Criteria for selection of sensors

SENSOR SELECTION

- **Application-specific selection**: performance characteristics such as physical size, input requirements, outputs, life, cost, etc.
- The sensor characteristics may be classified as **design, electrical, static, and dynamic characteristics** which are listed in their datasheets.
- The transducer converts the detected measurand into a convenient form for subsequent use, e.g., for **control or actuation.**
- The transducer signal may be **filtered, amplified, and suitably modified.**

Sensor Characteristics

- The characteristics of a sensor related to **steady state output** when a constant input is applied are known as static characteristics.
- Dynamic characteristics are related to the response or output of the sensor for time-varying input. The input signals can be step, ramp, impulse, or sinusoidal.
- The characteristics of sensors can also be classified as input, transfer, and output characteristics.

Sensor characteristics

- Range
- Sensitivity
- Linearity
- Response time
- Bandwidth
- Accuracy
- Repeatability and precision
- Resolution and Threshold
- Hysterisis
- Type of output
- Size and weight
- Environment
- Reliability and maintainability
- Interfacing

1. Range

- Range or span is a measure of the difference between the minimum and maximum values of its input or output (response) so as to maintain a required level of output accuracy.
- It is defined as the limits between which inputs can vary.

1. Range

- Eg: strain gauge might be able to measure output values over the range from 0.1 to 10 Newtons
- The range of LM35 is -55^0C to 150^0C, and span is $200\ ^0C$

2. Sensitivity

- It is the ability of the measuring instrument to respond to changes in measured quantity
- Sensitivity is defined as the ratio of the change of output to change in input.
- Eg., if a movement of 0.025 mm in a linear potentiometer causes an output voltage by 0.02 volt then the sensitivity is 0.8 volts per mm.

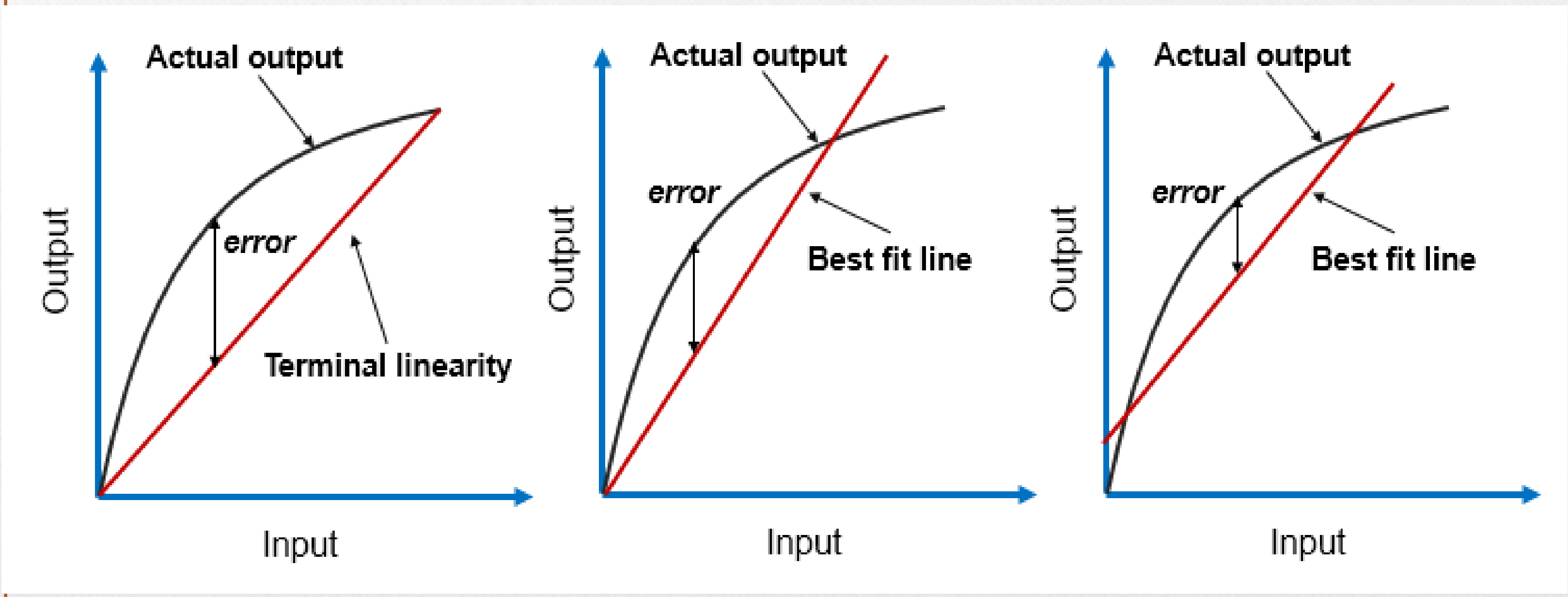
2. Sensitivity

- It is sometimes used to indicate the smallest change in input that will be observable as a change in output.
- Usually, maximum sensitivity that provides a linear and accurate signal is desired
- In the case of LM35, output is voltage, sensitivity is defined as 10 $mV/^0C$.

3. Linearity

- Perfect linearity would allow output versus input to be plotted as a straight line on a graph paper.
- Linearity is a measure of the constancy of the ratio of output to input.
- In the form of an equation, it is $y = mx$ where x is input and y is output, and m is a constant.
- If m is a variable, the relationship is not linear.

- Linearity error is the deviation of the sensor output curve from a specified straight line over a desired range.
- This linearity error is also defined as non-linearity



4. Response Time

- Response time is the time required for a sensor to respond completely to a change in input.
- The response time of a system with sensors is the combination of the responses of all individual components, including the sensor.
- An important aspect in selecting an appropriate sensor is to match its time response to that of the complete system.

5. Bandwidth

- It determines the maximum speed or frequency at which an instrument associated with a sensor is capable of operating.
- High bandwidth implies a faster speed of response.
- Instrument bandwidth should be several times greater than the maximum frequency of interest in the input signals.

6. Accuracy

- Accuracy is a measure of the difference between the measured and actual values.
- Accuracy describes 'closeness to true values.'
- An accuracy of ±0.025 mm means that under all circumstances considered, the measured value will be within 0.025 mm of the actual value.

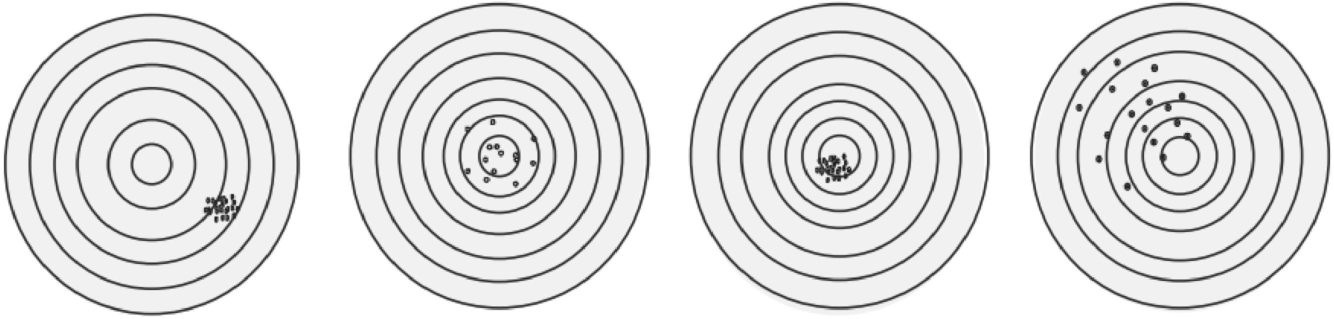
7. Repeatability and Precision

- Repeatability is a measure of the difference in value between two successive measurements under the same conditions.
- As long as the forces, temperature, and other parameters have not changed, one would expect the successive values to be the same, however poor the accuracy is.
- It is the ability to reproduce the output signal exactly when the same measured quantity is applied repeatedly under the same environmental conditions.
- The repeatability is defined for a specific value of input or measurand.

Precision

- Precision, which means the 'closeness of agreement' between independent measurements of a quantity under the same conditions without any reference to the true value.
- The number of divisions on the scale of the measuring device generally affects the consistency of repeated measurement and, therefore, the precision.

Interpretation of accuracy and precision



(a) Poor Accuracy Good precision

(b) Good Accuracy Poor precision

(c) Good Accuracy Good precision

(d) Poor Accuracy Poor precision

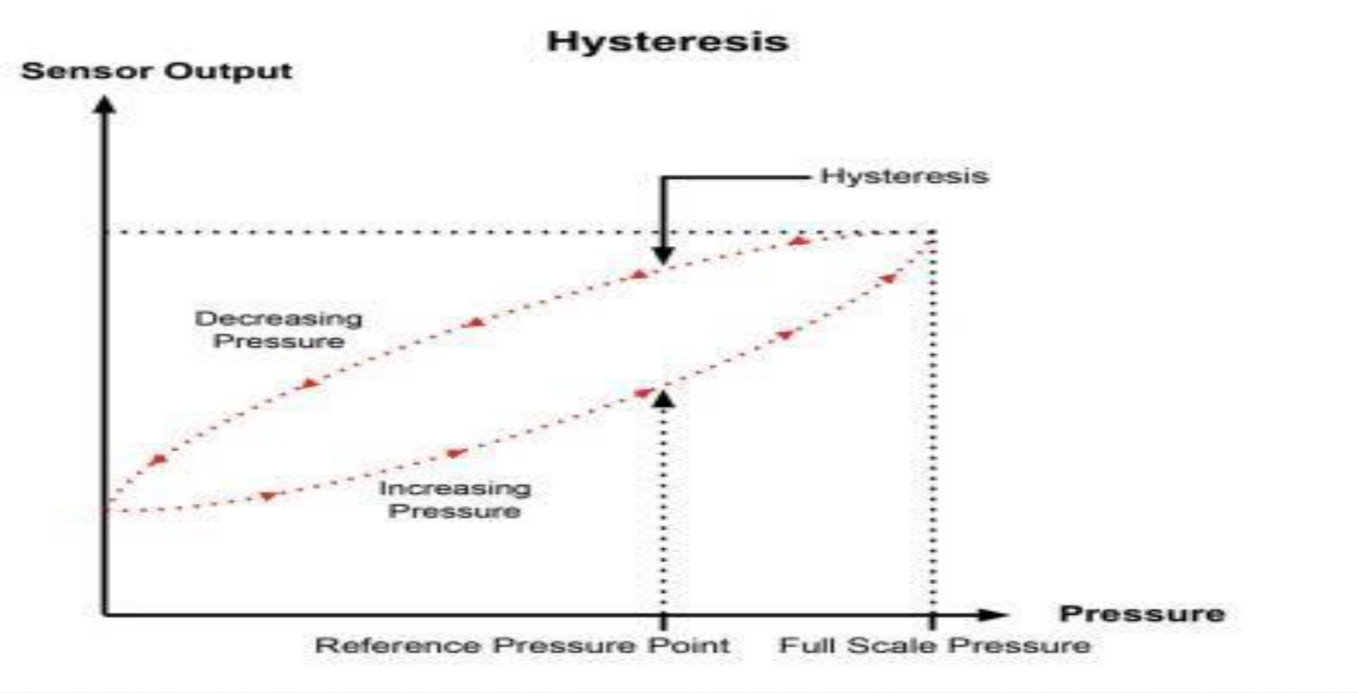
8. Resolution and Threshold

- The sensor resolution or measurement resolution is the smallest change that can be detected in the quantity that is being measured which is observable.
- Threshold is a particular case of resolution.
- Threshold is defined as the minimum value of input below which no output can be detected.

9. Hysteresis

- It is defined as the change in the input/ output curve when the sign of measurement changes.
- The effect of obtaining different outputs for the same input when input is increasing and decreasing.
- This behaviour is common in loose components such as gears, which have backlash, and magnetic devices with ferromagnetic media, and others.

9. Hysteresis



10. Type of Output

- Output can be in the form of a mechanical movement, an electrical current or voltage, a pressure, or liquid level, a light intensity, or another form.
- To be useful, it must be converted to another form, as in the LVDT (Linear Variable Differential Transducer) or strain gauges.

11. Size and Weight

- Size and weight are usually important physical characteristics of sensors.
- If the sensor is to be mounted on the robot's hand or arm, it becomes a part of the mass that must be accelerated and decelerated by the drive motors of the wrist and arm.
- So, it directly affects the performance of the robot.
- It is a challenge to sensor designers to reduce size and weight.
- An early wrist force-torque sensor, for example, was about 125 mm in diameter but was reduced to about 75 mm in diameter through careful redesign.

12. Environmental Conditions

- Power requirement and its easy availability should be considered.
- Besides, conditions like chemical reactions including corrosion, extreme temperatures, light, dirt accumulation, electromagnetic field, radioactive environments, shock and vibrations, etc., should be taken into account while selecting a sensor or considering how to shield them.

13. Reliability and Maintainability

- Reliability is of major importance in all robot applications.
- It can be measured in terms of Mean Time To Failure (MTTF) as the average number of hours between failures that cause some part of the sensor to become inoperative.
- In industrial use, the total robot system is expected to be available as much as 98 or 99% of the working days.

13. Reliability and Maintainability

- Since there are hundreds of components in a robot system, each one must have a very high reliability.
- Some otherwise good sensors cannot stand the daily environmental stress and, therefore, cannot be used with robots.

Maintainability

- Part of the requirement for reliability is ease of maintenance.
- A sensor that can be easily replaced does not have to be as reliable as one that is hidden in the depths of the robot.
- Maintainability is a measure in terms of Mean Time To Repair (MTTR)

14. Interfacing

- Interfacing of sensors with signal-conditioning devices and the controller of the robot is often a determining factor in the use of sensors.
- Nonstandard plugs or requirements for nonstandard voltages and currents may make a sensor too complex and expensive to use.
- The signals from a sensor must be compatible with other equipment being used if the system is to work properly.

15. Others

- Other aspects like
  - initial cost,
  - maintenance cost,
  - cost of disposal and replacement,
  - reputation of manufacturers,
  - operational simplicity,

15. Others

- Ease of availability of the sensors and their spares should be taken into account.
- In many occasions, these non-technical considerations become the ultimate deciding factor in the selection of sensors for an application.

MODULE II

CLASSI

MODULE II

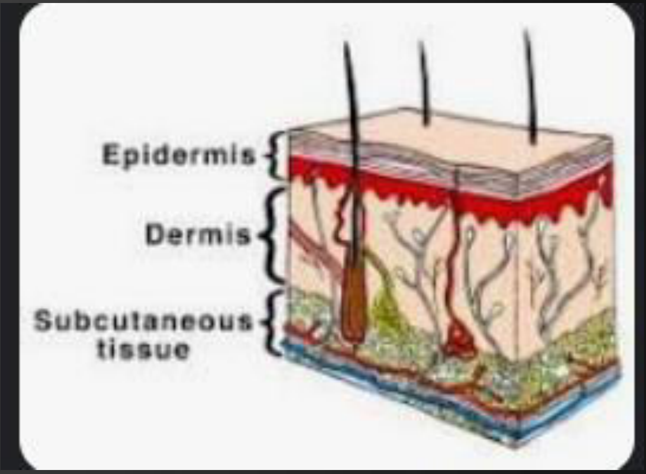
- Sensor classification- touch, force, proximity, vision sensors.
- Internal sensors-Position sensors, velocity sensors
- Acceleration sensors, Force sensors;
- External sensors-contact type, non-contact type
- Digital Camera - CCD camera - CMOS camera
- Omnidirectional cameras - Sensor characteristics
- Actuators - DC Motors - H-Bridge - Pulse Width Modulation
- Stepper Motors – Servos - Control - On-Off Control
- PID Control - Velocity Control and Position Control

TOUCH SENSORS

- Tactile sensors are data acquisition devices, or transducers, which consist of an array of touch-sensitive sites, which works through direct physical contact.
- Tactile sensors can be used to sense a **diverse range of stimuli** ranging from detecting the presence or absence of a grasped object to a complete tactile image.
- The contact forces measured by a sensor are able to convey a large amount of information about the state of a grip and it is **capable of measuring more than one property .**
- Texture, slip, impact and other contact conditions generate force and position signatures, that can be used to identify the state of manipulation.

TOUCH SENSORS: THE SOMATOSENSORY SYSTEM.

- Our sense of touch is controlled by a huge network of nerve endings and touch receptors in the skin known as the somatosensory system.
- This system is responsible for all the sensations we feel – cold, hot, smooth, rough, pressure, tickle, itch, pain, vibrations, and more.
- **Cutaneous touch** has the capability of detecting the stimuli resulting from mechanical stimulation, pain, and temperature.
- **The kinesthetic touch** receives sensor inputs from the receptors present inside the muscles, tendons, and joints
- Tactile Sensor → Cutaneous Sensory Receptors



APPLICATIONS

Tactile sensors are used in

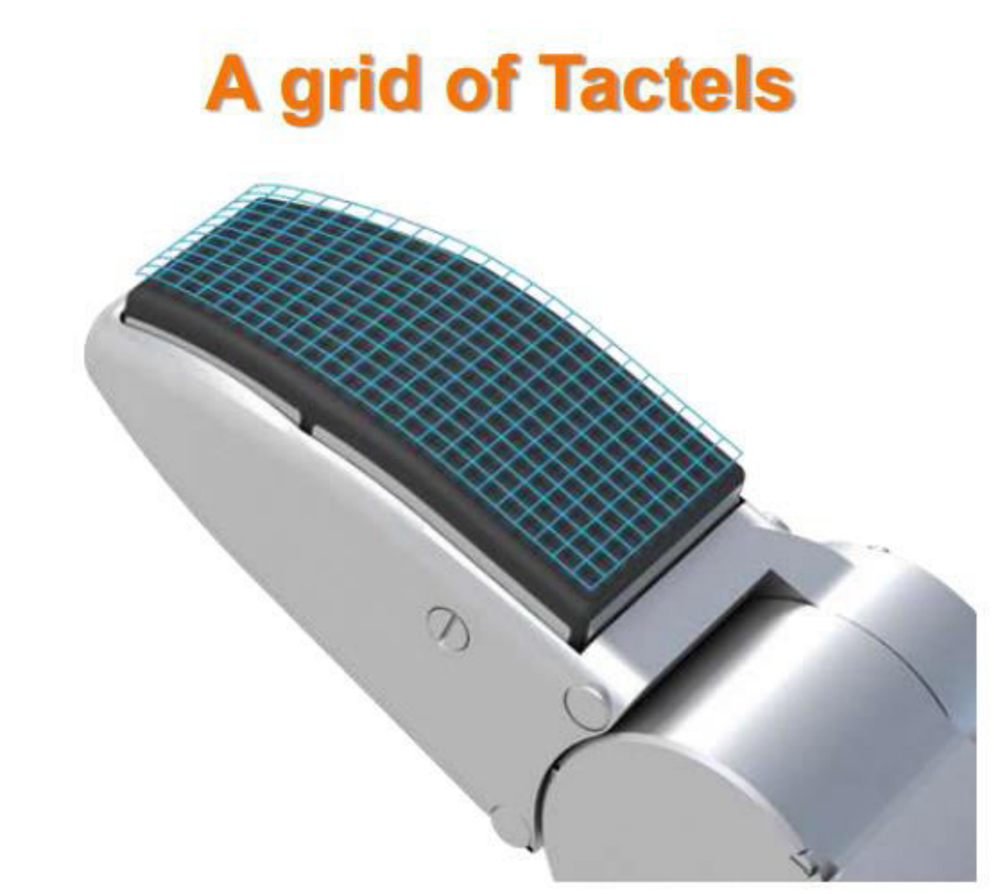
- Robotics,
- computer hardware (touchscreen of the mobile phones and in computers.)
- security systems
- Elevator button
- vibration sensing.
- It is also pressure-sensitive device

ROBOTIC APPLICATIONS

- Manipulation : Grasp force control, contact locations, kinematics, and stability assessment.
- Exploration : Surface texture, friction, and hardness; thermal properties, local features.
- Response: Detection and reaction to contact from external agents.

TOUCH SENSORS: MAJOR COMPONENTS

- Touch surface
- Transduction medium
- Structure
- Control interface

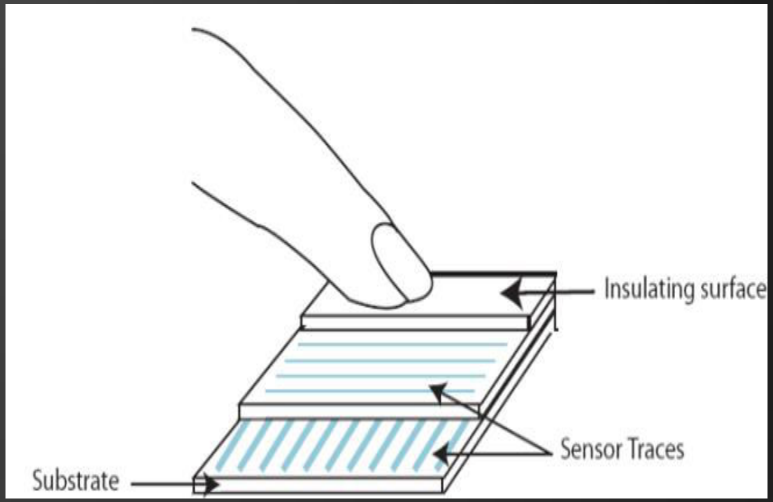


TOUCH SURFACE: RESISTIVE SENSING ELEMENTS

- Strain gauge: A thin film having a metal pattern **changes its resistance when strained.**
- **Piezoelectric element :** **P**ressure on the element causes the material to compress changing its resistance.
- Advantages: Very simple construction, durable, good dynamic range, easy read out.
- Disadvantages: nonlinearity, hysteresis, and low sensitivity.

TOUCH SURFACE: CAPACITIVE SENSING ELEMENTS

- Mechanical deformation, changes the capacitance of parallel conducting plates
- Applications in touch screens
- Advantages : Good dynamic range, Linearity.
- Disadvantages: Noise and measuring capacitance is hard!!



TOUCH SURFACE: MAGNETIC SENSING ELEMENTS

- There are two approaches to the design of touch or tactile sensors based on magnetic transduction.
  - The movement of a small magnet by an applied force will cause the flux density at the point of measurement to change. The flux measurement can be made by either a Hall effect or a magneto-resistive device.
  - The core of the transformer or inductor can be manufactured from a magnetoelastic material that will deform under pressure and cause the magnetic coupling between transformer windings, or a coil's inductance to change.
  - Advantages : high sensitivity and dynamic range, no measurable mechanical hysteresis, a linear response, and physical robustness.

TOUCH SURFACE: OPTICAL SENSING ELEMENTS

- The operating principles of optical-based sensors fall into two classes:
  - Intrinsic, where the optical phase, intensity, or polarization of transmitted light are modulated without interrupting the optical path.
  - Extrinsic, where the physical stimulus interacts externally with the primary light path.

TOUCH SURFACE: OPTICAL SENSING ELEMENTS

- For robotic touch and force-sensing applications, the extrinsic sensor based on intensity measurement is the most widely used due to its simplicity of construction and subsequent information processing.

  Advantages:

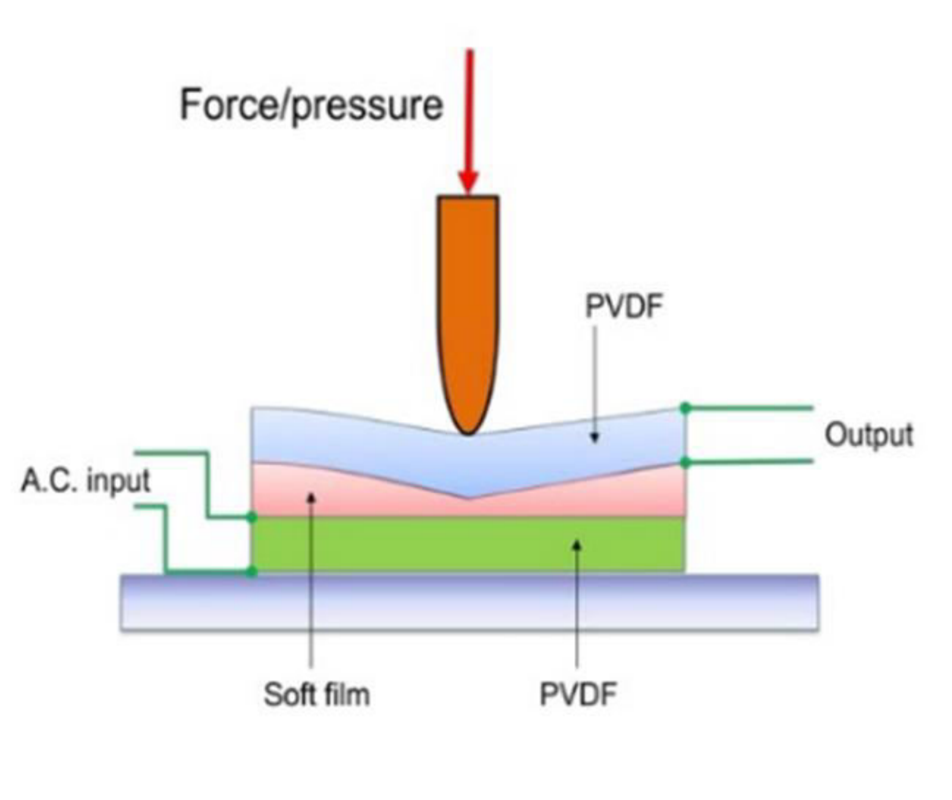
  - Immunity to external electromagnetic interference,
  - Intrinsically safe.
  - The use of optical fibre allows the sensor to be located some distance from the optical source and receiver.
  - Low weight and volume.

TOUCH SURFACE: PIEZOELECTRIC SENSING ELEMENTS

- Polymeric materials that exhibit piezoelectric properties are suitable for use as touch or tactile sensors
- Polyvinylidene fluoride is not piezoelectric in its raw state, but can be made piezoelectric **by heating** the PVDF within an electric field.
- PVDF is used in the form of sheets with **5 microns-2 mm thickness**, and has good mechanical properties.
- **A thin layer of metallization** is applied to both sides of the sheet to collect the charge and permit electrical connections being made.

TOUCH SURFACE: PIEZOELECTRIC SENSING ELEMENTS

- It has **two PVDF layers** separated by a soft film that transmits the vibrations.
- An **alternating current is applied to the lower PVDF layer** which generates vibrations due to the reverse piezoelectric effect.
- These vibrations are **transmitted to the upper PVDF layer** via soft film. These vibrations cause the 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.

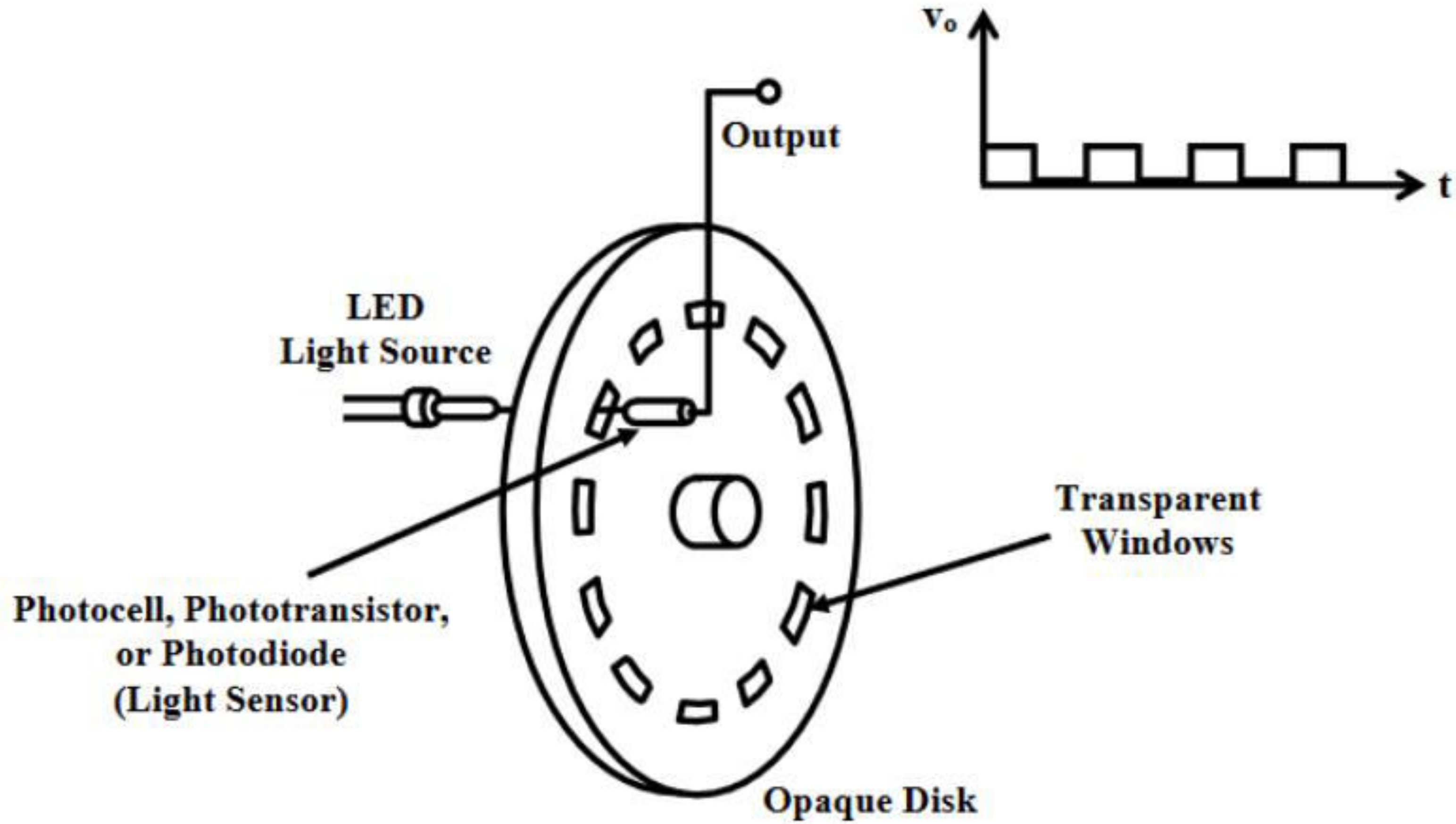


Velocity sensors

Velocity sensors

- A velocity or speed sensor measures consecutive position measurements at known intervals and computes the time rate of change in the position values.
- **All Position Sensors:**
  - Basically, all position sensors when used with certain time bounds can give velocity, e.g., the number of pulses given by an incremental position encoder divided by the time consumed in doing so.
  - But this scheme puts some computational load on the controller which may be busy in some other computations.

Speed sensors



Tachogenerator

Tacho Generator

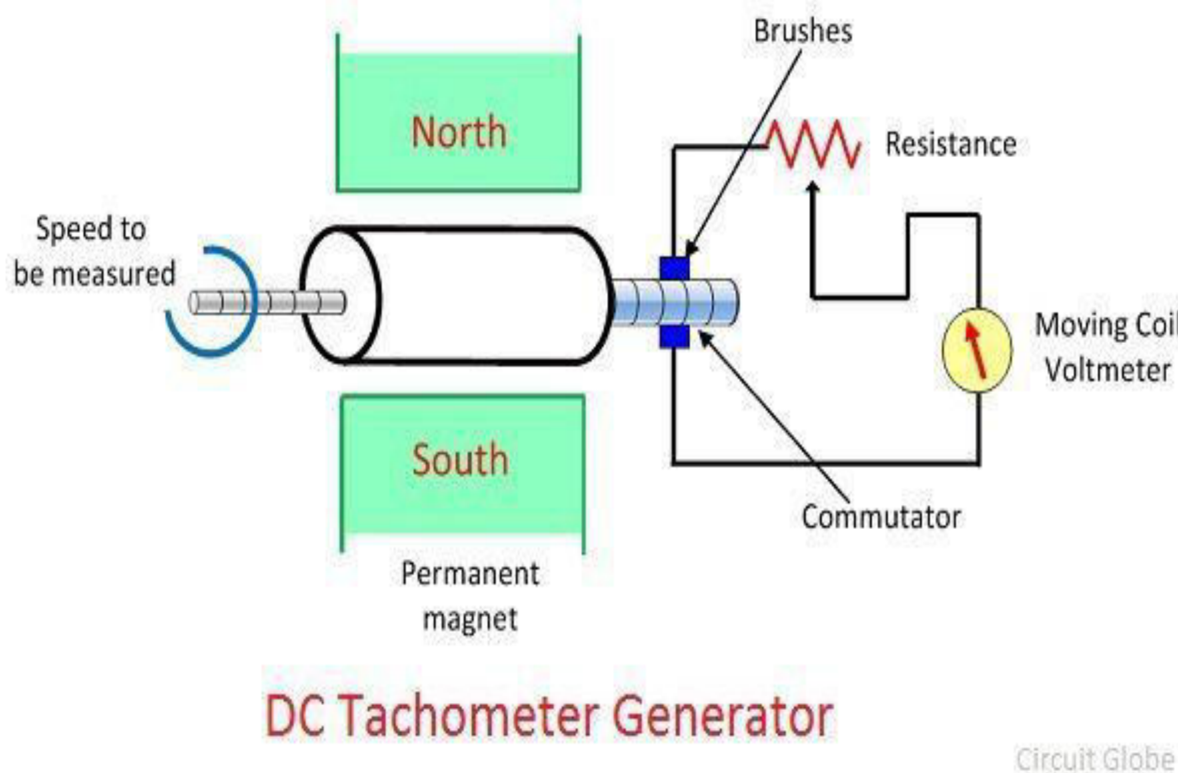
- The word Tachogenerator comes from Greek word 'TACHO'.
- In Greek, Tacho means speed. Generator means an instrument which generate power.
- Tachogenerator, is a device which is used for measuring the speed of a shaft and converting into a voltage so that it can be measured.
- In other words, it converts angular velocity into voltage.

Types of Tachogenerator

- Depends on the natures of the induced voltage the electrical tachometer is categorized into two types.
  - DC Tachogenerator - A DC Tachogenerator is a small DC generator, which generate electrical voltage corresponding to the speed of rotating machine.
  - AC Tachogenerator - The AC tachogenerator is a small brushless alternator with a rotating multi-pole permanent magnet. The output voltage is again measured by a voltmeter although the varying frequency will affect the accuracy of this instrument

DC Tachogenerator

- Permanent magnet, armature, commutator, brushes, variable resistor, and the moving coil voltmeter are the main parts of the DC tachometer generator



- The machine whose speed is to be measured is coupled with the shaft of the DC tachometer generator.

Working

- The DC tachometer works on the principle that when the closed conductor moves in the magnetic field, EMF induces in the conductor. The magnitude of the induces emf depends on the flux link with the conductor and the speed of the shaft.
- The armature of the DC generator revolves between the constant field of the permanent magnet. The rotation induces the emf in the coil. The magnitude of the induced emf is proportional to the shaft speed.
- The commutator converts the alternating current of the armature coil to the direct current with the help of the brushes.
- The moving coil voltmeter measures the induced emf. The polarity of the induces voltage determines the direction of motion of the shaft.
- The resistance is connected in series with the voltmeter for controlling the heavy current of the armature.

- The emf induces in the dc tachometer generator is given as

$$E = \frac{\emptyset PN}{60} \times \frac{z}{a}$$

  - Where, E – generated voltage
    Φ – flux per poles in Weber
    P- number of poles
    N – speed in revolution per minutes
    Z – the number of the conductor in armature windings.
    a – number of the parallel path in the armature windings.

- $$E \;\alpha\; N$$

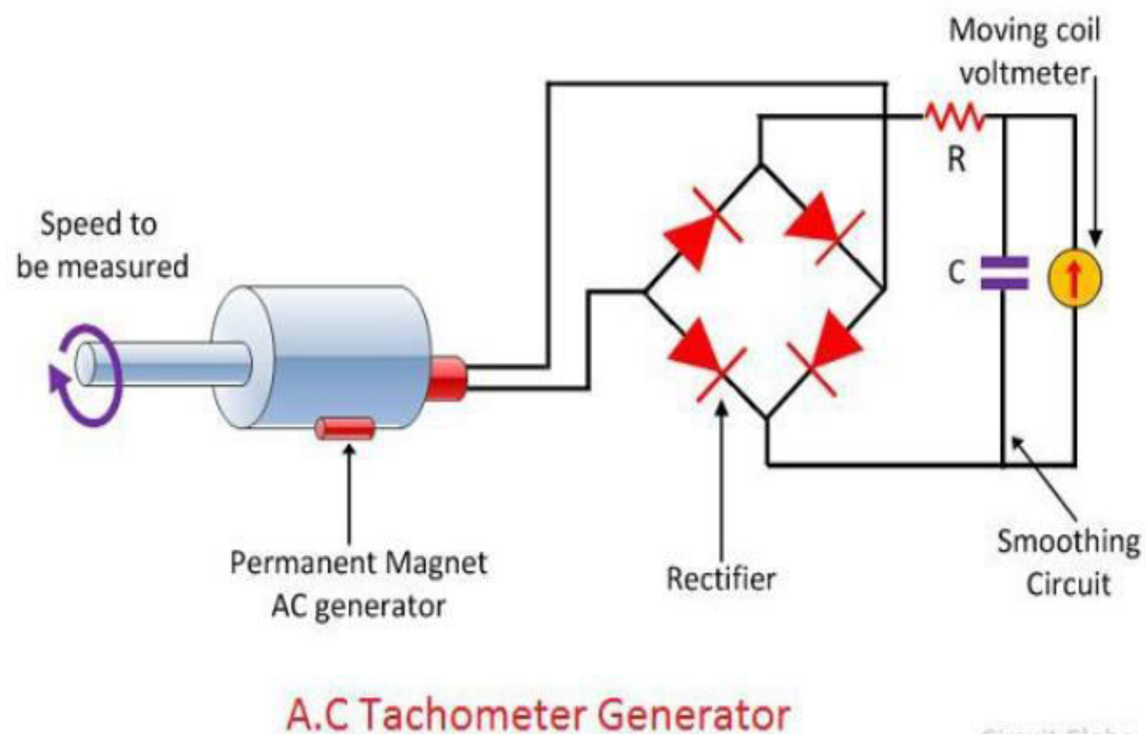
  $$E = KN$$

  $$K = Constant = \frac{\emptyset P}{60} \times \frac{z}{a}$$

- Advantages of the DC Tachometer.
  - The polarity of the induces voltages indicates the direction of rotation of the shaft.
  - The conventional DC type voltmeter is used for measuring the induces voltage.
- Disadvantages of DC Generator
  - The commutator and brushes require the periodic maintenance.
  - The output resistance of the DC tachometer is kept high as compared to the input resistance. If the large current is induced in the armature conductor, the constant field of the permanent magnet will be distorted.

AC Tachometer Generator

- It consists of:
  - Permanent Magnet
  - Coil (Stator)
  - Rectifier Bridge
  - Moving Coil (MC) Voltmeter



working

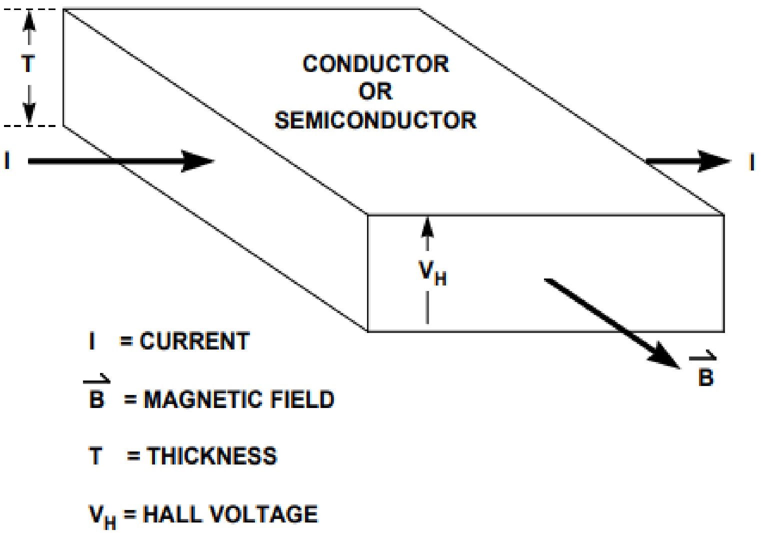
- The AC tachometer has stationary armature and rotating magnetic field. Thus, the commutator and brushes are absent in AC tachometer generator.
- The rotating magnetic field induces the EMF in the stationary coil of the stator. The amplitude and frequency of the induced emf are equivalent to the speed of the shaft. Thus, either amplitude or frequency is used for measuring the angular velocity.
- For measuring the speed of the rotor by considering the amplitude of the induced voltage. The induced voltages are rectified and then passes to the capacitor filter for smoothening the ripples of rectified voltages.

Hall effect sensor

- A **Hall effect sensor** is a transducer that varies its output voltage in response to a magnetic field.
- Hall effect sensors are non-contact, which means that they do not have to come in contact with a physical element.
- They can produce either a digital (on and off) or analog (continuous) signal depending on their design and intended function.
- Hall effect sensors are used for
  - proximity switching,
  - positioning,
  - speed detection
  - current sensing applications.

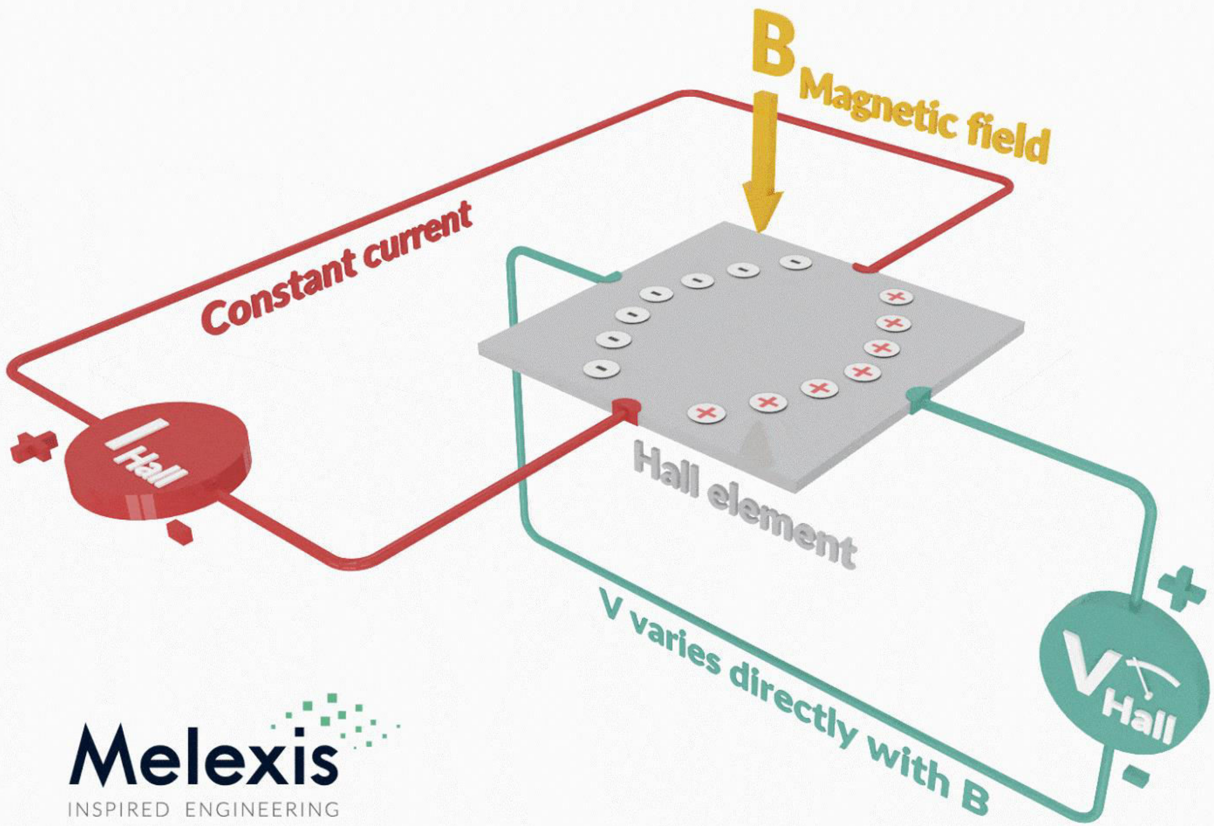
HALL EFFECT SENSORS

- If a current flows in a conductor (or semiconductor) and there is a magnetic field present which is perpendicular to the current flow, then the combination of current and magnetic field will generate a voltage perpendicular to both.
- This phenomenon is called the Hall Effect, was discovered by E. H. Hall in 1879. The voltage, V_H, is known as the Hall Voltage.
- V_H is a function of the current density, the magnetic field, and the charge density and carrier mobility of the conductor.



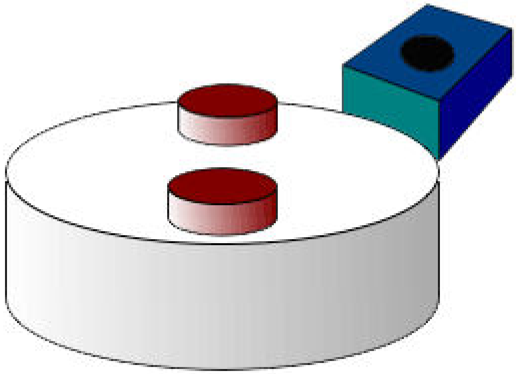
Hall Effect Sensors

- **Hall Effect Sensors** consist basically of a thin piece of rectangular p-type semiconductor material such as gallium arsenide (GaAs), indium antimonide (InSb) or indium arsenide (InAs) passing a continuous current through itself.
- When the device is placed within a magnetic field, the magnetic flux lines exert a force on the semiconductor material which deflects the charge carriers, electrons and holes, to either side of the semiconductor slab.
- This movement of charge carriers is a result of the magnetic force they experience passing through the semiconductor material.
- As these electrons and holes move side wards a potential difference is produced between the two sides of the semiconductor material by the build-up of these charge carriers.
- Then the movement of electrons through the semiconductor material is affected by the presence of an external magnetic field which is at right angles to it and this effect is greater in a flat rectangular shaped material.

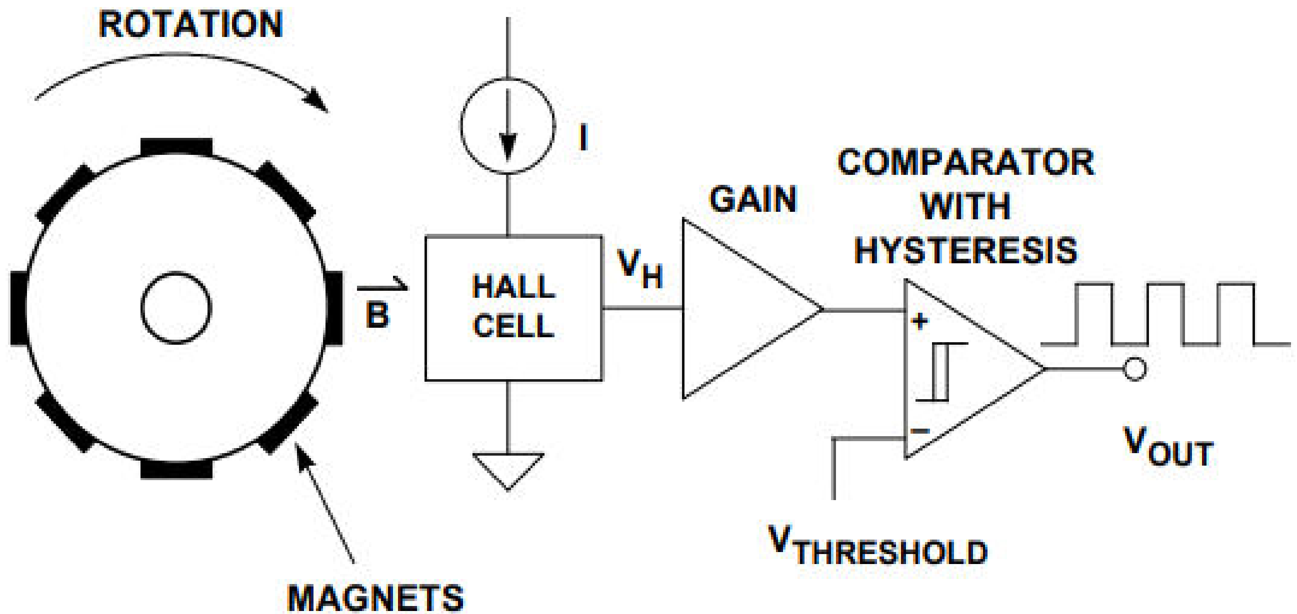


B
Magnetic field
Constant current
I Hall
Hall element
V varies directly with B
V Hall
Melexis
INSPIRED ENGINEERING

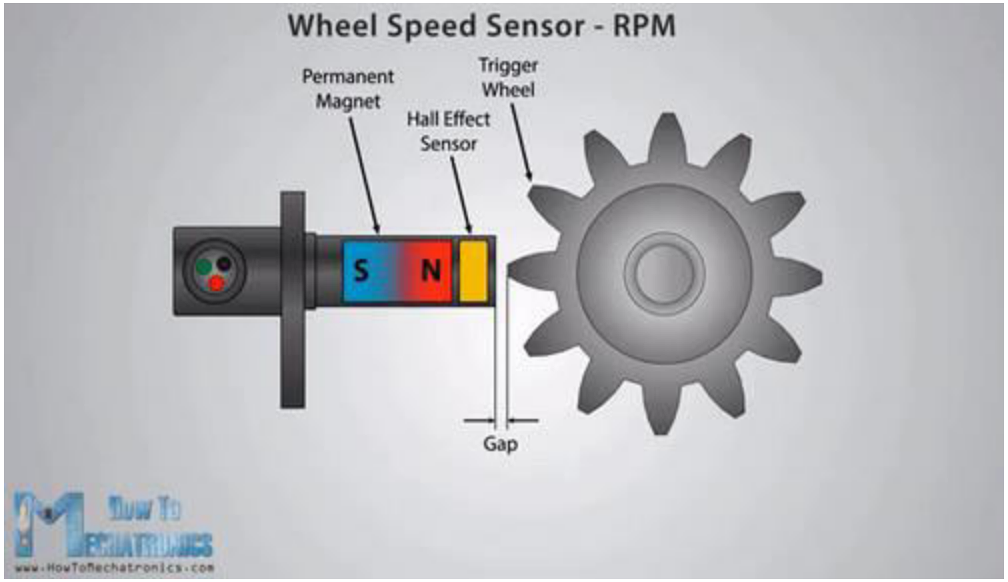
A wheel containing two magnets passing by a Hall effect sensor



HALL EFFECT SENSOR USED AS A ROTATION SENSOR



- Although several materials can be used for Hall effect sensors, silicon has the advantage that signal conditioning circuits can be integrated on the same chip as the sensor.
- CMOS processes are common for this application.
- A simple rotational speed detector can be made with a Hall sensor, a gain stage, and a comparator.
- The circuit is designed to detect rotation speed as in automotive applications.
- It responds to small changes in field, and the comparator has built-in hysteresis to prevent oscillation.
- Several companies manufacture such Hall switches, and their usage is widespread.

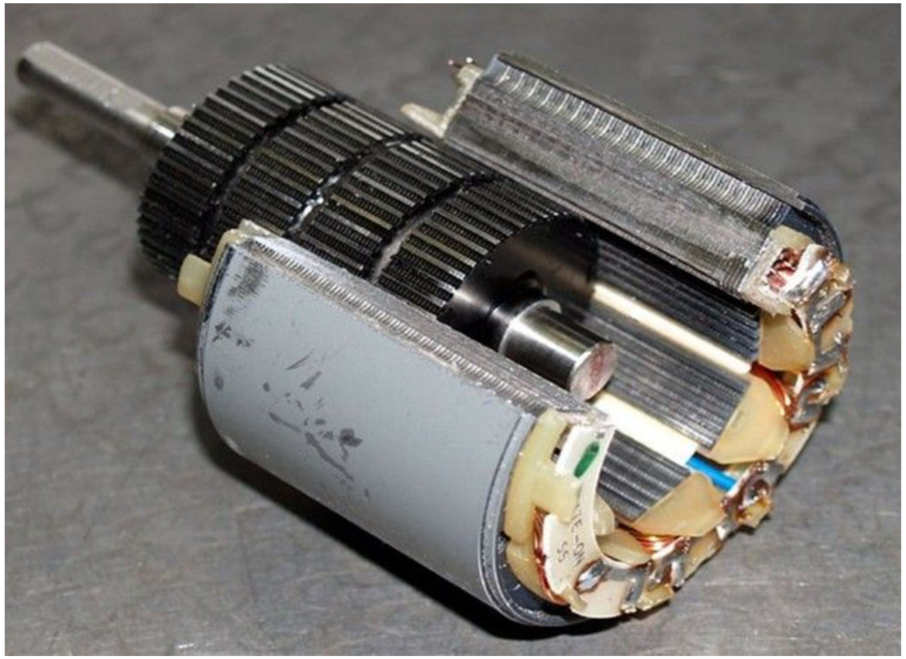


Wheel Speed Sensor - RPM
Permanent
Magnet
Trigger
Wheel
Hall Effect
Sensor
S
N
Gap
www.HowToMechatronics.com

- The output voltage, called the Hall voltage, (V_H) of the basic Hall Element is directly proportional to the strength of the magnetic field passing through the semiconductor material (output $\propto$ H). This output voltage can be quite small, only a few microvolts even when subjected to strong magnetic fields so most commercially available Hall effect devices are manufactured with built-in DC amplifiers, logic switching circuits and voltage regulators to improve the sensors sensitivity, hysteresis and output voltage.

- One of the main uses of magnetic sensors is in automotive systems for the sensing of position, distance and speed.
- For example,
  - the angular position of the crank shaft for the firing angle of the spark plugs,
  - the position of the car seats and seat belts for air-bag control wheel speed detection for the anti-lock braking system, (ABS).

STEPPER MOTOR



Contents

- Introduction of the Stepper motor
- Principle of the Stepper motor
- Classification of the Stepper motor
- Systems of the Stepper motor
- Advantages of the Stepper motor
- Applications of the Stepper motor

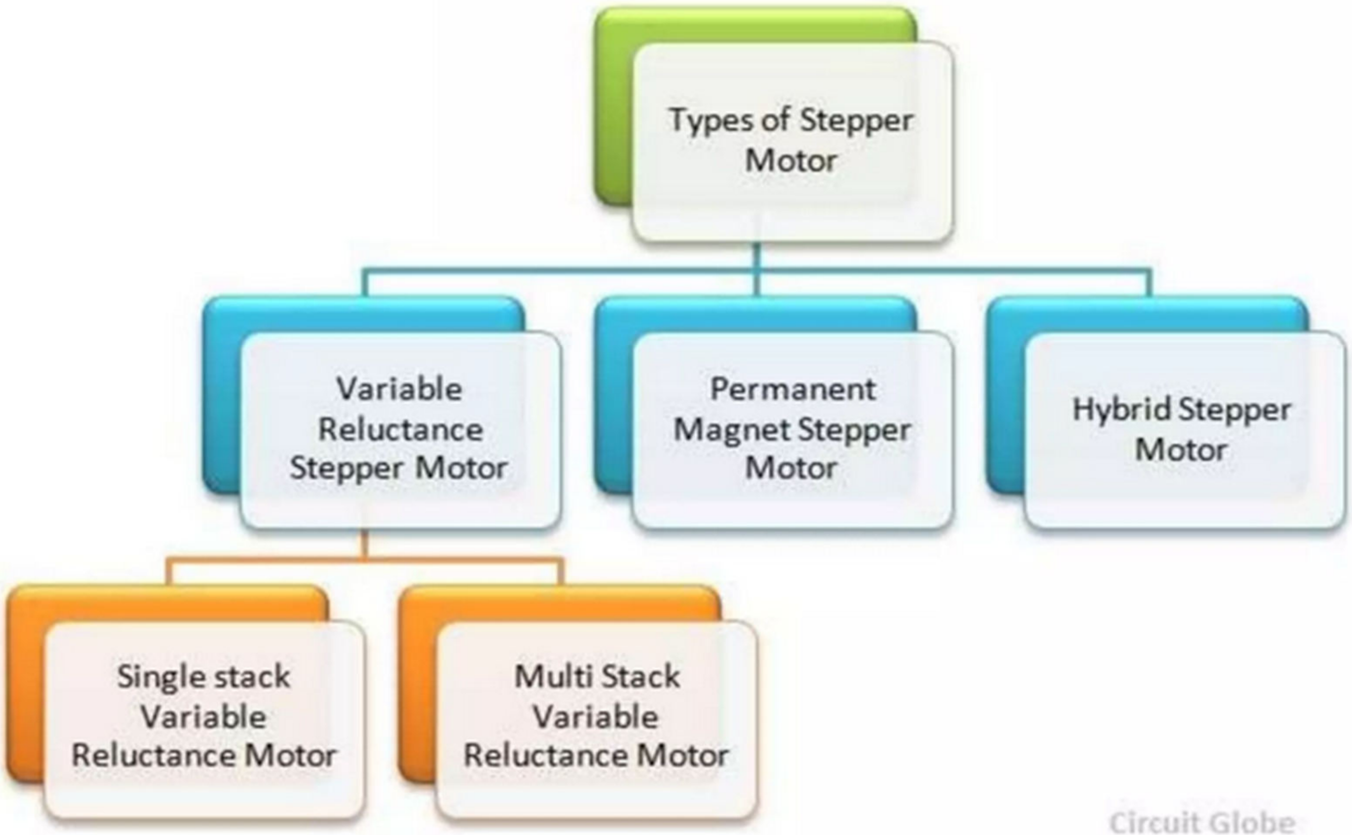
Introduction

- A stepper motor, also known as step motor or stepping motor, is a brushless DC electric motor that divides a full rotation into a number of equal steps.
- A standard motor will have a step angle of 1.8 degrees with 200 steps per revolution.

Principle of the Stepper Motor

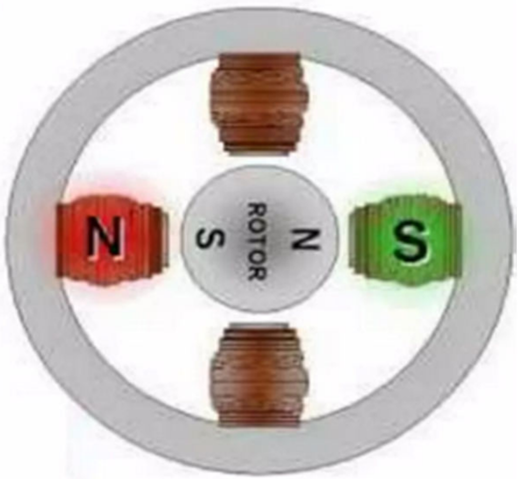
- The operation of this motor works on the principle that unlike poles attract each other and like poles repel each other. When the stator windings are excited with a DC supply, it produces magnetic flux and establishes the North and South poles.

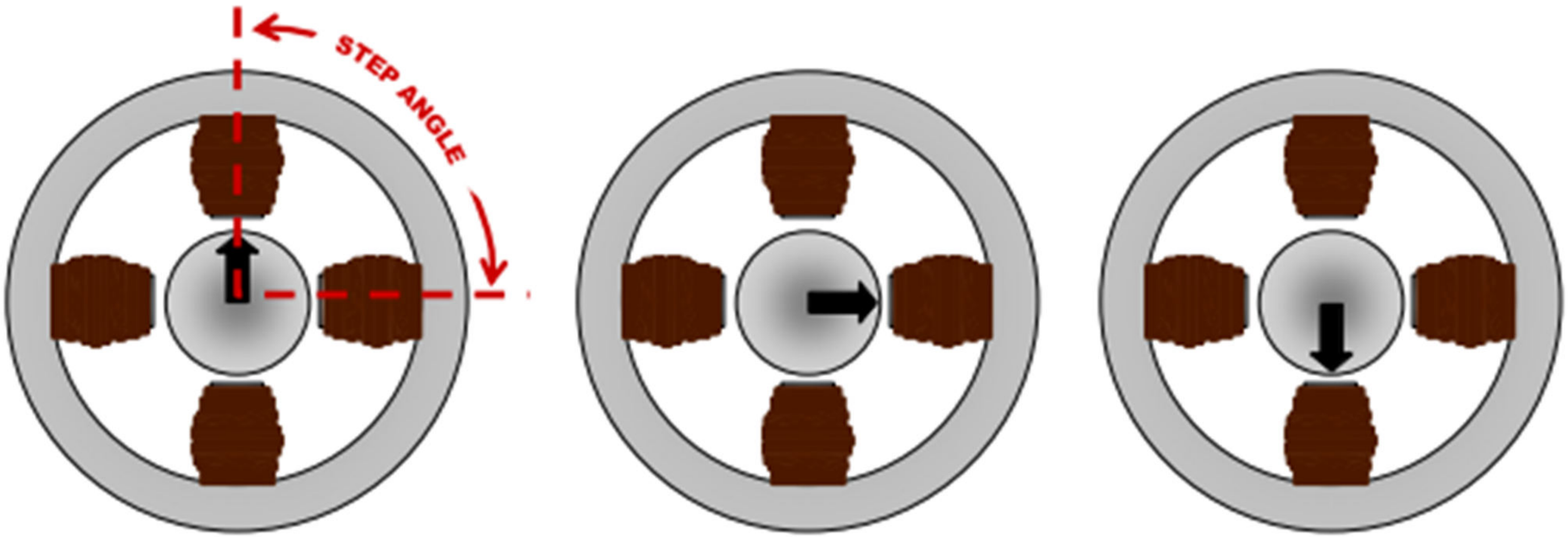
Classification



Permanent Magnet Motors

- Permanent magnet motors use a permanent magnet (PM) in the rotor and operate on the attraction or repulsion between the rotor PM and the stator electromagnets.





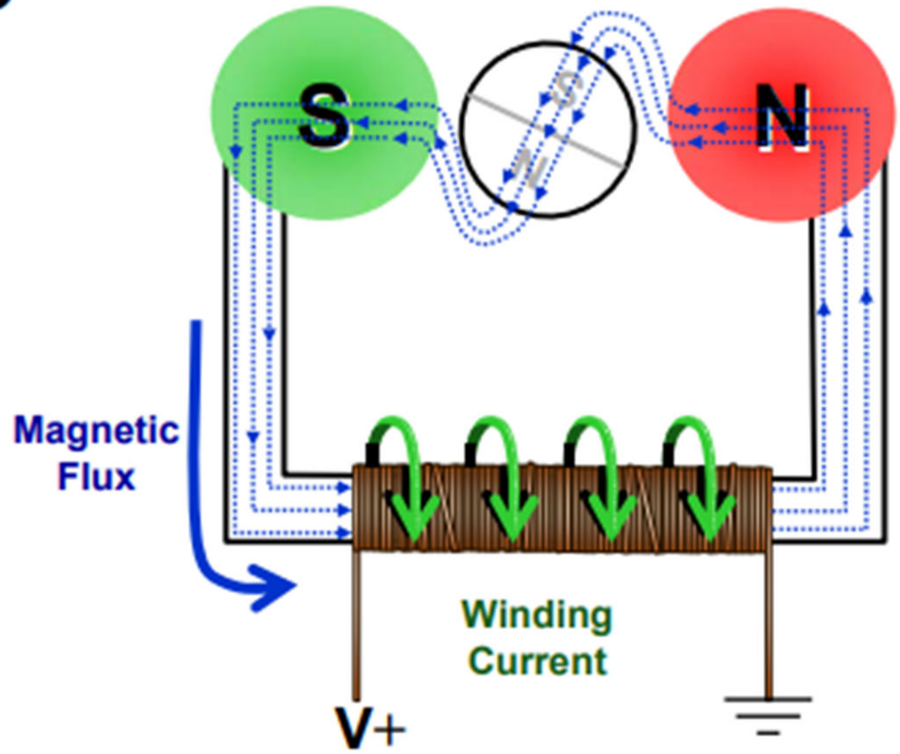
Start Position

Step 1

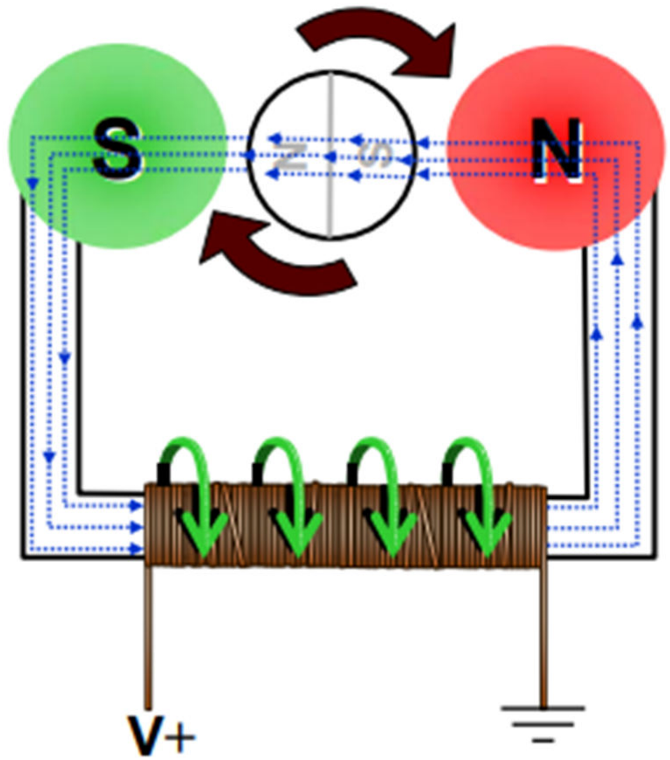
Step 2

- Voltage applied to winding initiates current flow

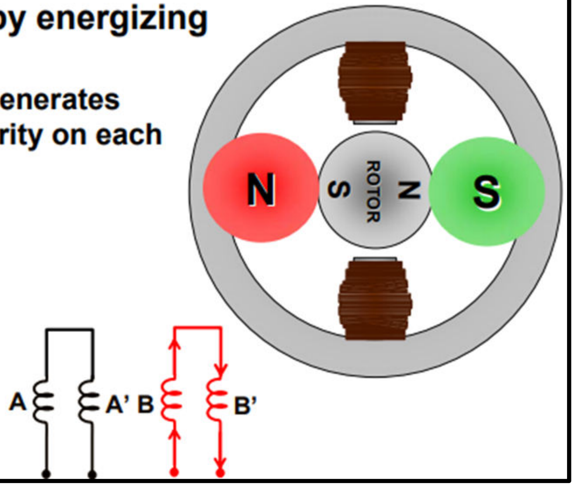
- Magnetic flux begins to flow



- Rotor rotates to minimize flux path (or reluctance)



- Rotor rotates by energizing each winding
  - Current flow generates magnetic polarity on each stator



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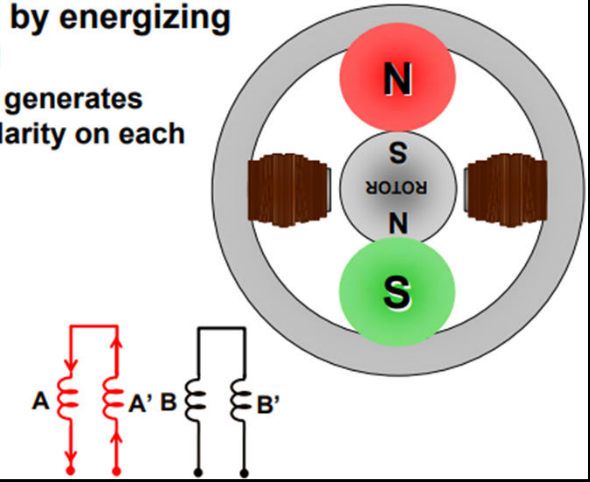
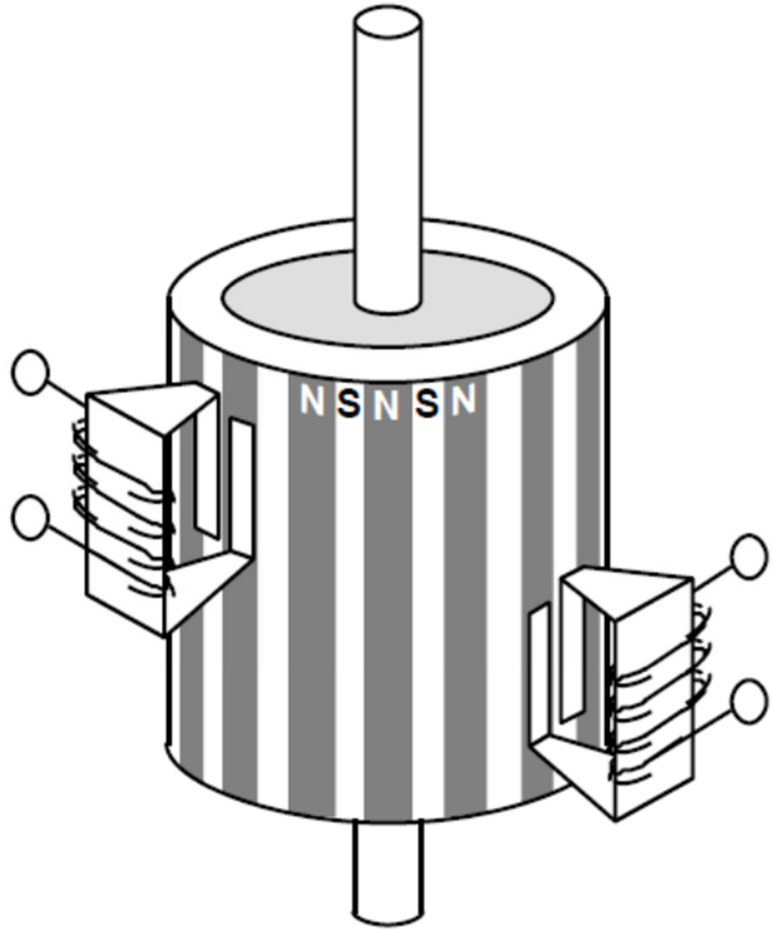
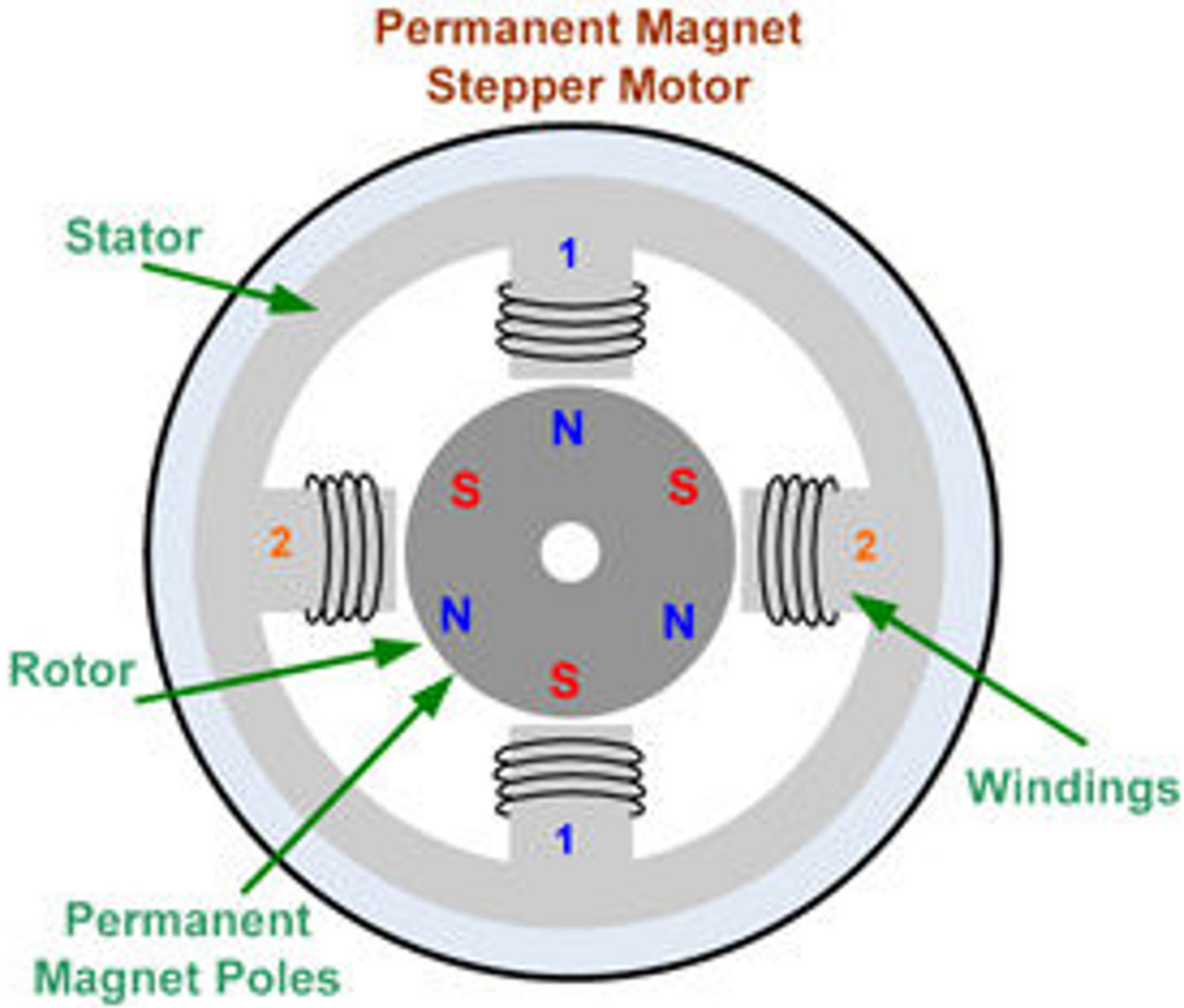


Permanent Magnet (PM) Motor:

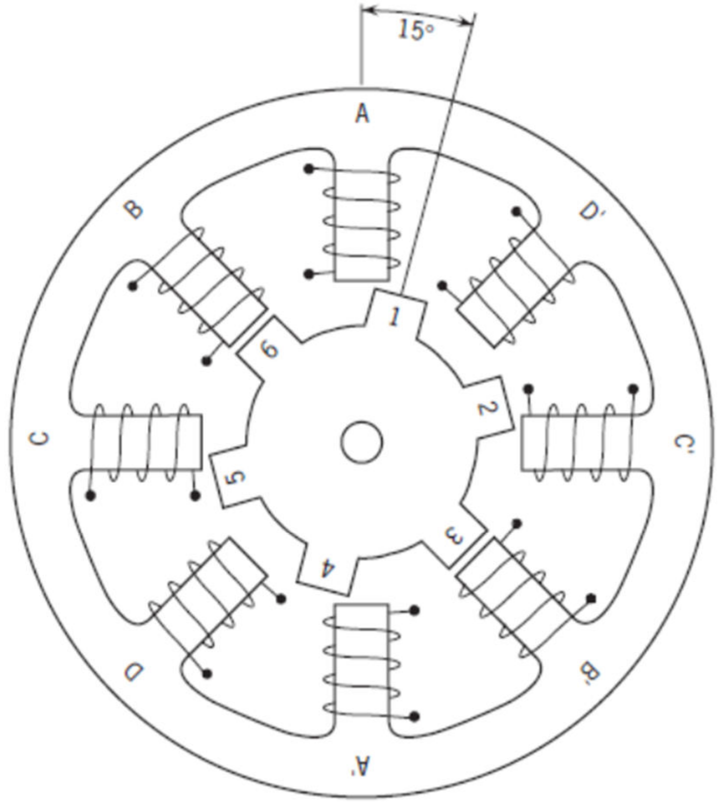
- It is a low cost and low resolution type motor.
- Typical step angles of 7.5° to 15°. (48-24 steps/revolution).
- The rotor is magnetized with alternating north and south poles situated in a straight line parallel to the rotor shaft.
- This structure provide an increased magnetic flux intensity and because of this the PM motor exhibits <u>improved torque characteristics</u> when compared with VR type.




Permanent Magnet
Stepper Motor
Stator
1
N
S
S
2
2
N
N
S
Rotor
1
Windings
Permanent
Magnet Poles

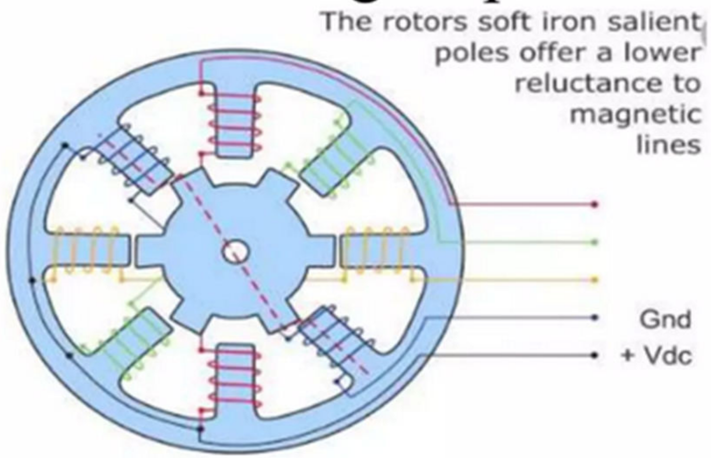
Variable Reluctance (VR) Motor:

- It composed of a soft iron multi-toothed rotor and salient wound stator.
- When the stator windings are energized with DC current the poles become magnetized.
- Rotation occurs when the rotor teeth are attracted to the energized stator poles.

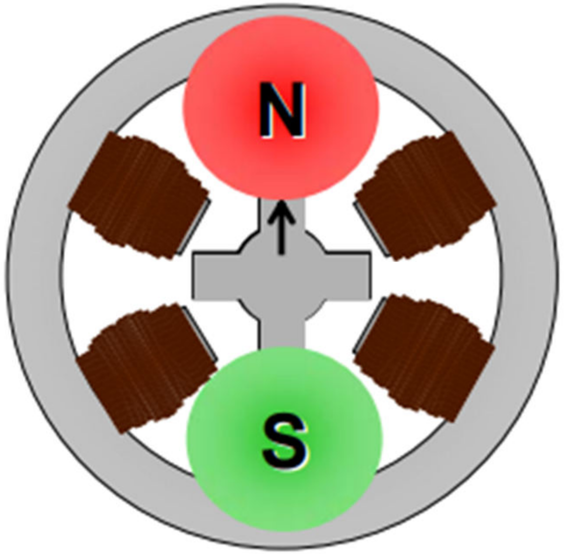


Variable Reluctance Motor

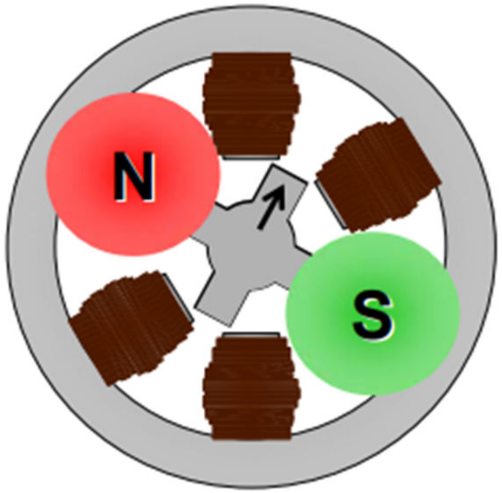
- Variable reluctance (VR) motors have a plain iron rotor and operate based on the principle that minimum reluctance occurs with minimum gap, hence the rotor points are attracted toward the stator magnet poles.

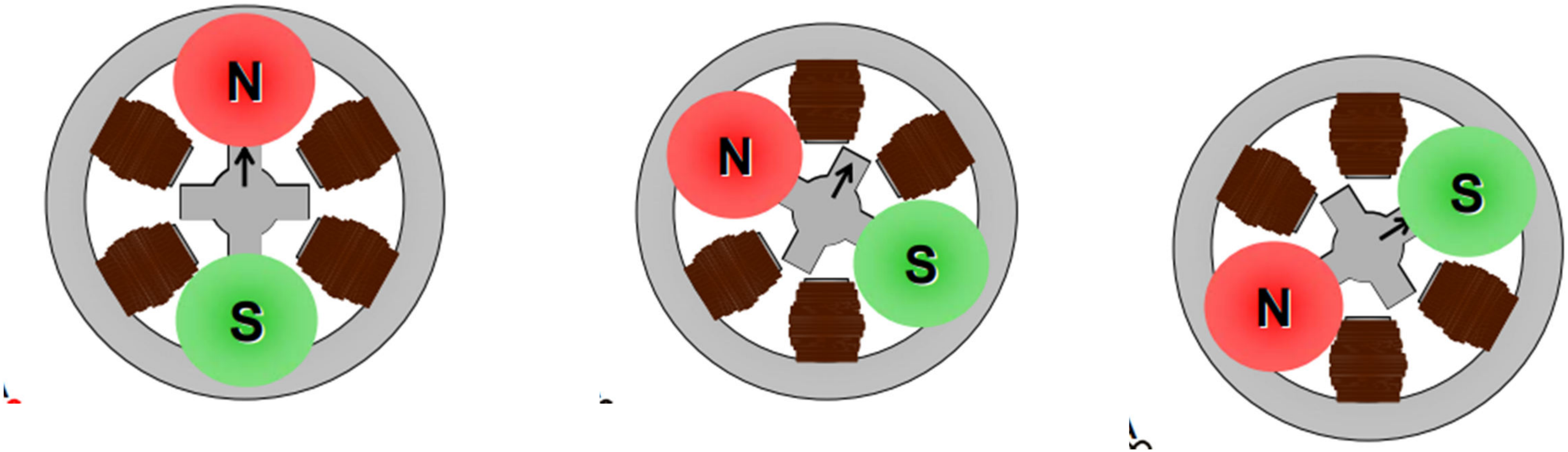


Each winding is again energized one at a time to create a polarity on the appropriate stator poles. The rotor rotates to minimize the reluctance of the magnetic flux path. What happens next differentiates the variable reluctance motor from most other Stepping Motor types.

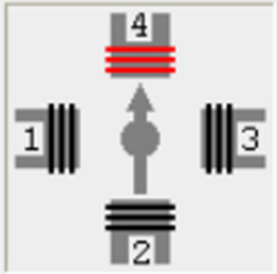
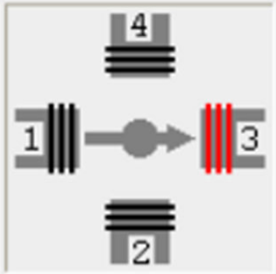
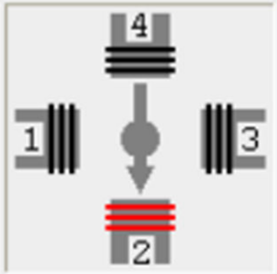
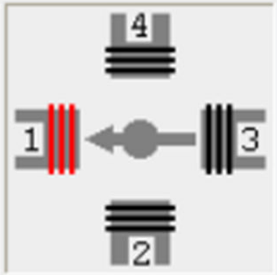


Notice that to rotate the motor in a particular direction, the stator pole/winding energizing sequence is actually reversed to that used in a permanent magnet motor. Also, note that the motors step angle is actually half what it is with a permanent magnet motor with the same number of stator/windings.

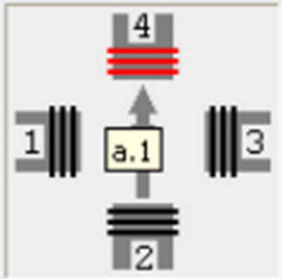
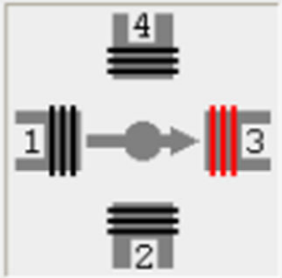



N
S
N
S
S
N

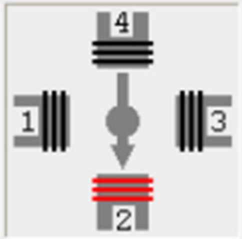
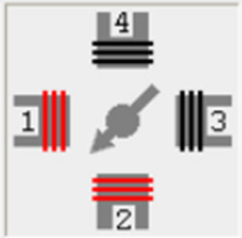
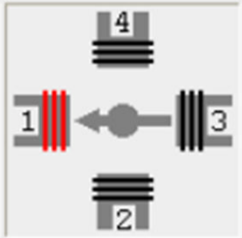
FULL STEP

Step	Coil 4	Coil 3	Coil 2	Coil 1	
a.1	on	off	off	off	
a.2	off	on	off	off	
a.3	off	off	on	off	
a.4	off	off	off	on	

HALF STEP

Step	Coil 4	Coil 3	Coil 2	Coil 1	
a.1	on	off	off	off	
b.1	on	on	off	off	
a.2	off	on	off	off	
b.2	off	on	on	off	

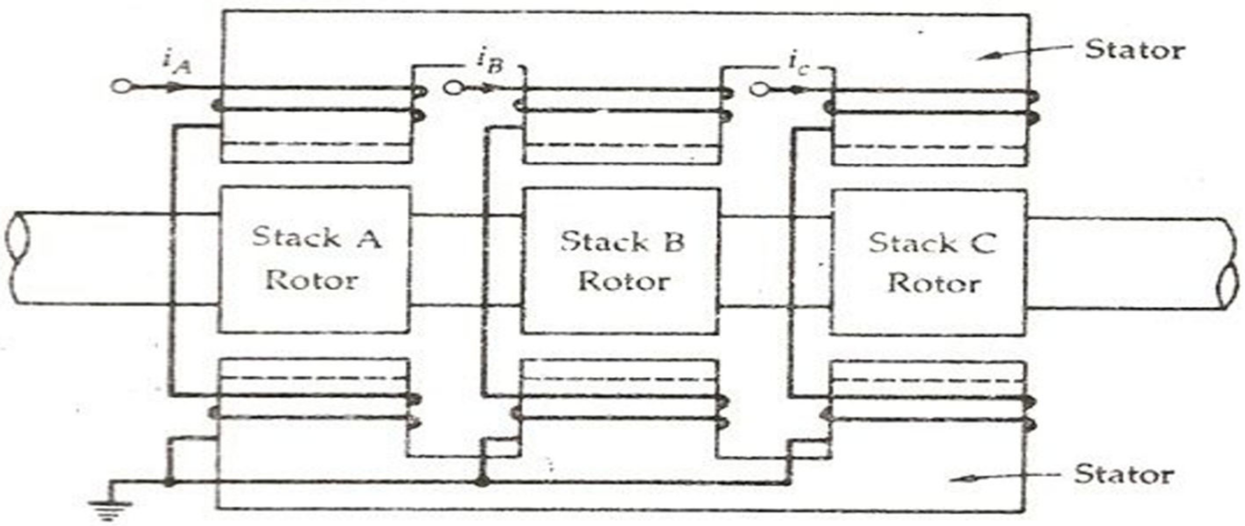
HALF STEP

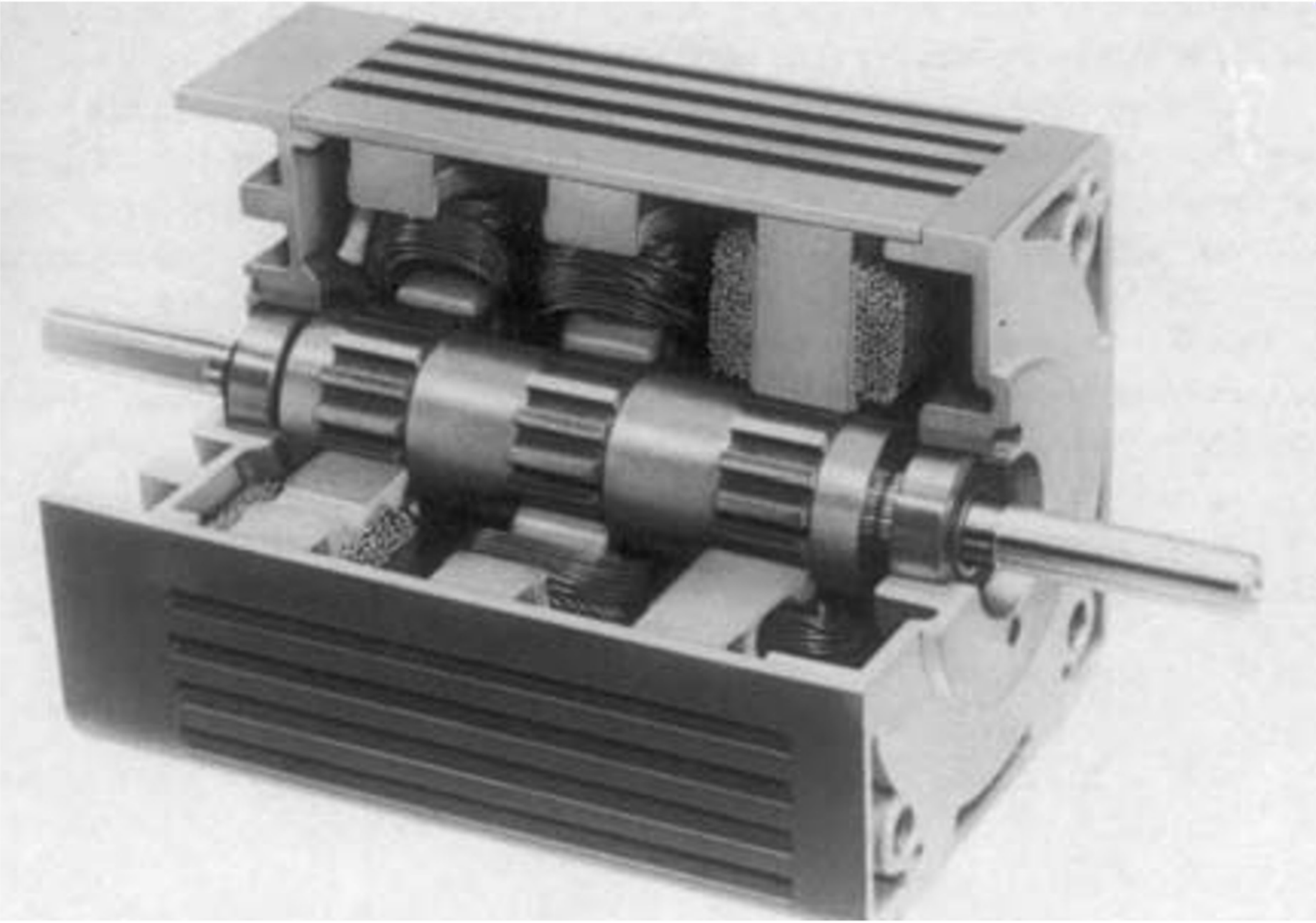
Step	Coil 4	Coil 3	Coil 2	Coil 1	
a.3	off	off	on	off	
b.3	off	off	on	on	
a.4	off	off	off	on	
b.4	on	off	off	on	

Micro-Step

- In the micro-step mode, a motor's natural step angle can be divided into much smaller angles.
- Typically, micro-step modes range from divide-by-10 to divide-by-256.
- This mode is only used where smoother motion or more resolution is required.

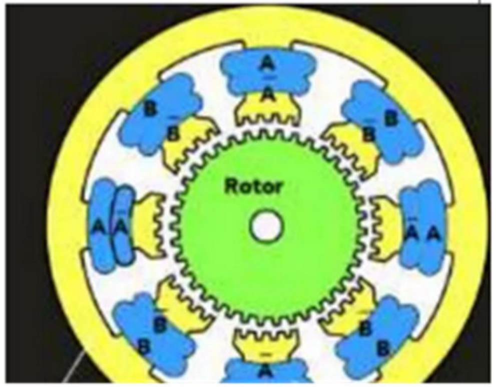
Multi-stack variable-reluctance motor





Hybrid Motors

- It is the combining the qualities of the Variable Reluctane motor and the Permanent Magnet motor.
- The hybrid motor has some of the desirable features of each. Normally, they exhibit step angle of 0.9 to 5 degrees.



System of the Stepper motor

- A stepper motor system consists of three basic elements, often combined with some type of user interface (host computer, PLC)

➢ Indexers

➢ Drivers

➢ Stepper motors

Indexers

The indexer (or controller) is a microprocessor capable of generating step pulses and direction signals for the driver. In addition, the indexer is typically required to perform many other sophisticated command functions.

Drivers

The driver (or amplifier) converts the indexer command signals into the power necessary to energize the motor windings. Not all drivers are suitable to run all motors.

Stepper motors

The stepper motor is an electromagnetic device that converts digital pulses into mechanical shaft rotation. Advantages of step motors are low cost, high reliability, high torque at low speeds and a simple.

$$\text{Step angle} = 360 \div (N_{Ph} \times Ph) = 360/N$$

N_{Ph} = Number of equivalent poles per phase = number of rotor poles

Ph = Number of phases

N = Total number of poles for all phases together

Advantages

- Low cost for control achieved
- High torque at startup and low speeds
- Ruggedness
- Simplicity of construction
- Can operate in an open loop control system
- Low maintenance
- Less likely to stall or slip
- Will work in any environment
- Can be used in robotics in a wide scale.
- High reliability

Applications

- The stepper motor is used for precise positioning with a motor like hard disk drives, robotics, telescopes and some toys.
- Industrial Machines-Stepper motors are used in automotive gauge and machine tooling automated production equipments.
- Security-New surveillance products for the security industry
- Medical-Stepper motors are used inside medical scanner , sampler and also found inside digital dental photography.

Acceleration sensors

Accelerometers

- Time rate of change of velocity is acceleration
- Consistent with Newton's second law of motion ($F = ma$), as an acceleration is applied to the device, a force develops which displaces the mass.
- Acceleration creates a force that is captured by the force-detection mechanism of the accelerometer.
- So the accelerometer really measures force, not acceleration; it basically measures acceleration indirectly through a force applied to one of the accelerometer's axes.

Why measure acceleration?

- Acceleration is a physical characteristic of a system.
- The measurement of acceleration is used as an input into some types of control systems.
- The control systems use the measured acceleration to correct for changing dynamic conditions

Accelerometers

- Accelerometers are mainly used for two specific types of acceleration measurement
  - Impact(shock):it is effectively large acceleration over a short interval of time .
  - Vibration: small repeatable acceleration.
- Accelerometers are normally mechanically bounded to the system whose acceleration is to be measured.
- They detects acceleration along one axis and insensitive in orthogonal directions.

Common Types of Accelerometers

- Spring mass damper type
- Capacitive-Metal beam or micro-machined feature produces capacitance; change in capacitance related to acceleration
- Piezoelectric-Piezoelectric crystal mounted to mass–voltage output converted to acceleration
- Piezo resistive-Beam or micro-machined feature whose resistance changes with acceleration
- Hall Effect-Motion converted to an electrical signal by sensing of changing magnetic fields
- Magneto resistive-Material resistivity changes in presence of magnetic field

The Applications of Accelerometer sensor are as follows:

- For inertial navigation systems, highly sensitive accelerometers are used.
- To detect and monitor vibrations in rotating machinery.
- To display images in an upright position on screens of digital cameras.
- For flight stabilization in drones.
- Accelerometers are used to sense orientation, coordinate acceleration, vibration, shock.
- Used to detect the position of the device in laptops and mobiles.

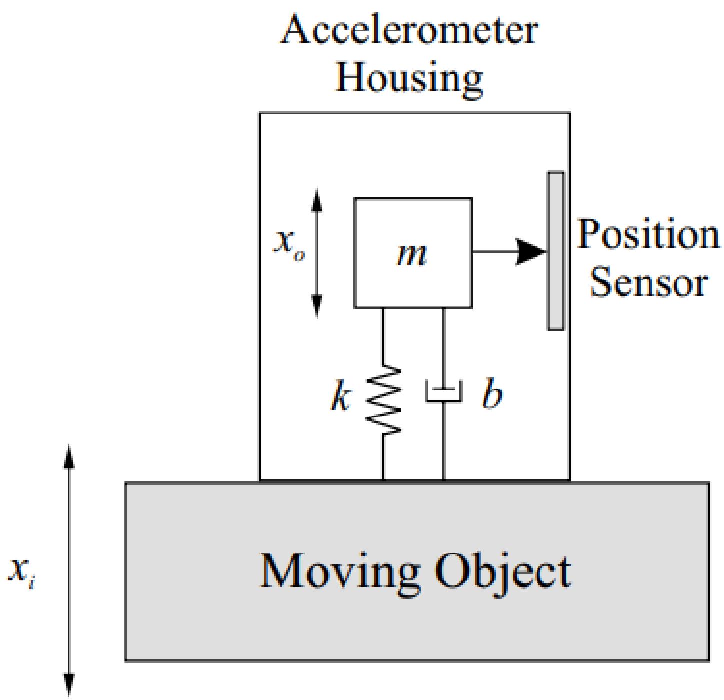
Cont.

- Machinery health monitoring.
- To detect faults in rotator machines.
- These are also used for building and structural monitoring to measure the motion and vibration of the structure when exposed to dynamic loads.
- To measure the depth of CPR chest compressions.
- Navigation systems make use of accelerometer sensors for knowing the direction.
- Remote sensing devices also use accelerometers to monitor active volcanoes.

Working principle

- Operation principle of an accelerometer is based on the inertial effect associated with a mass connected to a moving object through a spring and a damper.
- When the moving object accelerate there is a relative displacement between object and the mass. The relative displacement is either measured directly through a position sensor such as a linear potentiometer(seismic accelerometer) or indirectly sensed by out put voltage of a piezoelectric crystal (piezoelectric accelerometer).

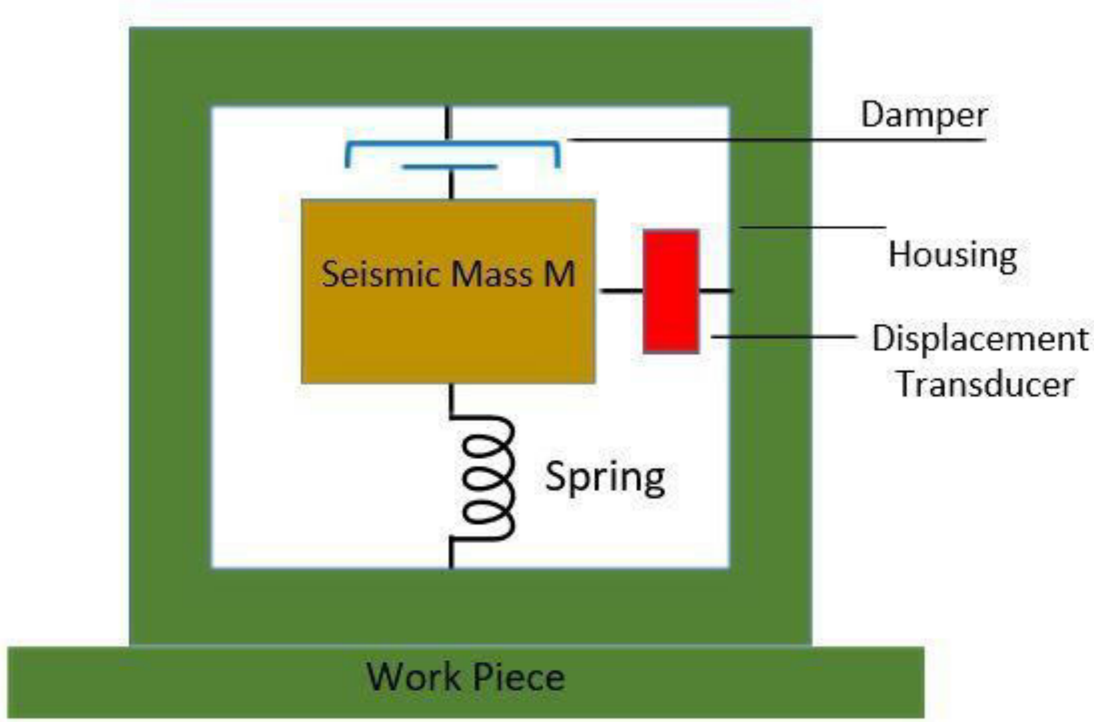
Seismic Accelerometer



Seismic Accelerometer

- The main parts of a seismic accelerometer are as follows:
  1. A seismic mass is suspended from the housing of the accelerometer through a spring.
  2. A damper is connected between the seismic mass and the housing of the accelerometer.
  3. The seismic mass is connected to an electric displacement transducer.

$$a = \frac{\partial v}{\partial t} = \frac{\partial^2 x}{\partial t^2}$$



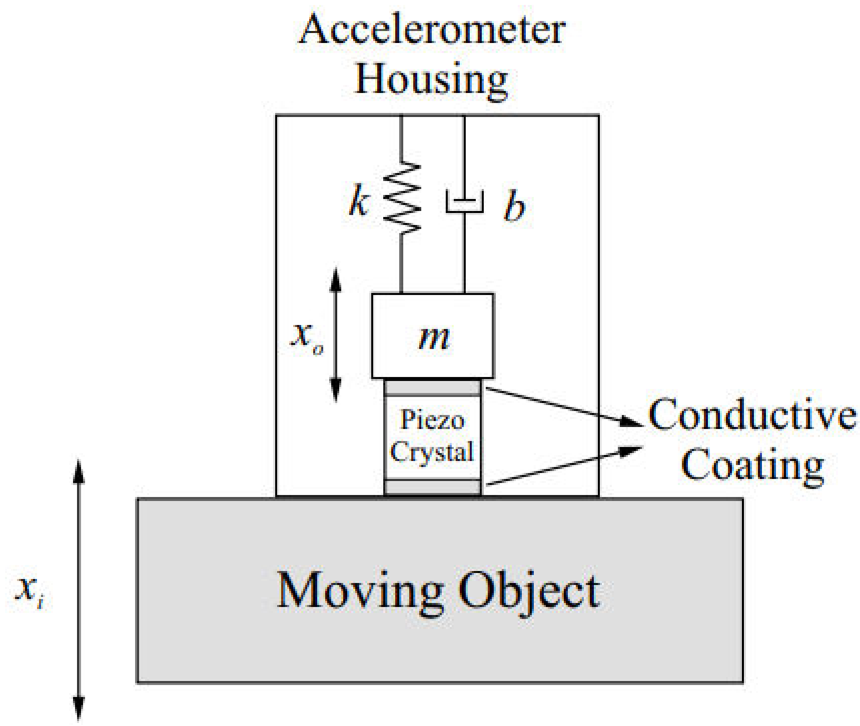
Seismic Transducer

working

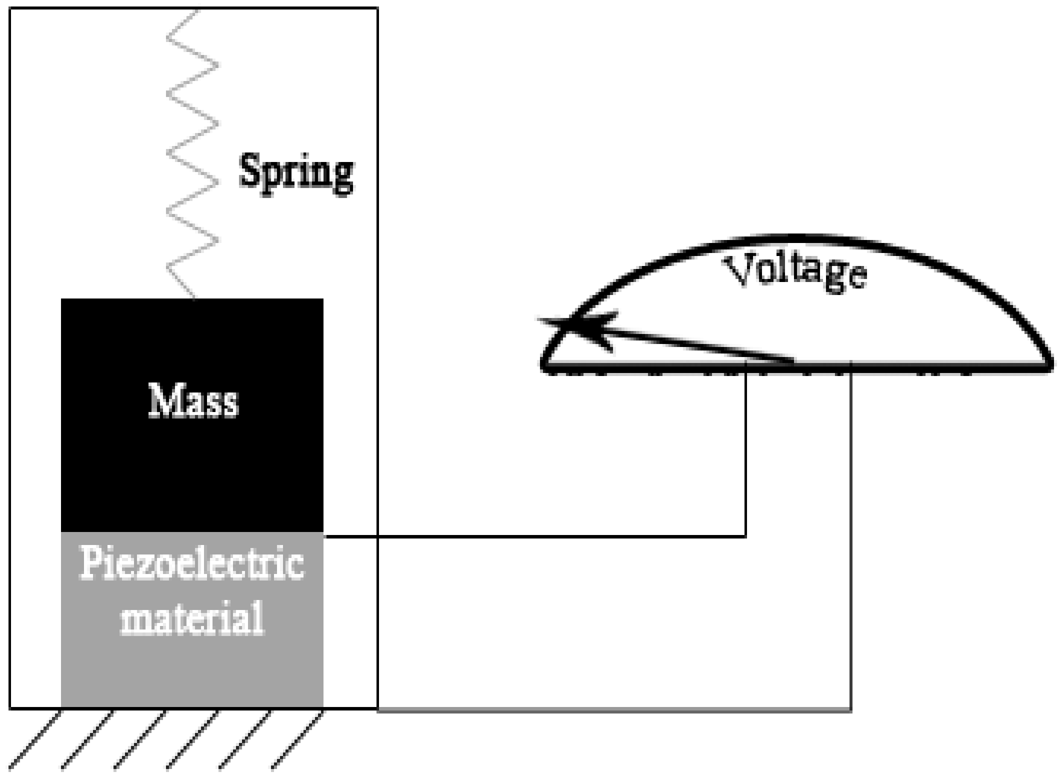
- When a spring mass damper system is subjected to acceleration, the mass is displaced, and this displacement of the mass is proportional to the acceleration.
- Hence a measure of displacement of the mass becomes a measure of acceleration (rate of change of velocity).
- As the mass is connected to an electric displacement transducer, the output of the transducer depends on the extent to which the mass is displaced.
- Hence the output of the transducer is calibrated to give a direct indication of the acceleration characteristics of the structure.

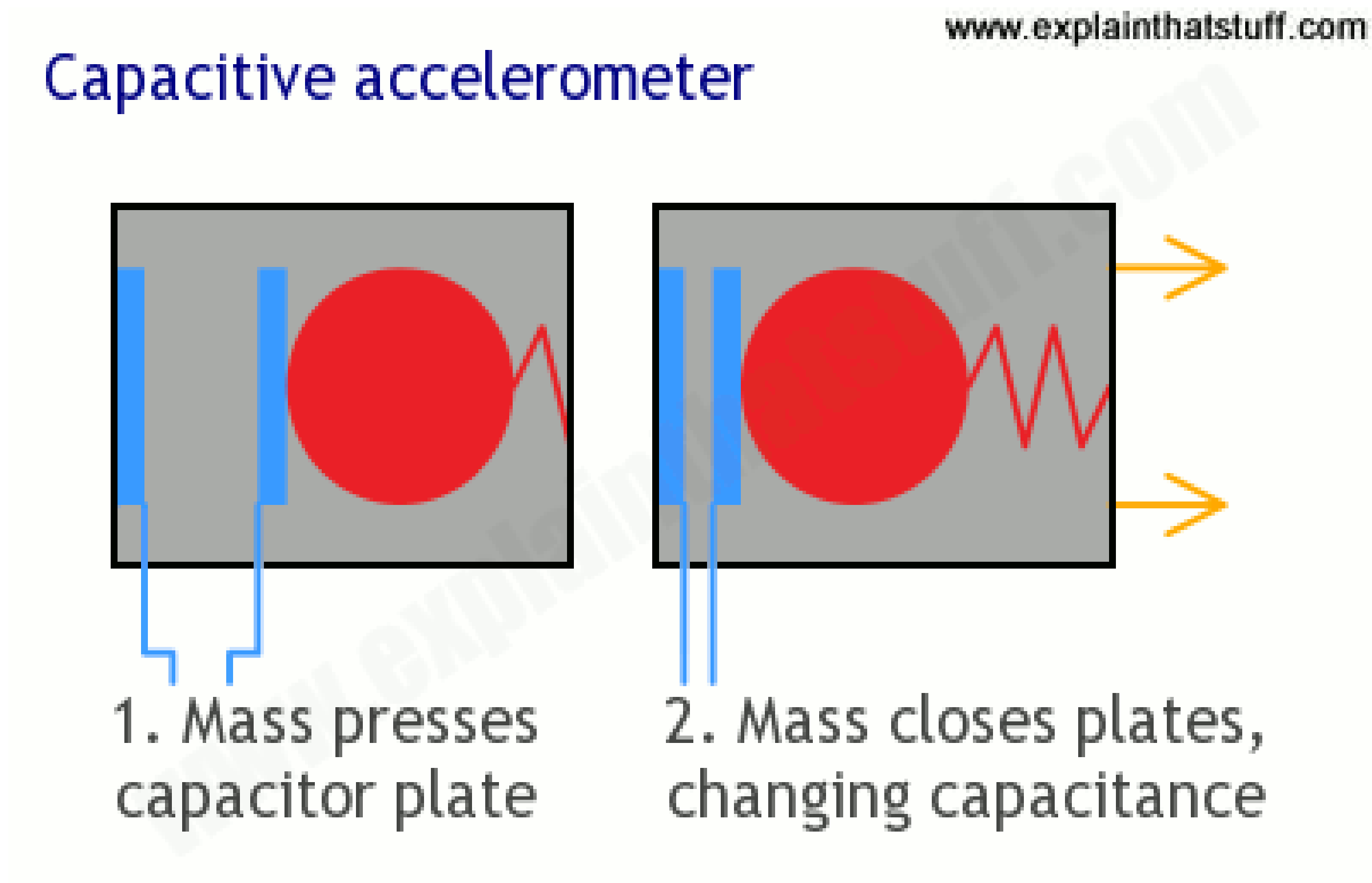
- Seismic accelerometers are mainly used to measure low-frequency vibrations since piezoelectric accelerometers do not give output for constant or slow varying acceleration.
- They are excellent for dynamic measurements such as high-frequency vibrations and impacts.

Piezoelectric Accelerometer



Piezoelectric
Accelerometer


Spring
Voltage
Mass
Piezoelectric
material


www.explainthatstuff.com
Capacitive accelerometer
1. Mass presses capacitor plate
2. Mass closes plates, changing capacitance

Heading sensors

Heading sensors

- Heading sensors can be proprioceptive (gyroscope, inclinometer) or exteroceptive (compass).
- They are used to determine the orientation and inclination of the robot.
- They allow us, together with appropriate velocity information, to integrate the movement to a position estimate.

Compass

- Compass sensor is a device whose function is to give the right directions with respect to the North and South magnetic poles of the earth.
- The needle present on a compass always points toward the geometric North of Earth.
- This device makes use of principles of magnetis for operation.
- But this magnetic force of the earth is so weak that people previously used to design compass by suspending a thin magnetic strip.
- In the Compass present in smartphones magnet is not used as a component because it causes interference in communication

Compass

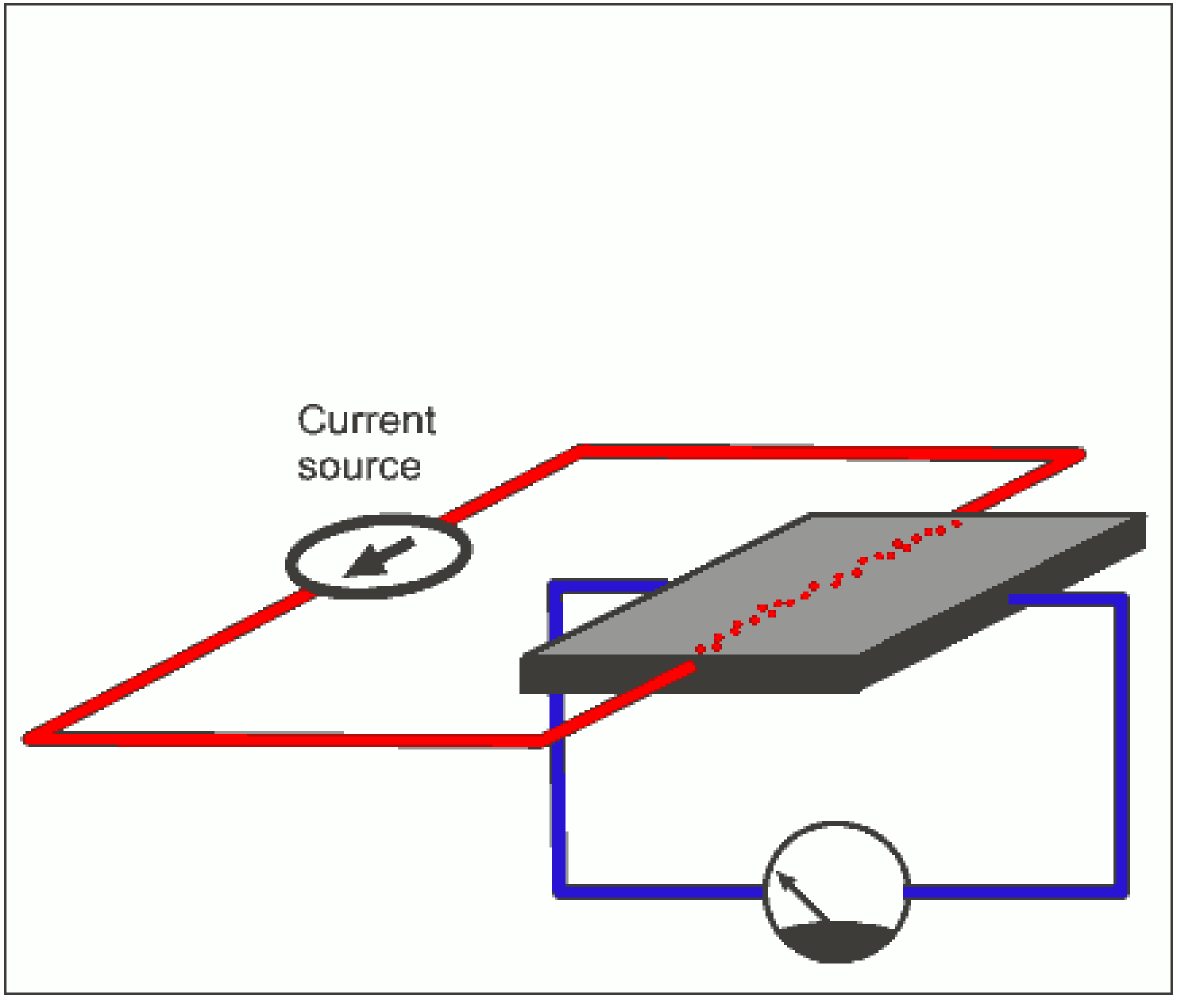
- Essentially a compass is a light weight magnet, generally a magnetized needle, on a free rotating pivot.
- This allows the needle to better react to nearby magnetic fields. Since opposites attract the southern pole of the needle is attracted to the Earth's natural magnetic north pole.
- This is how navigators are able to discern north.
- The Earliest compasses were water compasses invented by the Chinese during the Song dynasty. These were a magnetized piece of metal floating in a bowl of water.

Digital Compass Sensor

- Digital Compass Sensor is actually a magnetometer that can measure the Earth's magnetic field. With the use of 'Hall Effect' and by calculating the ultralow frequency signals coming from the North or South direction, this sensor can calculate the orientation and direction.
- Passing a current through a conductor and measuring changes in voltage caused by the Earth's magnetic field.

- Hall Effect digital compasses are popular in mobile robotics, and contain two such semiconductors at right angles, providing two axes of magnetic field (thresholded) direction, thereby yielding one of 8 possible compass directions. The instruments are inexpensive but also suffer from a range of disadvantages. Resolution of a digital hall effect compass is poor. Internal sources of error include the nonlinearity of the basic sensor and systematic bias errors at the semiconductor level.

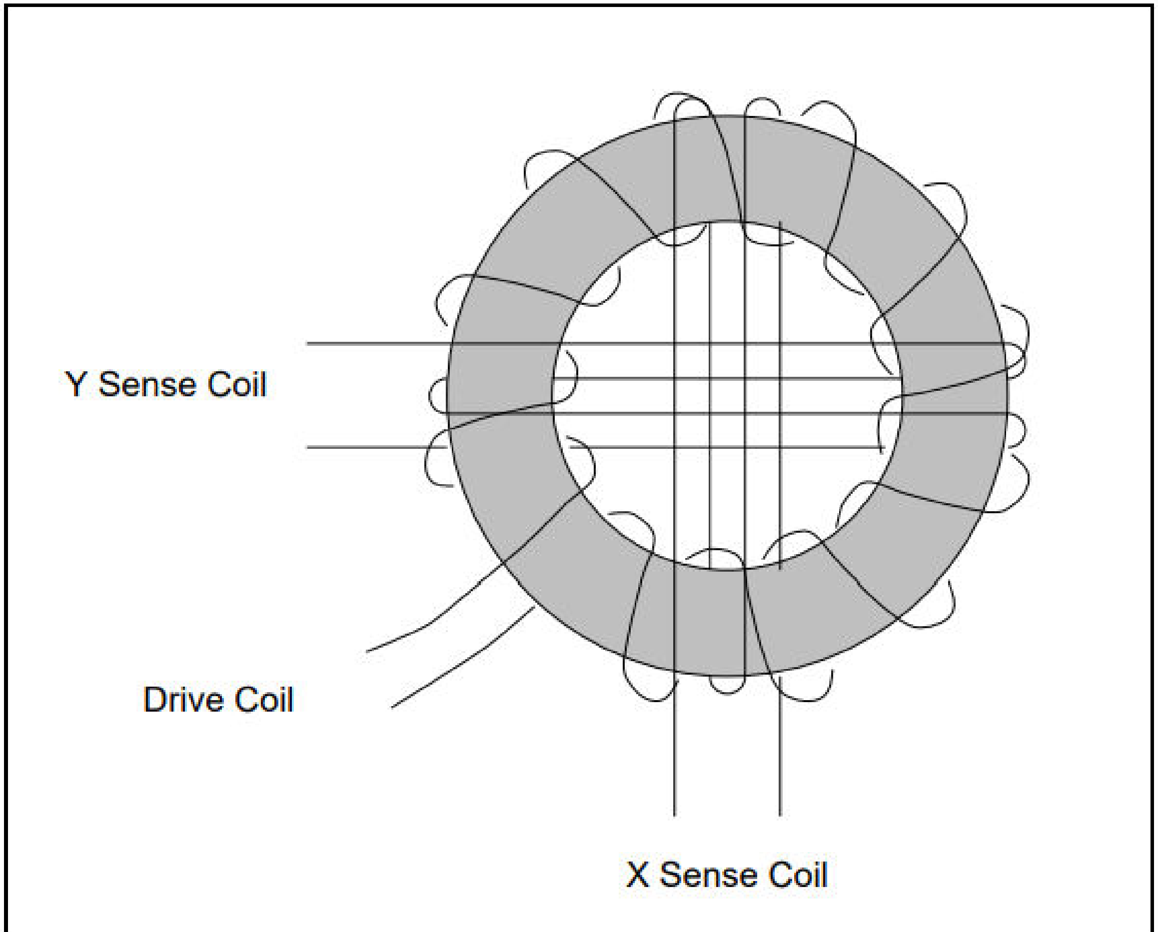
Hall Effect



Flux Gate compass

- It operates on a different principle.
- A typical fluxgate compass has three small coils of wires, each wound around a core of highly permeable magnetic material.
- Two small coils are wound on ferrite cores and are fixed perpendicular to one-another.

Typical configuration of a flux gate magnetometer sensor



- The fluxgate compass consists of a coil wound around a permeable core which again, is surrounded by a second coil. This core is magnetically saturated by an alternating (sine- or square) cycle in opposing directions called excitation.
- This will result into a plus and minus saturation of the core. When no external magnetic field present, the flux in one half cancels out the flux in the other coil.
- When an external magnetic field is briefly applied, a net flux imbalance will occur between the two coils which means the two coils do not cancel out each other anymore.

- At this stage current pulses are induced in the second coil which result in a signal that is dependent on polarity and the external magnetic field.
- This particular signal can be used for feedback and recovery. For instance the direction of any vehicle can be altered by using this signal as an input.
- In this way for instance, it can control an autopilot.

Applications of fluxgate compass

- The most common use is for steering, giving direct feedback to the pilot or the captain through a display.
- In the case of using autopilot the fluxgate compass can be used as immediate feedback for the autopilot equipment. A The digital output can also be used for other navigational equipment like radar and chart plotters.
- The fluxgate compasses are mostly used on (cruise) ships and other kinds of vessels.
- The fluxgate compasses can be extremely light; the robotic versions only weigh a few ounces and are quite inexpensive.

Disadvantages

- Regardless of the type of compass used, a major drawback concerning the use of the Earth's magnetic field for mobile robot applications involves disturbance of that magnetic field by other magnetic objects and man-made structures, as well as the bandwidth limitations of electronic compasses and their susceptibility to vibration.
- Particularly in indoor environments mobile robotics applications have often avoided the use of compasses, although a compass can conceivably provide useful local orientation information indoors, even in the precense of steel structures.

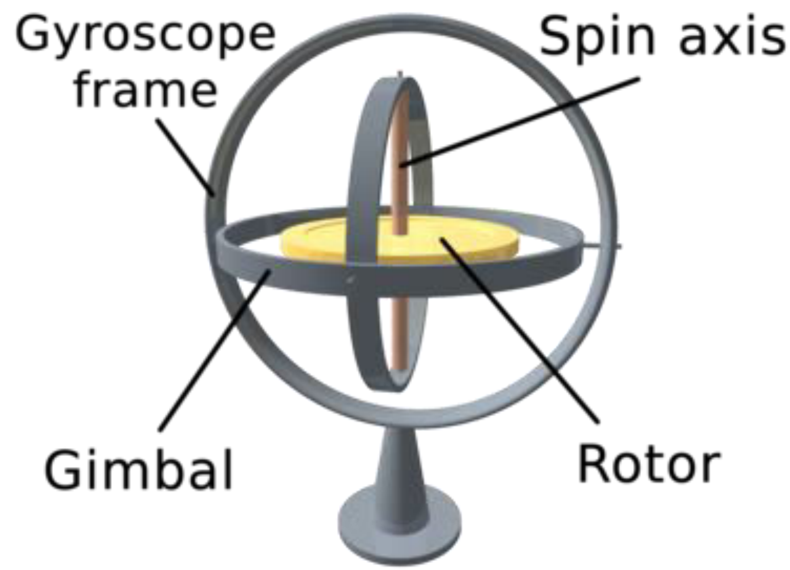
Gyroscope Sensor

Gyroscope

- A **gyroscope** ("circle" and "to look") is a device used for measuring or maintaining orientation and angular velocity.
- An accelerometer measures the linear acceleration or directional movement of an object, whereas Gyroscope Sensor measures the angular velocity or tilt or lateral orientation of the object.

Gyroscope

- It is a spinning wheel or disc in which the axis of rotation (spin axis) is free to assume any orientation by itself.
- When rotating, the orientation of this axis is unaffected by tilting or rotation of the mounting, according to the conservation of angular momentum.



- Gyroscopes are heading sensors which preserve their orientation in relation to a fixed reference frame.
- Thus they provide an absolute measure for the heading of a mobile system.
- Gyroscopes can be classified in different categories,
- mechanical gyroscopes
- optical gyroscope

- A gyroscope can be considered as a massive rotor that is fixed on the supporting rings known as the gimbals.
- The central rotor is isolated from the external torques with the help of frictionless bearings that are present in the gimbals.
- The spin axis is defined by the axle of the spinning wheel.
- The rotor has exceptional stability at high speeds as it maintains the high-speed rotation axis at the central rotor. The rotor has three degrees of rotational freedom.

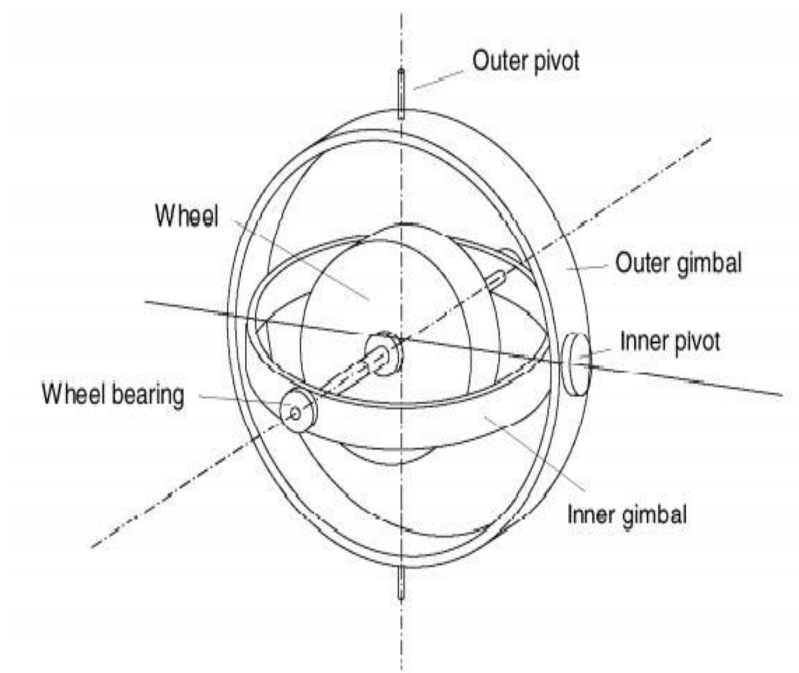
Gyroscope Working Principle

- The working principle of gyroscope is based on gravity and is explained as the product of angular momentum which is experienced by the torque on a disc to produce a gyroscopic precession in the spinning wheel.
- This process is termed gyroscopic motion or gyroscopic force and is defined as the tendency of a rotating object to maintain the orientation of its rotation.
- Rotating object possesses angular momentum and this needs to be conserved. This is done because when there is any change in the axis of rotation, there will be a change in the orientation which changes the angular momentum. ***Therefore, it can be said the working principle of gyroscope is based on the conservation of angular momentum.***

- Gyroscopes have two basic properties: Rigidity and Precession

  1. RIGIDITY: The axis of rotation (spin axis) of the gyro wheel tends to remain in a fixed direction in space if no force is applied to it.
  2. PRECESSION: The axis of rotation has a tendency to turn at a right angle to the direction of an applied force

- A gyroscope consists of a rotor mounted in the inner gimbal. The inner gimbal is mounted in the outer gimbal which itself is mounted on a fixed frame
- When the rotor spins about X-axis with angular velocity ω rad/s and the inner gimbal precesses (rotates) about Y-axis, the spatial mechanism is forced to turn about Z-axis other than its own axis of rotation, and the gyroscopic effect is thus setup.
- The resistance to this motion is called gyroscopic effect.

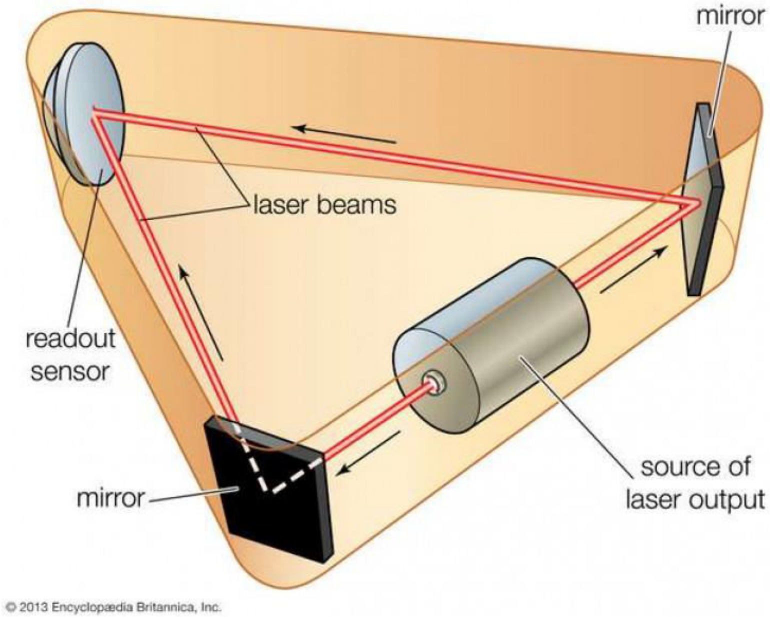


- Sensing systems (pick-offs): These are capable of reading angular displacements between the two adjacent gimbals and to transduce them into electric signals by means of potentiometers, resolvers or encoders, thus constituting the input for a computing unit.

Optical gyroscopes

- Optical gyroscopes, with virtually no moving parts, are used in commercial jetliners, booster rockets, and orbiting satellites.
- Such devices are based on the Sagnac effect.
- In Sagnac's demonstration, a beam of light was split such that part traveled clockwise and part counterclockwise around a rotating platform.
- Although both beams traveled within a closed loop, the beam traveling in the direction of rotation of the platform returned to the point of origin slightly after the beam traveling opposite to the rotation.
- As a result, a "fringe interference" pattern (alternate bands of light and dark) was detected that depended on the precise rate of rotation of the turntable.

- In reality, the "closed loop" are usually triangles, squares, or rectangles filled with inert gases through which the beams are reflected by mirrors.
- As the vehicle executes a turning or pitching motion, interference patterns created in the corresponding rings of the gyroscope are measured by photoelectric cells.
- The patterns of all three rings are then numerically integrated in order to determine the turning rate of the craft in three dimensions.



Gyroscopes applications

- Gyroscopes find applications in the compasses of boats, spacecraft, and aeroplanes. The orientation and the pitch of the aeroplane are determined against the steady spin of the gyroscope.
- In spacecraft, the navigation of the desired target is done with the help of a gyroscope. The spinning centre of the gyroscope is used as the orientation point.
- The stabilization of the large boats and satellites is done with the help of massive gyroscopes.
- Gyroscopes along with accelerometers are used in the design of smartphones providing excellent motion sensing.

Application of gyroscope

. In Aeronautics and Aviation:-

1. Remote control flying devices, helicopters, some hovercraft, some planes, etc. rely on gyroscopes to prevent them from flipping over or going into a spin.

2. Spacecraft rely on gyroscopes for orientation while in space.

3. Aircraft and aircraft autopilots rely on gyroscopes to account for changes in direction & altitude

. In Naval field

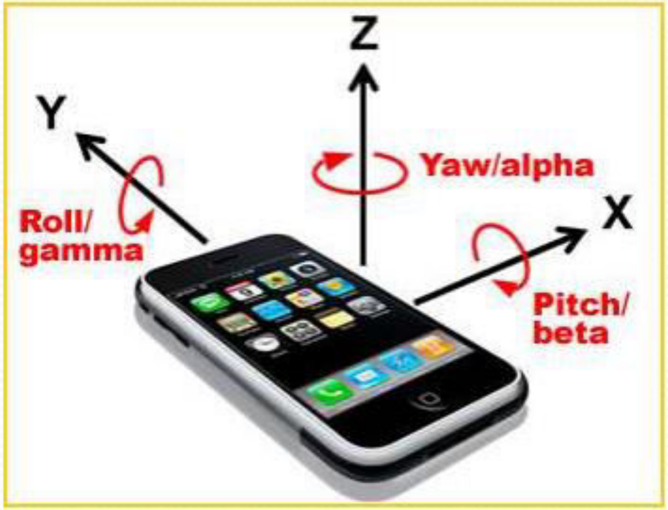
1. Gyroscope are used in ships to maintain stability as the effect of gyroscopic couple is on:-

(a.) Steering

(b.) Pitching

(c.) Rolling

1. Gyroscopes are used in various fields nowadays such as in smartphones, video game controllers, computer mouses and presentation mouses.



IMU

IMU

- The term IMU stands for "Inertial Measurement Unit,"
- A collection of measurement tools.
- When installed in a device, these tools can capture data about the device's movement.
- IMUs contains sensors such as accelerometers, gyroscopes, and magnetometers.

How Does an IMU Work?

- IMUs can measure a variety of factors, including speed, direction, acceleration, specific force, angular rate, and magnetic fields surrounding the device.
- Each tool in an IMU is used to capture different data types:
  - **Accelerometer**: measures velocity and acceleration
  - **Gyroscope**: measures rotation and rotational rate
  - **Magnetometer**: establishes cardinal direction (directional heading)
- IMUs combine input from several different sensor types in order to accurately output movement.
- Typical configurations contain one accelerometer, gyro, and magnetometer per axis for each of the three principal axes: pitch, roll and yaw

IMU APPLICATION

- You commonly see IMUs used in navigational devices or as components of navigational equipment, such as:
- **- Manned and unmanned aircraft**. A connected (or onboard) computer can use an IMU's measurements to calculate altitude and relative position to a reference frame, making them exceedingly useful in aircraft applications.
- **- GPS positioning systems** IMUs serve as a supplement to GPS positioning systems, allowing the navigational device to continue with an estimated position and heading if it loses satellite connection.
- Beyond their obvious applications in navigation, you can apply an IMU in nearly any field where motion detection comes into play:
- - Most smartphones, tablets and fitness tracking devices contain a low-cost IMU
- - IMUs are involved in sports training applications that need to measure, for example, the precise angle and force of a swing in golf or baseball.
- - IMUs drive the self-balancing systems of personal transportation devices like Segways and hoverboards.

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- - IMUs are involved in sports training applications that need to measure, for example, the precise angle and force of a swing in golf or baseball.
- - IMUs drive the self-balancing systems of personal transportation devices like Segways and hoverboards.

- Common applications for IMUs include determining direction in a GPS system, tracking motion in consumer electronics such as cell phones and video game remotes, or following a user's head movements in AR (augmented reality) and VR (virtual reality) systems. This motion and orientation information also apply to maintaining a drone's balance, improving the heading of your robot vacuum cleaner, and other IoT and connected home devices.
- In industrial use, you may use IMUs to align and measure positioning of equipment like antennas.
- IMUs are also used to help maneuver aircraft, with or without a manned pilot.
- In the consumer airspace, some in-flight entertainment systems use IMUs in their remotes to add accessibility in addition to touch.

Disadvantages of IMUs

The principal disadvantage of an IMU is that they are prone to error that accumulates over time, also known as "drift." Because the device is always measuring changes relative to itself (not triangulating against an absolute or known outside device), the IMU constantly rounds off small fractions in its calculations, which accumulate over time. Left uncorrected, these tiny imprecisions can add up to significant errors.

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Criteria for selection of sensors

SENSOR SELECTION

- In using sensors, one must first decide what the sensor is supposed to do and what result one expects.
- A sensor detects the quantity to be measured (the measurand).
- The transducer converts the detected measurand into a convenient form for subsequent use, e.g., for control or actuation.
- The transducer signal may be filtered, amplified and suitably modified.

SENSOR SELECTION

- The selection of a correct sensor for the application in hand depends on the understanding of its performance characteristics such as physical size, input requirements, outputs, life, cost, etc.
- These characteristics are listed in their datasheet.
- Sensor manufacturing community have defined these characteristics depending on the sensing .
- The sensor characteristics may be classified as design, electrical, static and dynamic characteristics.

Sensor Characteristics

- The characteristics of a sensor related to steady state output when constant input is applied is known as static characteristics.
- Dynamic characteristics are related to response or output of the sensor for time varying input. The input signals can be step, ramp, impulse, sinusoidal.
- The characteristics of sensors can also be classified as input, transfer and output characteristics.

STATIC CHARACTERISTICS

1. Range

- Range or span is a measure of the difference between the minimum and maximum values of its input or output (response) so as to maintain a required level of output accuracy.
- It is defined as the limits between which inputs can vary.
- Span is maximum value minus the minimum value of the input
- Eg: strain gauge might be able to measure output values over the range from 0.1 to 10 Newtons
- The range of LM35 is -55^{0}C to 150^{0}C, and span is 200 ^0C

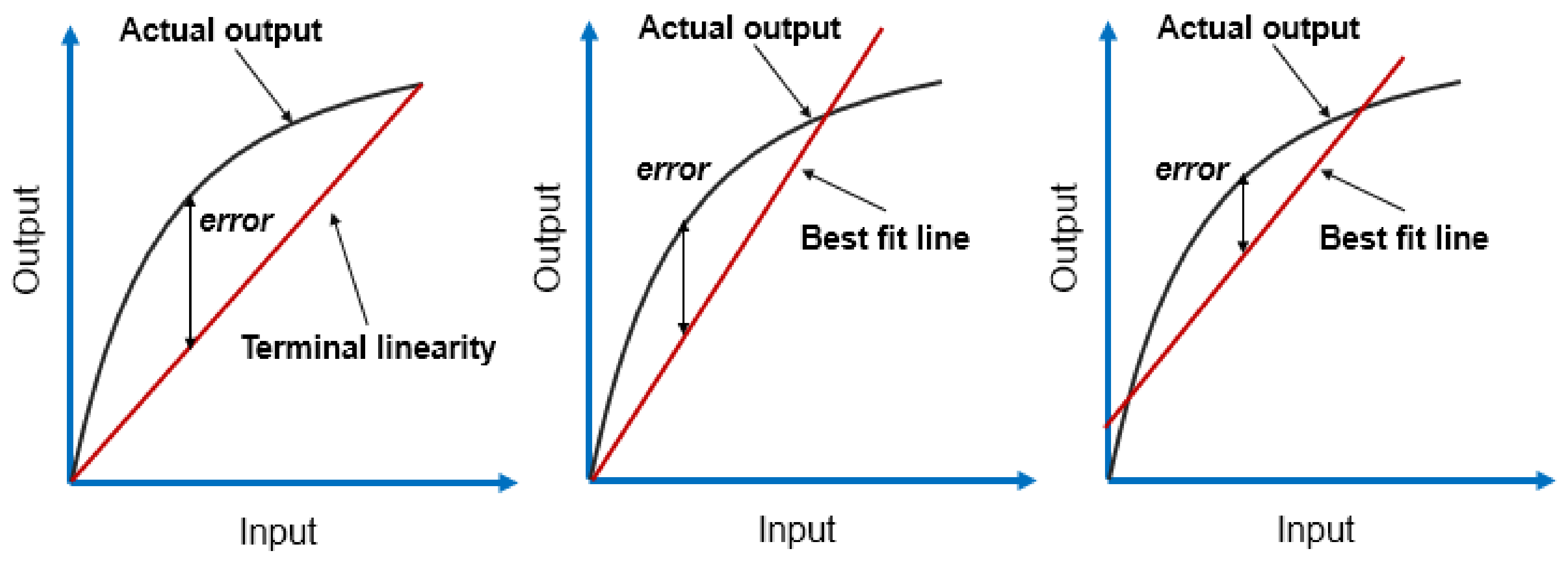
2. Sensitivity

- It is the ability of the measuring instrument to respond to changes in measured quantity
- Sensitivity is defined as the ratio of the change of output to change in input.
- Eg., if a movement of 0.025 mm in a linear potentiometer causes an output voltage by 0.02 volt then the sensitivity is 0.8 volts per mm.
- It is sometimes used to indicate the smallest change in input that will be observable as a change in output.
- Usually, maximum sensitivity that provides a linear and accurate signal is desired
- In the case of LM35, output is voltage, sensitivity is defined as 10 $mV/^0C$.

3. Linearity

- Perfect linearity would allow output versus input to be plotted as a straight line on a graph paper.
- Linearity is a measure of the constancy of the ratio of output to input.
- In the form of an equation, it is $y = mx$ where x is input and y is output, and m is a constant.
- If m is a variable, the relationship is not linear.

- Linearity error is the deviation of the sensor output curve from a specified straight line over a desired range.
- This linearity error is also defined as non-linearity



4. Response Time

- Response time is the time required for a sensor to respond completely to a change in input.
- The response time of a system with sensors is the combination of the responses of all individual components, including the sensor.
- An important aspect in selecting an appropriate sensor is to match its time response to that of the complete system.

5. Bandwidth

- It determines the maximum speed or frequency at which an instrument associated with a sensor or otherwise is capable of operating.
- High bandwidth implies faster speed of response.
- Instrument bandwidth should be several times greater than the maximum frequency of interest in the input signals.

6. Accuracy

- Accuracy is a measure of the difference between the measured and actual values.
- Accuracy describes ‘closeness to true values.’
- An accuracy of ±0.025 mm means that under all circumstances considered, the measured value will be within 0.025 mm of the actual value.

- In positioning a robot and its end-effector, verification of this level of accuracy would require careful measurement of the position of the end-effector with respect to the base reference location with an overall accuracy of 0.025 mm under all conditions of temperature, acceleration, velocity, and loading.
- Precision-measuring equipment, carefully calibrated against secondary standards, would be necessary to verify this accuracy.

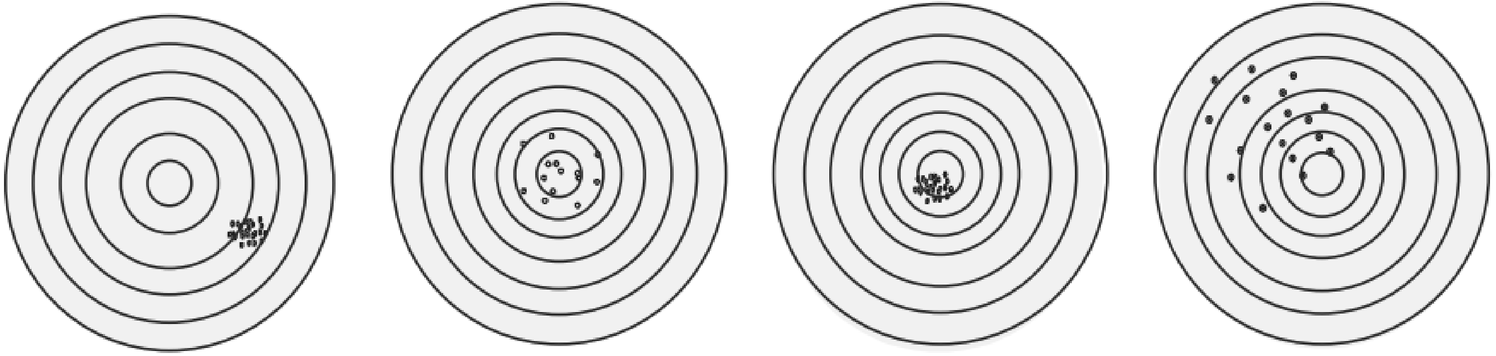
7. Repeatability and Precision

- Repeatability is a measure of the difference in value between two successive measurements under the same conditions.
- As long as the forces, temperature, and other parameters have not changed, one would expect the successive values to be the same, however poor the accuracy is.
- It is the ability to reproduce the output signal exactly when the same measured quantity is applied repeatedly under the same environmental conditions.
- The repeatability is defined for a specific value of input or measurand.

Precision

- Precision, which means the ‘closeness of agreement’ between independent measurements of a quantity under the same conditions without any reference to the true value.
- The number of divisions on the scale of the measuring device generally affects the consistency of repeated measurement and, therefore, the precision.

Interpretation of accuracy and precision



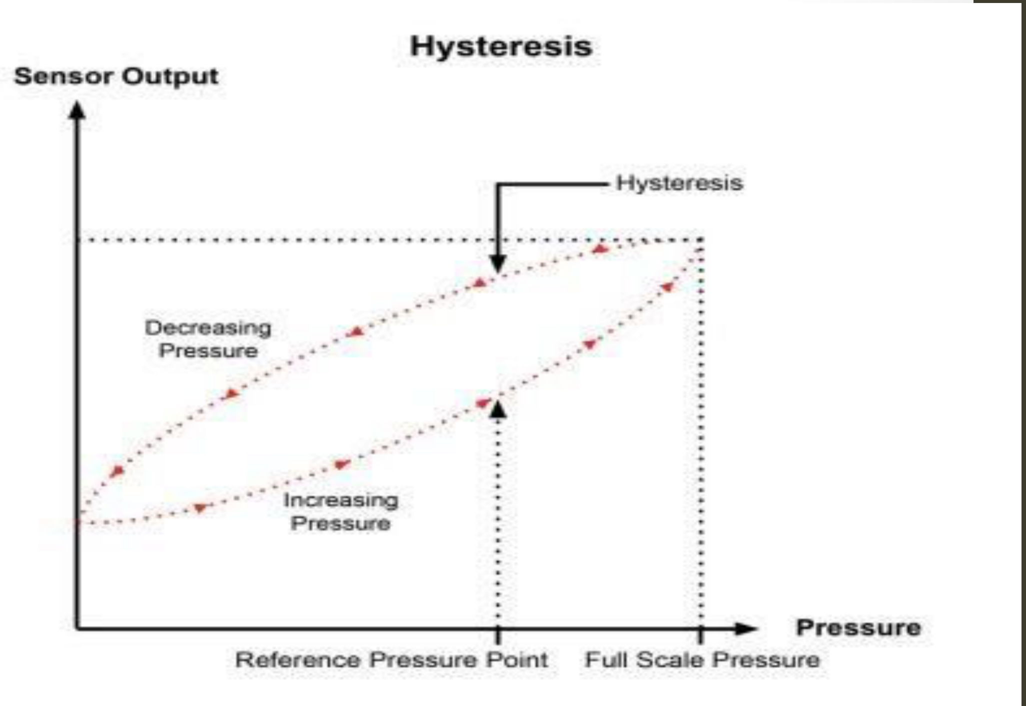
(a) Poor Accuracy Good precision | (b) Good Accuracy Poor precision | (c) Good Accuracy Good precision | (d) Poor Accuracy Poor precision

8. Resolution and Threshold

- Resolution is a measure of the number of measurements within a range from minimum to maximum.
- It is also used to indicate the value of the smallest increment of value that is observable,
- Threshold is a particular case of resolution.
- Threshold is defined as the minimum value of input below which no output can be detected.

9. Hysteresis

- It is defined as the change in the input/ output curve when the direction of motion changes.



- The effect of obtaining different output for the same input when input is increasing and decreasing.
- This behaviour is common in loose components such as gears, which have backlash, and in magnetic devices with ferromagnetic media, and others.

10. Type of Output

- Output can be in the form of a mechanical movement, an electrical current or voltage, a pressure, or liquid level, a light intensity, or another form.
- To be useful, it must be converted to another form, as in the LVDT (Linear Variable Differential Transducer) or strain gauges.

11. Size and Weight

- Size and weight are usually important physical characteristics of sensors.
- If the sensor is to be mounted on the robot hand or arm, it becomes a part of the mass that must be accelerated and decelerated by the drive motors of the wrist and arm.
- So, it directly affects the performance of the robot.
- It is a challenge to sensor designers to reduce size and weight.
- An early wrist force-torque sensor, for example, was about 125 mm in diameter but was reduced to about 75 mm in diameter through careful redesign.

12. Environmental Conditions

- Power requirement and its easy availability should be considered.
- Besides, conditions like chemical reactions including corrosion, extreme temperatures, light, dirt accumulation, electromagnetic field, radioactive environments, shock and vibrations, etc., should be taken into account while selecting a sensor or considering how to shield them.

13. Reliability and Maintainability

- Reliability is of major importance in all robot applications.
- It can be measured in terms of Mean Time To Failure (MTTF) as the average number of hours between failures that cause some part of the sensor to become inoperative.
- In industrial use, the total robot system is expected to be available as much as 98 or 99% of the working days.
- Since there are hundreds of components in a robot system, each one must have a very high reliability.
- Some otherwise good sensors cannot stand the daily environmental stress and, therefore, cannot be used with robots.

- Part of the requirement for reliability is ease of maintenance.
- A sensor that can be easily replaced does not have to be as reliable as one that is hidden in the depths of the robot.
- Maintainability is a measure in terms of Mean Time To Repair (MTTR)

14. Interfacing

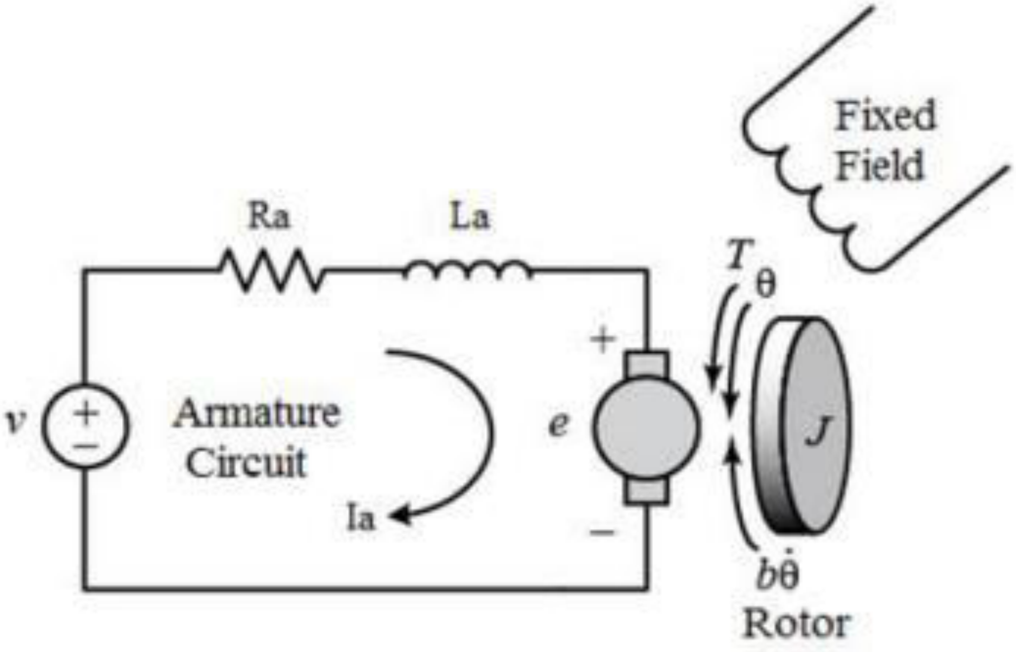
- Interfacing of sensors with signal-conditioning devices and the controller of the robot is often a determining factor in the usefulness of sensors.
- Nonstandard plugs or requirements for nonstandard voltages and currents may make a sensor too complex and expensive to use.
- The signals from a sensor must be compatible with other equipment being used if the system is to work properly.

15. Others

- Other aspects like
  - initial cost,
  - maintenance cost,
  - cost of disposal and replacement,
  - reputation of manufacturers,
  - operational simplicity,
  - ease of availability of the sensors and their spares
- should be taken into account.
- In many occasions, these nontechnical considerations become the ultimate deciding factor in the selection of sensors for an application.

HBRIDGE

MATHEMATICAL FORMULATION FOR A SEPARATELY EXCITED D.C MOTOR



DC Motor Equalivent Circuit

$$V_f = i_f . R_f + L_f \frac{di_f}{dt} \tag{1}$$

$$e = K_E . \Phi . \omega \tag{2}$$

For a separately excited D.C motor, the armature instantaneous voltage equation is given as:

$$v = i_a . R_a + L_a \frac{di_a}{dt} + e \tag{3}$$

$$V_a = I_a . R_a + e \tag{4}$$

$$V_a = I_a.R_a + K_E.\Phi.\omega \tag{5}$$

The motor speed can be easily derived:

$$\omega = \frac{V_a - I_a.R_a}{K_E.\Phi} \tag{6}$$

If R_a is a small value (which is usual), or when the motor is lightly loaded, i.e. I_a is small,

$$\omega = \frac{V_a}{K_E.\Phi} \tag{7}$$

PWM TECHNIQUE

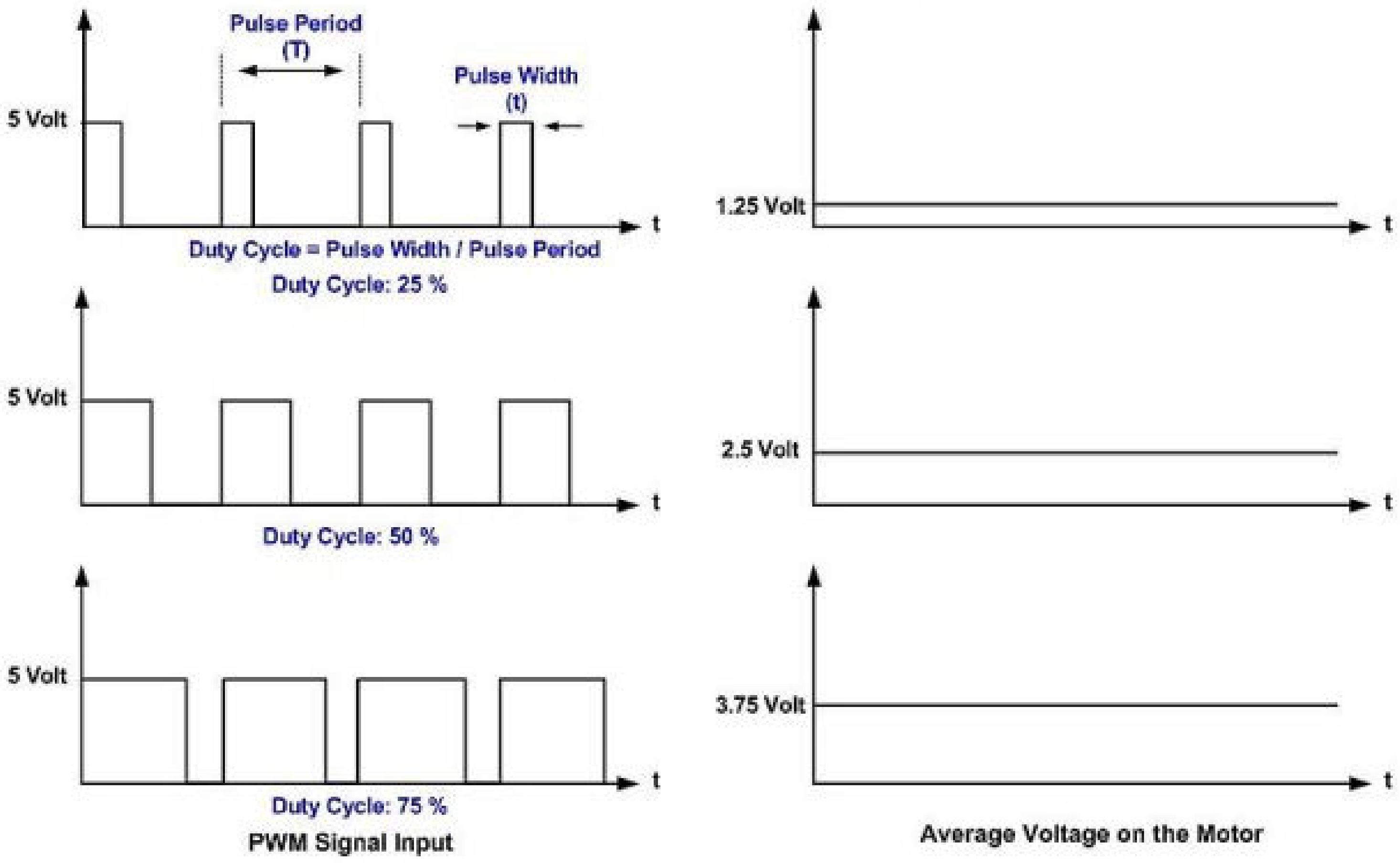
- The average value of voltage fed to the load is controlled by turning the switch between supply and load ON and OFF at a fast pace.
- The longer the switch is ON compared to the OFF periods, the higher the power supplied to the load is.
- The term duty cycle describes the proportion of ON time to the regular interval or period of time, a low duty cycle corresponds to low power, because the power is OFF for most of the time.
- Duty cycle is expressed in percent 100% being fully ON.

PWM TECHNIQUE

$$Duty\ Cycle\ (\%) = \frac{OnTime}{Period} \times 100$$

$$PWM\ \ Frequency = \frac{1}{Period}$$

PWM TIMING DIAGRAM

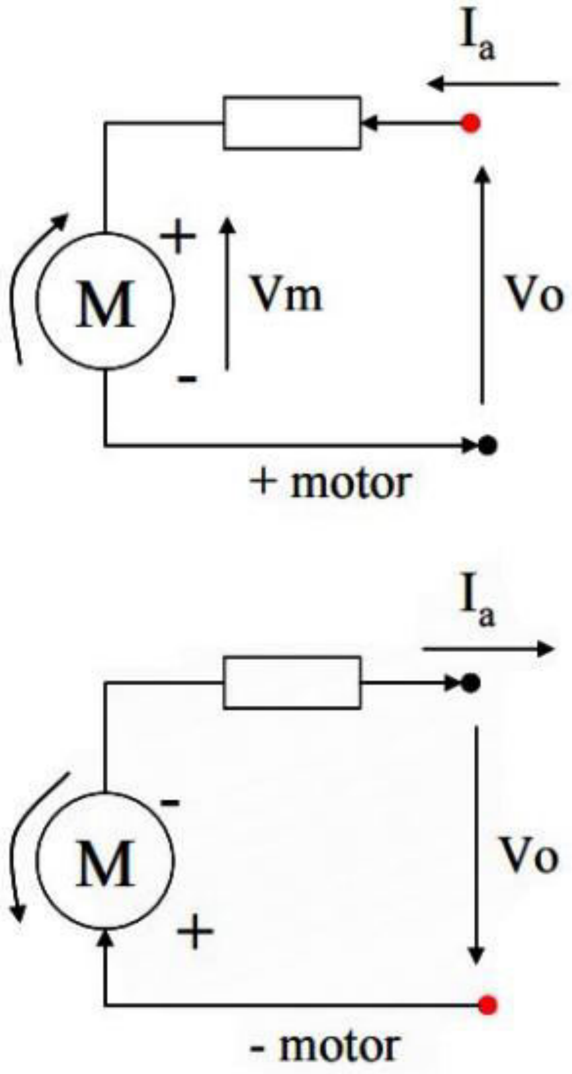


Overview

- What is an H-bridge?
- How does it work?
- How will we use them?

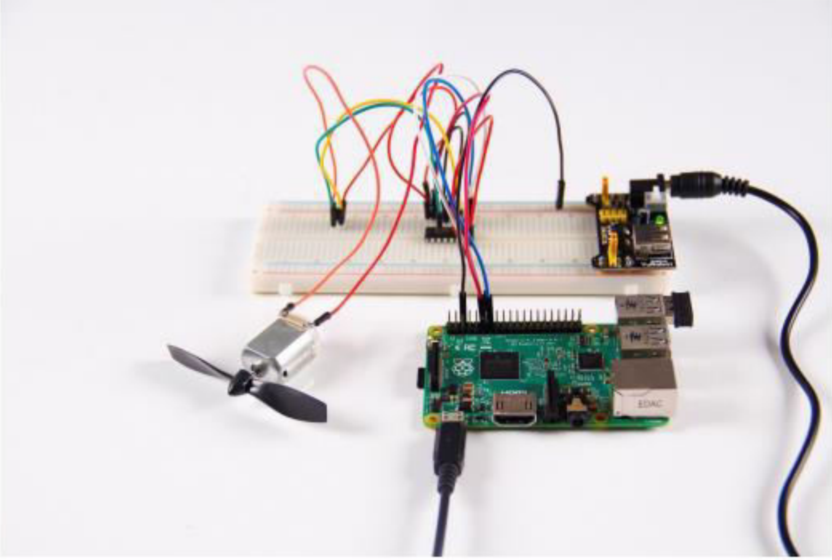
DC motor

- Velocity depends on $V_{o,avg}$
- Torque varies with I_a

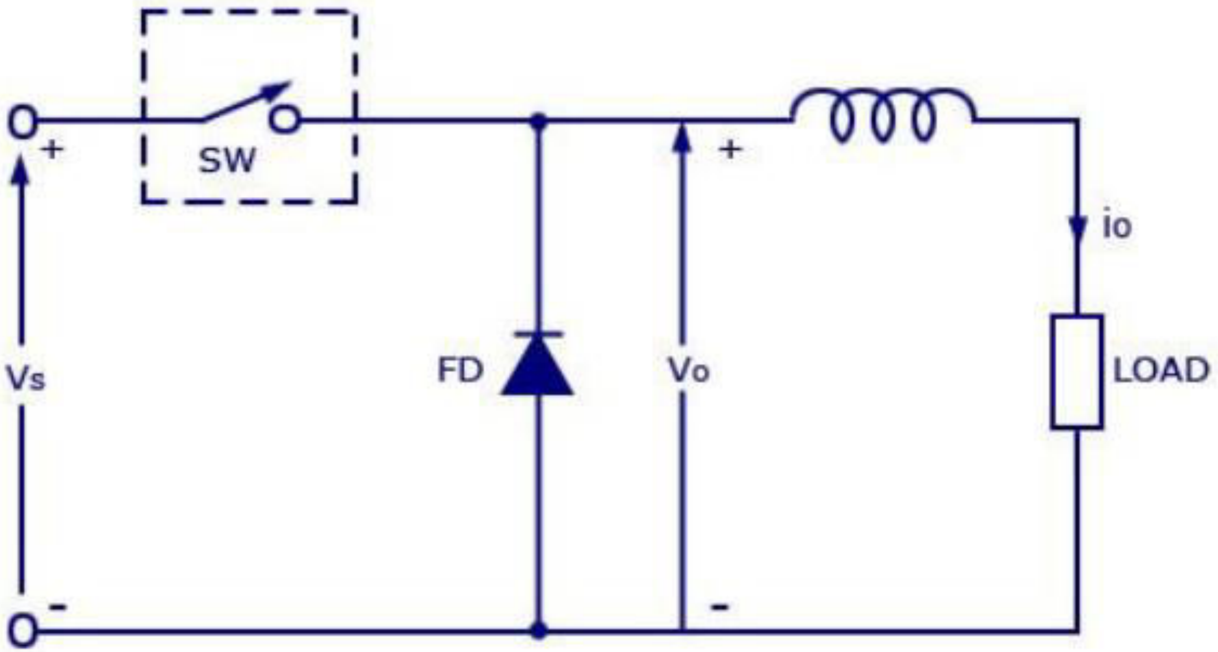


DC motor control

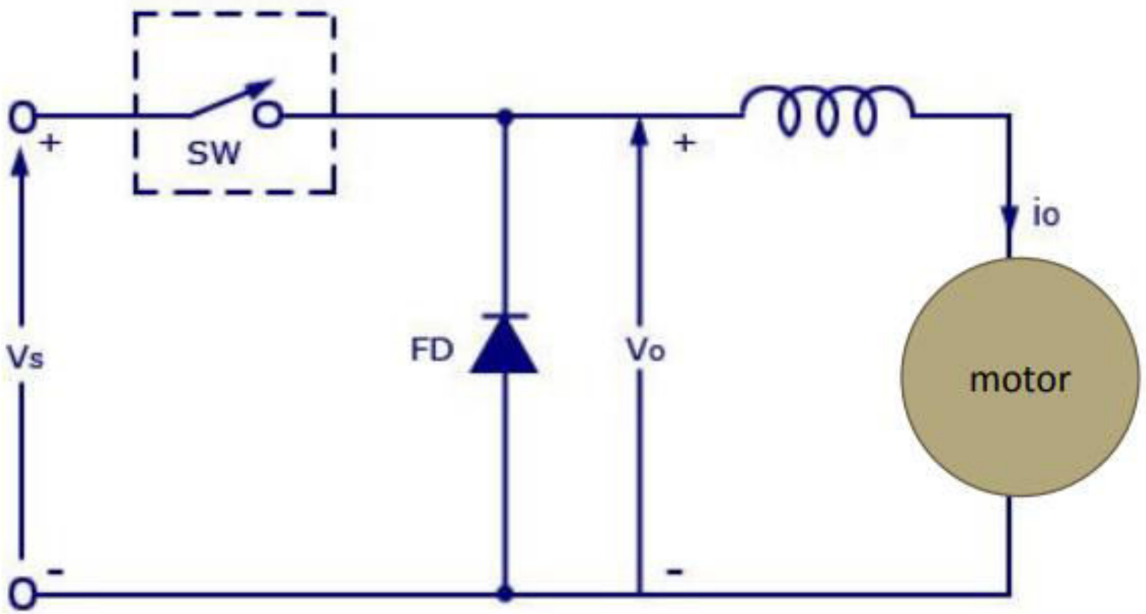
- Direction
  - Chopper (Unidirectional)
  - H-bridge (Bidirectional)
- Velocity
  - Varying voltage
  - PWM



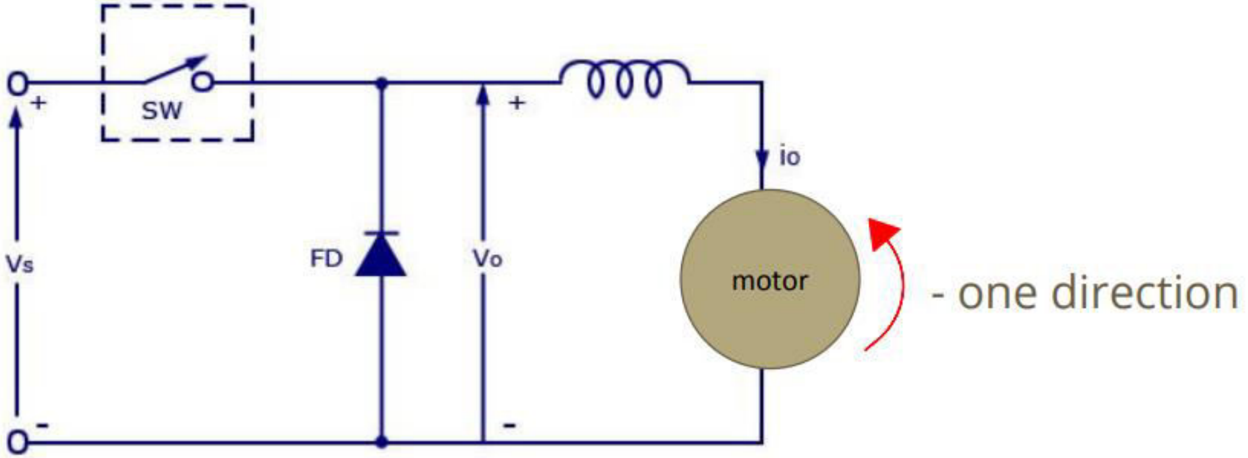
Chopper

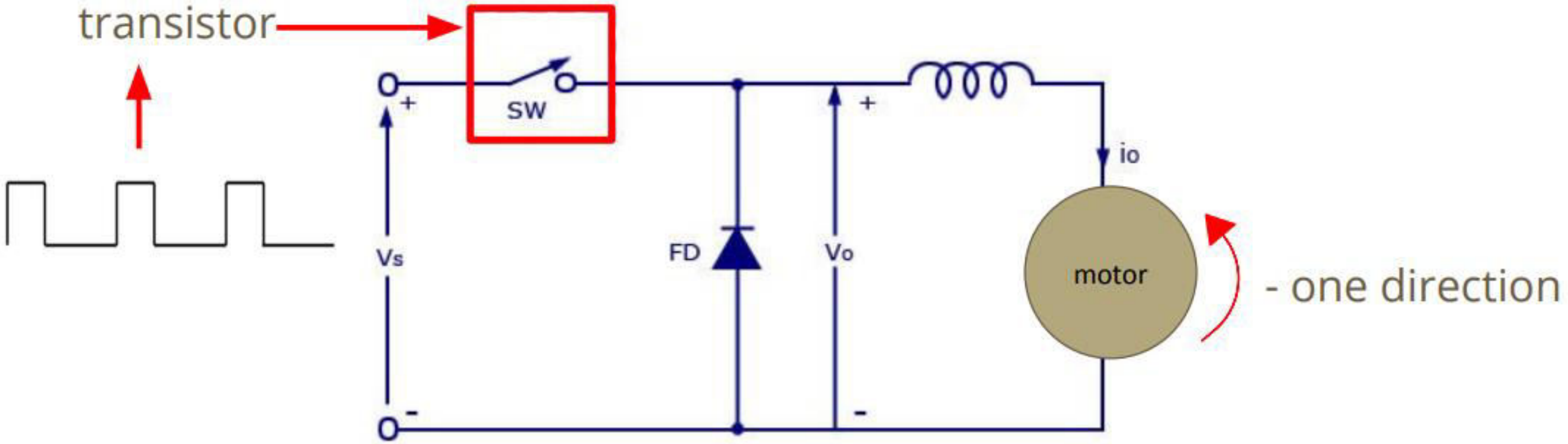


Chopper



Chopper


SW
Vs
FD
Vo
io
motor
- one direction


transistor
SW
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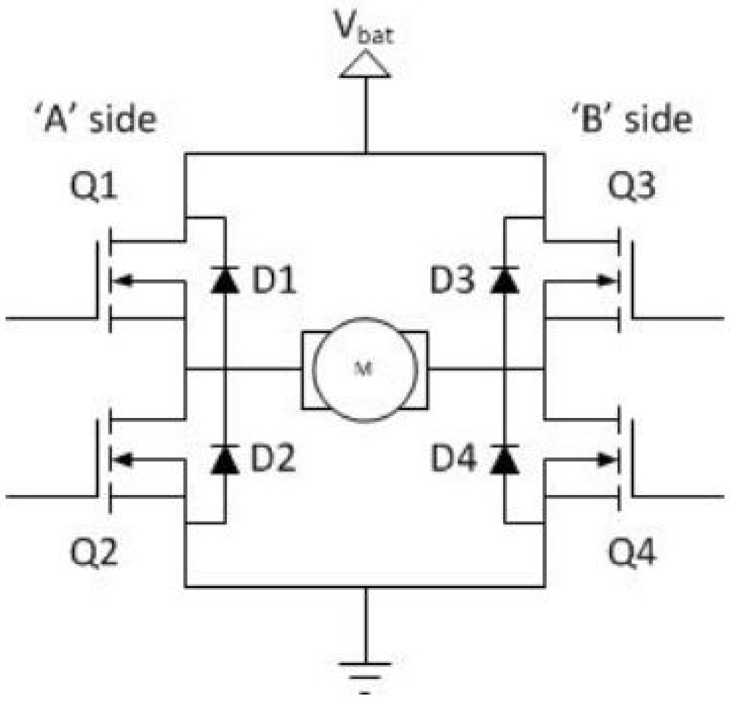
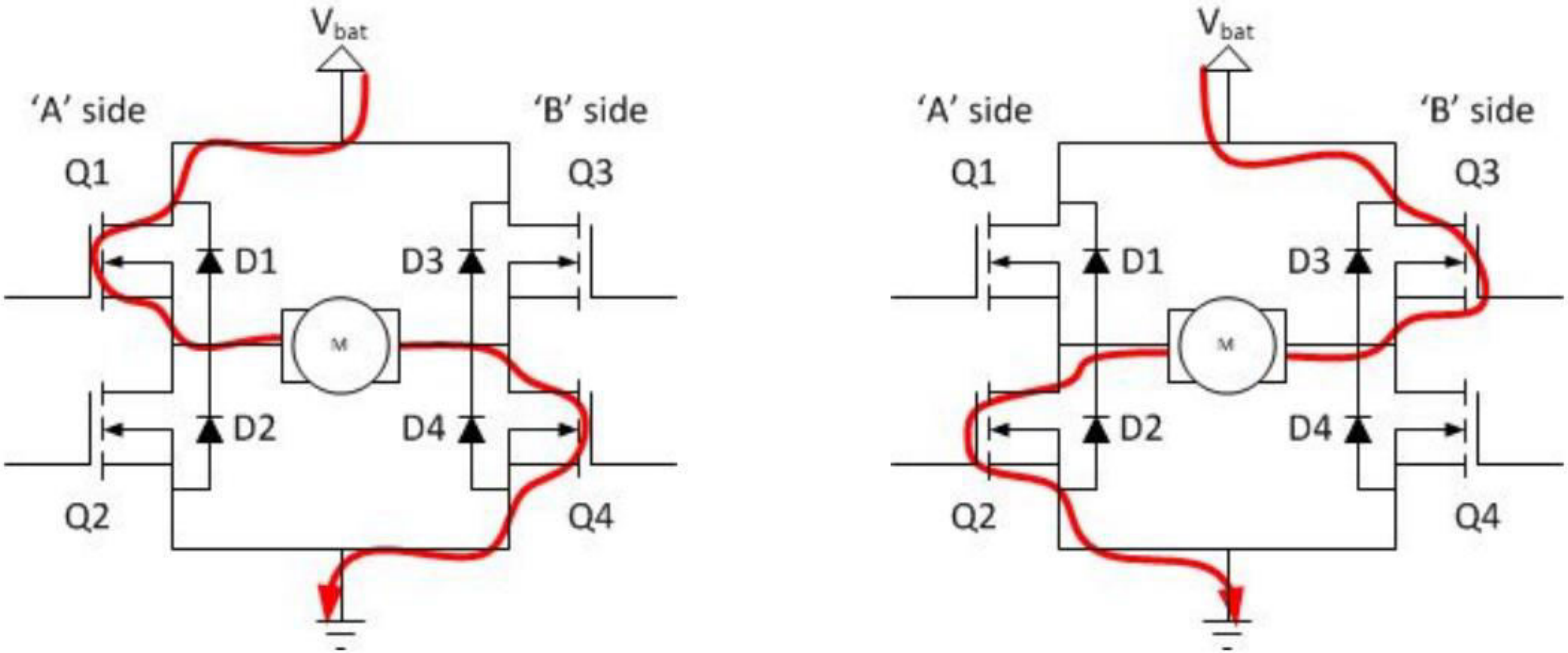
H-bridge

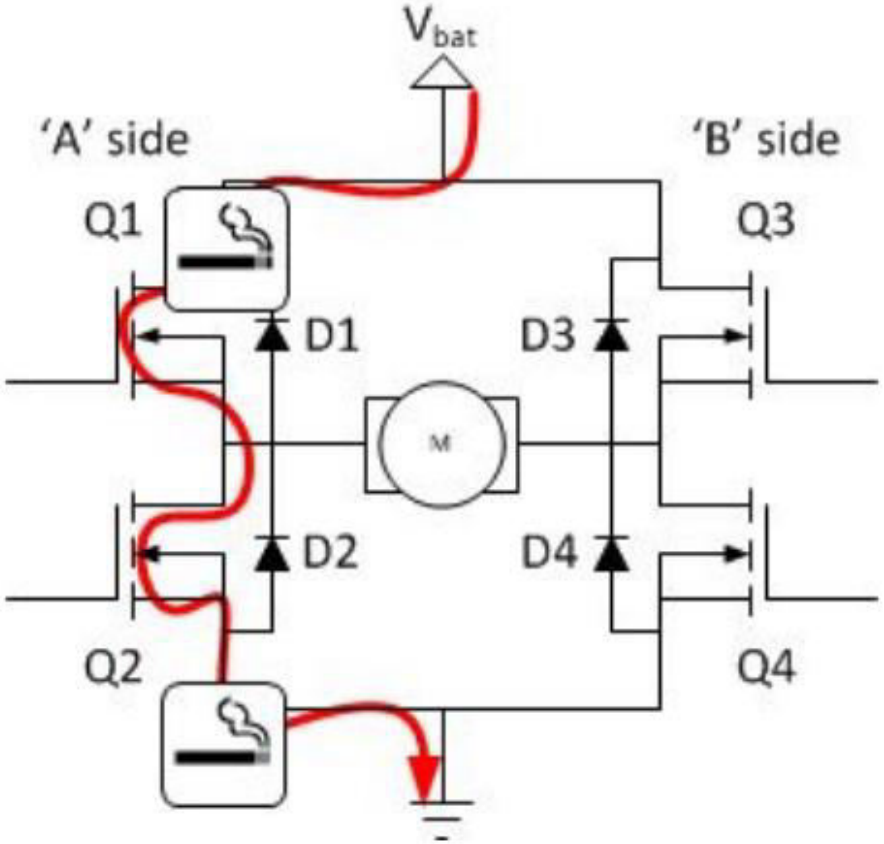
- Circuit containing 4 switching elements + 4 catch diodes
  - Switching elements are usually bipolar transistors or MOSFETs
  - Catch diodes are used to prevent short circuiting
- Path of current controlled by switches



Potential paths and switch combinations



Incorrect path



Building your own H-bridge

- Make sure you never close both transistors on one side
- Use catch diodes (or something similar) to prevent short circuiting
  - There may be delays in switching times
- Also consider
  - Internal resistance of transistor
  - Delay time of transistors (high → low and low → high)

Things to consider when choosing an H-bridge

- Needed input voltage for motor - determines motor speed
- Needed input current for motor - determines torque provided by motor
- May need heat sink for high power

Comparisons

Characteristic	L298	SN754410
Power Supply	Up to 46V	4.6-36V
Logic Supply Voltage	5V (typical), 7V (max) (Vss)	5V (Vcc)
Peak Output Current	3A	2A