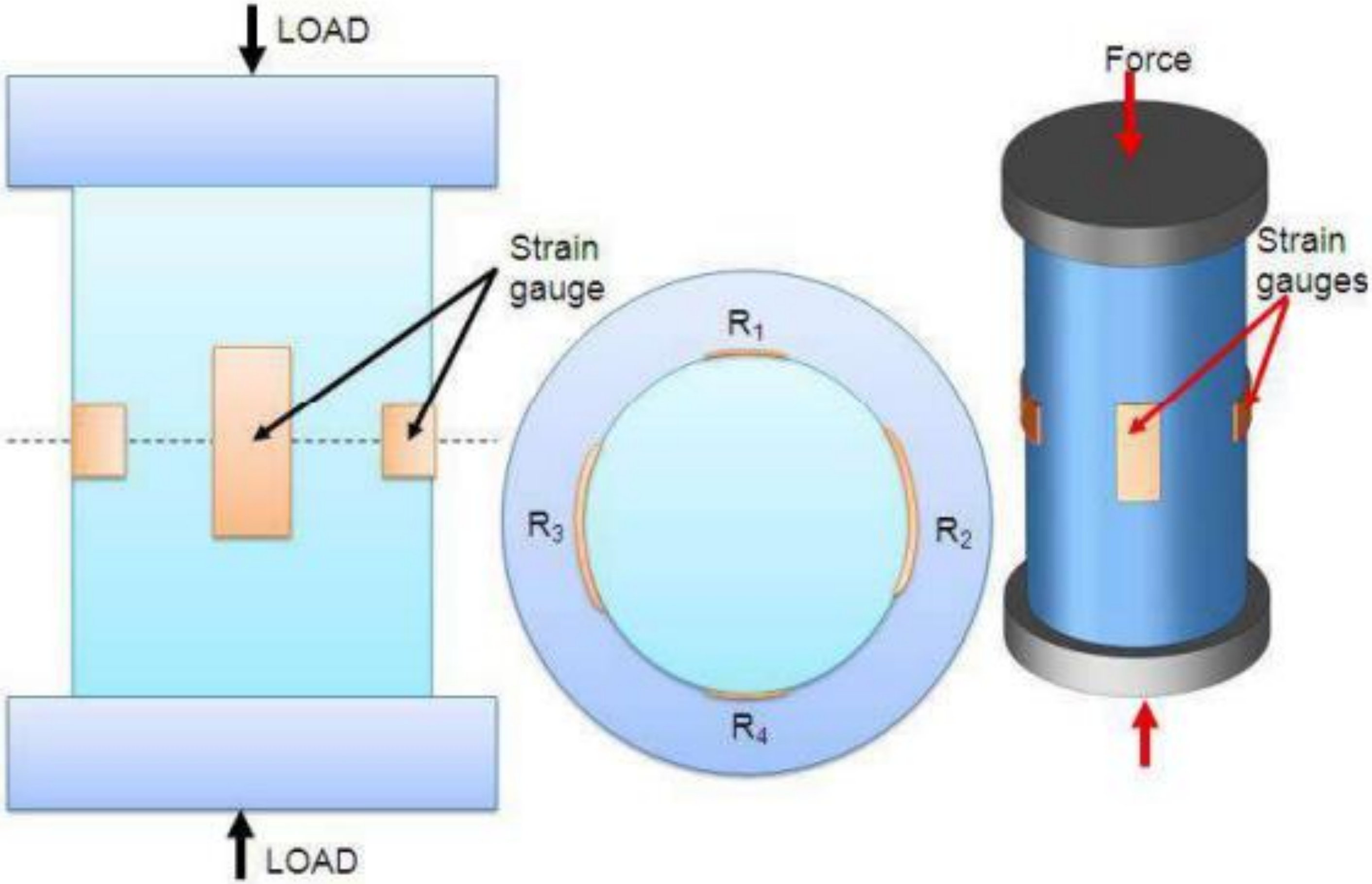


Figure: Strain gauge based Load cell

- Strain gauge based sensors work on the principle of change in electrical resistance.
- 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.
- Figure above shows a strain gauge load cell.
- It comprises of cylindrical tube to which strain gauges are attached. A load applied on the top collar of the cylinder compress the strain gauge element which changes its electrical resistance.
- Generally strain gauges are used to measure forces up to 10 MN.
- The non-linearity and repeatability errors of this transducer are ±0.03% and ±0.02% respectively.

Accelerometer

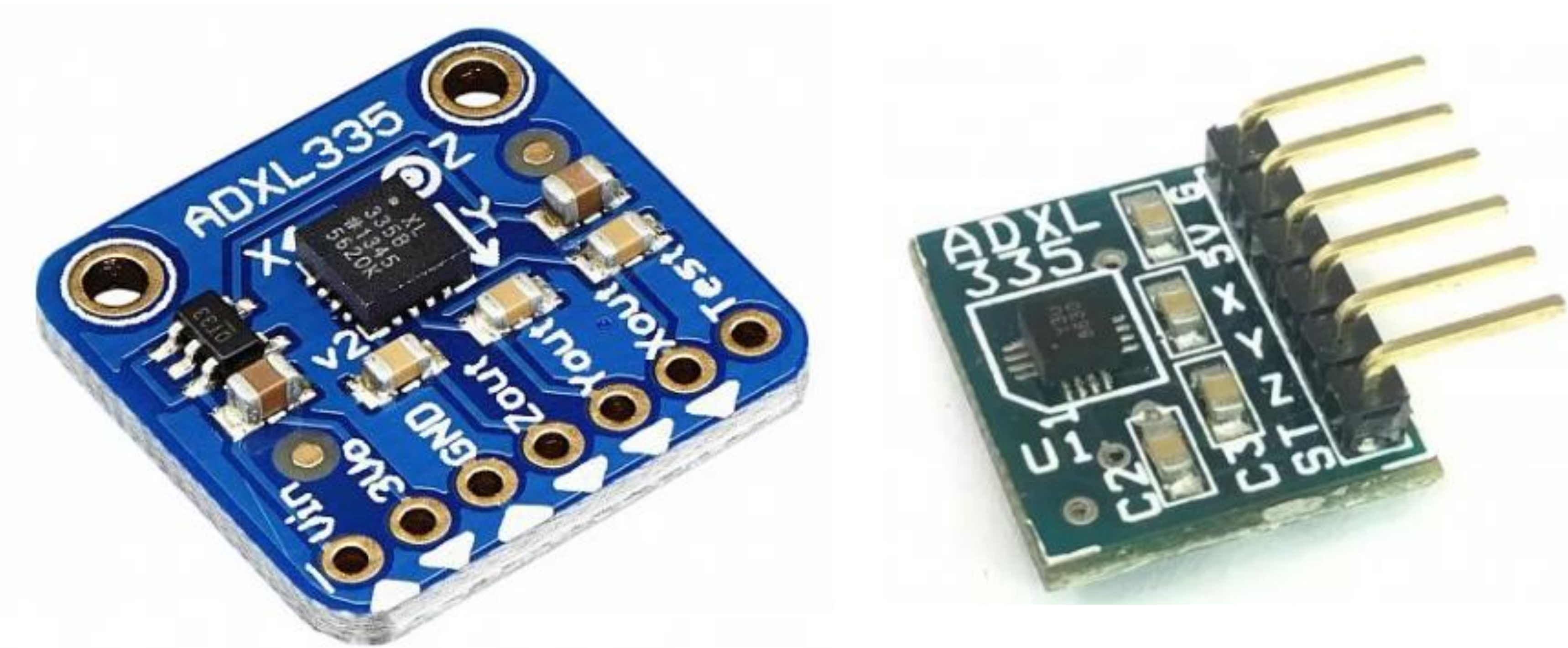


Figure: Accelerometer Sensor

- An accelerometer is a tool that measures the vibration, motion, or acceleration of a structure. Cameras and smartphones these days use an accelerometer consisting of an axis-based motion sensor. It is an electromechanical device that measures either static or dynamic acceleration. Acceleration, as we know, is the measure of change in velocity upon a given time.
- Accelerometers are used in the compass app you use on your phone. The motion sensors in accelerometers can detect earthquakes too. Another example is when the accelerometers measure the gravitational pull to determine at which angle is the device being titled.

Working principle of Accelerometer

- When the accelerometer is in equilibrium, it measures the acceleration to be 1g which is equivalent to 9.81 m/s2. The accelerometers usually are multiple axes rather than single-axis which helps determine their movement in three dimensions. There are generally two types of accelerometers: a piezoelectric one and a capacitive one.
- The piezoelectric sensor works on the principle that when pressure is applied to the piezoelectric material it generates an electric charge. So the accelerometer consists of microscopic piezoelectric particles with a mass mounted on it. As the acceleration will exert force on the piezoelectric material, this will in turn generate a charge which will be converted into the value of velocity, and orientation is based on the amount of charge generated.

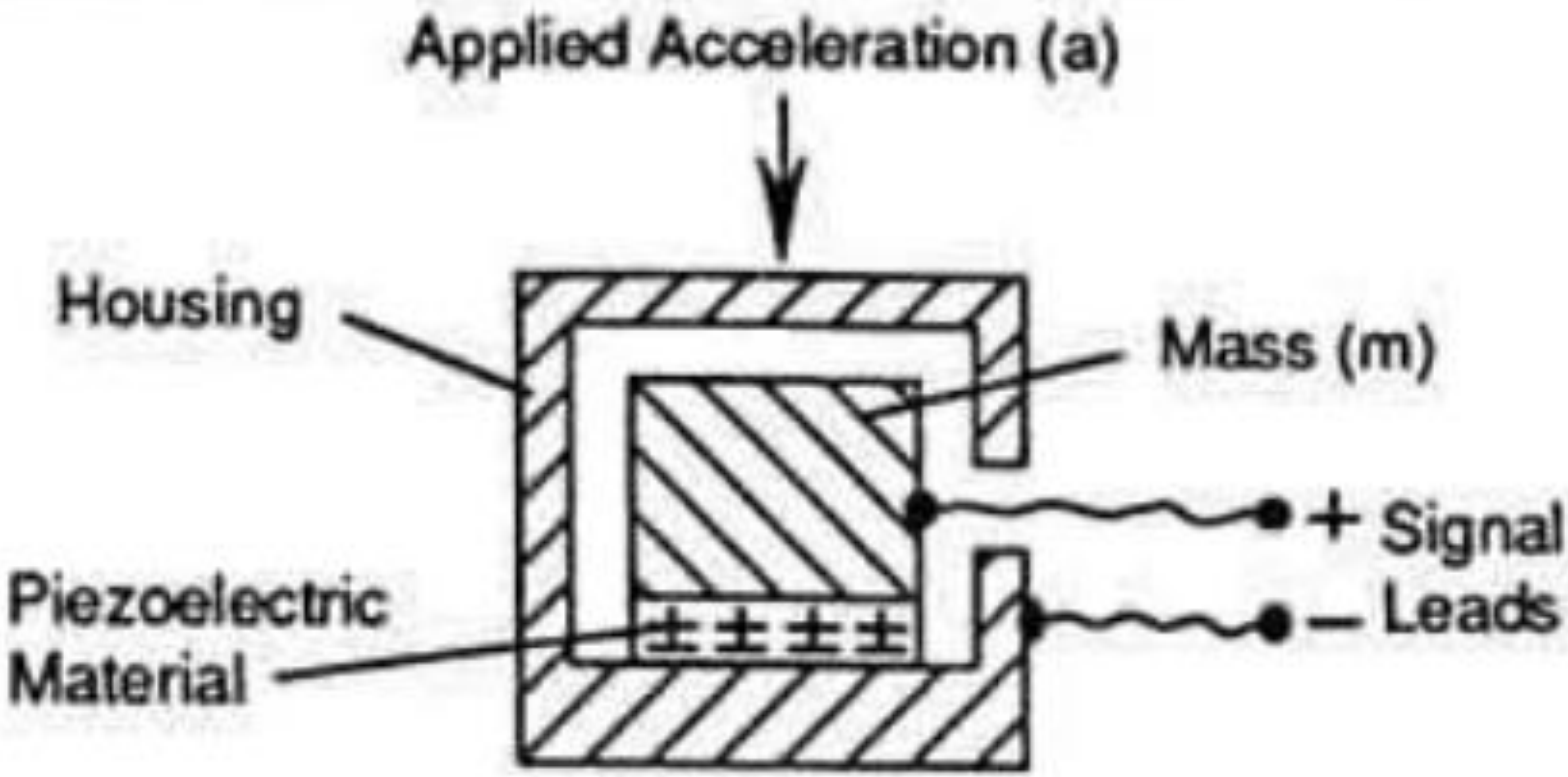


Figure: Working of Accelerometer Sensor

Capacitive accelerometer

- The capacitive accelerometer work based on the principle that when the distance between the plates changes, the capacitance also changes. There are two types of capacitive accelerometers. One type includes two parallel movable plates connected to a spring. As the acceleration force is applied to the plates, the distance between the plates changes which changes the overall capacitance. This change in capacitance is used to calculate the acceleration and orientation of the object.
- The second type of accelerometer is called the differential capacitive accelerometer. Here there are multiple capacitors used to measure the acceleration of the object.

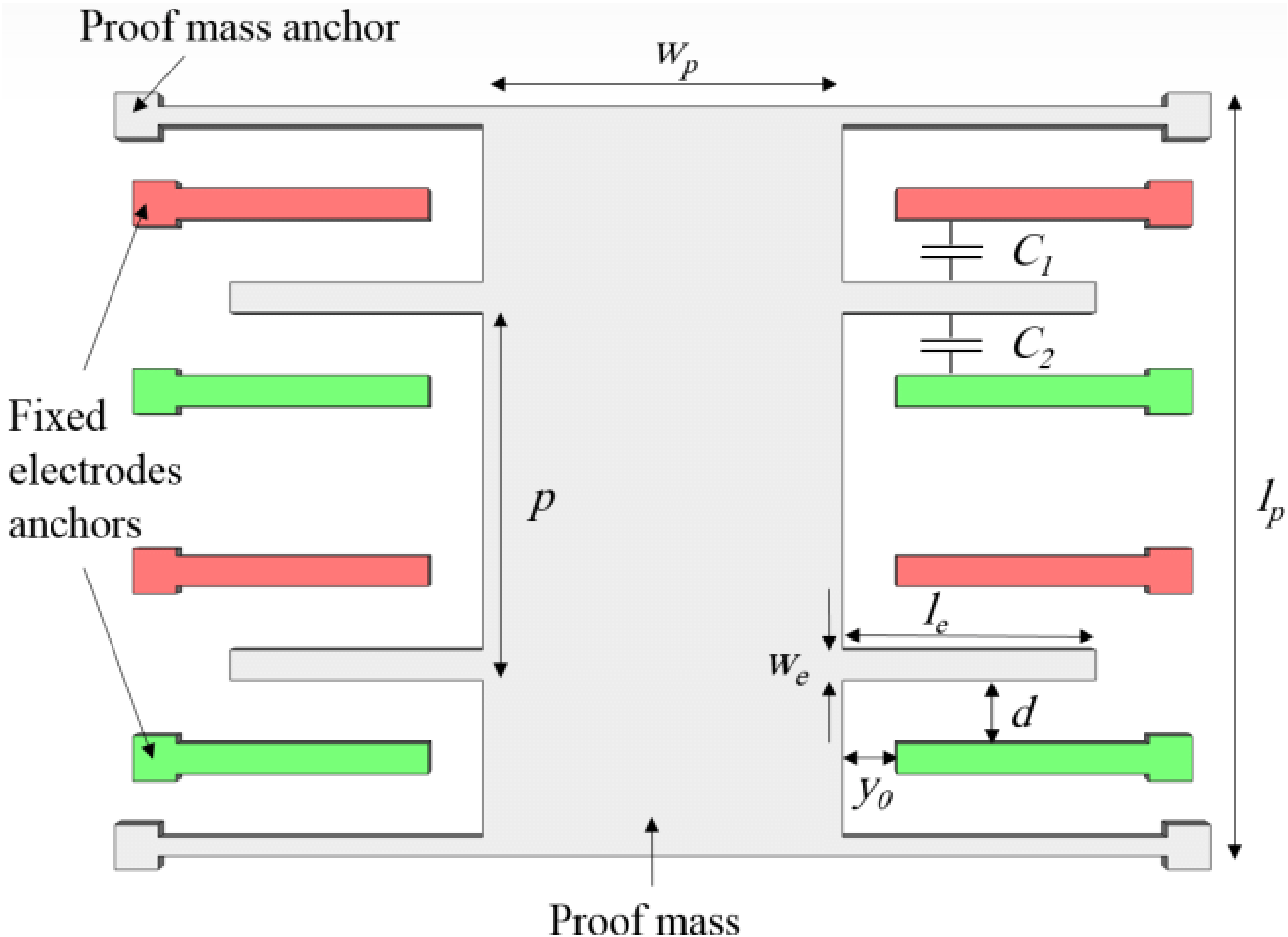


Figure: Working of Capacitive accelerometer

- As shown in the above picture, the capacitors are fixed on to the fixed electrode anchors, and the proof mass is movable. As the acceleration is applied to the sensor, the mass shifts changing the distance between the capacitors and the electrodes.
- This consequently changes the capacitance of the capacitor. The change in capacitance is measured and the acceleration value is calculated based on the capacitance.
- Capacitive accelerometers use silicon-based materials.

Working principle of the accelerometer ADXL335

- There are generally two types of capacitive accelerometers right now. One is MEMS (Micro electro mechanical sensor). MEMS generally have a silicon-based material with a mass attached to it and it is integrated into a circuit. As the acceleration is applied, the mass moves, and thus the silicon material also moves. This creates a charge in the circuit. The charge is used to calculate the acceleration.
- The other type is analog accelerometers. They work on two different principles which we discuss above: piezoelectric sensing and capacitive sensing. ADXL335 works on the principle of capacitive.
- ADXL335 is a capacitive accelerometer. It works on the principle that when the acceleration is applied to the sensor, the capacitance inside the sensor changes. This change in capacitance is then used to measure the acceleration of the object.
- This is a 3-axis accelerometer. So it can be used to calculate all the accelerations in three dimensions.

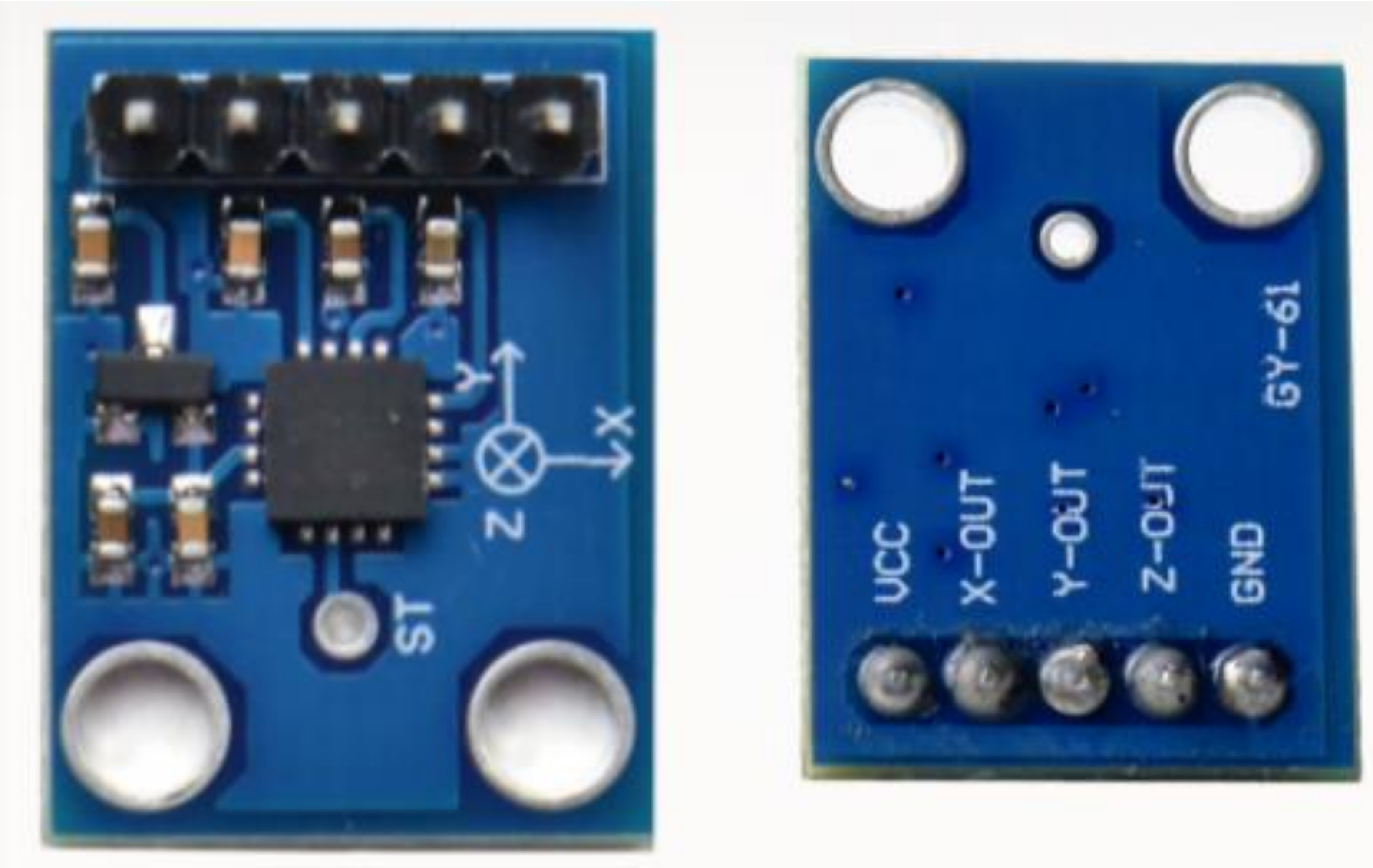


Figure : Accelerometer ADXL335

The ADXL335 sensor has 6 pins and an integrated chip on the front of the board. The pins are soldered at the back of the board.

- VCC pin is used for the power supply.
- X-out is the output to measure the acceleration along the x-axis.
- Y-out is the output to measure the acceleration along the y-axis.
- Z-out is the output to measure the acceleration along the z-axis.
- GND is the ground pin.
- ST pin located above the integrated chip is the self-test feature. This self-test feature allows us to check the functioning of the accelerometer in the final model.

Applications of accelerometer

- Smartphones include an accelerometer which is used in features like auto-rotate and games etc.
- Smartwatches have an accelerometer to track your speed and orientation during activities like running, cycling, swimming, volleyball, cricket, football, etc.
- Cameras use accelerometers for the stabilization of their pictures and videos.
- Drones use accelerometers to increase their stability during flight.
- Accelerometers are widely used to measure seismic activity all over the world.

Bridge circuit

- A bridge circuit is an electrical circuit in which two nodes are "bridged" by the circuit elements.
- In a bridge circuit, the voltage across one node is equal to the voltage across the other node.
- The bridge circuit is commonly used to measure unknown impedance values and to cancel out unwanted signals in a circuit.
- It can also be used in power supplies, signal conditioning, and filtering. Bridge circuits can be used to measure AC or DC voltages, current, resistance, power, and inductance.

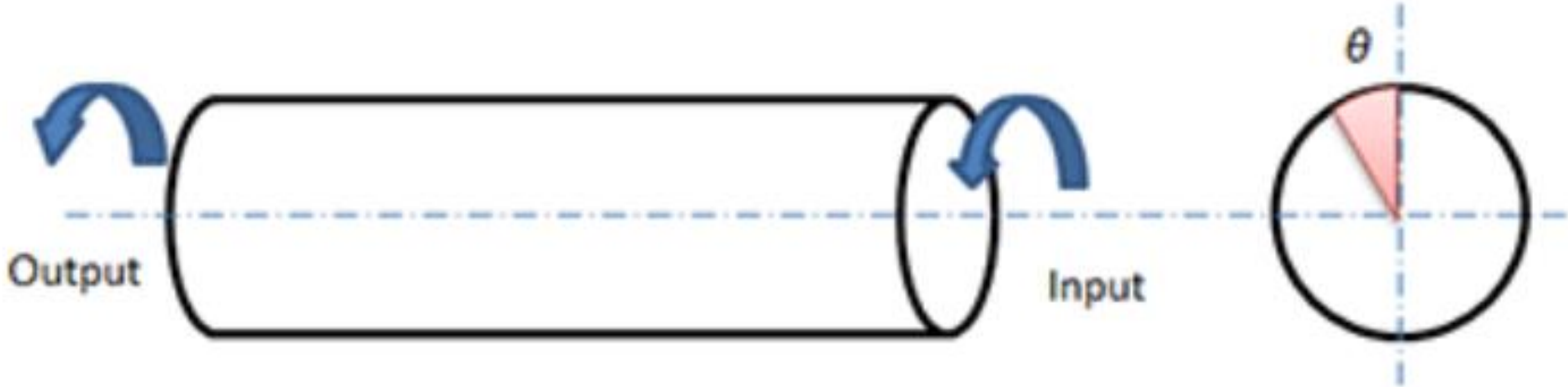
- In a basic bridge circuit, four resistors are connected in a “diamond” pattern. Two of the resistors, R1 and R4, are connected in series, while the other two, R2 and R3, are connected in parallel. The bridge is then connected to a voltage source, usually a battery or a power supply, and a load.
- When voltage is applied to the circuit, current flows through the resistors and the load. The current flowing through R2 and R3 is equal to the current flowing through R1 and R4, and the voltage across R2 and R3 is equal to the voltage across R1 and R4. This creates a bridge circuit, with the voltage across each node being the same.

- The bridge circuit can then be used to measure the unknown impedance of a device or to filter out unwanted signals. For example, if an AC signal is applied to the bridge, the AC signal can be filtered out using a capacitor. Similarly, if a DC signal is applied, the DC signal can be filtered out using a diode.
- Bridge circuits can also be used to measure the resistance of a device or to measure the inductance of a coil. By connecting the device or coil to the bridge, the resistance or inductance can be measured. The bridge can also be used to measure the power consumed by a device or to monitor the voltage or current in a circuit.

Torque sensors

- Torque sensors measure the torque applied to a rotating object such as an engine, motor, or shaft.
- They are used to measure the amount of torque being applied, which can help identify problems in the system or provide data for performance analysis.
- Torque sensors can also be used in safety systems to prevent overloads or detect wear.

- A torque sensor, which is also called a torque transducer, is an instrument for measuring and monitoring the torque on a rotating system, such as an engine crankshaft.
- Torque sensors convert a torsional mechanical input into an electrical output signal.
- Torque is measured by sensing the shaft deflection caused by a twisting force. Since L, G and Ip, defined in the figure, are properties of the shaft, the torque value can be determined by measuring the rotation angle of one end of the shaft relative to the other. There are two types of torque to be measured, static torque and dynamic torque.



$$T = \theta \cdot (I_p \cdot G)/L$$

L = length of shaft (mm, in)

G = modulus of rigidity (Mpa, psi)

I_p = "polar moment of inertia" of cross section (mm^4, in^4)

Figure: Torque calculation

Flow Measurement

- Flow measurement is the process of measuring the rate of flow of a fluid passing through a pipe or other container.
- Flow measurement is used for many applications, including industrial process control, environmental protection, and water resource management.
- Flow measurements are typically made by inserting a flow meter into the pipe or container in which the fluid is flowing. Flow meters measure the velocity of the fluid, and the amount of fluid passing the meter over a given period of time.
- Common types of flow meters include: positive displacement, variable area, turbine, ultrasonic, and electromagnetic flow meters.

Bernoulli flowmeter

- A Bernoulli flowmeter is a type of device used to measure the flow rate of a fluid.
- It works by measuring the pressure drop across a constriction in the pipe, or the difference between two points in the pipe.
- This pressure drop is related to the flow rate, so the flow rate can be determined from the pressure drop.
- The Bernoulli flowmeter is used in many different applications, such as measuring the flow rate of water in a pipe, the flow rate of air in an air conditioning system, and the flow rate of gases in an industrial process.

Advantages of Bernoulli flowmeter

1. **Simple and Rugged:** Bernoulli flowmeters are simple and rugged in construction, which makes them relatively easy to install and maintain.

2. **Low Pressure Loss:** Pressure loss in a Bernoulli flowmeter is minimal due to its design, making them ideal for applications where pressure drop is a concern.

3**. Cost-Effective:** Bernoulli flowmeters are generally more cost-effective than other types of flowmeters, making them an attractive option for many applications.

4. **Accurate Measurements:** Bernoulli flowmeters provide accurate measurements of volumetric and mass flow rates, making them a reliable choice for many industrial applications.

5. **No Moving Parts:** Bernoulli flowmeters have no moving parts, making them a good choice for applications in which regular maintenance is not feasible or desirable.

Disadvantages of Bernoulli flowmeter

1. **Expensive:** The cost of a Bernoulli flowmeter can be quite expensive when compared to other types of flowmeters. This can make it difficult for some companies to justify its purchase.
2. **Limited Accuracy:** Bernoulli flowmeters are not as accurate as other types of flowmeters. This can be a problem for certain applications where precise measurements are necessary.
3. **Vulnerable to Clogging:** The orifice plate in a Bernoulli flowmeter can easily become clogged with debris, which can interfere with readings. This requires regular maintenance and cleaning.
4. **Pressure Dependence:** The accuracy of the readings from a Bernoulli flowmeter is dependent on the pressure of the fluid being measured. If the pressure changes, then the readings can be inaccurate.

Ultrasonic flowmeter

- An ultrasonic flowmeter is a device used to measure the speed and volume of a liquid or gas moving through a pipe.
- It uses ultrasonic sound waves to measure the time taken for an echo to return from the walls of the pipe and thus calculate the fluid's velocity.
- Ultrasonic flowmeters are often used to measure the flow of water, oil, and other liquids in industrial and commercial applications.

Advantages of Ultrasonic flowmeter

1. High accuracy: Ultrasonic flowmeters can measure flow accurately and with repeatability.

2. No moving parts: Ultrasonic flowmeters do not require the use of any moving parts, which makes them durable and low maintenance.

3. Low cost: Ultrasonic flowmeters are cost-effective when compared to other types of flowmeters.

4. Wide range: Ultrasonic flowmeters can measure a wide range of flow rates, from very low to very high.

5. Non-intrusive: Ultrasonic flowmeters are non-intrusive and can be installed without breaking into the pipe.

6. Temperature and pressure independent: Ultrasonic flowmeters are not affected by temperature or pressure changes.

7. Versatile: Ultrasonic flowmeters are versatile and can be used in a variety of applications.

Disadvantages of Ultrasonic flowmeter

1. Expensive.
2. Not suitable for measuring gas flow.
3. Sensitive to changes in the physical properties of the liquid, such as temperature, viscosity and density.
4. Not suitable for low flow rates or low-pressure applications.
5. Can be affected by the presence of foam or other gas bubbles in the liquid.

Magnetic flow meter

- A magnetic flow meter is a device used to measure the flow rate of a fluid in a closed conduit.
- It uses Faraday's law of induction to measure the velocity of the fluid by measuring the voltage generated by the fluid as it flows through a magnetic field.
- The meter consists of electrodes that are placed in the pipe, a transmitter that generates the magnetic field, and a sensor that measures the voltage generated.
- The voltage is then converted into a flow rate. The flow rate can be displayed in various units, such as gallons per minute or cubic feet per second.

Advantages of Magnetic flow meter

1. High accuracy: The magnetic flow meter can measure the flow rate of liquid accurately and reliably, which ensure the accuracy of the measured data.

2. High repeatability: The magnetic flow meter has high repeatability, which can ensure the accuracy of the measured data.

3. Low pressure loss: The magnetic flow meter has low pressure loss, which is beneficial to save energy and reduce production costs.

4. No moving parts: The magnetic flow meter has no moving parts, which reduces wear and tear and improves the service life of the flow meter.

5. Wide range of applications: The magnetic flow meter can measure various liquids, such as water, sea water, oil, etc., and can be used in a wide range of industries.

Disadvantages of Magnetic flow meter

1. Not suitable for measuring corrosive liquids.
2. Vulnerable to fouling or buildup of material on the sensor.
3. Can be sensitive to external electromagnetic fields.
4. The cost of the magnetic flow meter can be expensive

Rotameter

- A rotameter is a device used to measure the flow rate of a liquid or gas.
- It is a type of variable area flow meter, consisting of a tube with a float inside. The float is connected to a stem that is sealed in the tube, which contains a tapered diameter.
- As more flow enters the tube, the float is forced up the tapered tube, which causes the area that the float occupies to increase.
- This increase in area is proportional to the flow rate, allowing the rotameter to measure the flow rate.
- Rotameters are often used in industrial applications, such as chemical processing plants, to measure the flow rate of a fluid.

Advantages of Rotameter

1. **Easy to install and maintain:** Rotameters are easy to install and require minimal maintenance, making them an ideal choice for many applications.
2. **Accurate and Reliable Measurements:** The measuring mechanism of a rotameter is highly reliable, providing accurate flow readings.
3. **Cost-effective:** Rotameters are an inexpensive option when compared to other flow meters and are often preferred for budget-constrained applications.
4. **Versatile:** Rotameters are available in a variety of sizes and can be used in a wide range of applications.
5. **Low Pressure Loss:** The design of the rotameter helps reduce pressure losses, making it ideal for low-pressure applications.
6. **Easy to Read:** The scale on the rotameter is clearly visible and easy to read, even from a distance.

Disadvantages of Rotameter

1. Rotameters are not suitable for measuring low flows as the minimum measurable flow rate is higher than for other flow meters.
2. Rotameters are not suitable for measuring corrosive liquids, as the float is usually made from plastic or stainless steel.
3. They require a straight, uninterrupted section of pipe and a large upstream and downstream pipe diameter to ensure accurate readings.
4. The flow rate must be kept constant for the meter to be accurate.
5. The accuracy of the readings is affected by the viscosity of the liquid and must be calibrated for each liquid.
6. Rotameters are not suitable for measuring highly turbulent or aerated flows.

Miscellaneous Sensors

- Leak detector
- Flame detector
- Smoke detector
- pH sensors
- Conductivity sensors
- Humidity sensors
- Potentiometric Biosensors
- Proximity sensors

Leak detector sensor

- A leak detector sensor is a device that is used to detect the presence of a liquid, gas, or other substance in an area where it is not wanted.
- They may be used to detect water leaks, gas leaks, refrigerant leaks, and other types of leakage. Leak detector sensors are often used in industrial, commercial, and residential settings to alert personnel to the presence of a potentially dangerous leak.
- They are also used in medical settings to detect leaks in medical equipment or supplies.
- Leak detector sensors come in a variety of shapes, sizes, and materials, and they can be wired or wireless.
- Some are designed to send an alarm when the presence of a leak is detected, while others are designed to shut down a system when a leak is detected.

Flame detector sensor

- A flame detector sensor is a device used to detect the presence of a flame or fire.
- It is often used in fire alarm systems to detect the presence of a fire in a building or area.
- The sensor usually consists of an infrared or ultraviolet light source and a detector, which is sensitive to the light.
- When a flame is detected, the detector triggers an alarm.

Smoke detector sensor

- A smoke detector sensor is a device that detects the presence of smoke in the air and triggers an alarm.
- It is typically used in buildings to alert occupants of a fire so that they can evacuate the area.
- Smoke detectors come in two main types: ionization and photoelectric.
- Ionization smoke detectors use a small amount of radioactive material to detect smoke particles, while photoelectric smoke detectors use a light beam to detect smoke.
- Both types of smoke detectors are powered either by a battery or an electrical outlet.

pH sensors

- pH sensors measure the acidity or alkalinity of a given solution.
- They are commonly used in water monitoring and quality control, as well as in laboratory experiments.
- pH sensors are typically composed of a glass electrode, a reference electrode, and a temperature sensor.
- The glass electrode contains a special glass membrane with a specific pH-sensitive ion-selective material that responds to the hydrogen ion activity in the given solution.
- The reference electrode, which is often a silver chloride electrode, provides a stable reference potential for the measurement.
- The temperature sensor measures the temperature of the solution, which is necessary for accurate pH measurements.
- The three components are interconnected and connected to a pH meter, which measures and displays the pH value.

Conductivity sensors

- Conductivity sensors measure the electrical conductivity within a solution.
- They are typically used in applications such as water quality monitoring, chemical processes, and environmental studies.
- They work by measuring the electrical current flowing through a solution.
- Conductivity sensors can be used to measure the concentration of dissolved salts, ions, and other conductive materials in a solution.
- They are also used to detect changes in the pH, temperature, and other characteristics of a solution.

Humidity sensors

- Humidity sensors are devices used to measure the relative humidity of a given environment.
- They are typically used in industrial, commercial, and residential applications to ensure the comfort and safety of occupants.
- They can also be used to monitor and control humidity levels in greenhouses, agricultural settings, and other areas where humidity levels can affect plant and animal health.
- Humidity sensors generally come in two main types: capacitive and resistive.
- Capacitive sensors measure the capacitance of two electrodes and the resistance of a third, while resistive sensors measure the resistance of a single electrode.

Potentiometric Biosensors

- Potentiometric biosensors are electrochemical sensors that measure the electrical potential of a biological sample.
- They are used to detect a variety of substances, including enzymes, proteins, ions, and metabolites.
- They are especially useful for detecting small concentrations of analytes, making them ideal for medical diagnostic applications.
- Potentiometric biosensors are also used in environmental monitoring and food safety.
- They are relatively simple to construct and operate, and they do not require a lot of energy to operate, making them cost-effective and efficient.

Proximity sensors

- Proximity sensors are devices that detect the presence of objects without physical contact.
- They are used in a variety of applications, such as in security systems, in robotics, and in factory automation.
- Proximity sensors use one of several technologies, including infrared, ultrasound, and capacitive sensing.
- They can be used to detect objects within a certain range, and can be programmed to trigger a response when an object is detected.
- Common uses of proximity sensors include detecting when an object is in a certain area, detecting when a person or vehicle is nearby, and providing feedback to automated systems.

Selection of sensors

- The selection of sensors depends on the application.
- Some of the most common types of sensors used in industrial applications include temperature sensors, pressure sensors, flow sensors, position sensors, and proximity sensors.
- Each type of sensor is designed to detect a specific physical parameter, such as temperature, pressure, or flow rate.
- Depending on the application, other types of sensors may be required, such as optical sensors, humidity sensors, or ultra-sonic sensors.

When selecting sensors, the following criteria should be considered:

1. **Accuracy:** The accuracy of a sensor is important, as it will determine how accurate the measurements taken are.

2. **Resolution:** The resolution of a sensor will determine how detailed the readings are.

3. **Sensitivity:** Sensitivity is important, as it will determine how sensitive the sensor is to changes in the environment.

4. **Range:** The range of a sensor should be checked to ensure that it is able to measure the required parameter over the desired range.

5. **Response time:** Response time is important, as it will determine how quickly the sensor can respond to changes in the environment.

6. **Cost:** Cost is an important consideration when selecting sensors, as more accurate and sensitive sensors tend to be more expensive.


Thank You