UNIT-2

Robotics and Automation

Links

- https://robocademy.com/2020/04/21/robot-kinematics-in-a-nutshell/

Contents

Classification of Robots

- Robots can be classified based on the **application,** by their **locomotion / kinematics and by their mobility.**

- **Classifying Robots by their Application:** Based on this classification, there are two broad ways of categorizing robots.

  1)Industrial Robots

  2)Service Robots

Industrial Robots: These were one of the first robots to be used commercially. In a factory assembly line, these are usually in the form of articulated arms specifically developed for such applications as welding, material handling, painting and others.

- They can be further subdivided as:

  1)Manufacturing Robots

  2)Logistics Robots

Classification of Robots

- **Manufacturing robots** are designed to **move materials**, as well as perform a variety of programmed tasks in manufacturing and production settings. They are often used to **perform duties that are dangerous or unsuitable for human workers.**

- **Logistics robots** are **mobile automated guided vehicles** primarily **used in warehouses and storage facilities** to transport goods.

Service robots: The International Organization for Standardization defines a service robot as '**a robot that performs useful tasks for humans.**' They can be further subdivided as:

1. Medical robots
2. Home robots
3. Defence robots
4. Entertainment robots
5. Agricultural robots
6. Educational robots

Classification of Robots

- **Medical robots** are professional service robots that are **used in and out of hospital settings to improve the level of patient care.** These robots reduce the **workload of the medical staff**, which allows them to **spend more time caring directly for patients**. Mobile medical robots **are used for the delivery of medication and other sensitive materials in a hospital.**
- **Home robots** automate tasks like cleaning and disinfecting.
- The primary purpose of **Education robots** is to make kids aware of their potential, utility, and help **kids build their own robots using readymade kits.** Educational robots are used extensively in schools, both in classrooms and in extracurricular activities.
- One of the most important uses of **robots in defence** is to ensure the safety of soldiers and civilians. For example, **remotely operated vehicles (ROVs) are used to carry out dangerous tasks or activities in hazardous environments**, drones are used for surveillance, and so on.
- **Agricultural robots** sense weather pattern and can adjust the watering of crop as needed, can be used for sowing, de-weeding, and harvesting crops.

Classification of Robots

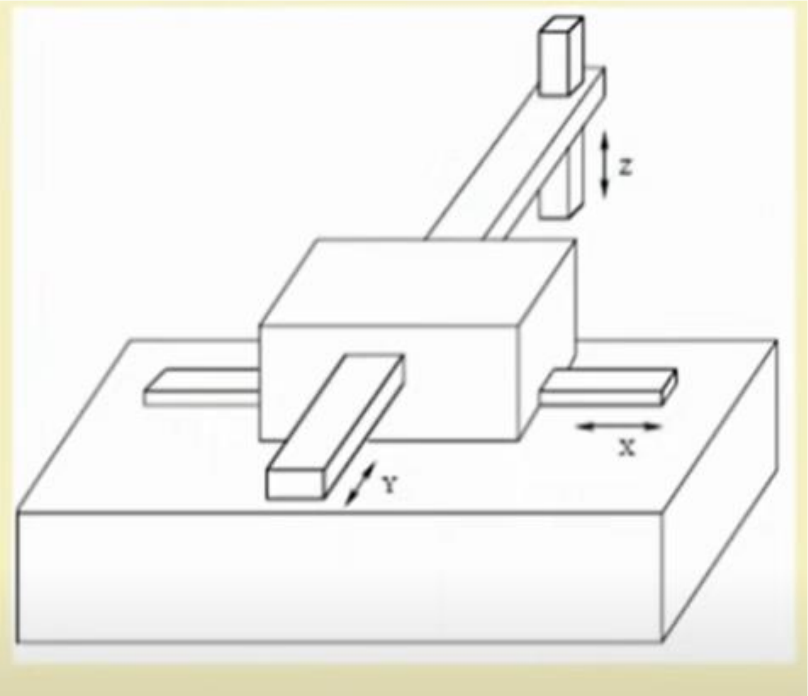
- **Entertainment Robots:** These robots are produced for providing pleasure and good emotions to us and they usually do not have other functions.

Eg: robotic dogs, Humanoid robots.

Classification of Robots

Classifying Robots by their Kinematics or Locomotion: Robots can also be classified according to how they move – or not move.

- **Cartesian Robots:** these are perhaps the most common types of robots. They have three axes which are linear i.e**, they can only move in straight lines rather than rotating and are mounted at right angles to each other.** Because of their rigid structure, this type of robots usually can offer good levels of **precision and repeatability**. Cartesian robots are mostly used in the industrial and the manufacturing sector for **pick and place type of operations**.

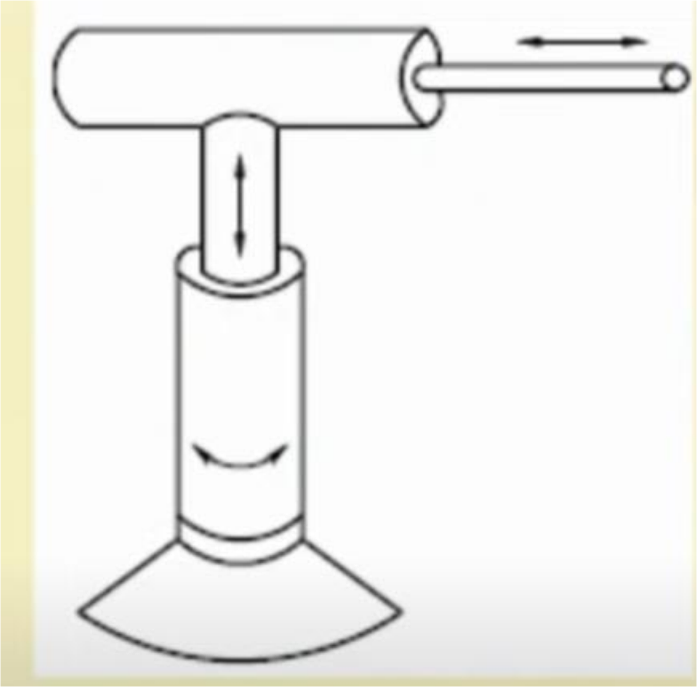


Examples: IBM's RS-1, Sigma robot

Classification of Robots

- **Cylindrical robots:** The body of this type of robot is such that the robotic arm can move up and down along a vertical member. The arm can rotate about that vertical axis and the arm can also extend or contract. This construction makes the manipulator able to work in a cylindrical space. They are used for **assembly operations, spot welding and for die casting machines**. These **cannot reach the objects lying on the floor.**

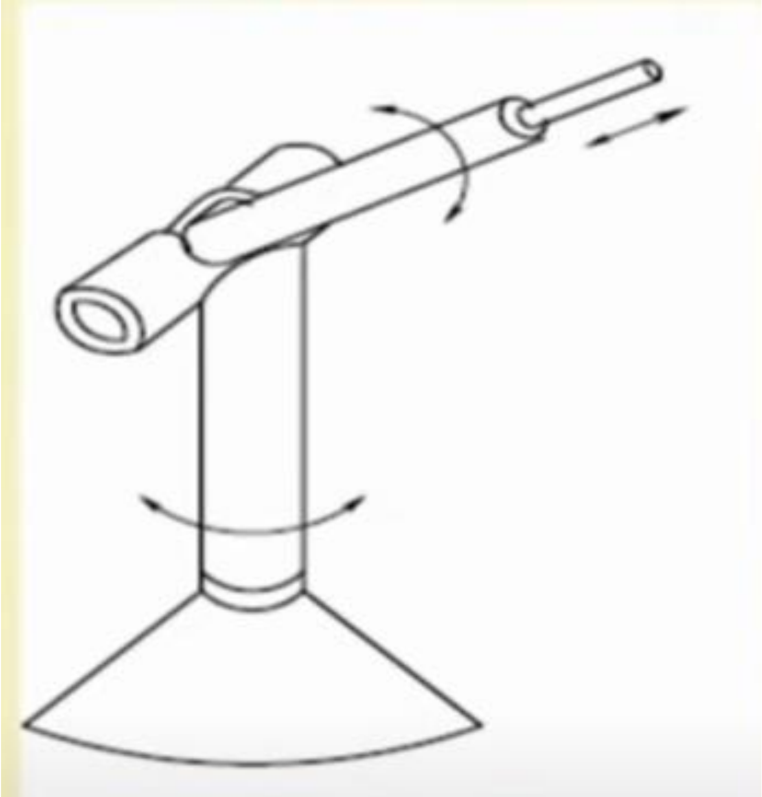
Examples: Versatran 600



Classification of Robots

- **Spherical coordinate Robots(Polar coordinate Robots):** This type of robot can move in a bi-angular and single linear direction. SCARA Robots: **SCARA stands for Selective Compliance Arm for Robotic Assembly.** This type of robot has one linear and two rotary movements. **Can be used to pick up objects lying on the floor**. **They are used for assembly purposes all over the world.**

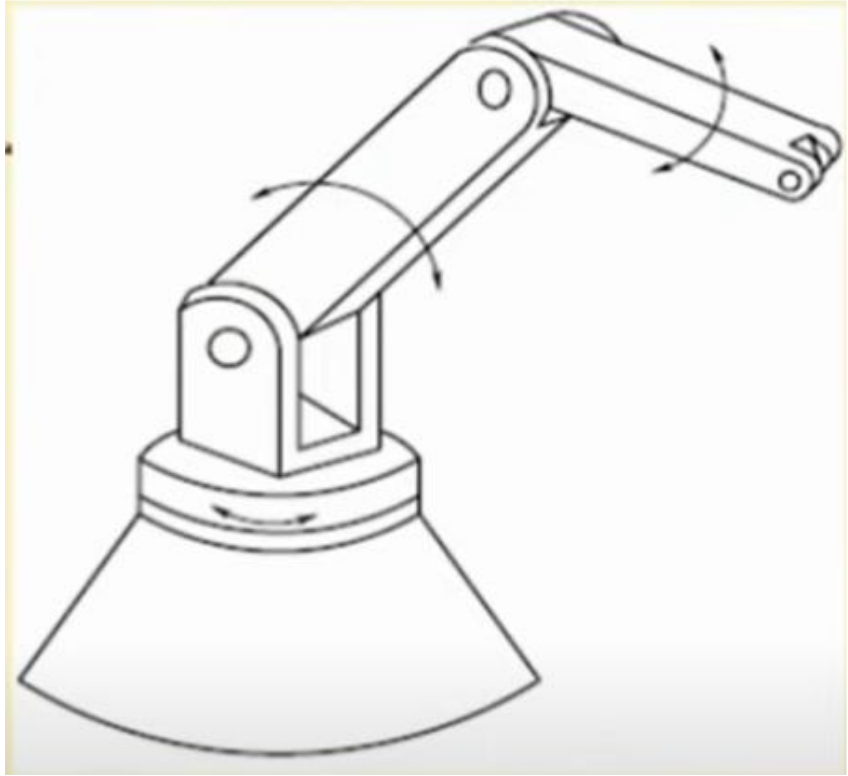
Examples: Unimate 2000B



Classification of Robots

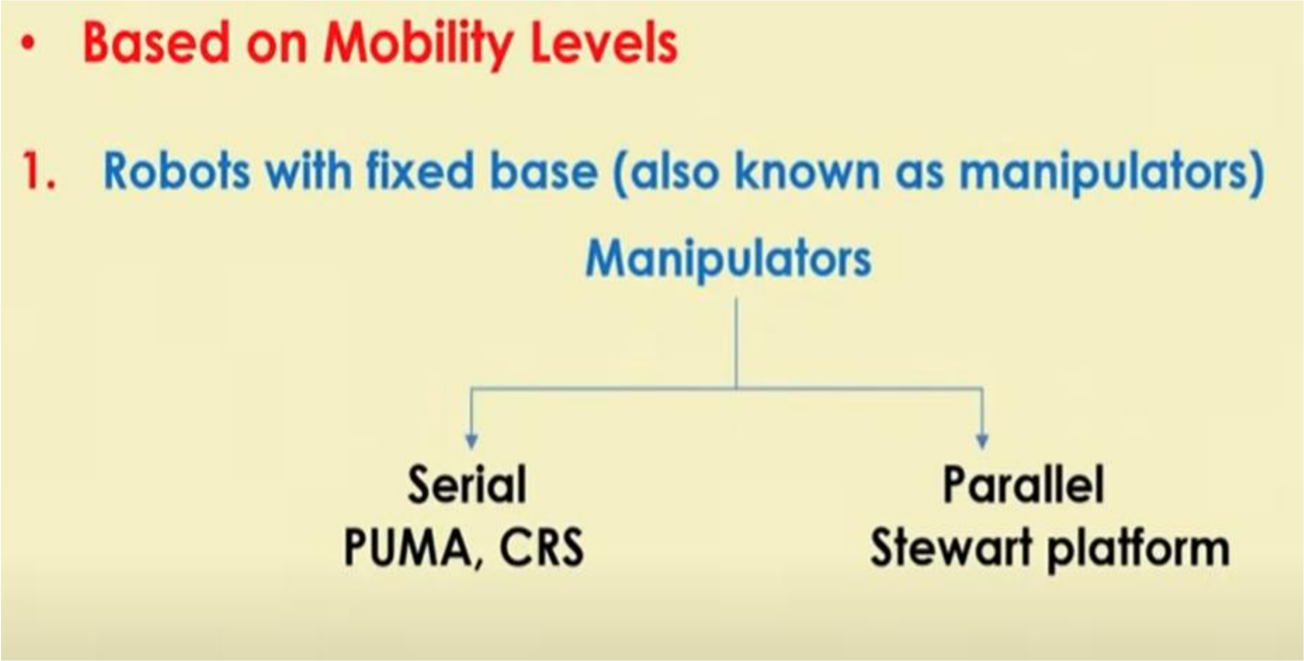
- **Revolute coordinate or Articulated Robots:** These are robots with a wide range of movements that include **forward, backward, upward and downward motion**. Because of their large work envelope, articulated robots can be used for several different applications like **assembly, arc welding, material handling, machine tending, and packaging.**

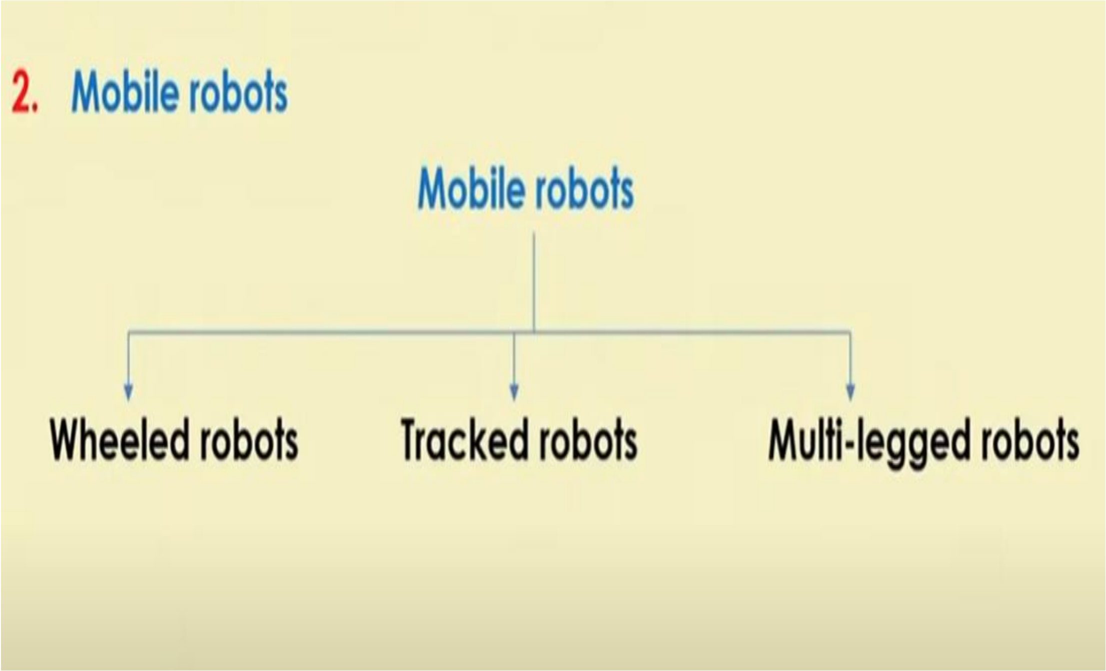
Rigidity and accuracy may not be good enough
Examples: T3, PUMA



Note: PUMA stands for Programmable Universal Machine for Assembly

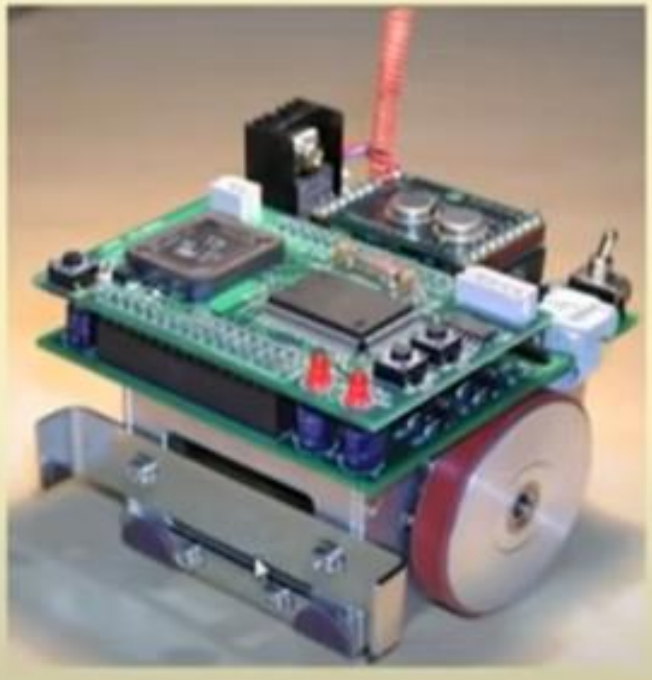
Classification of Robots





Classification of Robots

- **Serial Manipulator:** This is the most common industrial robot ,designed as a series of links connected by motor actuated joints.
- **Parallel Manipulator:** It is a closed loop kinematic chain where several serial chains are used to control a single platform.
- Load carrying capacity for parallel manipulators will be more than serial manipulators..
- **Mobile Robots:** Robots with moving base are called as mobile robots.
- Wheeled robots can be used on smooth terrains.
- For rough terrains or for staircases we can go for multi-legged robots.
- If the terrain is neither to smooth nor too rough then we go for tracked robots.



Wheeled Robot

Six-legged Robot

TRACKED ROBOT

Classification of Robots

- Based on the Type of Controllers

1. Non-Servo-Controlled Robots

- Open-loop control system

Examples: Seiko PN-100

- Less accurate and less expensive

2. Servo-Controlled Robots

- Closed-loop control system

Examples: Unimate 2000, PUMA, T^3

- More accurate and more expensive

Classification of Robots

Other types:

- **Airborne Robots:** these robots can fly through the air. Drones are an extremely popular example of flying robots.

- **Aquatic Robots:** These robots can work on or under water. They are mostly used for underwater exploration of oil, gas or minerals.

Links and Joints

- The mechanical structure of a robotic manipulator is a mechanism whose members are **rigid links or bars connected by means of joints(Articulations**), is segmented into an arm that ensures mobility and reachability , a wrist that confers orientation and an end effector that performs the required task.
- A rigid link that can be connected with at most two other links is referred to as a binary link.
- Figure below shows two rigid binary links 1 and 2 each with two holes at the ends A,B and C,D respectively to connect with each other or to other links.

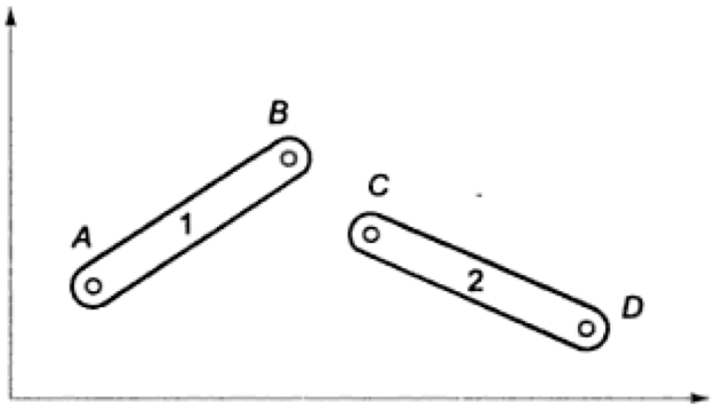


Fig. 1.6 *Two rigid binary links in free space*

Links and Joints

- Two links are connected together by a joint.
- By putting a pin through holes B and C of links 1 and 2,an open kinematic chain is formed as shown in the next slide.
- The joint formed is called a pin joint also known as revolute or rotary joint.
- The kinematic chain formed by joining two links is extended by connecting more links. To form a manipulator , one end of the chain is connected to the base or ground with a joint.
- Such a manipulator is an open kinematic chain.
- The end effector is connected to the free end of the last link as shown in figure 1.5.
- Closed kinematic chains are used in special purpose manipulators, such as parallel manipulators , to create certain kind of motion of the end effector.
- Relative rotary motion between the links is possible and the **two links are said to be paired. Links are represented by straight lines and rotary joint by a small circle.**
- At a joint ,links are connected such that they can be made to move relative to each other by the actuators.

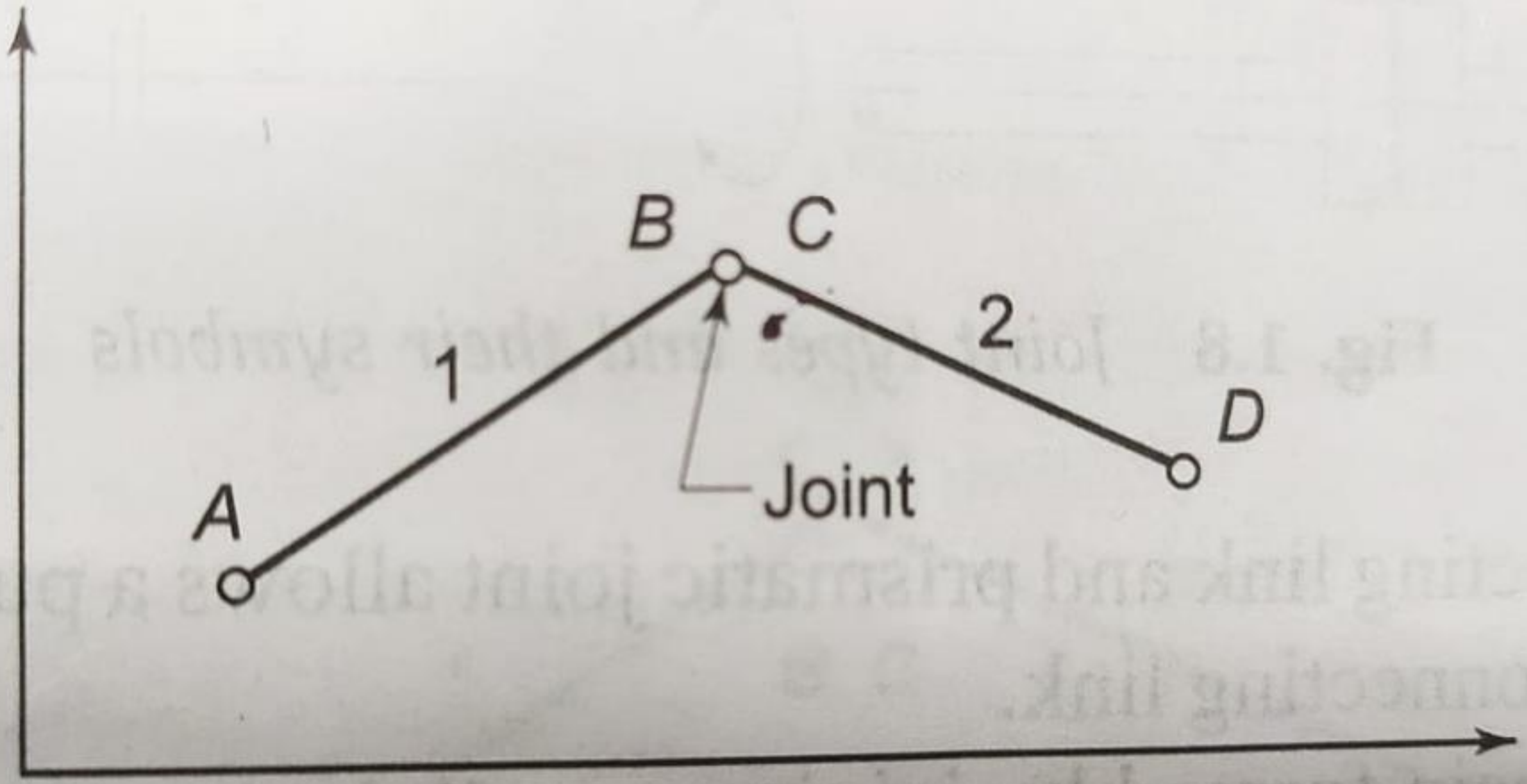


Fig. 1.7 *An open kinematic chain formed by joining two links*

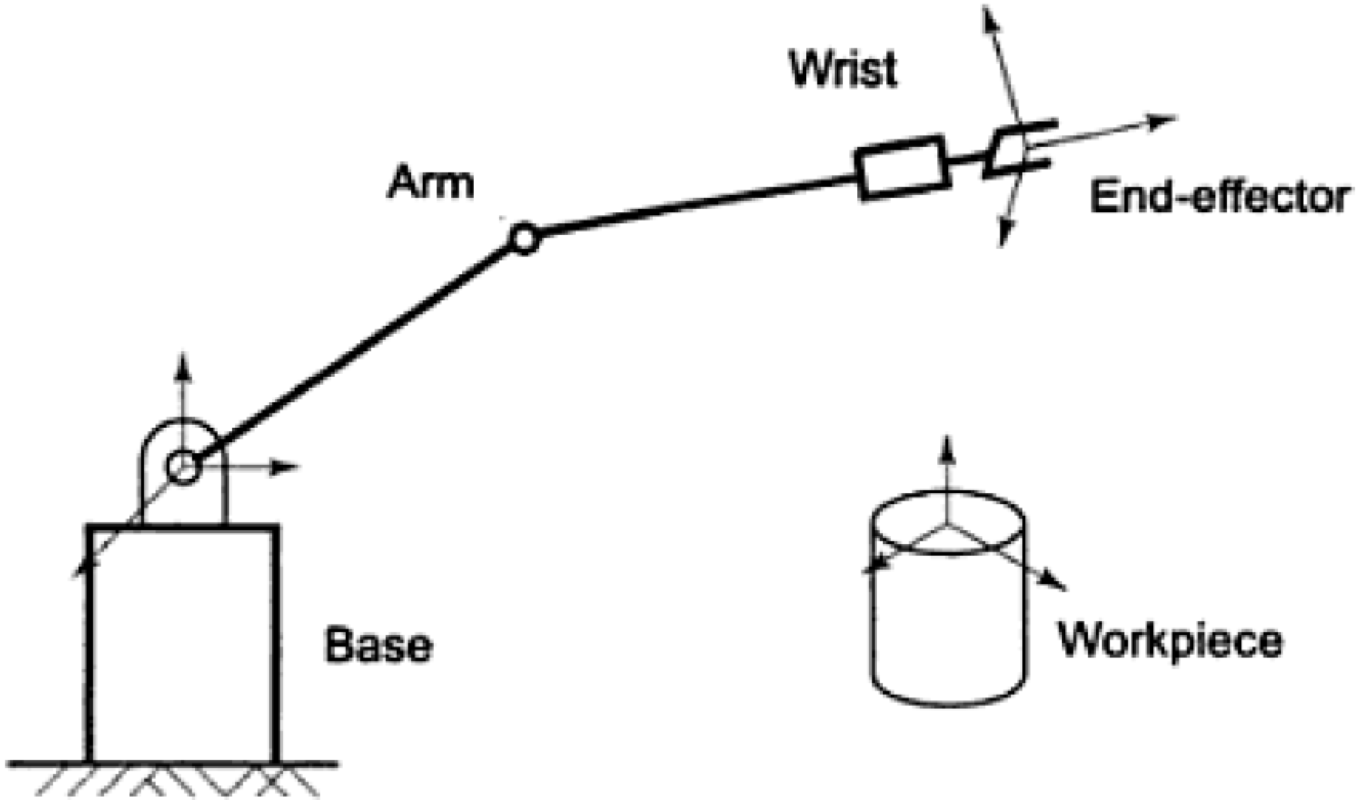


Fig. 1.5 *The base, arm, wrist, and end-effector forming the mechanical structure of a manipulator*

Joint and Joint Notation scheme

- Two basic types types of joints are used in industrial robots

1)Revolute

2)Prismatic

- The relative motion of the adjoining links of a joint is either rotary or linear depending on the type of joint.
- **Revolute Joint:** The two links are joined by a pin about the axis of which the links can rotate with respect to each other.
- **Prismatic joint:** The two links are joined so that these can slide(linearly move) with respect to each other. Screw and nut(slow linear motion of the nut),rack and pinion are ways to implement prismatic joints.
- A **rotary joint** allows a pure rotation of one link relative to the connecting link and **prismatic joint** allows a pure translation of one link relative to the connecting link.

Joint and Joint Notation scheme

- **Orthogonal joint(o-joint):** This type of joint allows a translational motion between the input and output links with the axis of thew links perpendicular to each other.
- **Linear Joint(L-joint):**This type of joint allows a translational motion between the input and output links with the axis of the links parallel to each other.
- Linear joints and orthogonal joints are prismatic joints.
- Other types of possible joints are planar(one surface sliding on the other surface),rotary(one link can rotate and slide about the axis),spherical(one link can move with respect to other in three dimensions.
- Another variant of rotary joint is twist joint where two links remain aligned along a straight line but one turns about the other around the link axis.

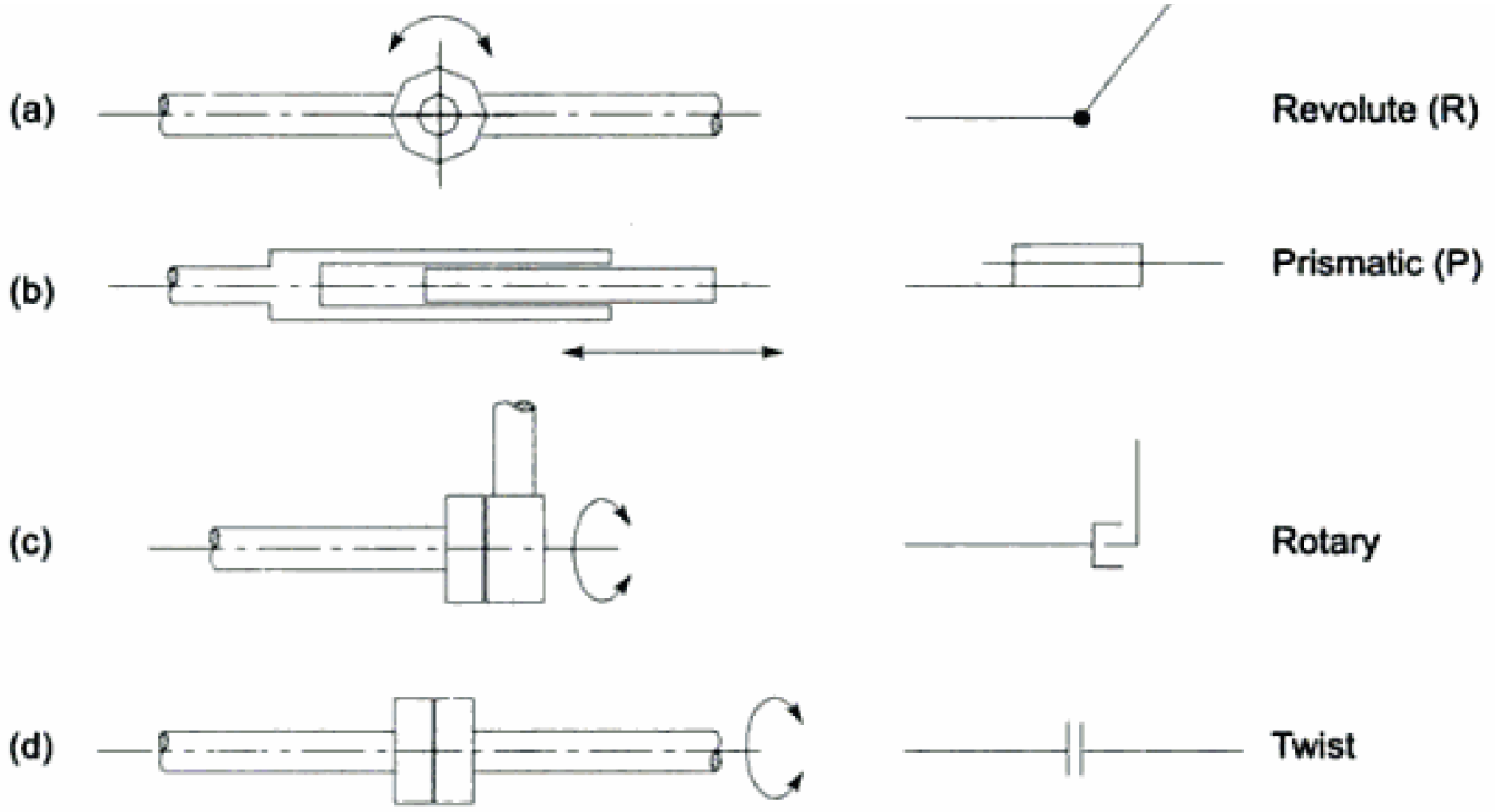
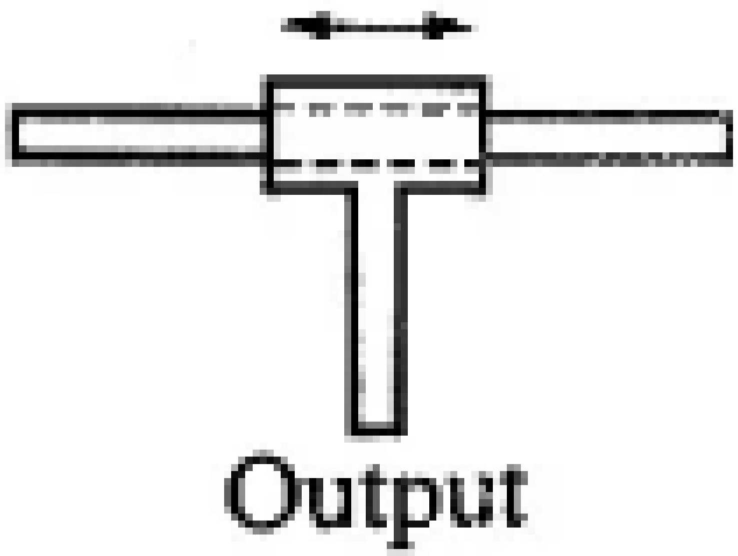


Fig. 1.8 *Joint types and their symbols*

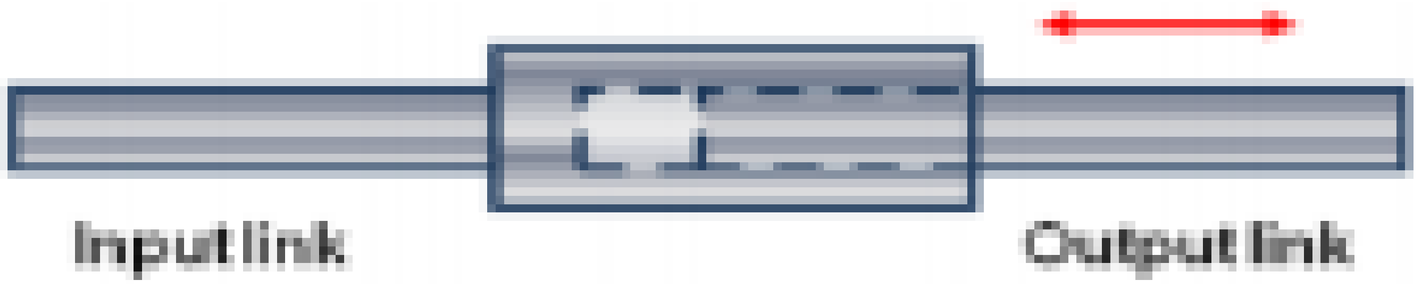
Joint and Joint Notation scheme

- **Cylindrical joint:** Cylindrical joint has one rotation degree of freedom where the link can rotate about the axis and one translational degree of freedom where it can translate through the axis.
- **Twisting Joint(T-Joint):** This type of joint allows rotary motion with the axis of rotation parallel to the axes of input and output link.
- **Spherical Joint(Ball-Socket joint):**One link can move with respect to other in three dimensions.

Orthogonal joint



Linear joint



(a) Linear Joint

Degrees of freedom

The number of independent movements that an object can perform in a 3-D space is called the number of *degrees of freedom* (DOF). Thus, a rigid body free in space has six degrees of freedom—three for position and three for orientation. These six independent movements pictured in Fig. 1.9 are:

(i) three translations (T_1, T_2, T_3), representing linear motions along three perpendicular axes, specify the position of the body in space.

(ii) three rotations (R_1, R_2, R_3), which represent angular motions about the three axes, specify the orientation of the body in space.

Note from the above that six independent variables are required to specify the location (position and orientation) of an object in 3-D space, that is, $2 \times 3 = 6$. Nevertheless, in a 2-D space (a plane), an object has 3-DOF—two translatory and one rotational. For instance, link 1 and link 2 in Fig. 1.6 have 3-DOF each.

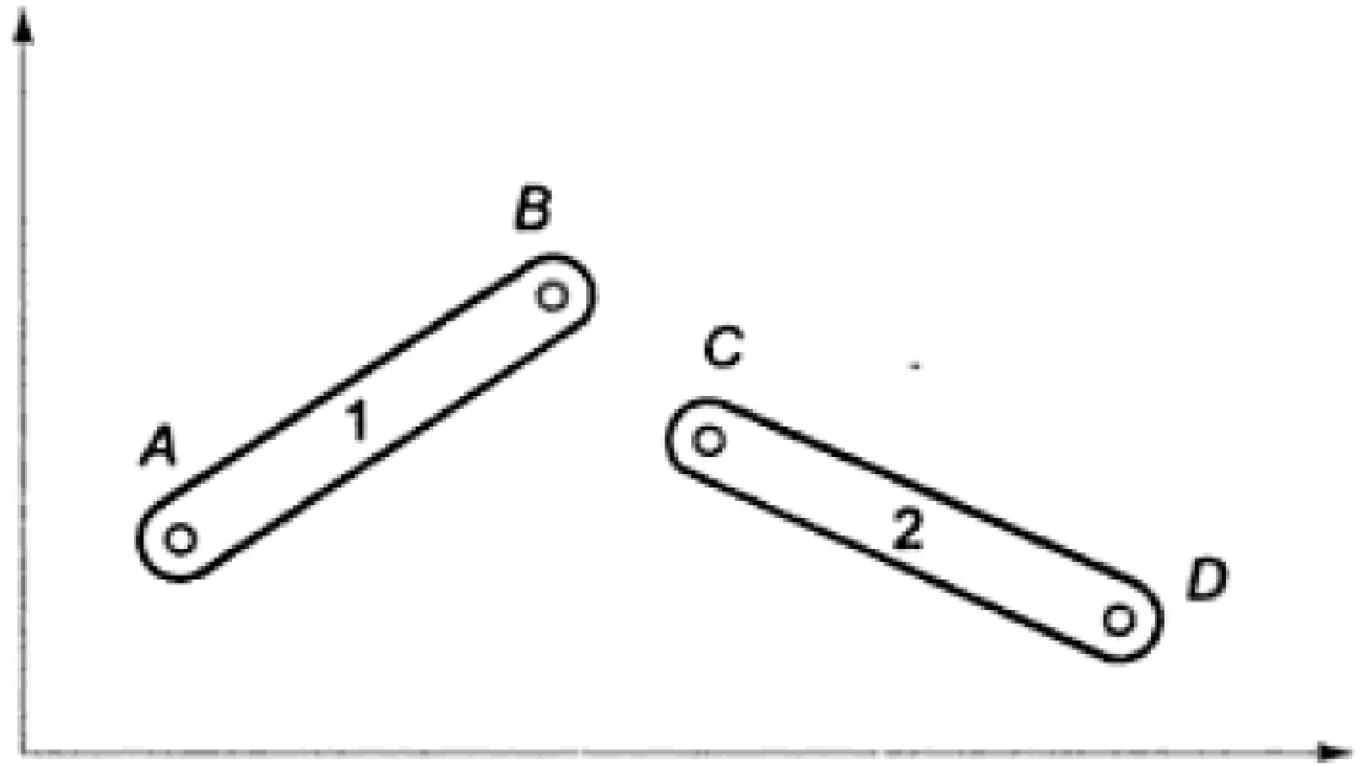
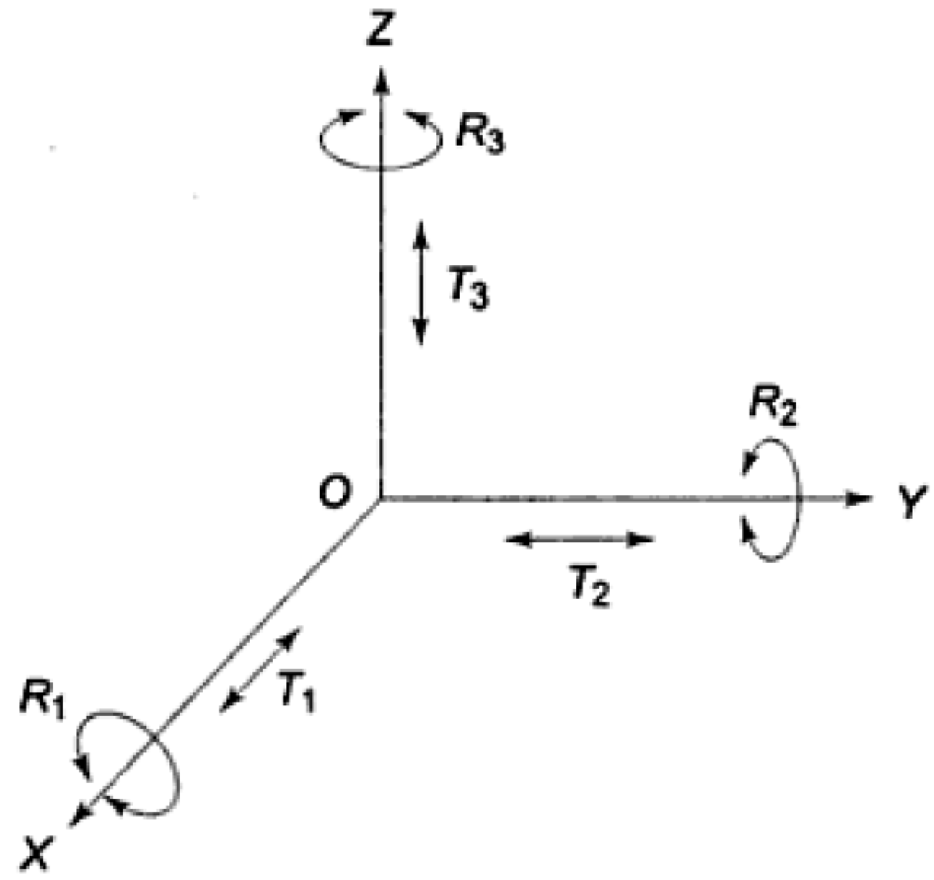


Fig. 1.6 *Two rigid binary links in free space*

Fig 1.9: Representation of six degrees of freedom



Degrees of freedom

Consider an open kinematic chain of two links with revolute joints at A and B (or C), as shown in Fig. 1.10. Here, the first link is connected to the ground by a joint at A. Therefore, link 1 can only rotate about joint 1 (J_1) with respect to ground and contributes one independent variable (an angle), or in other words, it contributes one degree of freedom. Link 2 can rotate about joint 2 (J_2) with respect to link 1, contributing another independent variable and so another DOF. Thus, by induction, conclude that an open kinematic chain with one end connected to the ground by a joint and the farther end of the last link free, has as many degrees of freedom as the number of joints in the chain. It is assumed that each joint has only one DOF.

Degree of freedom

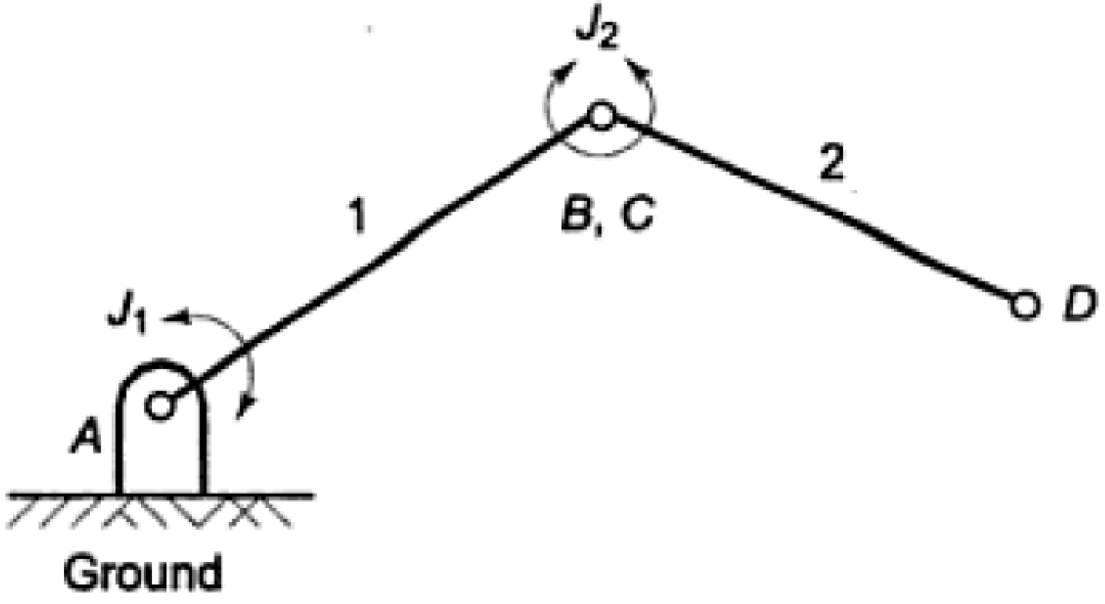


Fig. 1.10 *A two-DOF planar manipulator–two links, two joints*

Degree of freedom

The DOF is also equal to the number of links in the open kinematic chain. For example, in Fig. 1.10, the open kinematic chain manipulator with two DOF has two links and two joints.

The variable defining the motion of a link at a joint is called a *joint-link variable*. Thus, for an n-DOF manipulator n independent joint-link variables are required to completely specify the location (position and orientation) of each link (and joint), specifying the location of the end-effector in space. Thus, for the two-link, in turn 2-DOF manipulator, in Fig. 1.10, two variables are required to define location of end-point, point D.

Degree of freedom

- To position and orient a body freely in 3-D space , **a manipulator with 6 degrees of freedom is required**. **Such a manipulator is called spatial manipulator.**

A manipulator with less than 6-DOF has constrained motion in 3-D space.

There are situations where five or even four joints (DOF) are enough to do the required job. There are many industrial manipulators that have five or fewer DOF. These are useful for specific applications that do not require 6-DOF. A *planar manipulator* can only sweep a 2-D space or a plane and can have any number of degrees of freedom. For example, a planar manipulator with three joints (3-DOF)— may be two for positioning and one for orientation —can only sweep a plane.

Degree of freedom

DOF of a system: Defined as **the minimum number of independent parameters /variables/coordinates needed to describe the system completely.**

Notes

- A point in 2-D: 2 dof; in 3-D space: 3 dof
- A rigid body in 3-D: 6 dof
- Spatial Manipulator: 6 dof
- Planar Manipulator: 3 dof

Degree of freedom

Redundant Manipulator

Either a Spatial Manipulator with more than 6 dof or a Planar Manipulator with more than 3 dof

Under-actuated Manipulator

Either a Spatial Manipulator with less than 6 dof or a Planar Manipulator with less than 3 dof

Eg:Minimover

Degree of freedom

Mobility/dof of Spatial Manipulator

Let us consider a manipulator with n rigid moving links and m joints

C_i: Connectivity of i-th joint; i = 1, 2, 3,………, m

No. of constraints put by i-th joint $= (6 - C_i)$

Total no. of constraints $= \sum_{i=1}^{m}(6 - C_i)$

Mobility of the manipulator $\mathrm{M} = 6n - \sum_{i=1}^{m}(6 - C_i)$

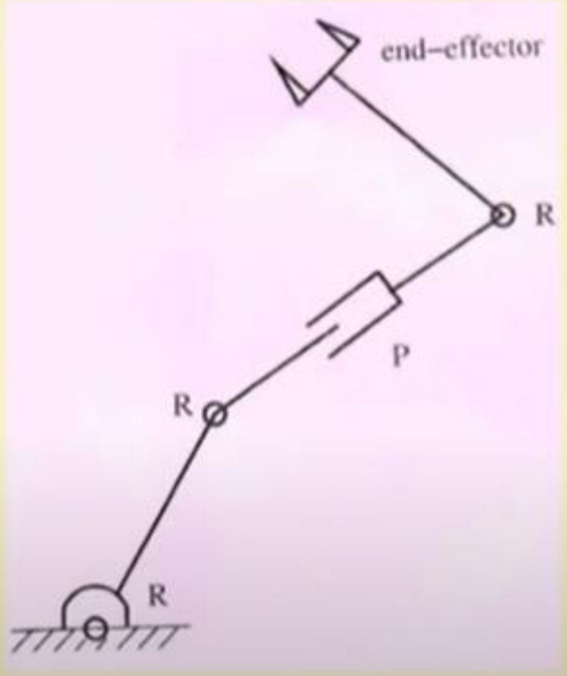
It is known as Grubler's criterion.

Connectivity / Degrees of Freedom of a Joint

It indicates the number of rigid (bodies) that can be connected to a fixed rigid body through the said joint

Degree of freedom

Serial planar manipulator



$$n = 4, \quad m = 4$$

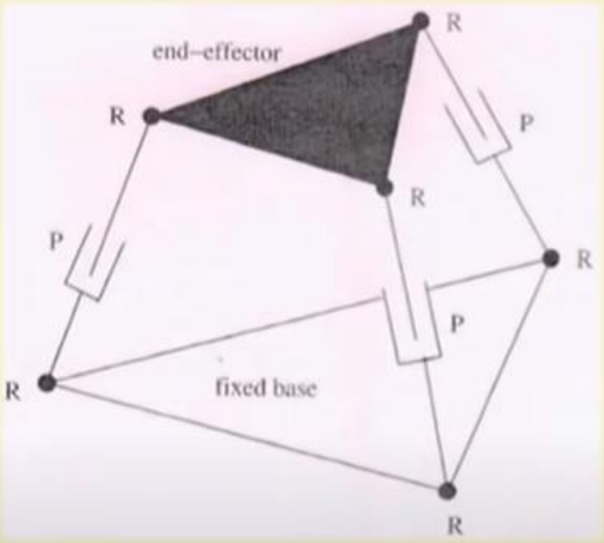
$$C_1 = C_2 = C_3 = C_4 = 1$$

Mobility/dof:

$$M = 3n - \sum_{i=1}^{m} (3 - C_i) = 3 \times 4 - 8 = 4$$

Degree of freedom

Parallel planar manipulator



$$n = 7, \quad m = 9$$

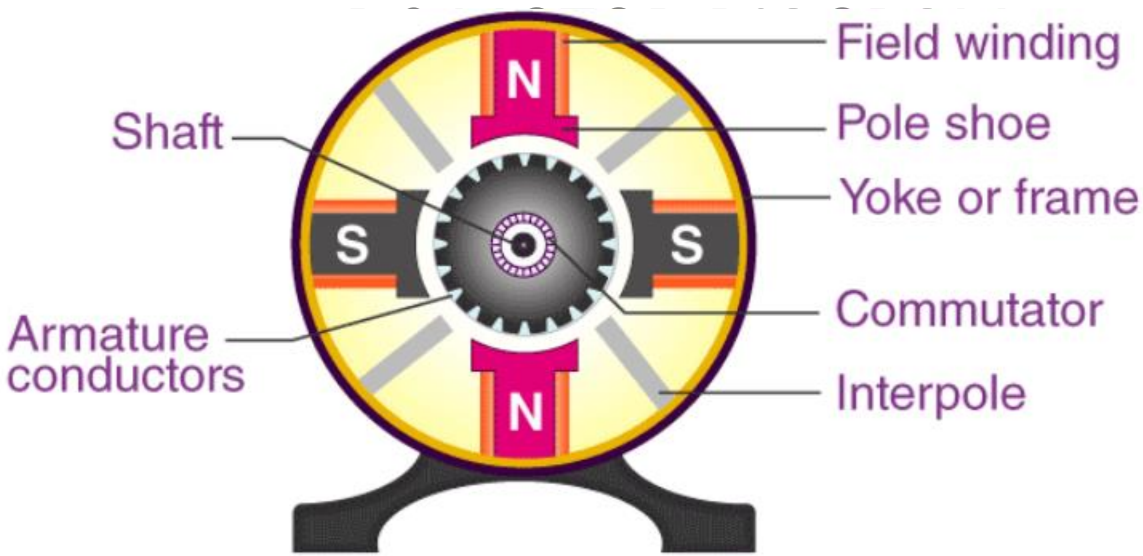
$$C_i = 1, \qquad where\ i = 1, \ldots, 9$$

Mobility/dof:

$$M = 3n - \sum_{i=1}^{m} (3 - C_i) = 3 \times 7 - 18 = 3$$

Motors

- Motors take electrical energy and produce mechanical energy. Electric motors are utilized to power hundreds of devices we use in everyday life.
- **DC Motor: A DC motor is defined as a class of electrical motors that convert direct current electrical energy into mechanical energy.**
- From the above definition, we can conclude that any electric motor that is operated using direct current or DC is called a DC motor.

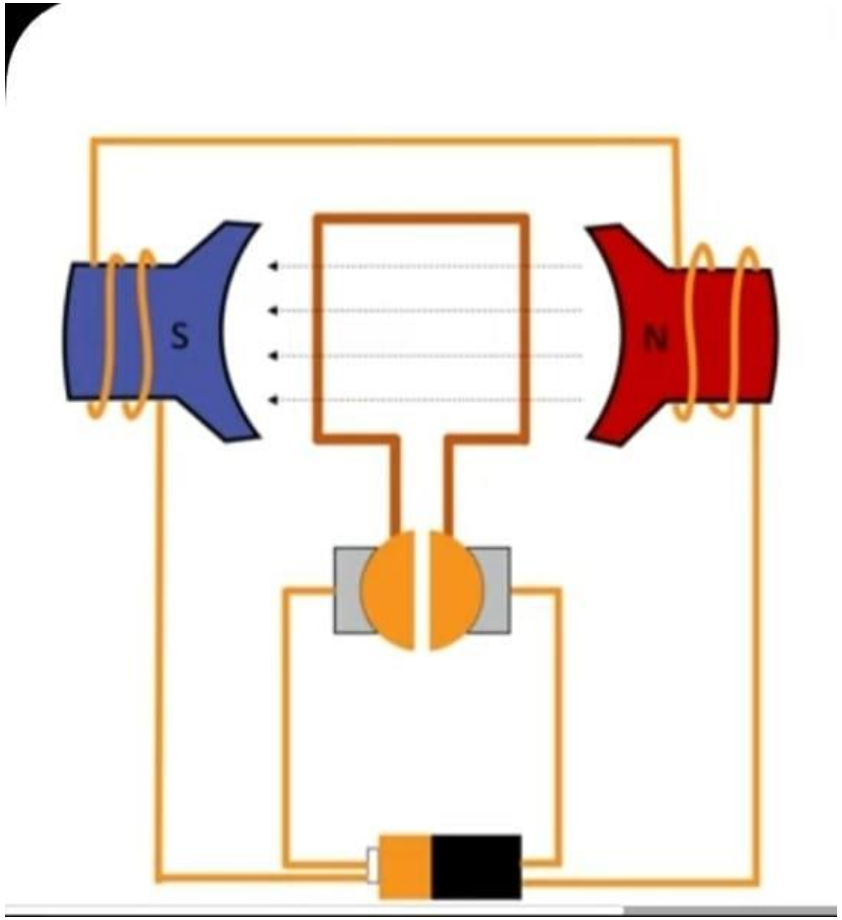


Motors

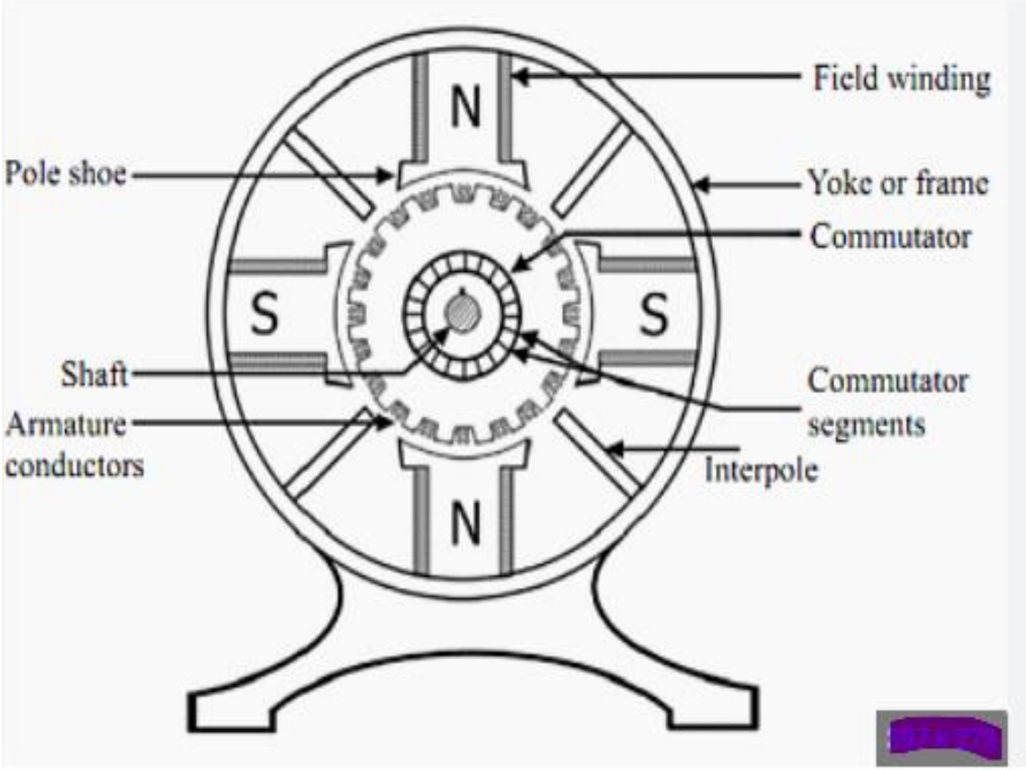
- In an electric motor, **the operation is dependent upon simple electromagnetism.** A current-carrying conductor generates a magnetic field. When this is then placed in an external magnetic field, **it will encounter a force proportional to the current in the conductor and to the strength of the external magnetic field.**
- DC Motor consists of field windings to provide the magnetic flux and armature which acts as the conductor.

  DC motor basically consists of two main parts.
- The **rotating part is called the rotor** and the **stationary part is also called the stator**. The rotor rotates with respect to the stator.
- The rotor consists of armature windings, the windings being electrically associated with the commutator. The geometry of the brushes, commutator contacts, and armature windings are such that when power is applied, **the polarities of the energized winding(armature windings) and the stator magnets are misaligned and the rotor will turn until it is very nearly aligned with the stator's field magnets.**

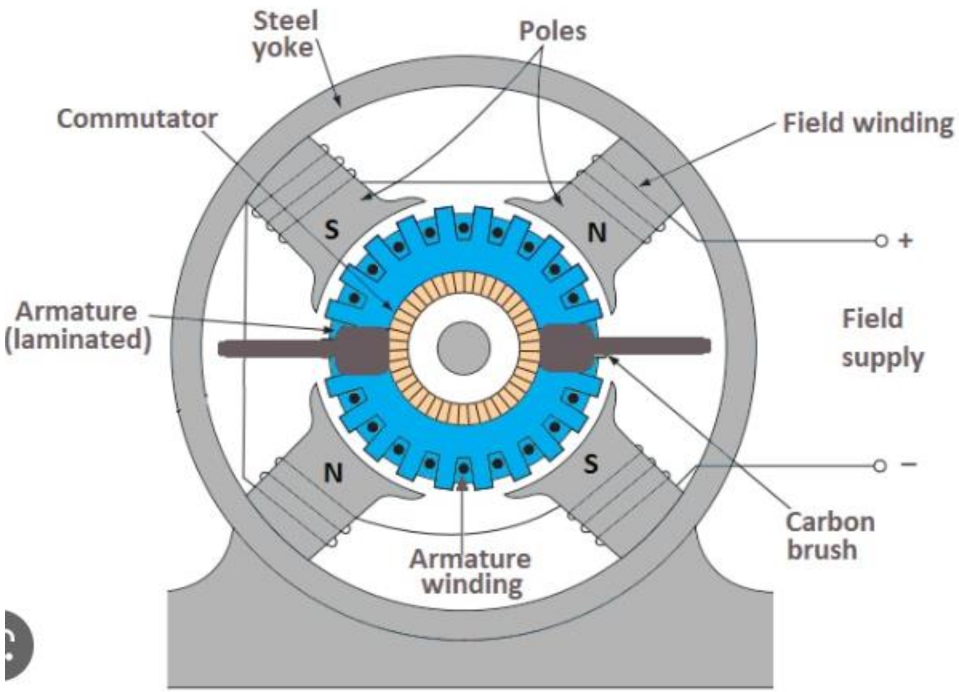
ELEMENTARY DC MOTOR



DC MOTOR



Field winding
Pole shoe
Yoke or frame
Commutator
N
S
S
N
Shaft
Armature
conductors
Commutator
segments
Interpole



Steel
yoke
Poles
Commutator
Field winding
S
N
N
S
+
Field
supply
−
Armature
(laminated)
Carbon
brush
Armature
winding

DC MOTOR

<u>Construction of a DC Motor</u>: The essential parts of this motor include armature as well as stator.

Stator

- A stationary part like a stator is one of the parts in DC motor parts which includes the field windings. The **main function of this is to get the supply**.. When the DC is passed through the field windings, it magnetizes poles that produce magnetic flux.
- Note: More stator poles to make the magnetic field felt by the coils as as uniform as possible and also to increase the torque.

Armature or Rotor

- The rotor is the dynamic part of the motor that is used to create the mechanical revolutions of the unit.

DC MOTOR

Commutator and Brushes

Commutator

- The commutator of a DC motor is a cylindrical structure that is made of copper segments stacked together but insulated from each other.

Brushes

- Brushes using a commutator mainly work as a bridge to fix the stationary electrical circuit toward the **rotor. The brushes of a DC motor are made with graphite and carbon structure**. These brushes conduct electric current from the external circuit to the rotating commutator. Hence, the **commutator and the brush unit are concerned with transmitting the power from the static electrical circuit to the mechanically rotating region or the rotor**.

Yoke

- The yoke acts as the outer cover of a DC motor and it is also known as the frame.

Poles

- Poles in the motor include two main parts like the pole core as well as pole shoes.The poles represents the number of permanent magnet poles for the rotating rotor and a motor with one pair of north/south poles is called a two pole motor.

DC MOTOR

DC Motor Working:

A magnetic field arises when the field coil of the DC motor is energized. The created magnetic field is in the direction of the radii of the armature. The magnetic field enters the armature from the North pole side of the field coil and “exits” the armature from the field coil’s South pole side.

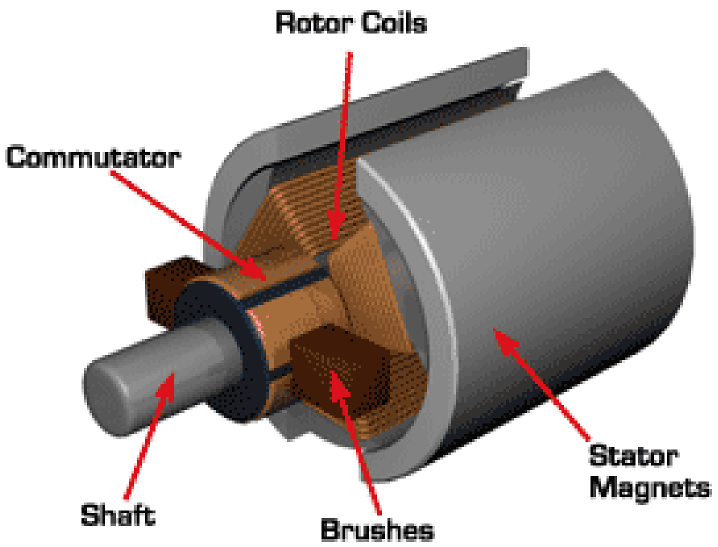
The conductors located on the poles are subjected to a force of the same intensity but in the opposite direction. These two opposing forces create a torque that causes the motor armature to rotate.

Working principle of DC motor

The DC motor working principle is that when a current-carrying conductor is located within the magnetic field, then it experiences a mechanical force. The magnitude and force direction can be decided through **Flemming’s left-hand rule .**

If the first finger is extended, the second finger, as well as the left hand’s thumb, will be vertical to each other & primary finger signifies the magnetic field’s direction, the next finger signifies the current direction & the third finger-like thumb signifies the force direction which is experienced through the conductor.

DC MOTOR



DC MOTOR

F = BIL Newtons

Where,

‘B’ is the magnetic flux density,

‘I’ is current

‘L’ is the conductor’s length in the magnetic field.

Whenever an armature winding is given a DC supply, then the flow of current will be set up within the winding. Field winding or permanent magnets will provide the magnetic field. So, armature conductors will experience a force because of the magnetic field . The Commutator is designed like sections to attain uni-directional torque

DC MOTOR

- The different types of dc motors are :

Geared DC Motors:

- Geared motors tend to reduce the speed of the motor but with a **corresponding increase in torque**. This property comes in handy, as DC motors can rotate at speeds much too fast for an electronic device to makes use of. **Geared motors commonly consist of a DC brush motor and a gearbox attached to the shaft**. No good robot can ever be built without gears.

Note: In robotics, torque is better than speed. With gears, it is possible to exchange the high velocity with better torque.

Torque: A force that tends to cause rotation.

Geared DC Motors

DC MOTOR

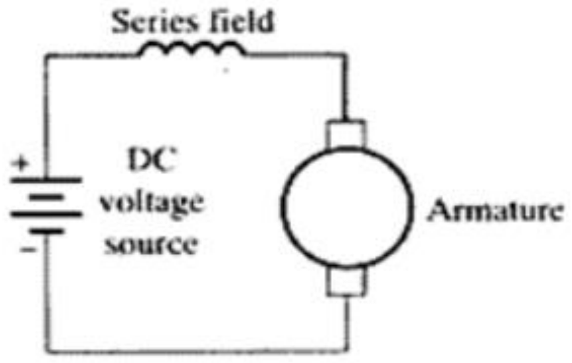
- Sometimes the objective of using a gear motor is to reduce the rotating shaft speed of a motor in the device being driven, for example in a small electric clock where the tiny synchronous motor may be turning at 1,200 rpm however is decreased to one rpm to drive the second hand

Types of **self excited motors(supply to field winding is obtained from armature voltage)**:

Series and Shunt

Series DC Motor

- A Series motor is a DC series motor where **field winding is connected internally in series to the armature winding**. The series motor provides high starting torque and can be used to **move very large shaft loads when it is first energized**. Series motors are also known as a series-wound motor.



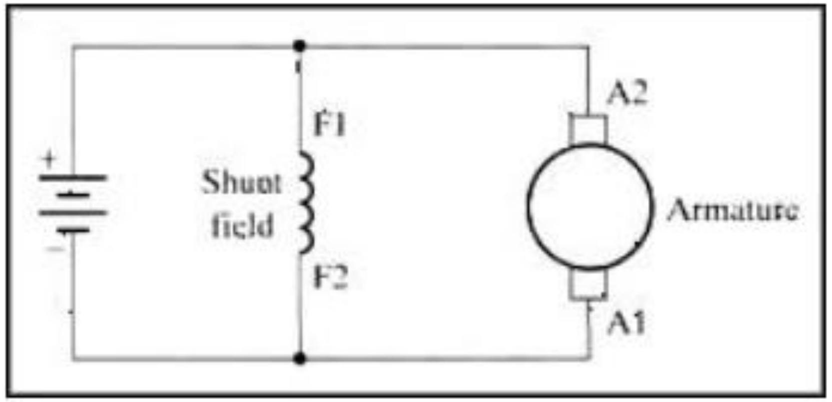
Series Motor

DC MOTOR

Shunt Motor:

Shunt motors are shunt DC motors, where **the field windings shunted to or are connected in parallel to the armature winding of the motor.**

- The **shunt DC motor is commonly used because of its best speed regulation**. the shunt motor has extremely low starting torque, which requires that the shaft load be quite little.

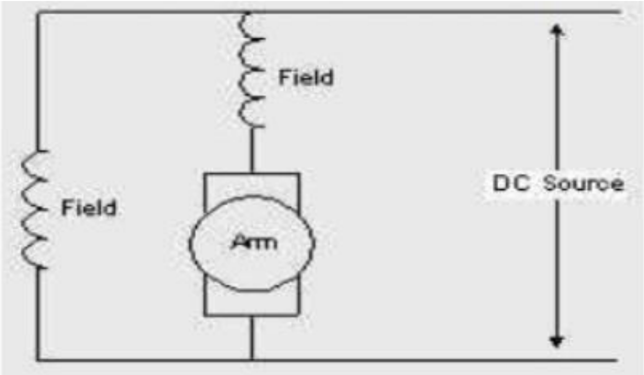


Shunt Motor

DC MOTOR

DC Compound Motors

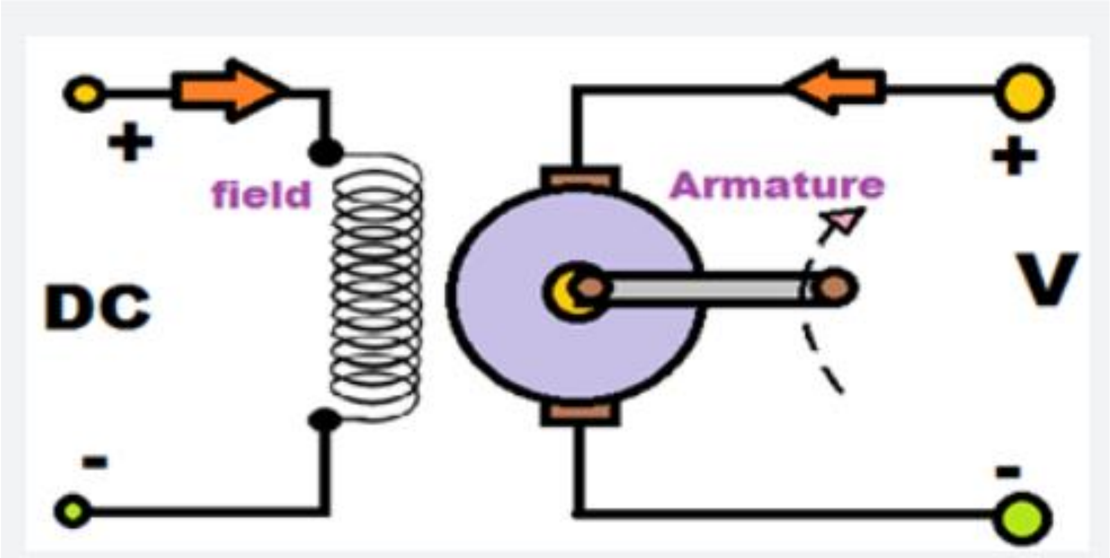
- DC motors having both shunt and series field winding is known as Compound DC motor.



- **Separately Excited:**In separately excited DC motors, the supply is given to the field and armature windings separately.
- **Permanent Magnet DC motor:** (PMDC motor) is a type of DC motor that uses a permanent magnet to create the magnetic field required for the operation of a DC motor

DC MOTORS

- Separately excited DC Motor



Stepper motor

- A stepper motor is an electromechanical device that **converts electrical power into mechanical power.**
- It is a synchronous electric motor(**synchronous motor: An electric motor having a speed exactly proportional to the current frequency**) that can divide a full rotation into an expansive number of steps. **A stepper motor generates discrete displacement in response to electrical signals.**

Construction & Working Principle:

- The construction of a stepper motor is fairly related to a DC motor. It **includes a permanent magnet like Rotor which is in the middle & it will turn once force acts on it.** This rotor is enclosed through a no. of the stator windings. The stator is arranged near to rotor so that **magnetic fields within the stators can control the movement of the rotor.**
- The **stepper motor can be controlled by energizing every stator one by one**. So the stator will magnetize & works like an electromagnetic pole which uses repulsive energy on the rotor to move forward. The stator's alternative magnetizing as well as demagnetizing will shift the rotor gradually &allows it to turn through great control.

Stepper motor

- There are three types of stepper motors:

1)Variable reluctance

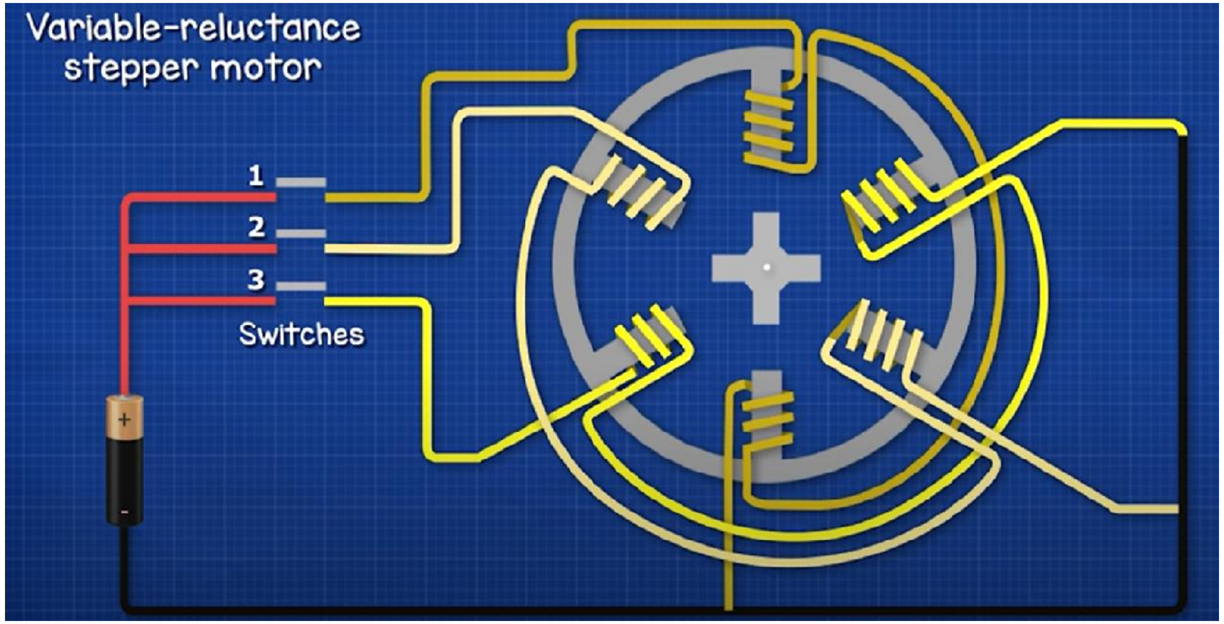
2)Permanent Magnet

3)Hybrid

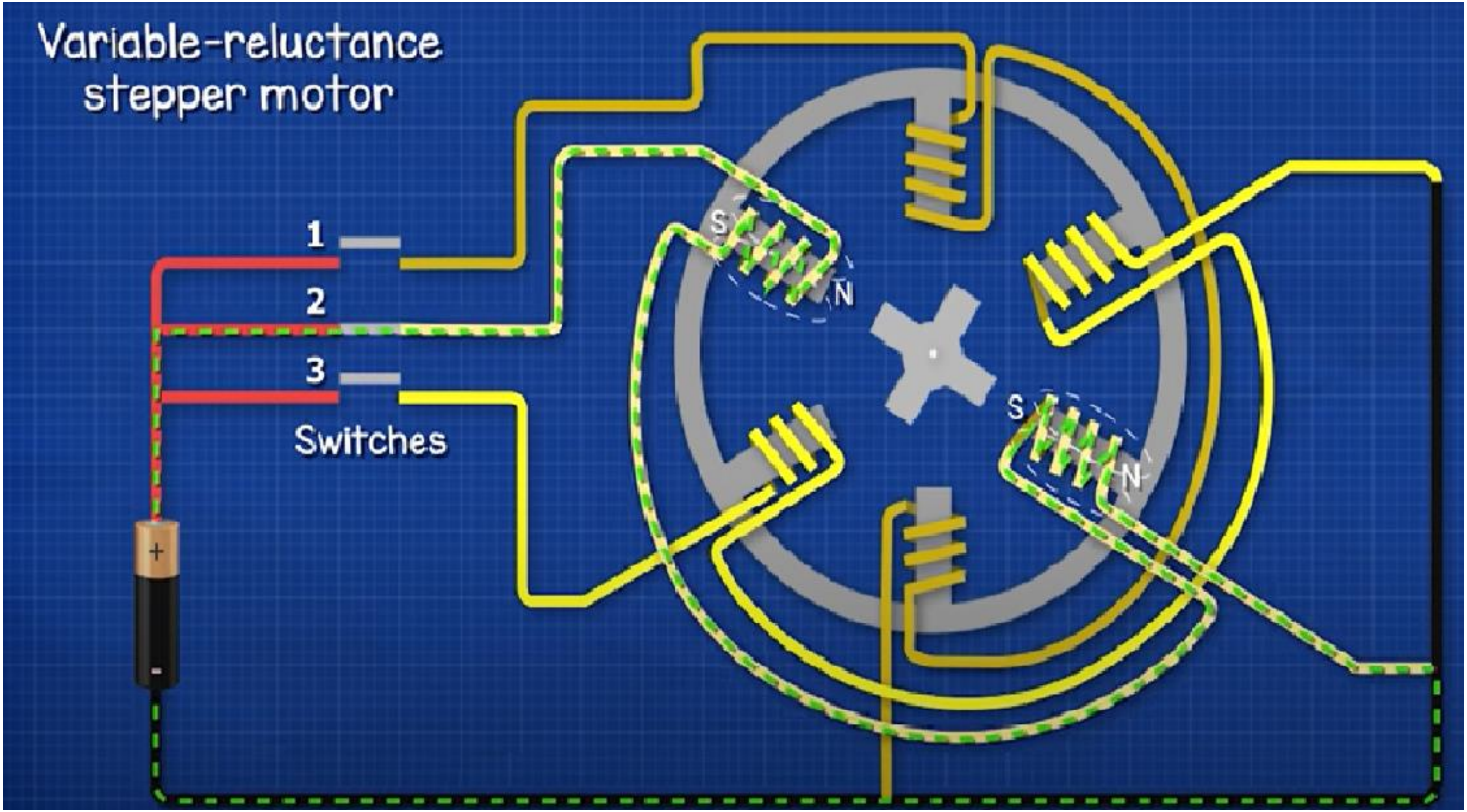
Variable reluctance stepper motor: This type of stepper motor uses a soft iron ferromagnetic rotor which gets attracted to the magnetic field.

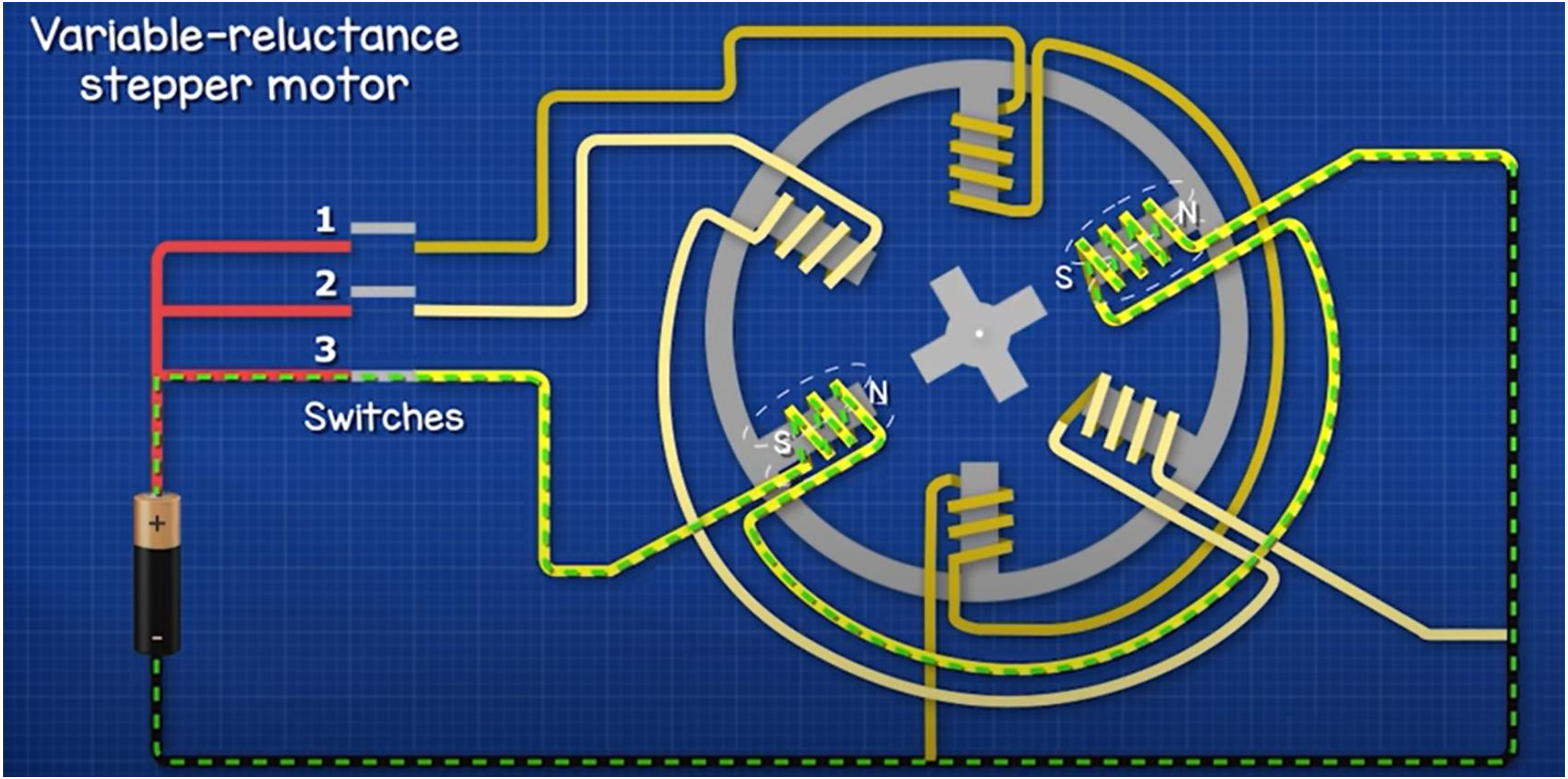
Stepper motor

- **By energizing one or more of the stator phases, a magnetic field is generated by the current flowing in the coil and the rotor aligns with this field**. By supplying power to different phases in sequence, the rotor can be rotated by a specific amount to reach the desired final position.

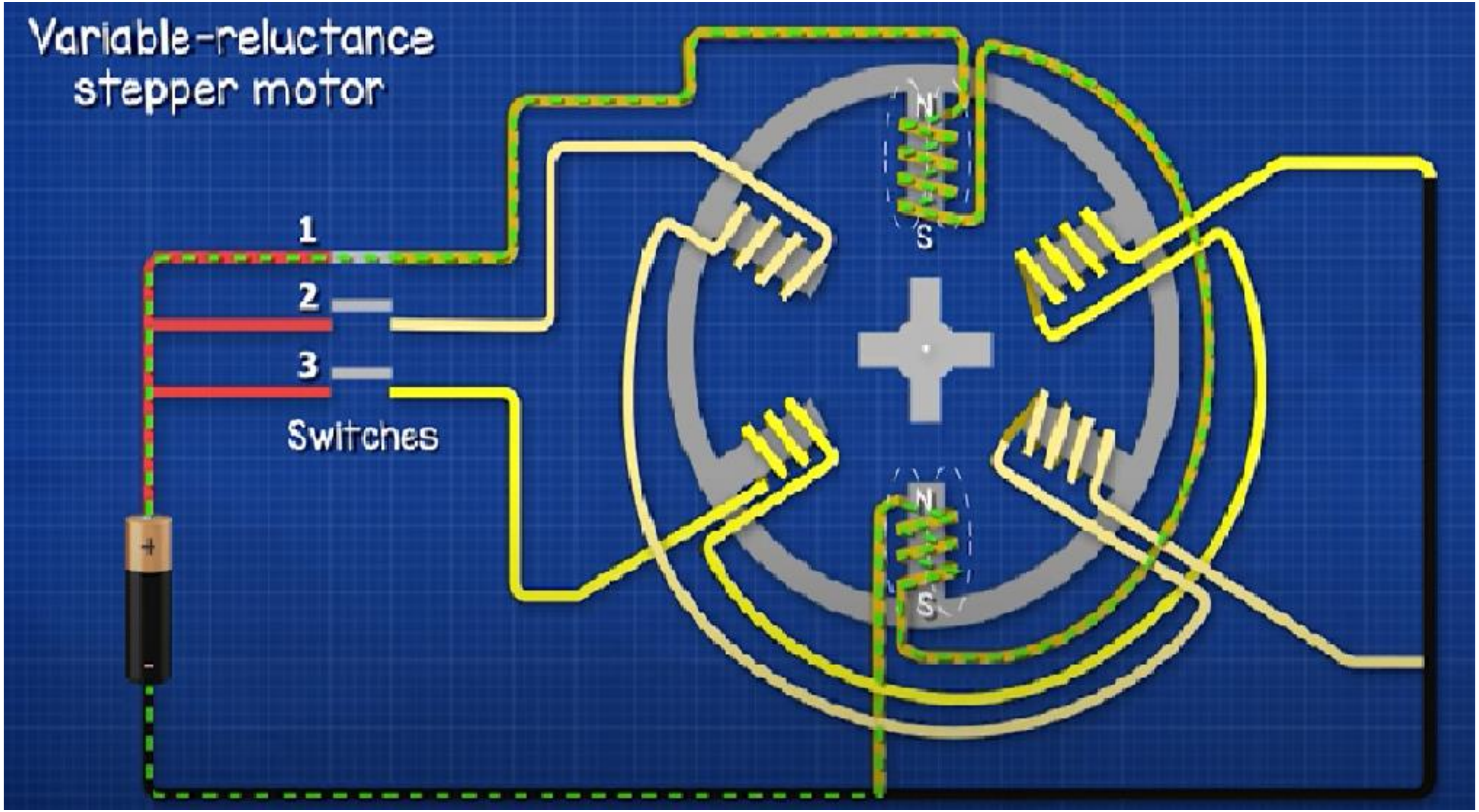


- **Below Figure** shows a representation of the working principle. At the beginning, coil A is energized and the rotor is aligned with the magnetic field it produces. When coil B is energized, the rotor rotates in clockwise direction to align with the new magnetic field. The same happens when coil C is energized. In the pictures, the colors of the stator teeth indicate the direction of the magnetic field generated by the stator winding.


Variable-reluctance
stepper motor
1
2
3
Switches
S
N
S
N
+



Variable-reluctance
stepper motor
1
2
3
Switches
N
S
N
S
+
-

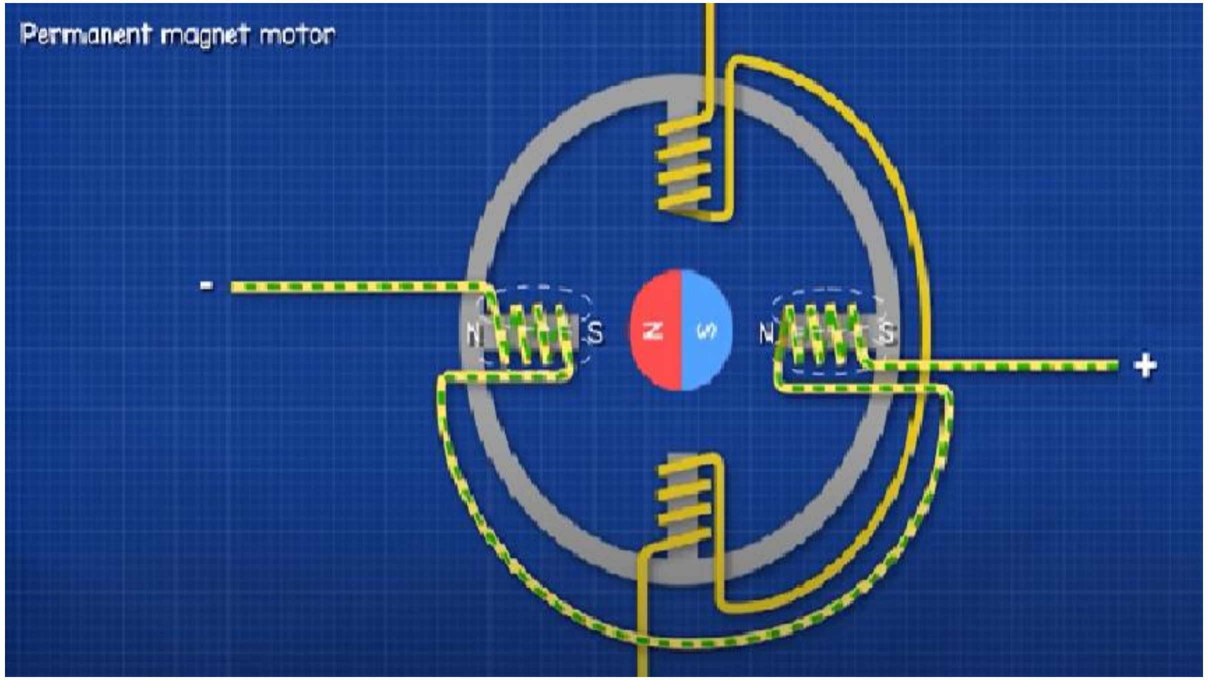

Variable-reluctance
stepper motor
1
2
3
Switches
N
S
N
S
+
-

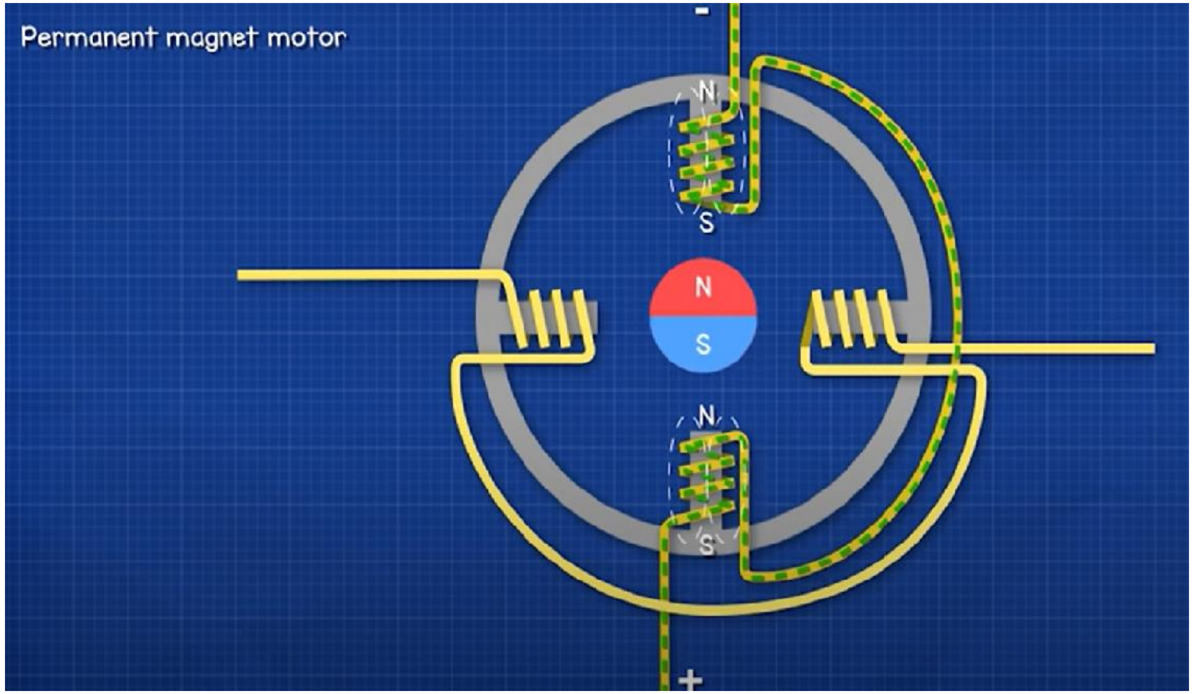
Stepper motor

- To achieve the motion of the rotor, it is necessary not only to energize the coils, but also to control the direction of the current, which determines the direction of the magnetic field generated by the coil itself .
- In stepper motors, the issue of controlling the current direction is solved with two different approaches.

Stepper motor

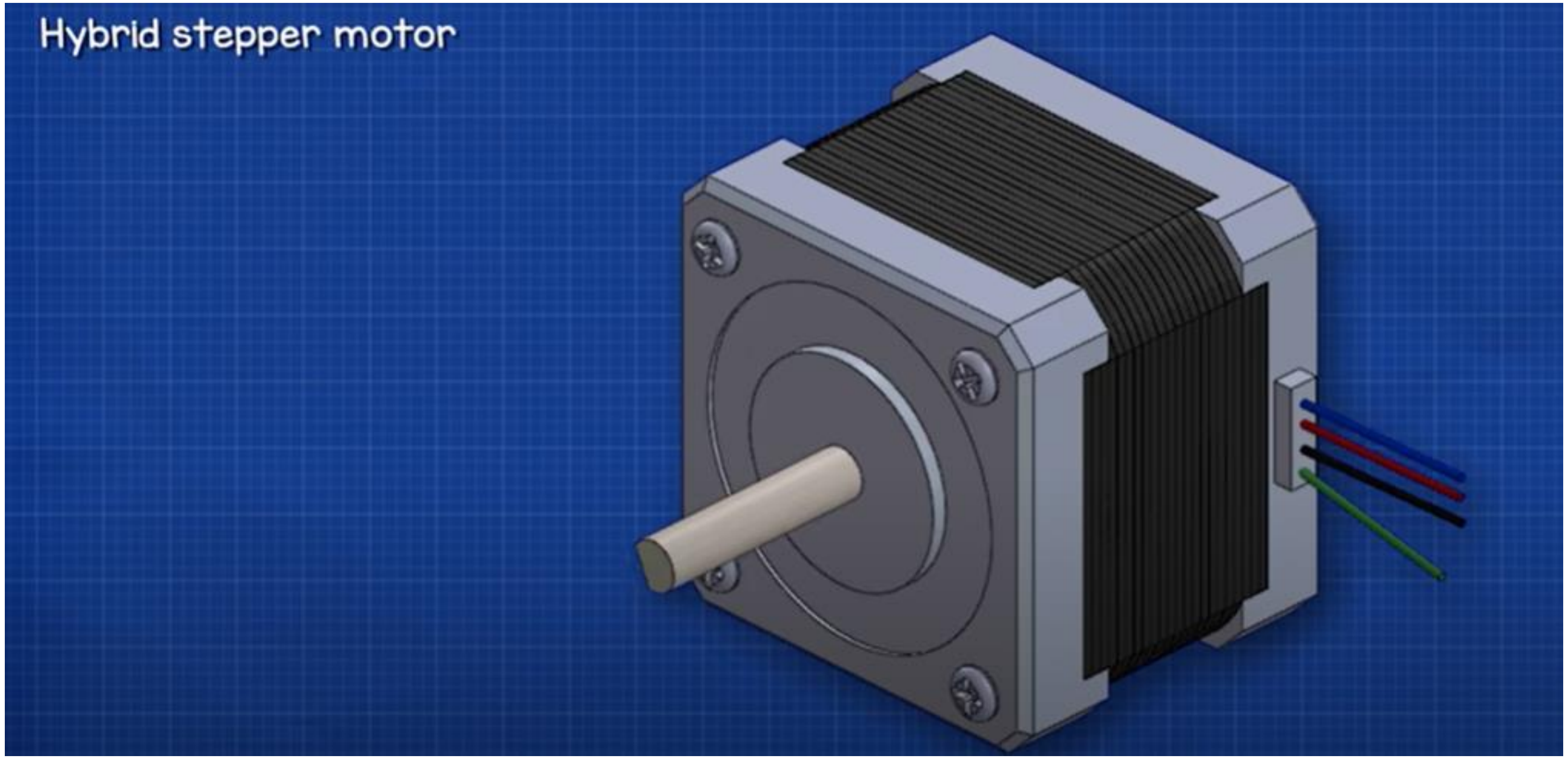
- **Permanent Magnet stepper motor:** It consists of a permanent magnet rotor which is diametrically magnetized. In its simplest version it consists of four coils connected as two separate groups. Based on the coil pair energized the rotor tries to align itself with the magnetic field . In this example the rotor rotates 90 degrees with each step.





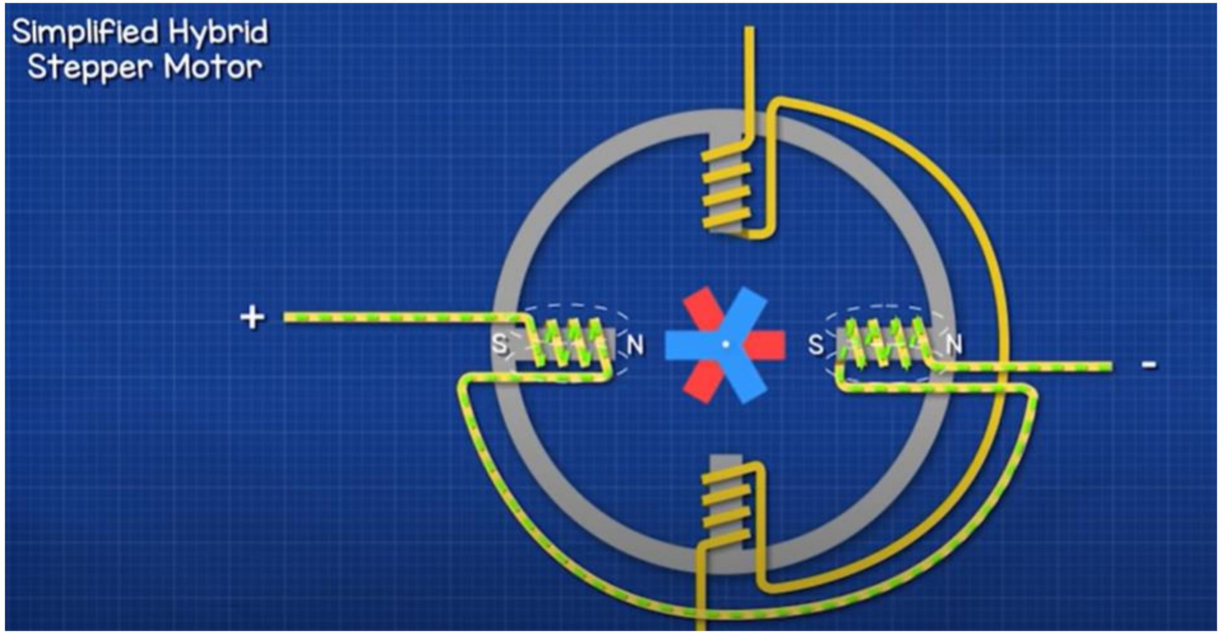
Stepper Motor

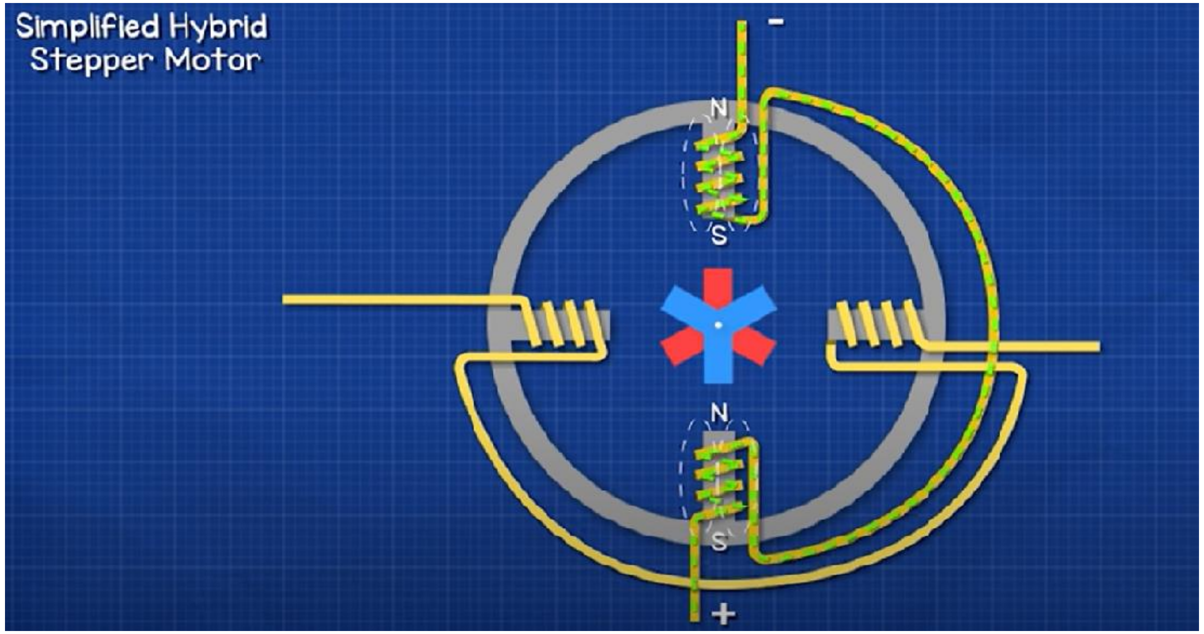
- **Hybrid Stepper Motor:** It is a combination of variable reluctance and permanent magnet stepper motor.



Stepper Motor

- The simplified version of hybrid stepper motor contains g=four coils connected as two pairs and an axially magnetized rotor . The rotor has three teeth on each magnetic pole. There are different number of teeth on stator and rotor teeth to prevent them from aligning all at once. When coils are energized ,the rotors magnets align with the stators magnetic field.





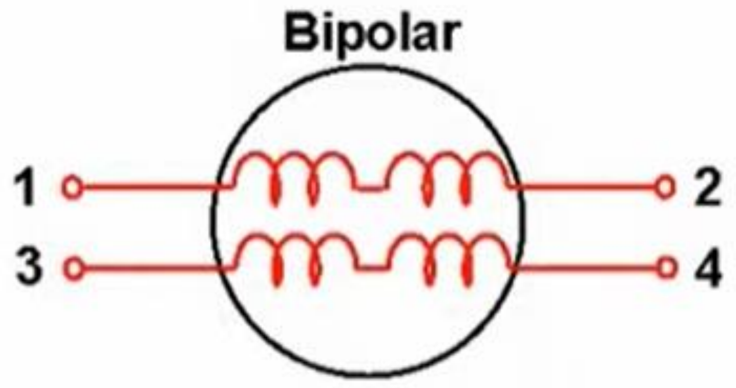
Stepper motor

- Based on how the leads from each phase winding come outside of the of the motor there are two types of stepper motors

1)Unipolar

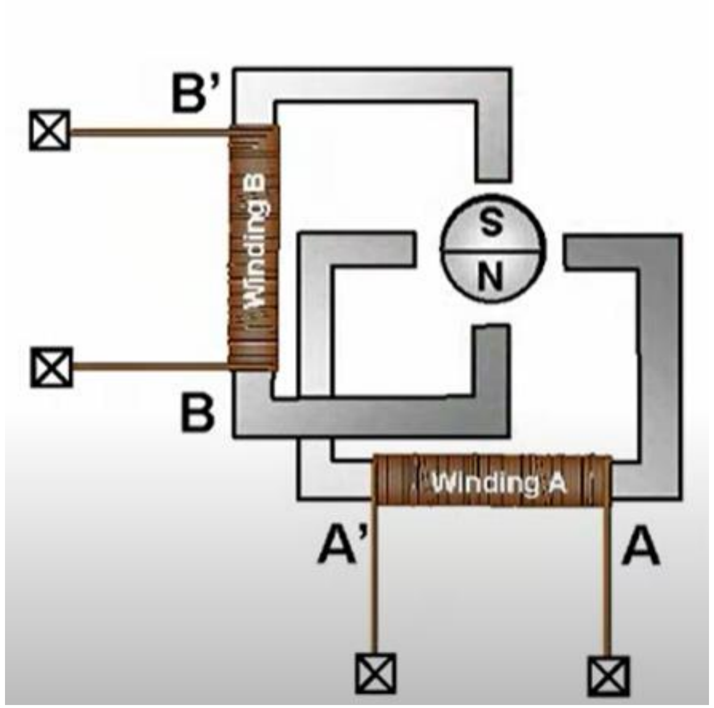
2)Bipolar

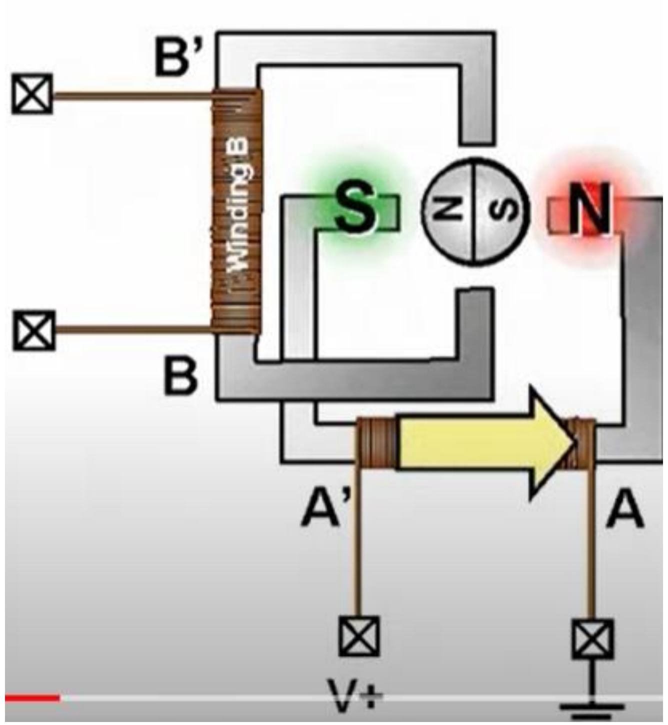
Bipolar: Each winding lead is brought out separately. This type of winding **depending on the voltage applied and to which lead can produce current flow in two directions**. This allows each stator pole to be either magnetized to north or south.



Stepper motor

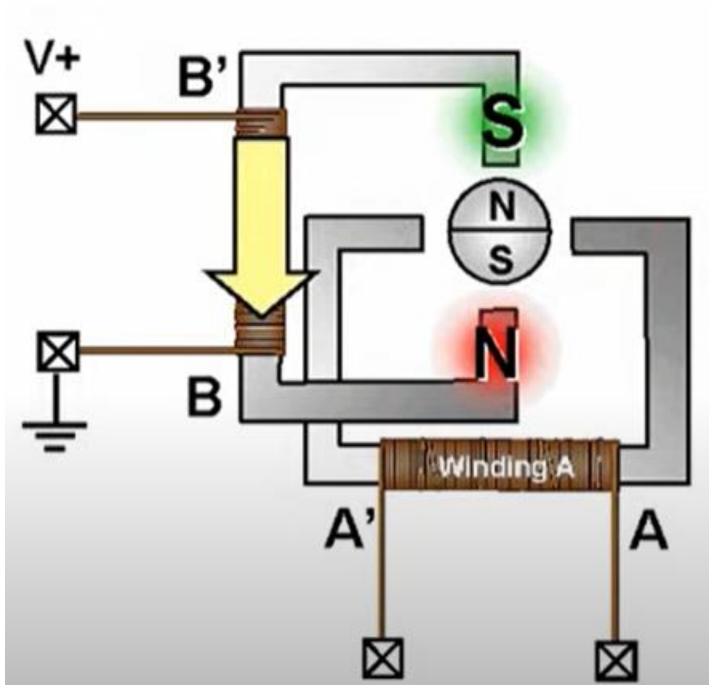
- Allow current to flow through both directions through each winding.
- Applying voltage to lead A’ and grounding lead A generates current flow resulting in stator polarity as shown below .





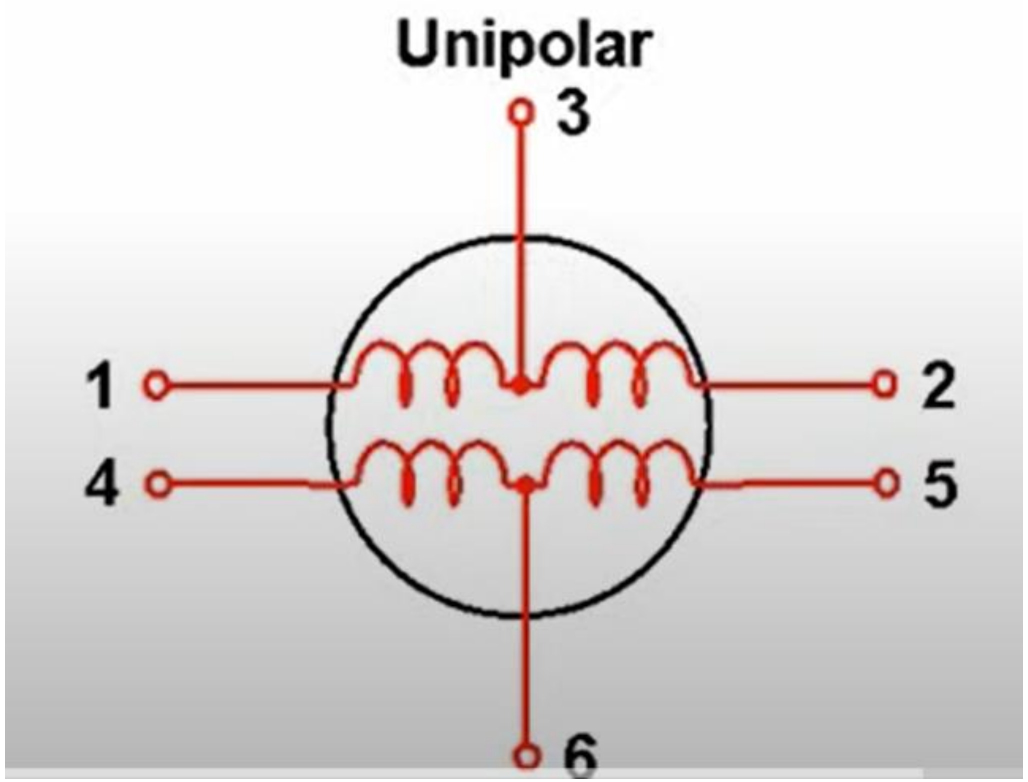
Stepper Motor

- Removing the voltage from winding A and applying a positive voltage to B' on winding B while driving winding B' to ground generates current flow and stator polarities as shown below. This continues to rotate the rotor 360 degrees.



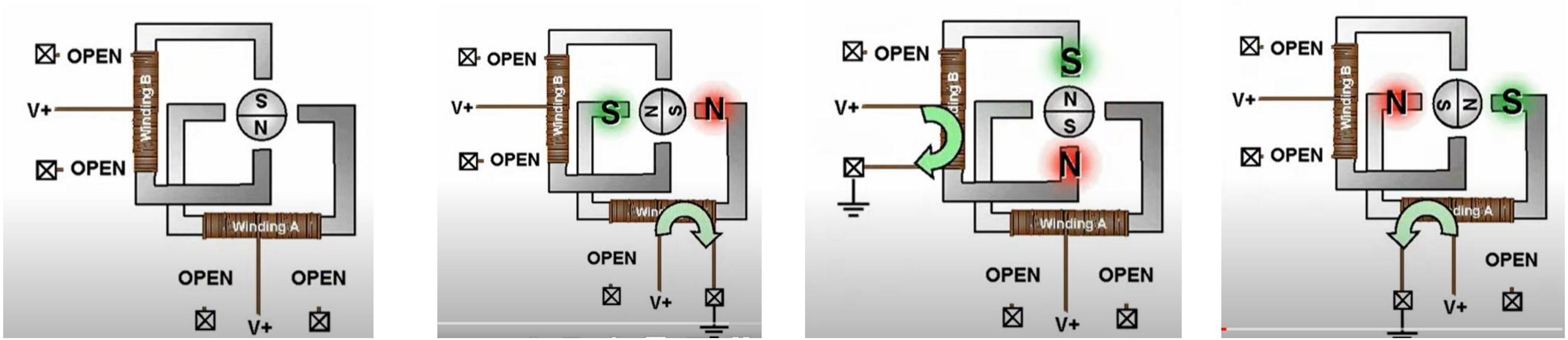
Stepper motor

- **Unipolar:** Allows **current flow only in half of the winding at one time**. Each winding has a center tap that is brought out of the motor along with each winding lead.



Stepper motor

- In unipolar stepper motor **the center tap is connected to a positive voltage source i**n the below example. Driving one of the leads on “Winding A ” to ground allows current to flow in one half of the winding generating a polarity on the stator poles and the rotor rotates accordingly.



Stepper motor

Driving Techniques

Wave step mode: In this mode only one phase is energized at a time i.e each coils of the phase is energized alternatively.

Step	Coil A	Coil B	Coil C	Coil D
1	H	L	L	L
2	L	H	L	L
3	L	L	H	L
4	L	L	L	H

Full Step Drive: In this technique, two stators are activated at a time instead of one in a very less time period. This technique results in high torque & allows the motor to drive the high load.

Step	Coil A	Coil B	Coil C	Coil D
1	H	H	L	L
2	L	H	H	L
3	L	L	H	H
4	H	L	L	H

Stepper motor

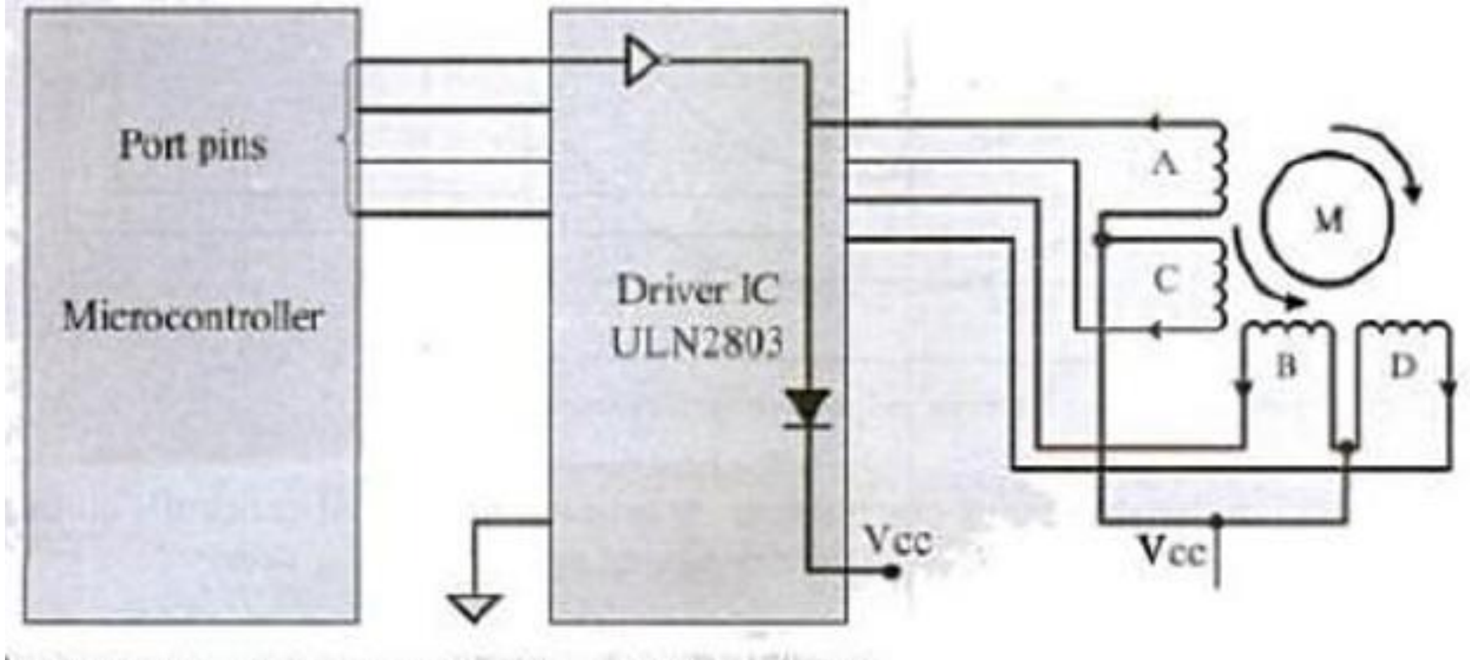
Half Step Drive

This technique is fairly related to the Full step drive because the two stators will be arranged next to each other so that it will be activated first whereas the third one will be activated after that. This kind of cycle for switching two stators first &after that third stator will drive the motor. This technique will result in improved resolution of the stepper motor while decreasing the torque.

Step	Coil A	Coil B	Coil C	Coil D
1	H	L	L	L
2	H	H	L	L
3	L	H	L	L
4	L	H	H	L
5	L	L	H	L
6	L	L	H	H
7	L	L	L	H
8	H	L	L	H

Stepper motor

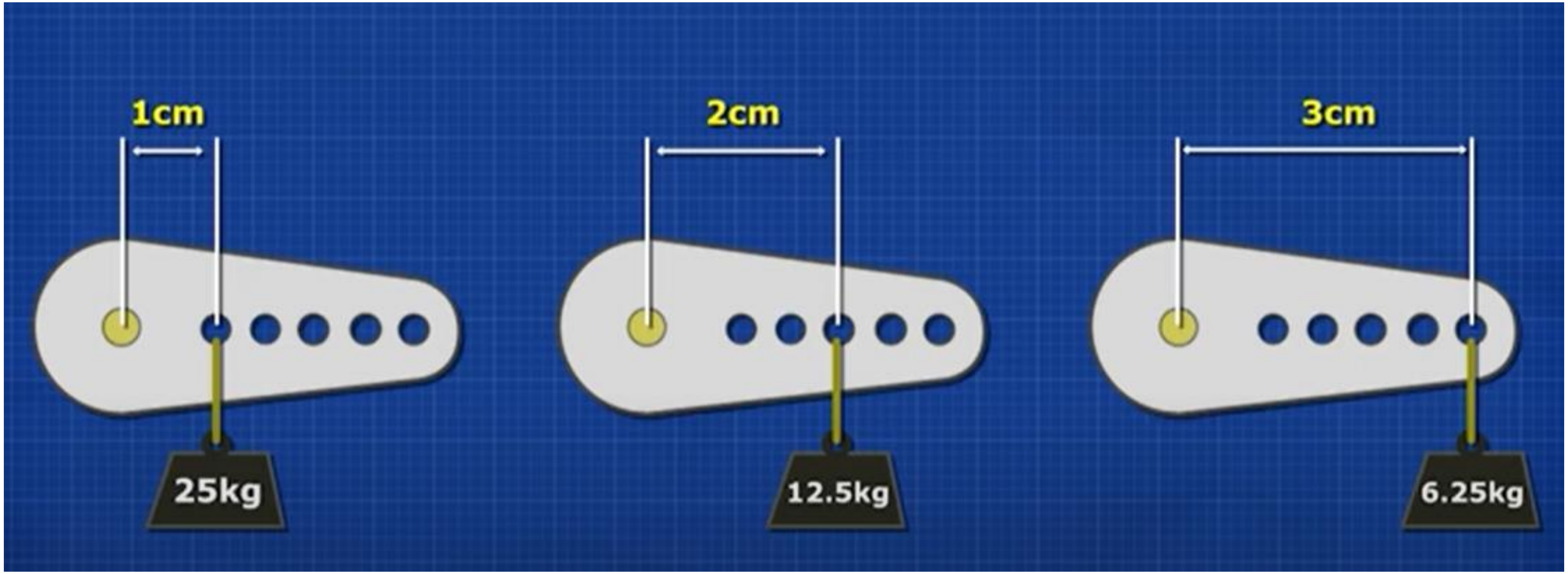
- The current requirement for stepper motor is little high and hence the port pins of a microprocessor or microcontroller may not be able to drive them directly . The supply voltage requirements vary from 5V to 24V.
- Depending on the current and voltage requirements special driving circuits are required to interface the stepper motor with microprocessor or a microcontroller.



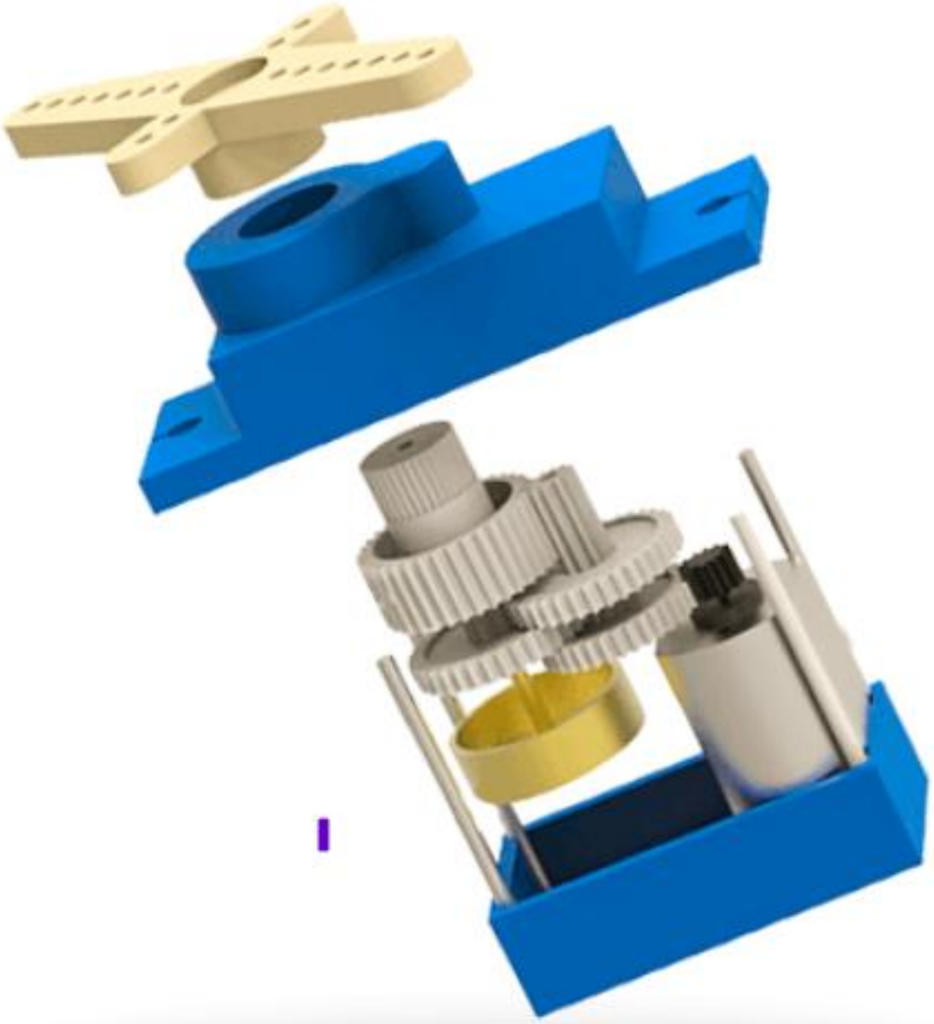
Interfacing of stepper motor through driver circuit

Servo Motor

- **A servo motor is a Self contained electrical device that rotates parts of a machine with high efficiency and with great precision.** Normally **this type of motor consists of a control circuit that provides feedback on the current position of the motor shaft. This feedback allows the servo motors to rotate with great precision.**
- **If you want to rotate an object at some specific angles or distance**, then you use a servo motor.
- If motor is **powered by a DC power supply** then it is called **DC servo motor,** and if it is **AC-powered motor** then it is **called AC servo motor**.
- A **servo motor usually comes with a gear arrangement** that allows us **to get a very high torque servo motor** in small and lightweight packages. Due to these features, they are being used in many applications like toy car, planes, Robotics, etc.
- **Servo motors are rated in kg/cm** (kilogram per centimeter).Most hobby servo motors are rated at 3kg/cm or 6kg/cm or 12kg/cm. **This kg/cm tells you how much weight your servo motor can lift at a particular distance**. For example: A 6kg/cm Servo motor should be able to lift 6kg if the load is suspended 1cm away from the motors shaft, **the greater the distance the lesser the weight carrying capacity.** The position of a servo motor is decided by electrical pulse and its circuitry placed beside the motor.


1cm
25kg
2cm
12.5kg
3cm
6.25kg


Splined gear



Servo Motors

Servo Motor Working Mechanism

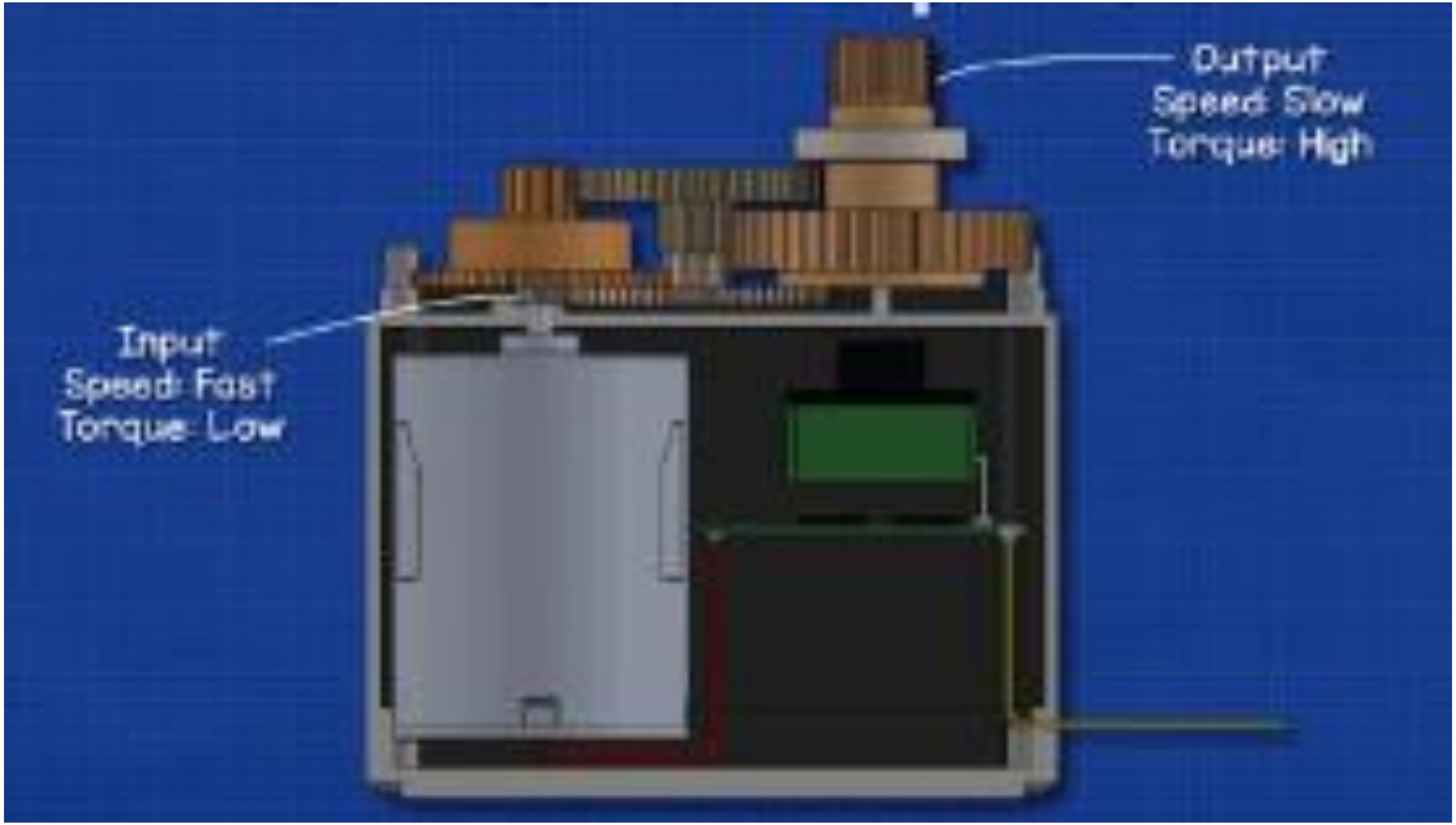
- It is a closed-loop system where it **uses a feedback system to control motion and the final position of the shaft.** Here the **device is controlled by a feedback signal generated by comparing output signal and reference input signal.**
- Here reference input signal is compared to the reference output signal and the third signal is produced by the feedback system. And this third signal acts as an input signal to the control the rotation of the motor and hence the device. This signal is present as long as there is a difference between the reference input signal and reference output signal.
- **Typically the motor will just rotate 180 degrees but we can get smaller or larger values.**

Servo Motor

A DC servo motor is an assembly of four major components.

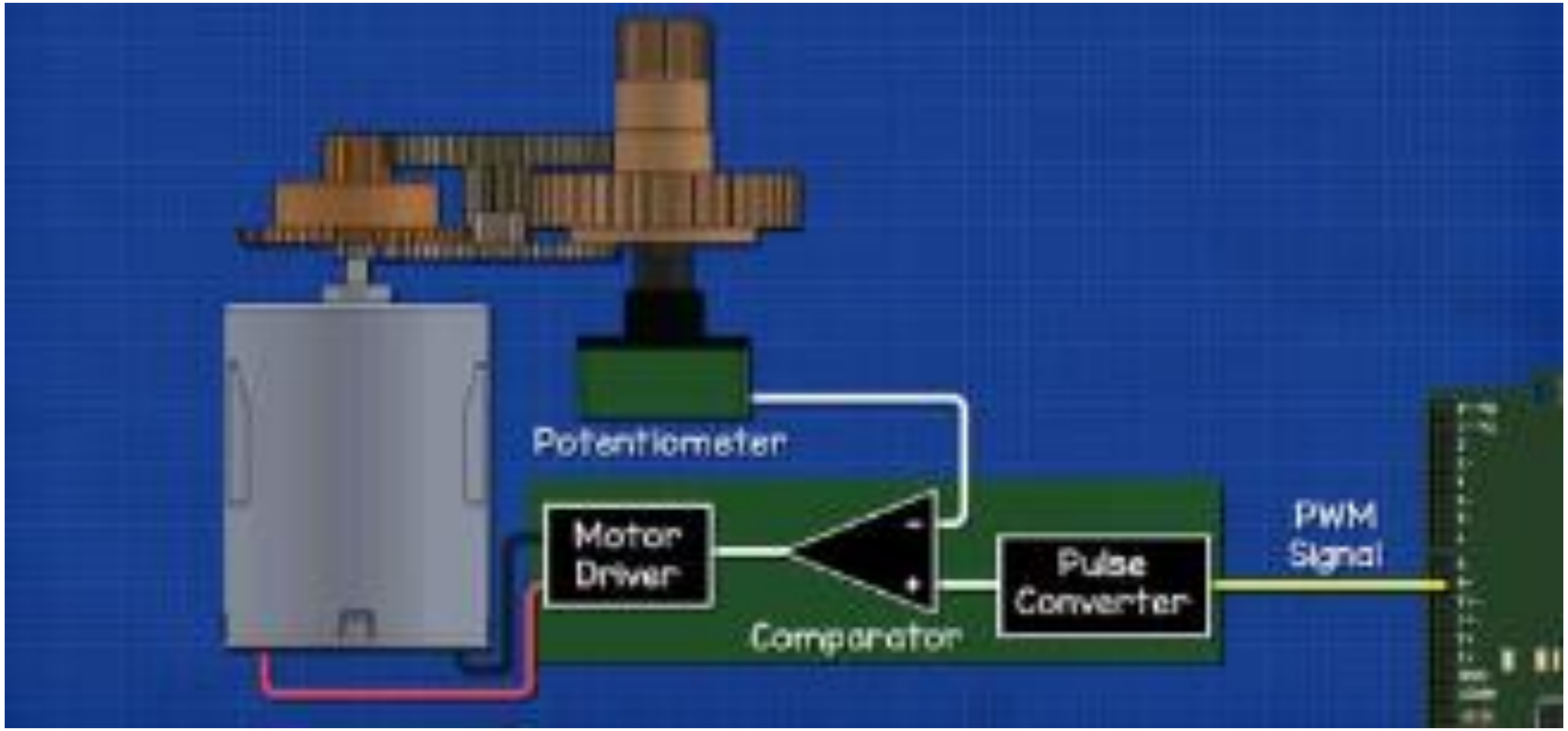
1. DC Motor
2. Position sensing device(Potentiometer)
3. Gear assembly
4. Control circuit

- **The motor is attached by gears to the control wheel**. As the **motor rotates**, the **potentiometer's resistance changes**, so the control circuit can precisely regulate how much movement there is and in which direction.
- When the shaft of the motor is at the desired position, power supplied to the motor is stopped. If not, the motor is turned in the appropriate direction. The desired position is sent via electrical pulses through the signal wire. The **motor's speed is proportional to the difference between its actual position and desired position**. So if the motor is near the desired position, it will turn slowly, otherwise it will turn fast. This is called proportional control.

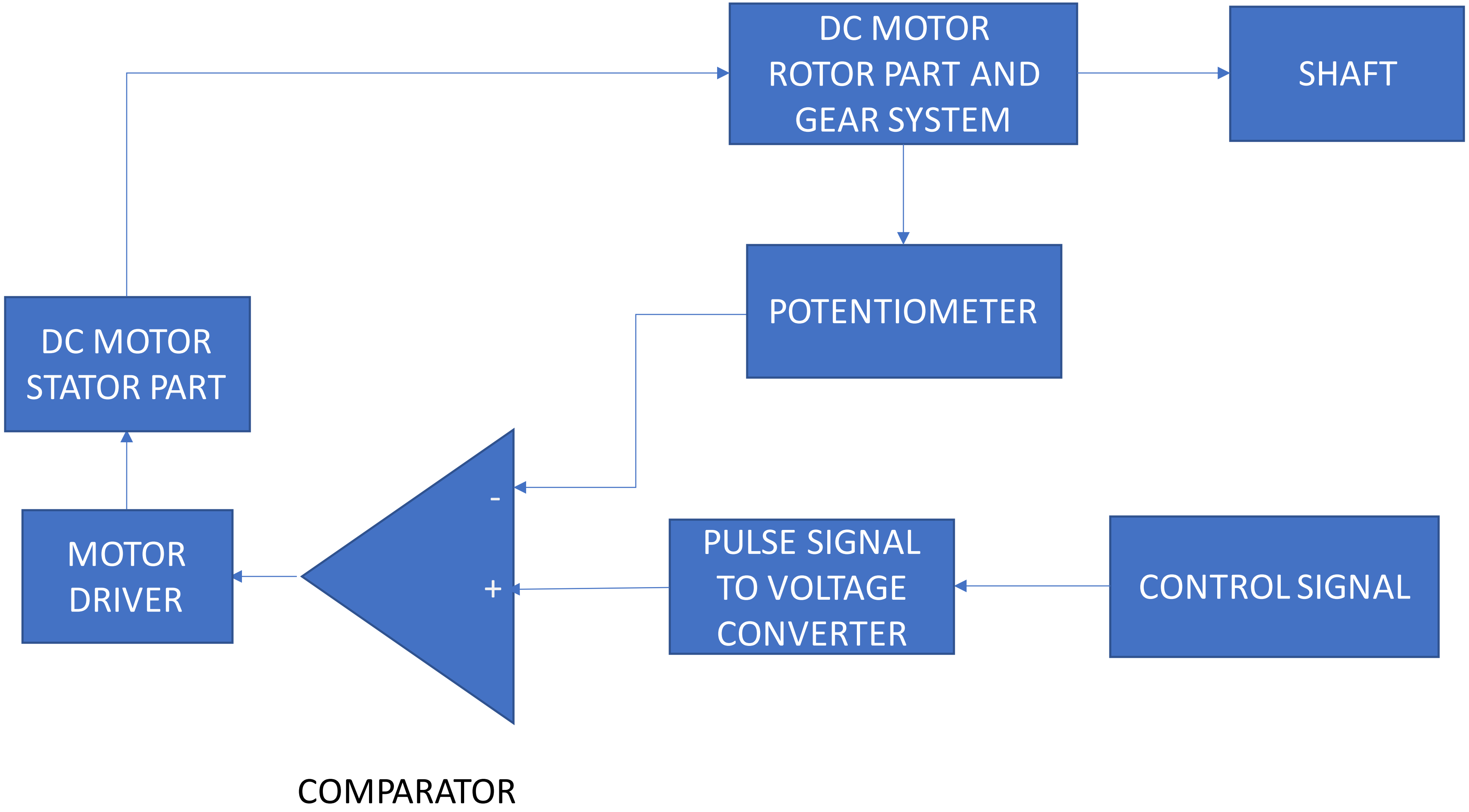

Output
Speed: Slow
Torque: High
Input
Speed: Fast
Torque: Low

Servo Motor

- In digital control, the microcontroller is used for generating the PWM pluses to produce more accurate control signals in order to decide the direction of rotation .



DC SERVO MOTOR CONSTRUCTION



Servo Motor

- The position sensor provides a feedback signal corresponding to the present position of the load. This sensor is normally a potentiometer that produces the voltage corresponding to the absolute angle of the motor shaft through gear mechanism. Then the feedback voltage value is applied on the input of the comparator
- The comparator then compares the voltage related to current position of the motor with desired voltage related to desired position of the motor and produces an error voltage which is then given to a motor driver.
- The motor driver then controls the rotation of the DC MOTOR. This rotation causes the gears to rotate.

Servo Motor

- **Working Principle**: Servo motor works on **PWM (Pulse width modulation)** principle, meaning its **angle of rotation is controlled by the duration of applied pulse** . The servo motor expects to see a pulse every 20 milliseconds (ms) and the length of the pulse will determine how far the motor turns. For example, a 1.5ms pulse will make the motor turn to the 90° position. Shorter than 1.5ms moves it in the counter clockwise direction toward the 0° position, and any longer than 1.5ms will turn the servo in a clockwise direction toward the 180° position.

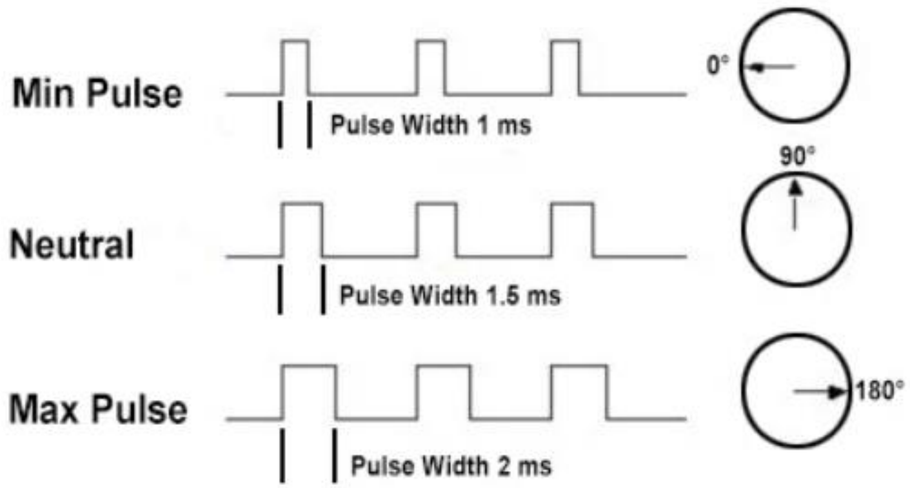


Fig:Variable Pulse width to control servo position

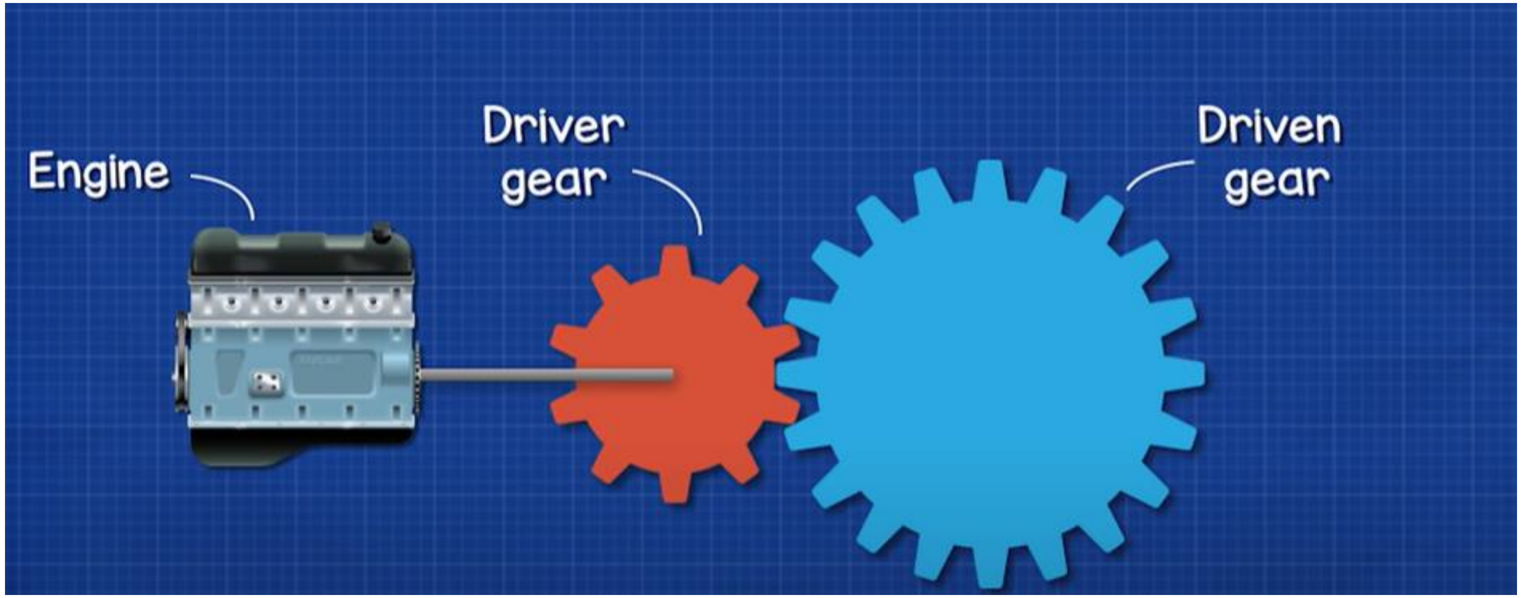
Gears

- A gear is a toothed cylindrical or roller shape component of a machine which meshes with another toothed cylindrical component to transmit power from one shaft to another. It is mainly used to obtain different torque and speed ratio or changing the direction of driving shaft and driven shaft.
- Low gear has low speed and high torque where as high gear has high speed and low torque.
- Torque is the measurement of force which cause something to rotate around a point.

Torque=Force x Length

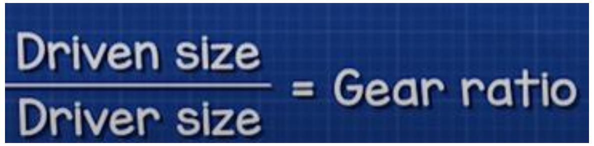
Gears

- If we were to connect two gears and rotate one of them ,then the other gear would also rotate. If we attach an engine to the first gear , the first gear is driver gear and the gear attached to the first gear is called the driven gear.

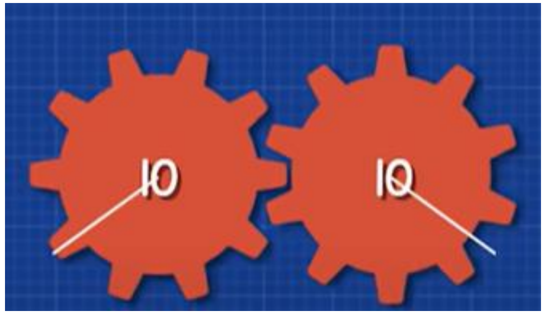


Gears

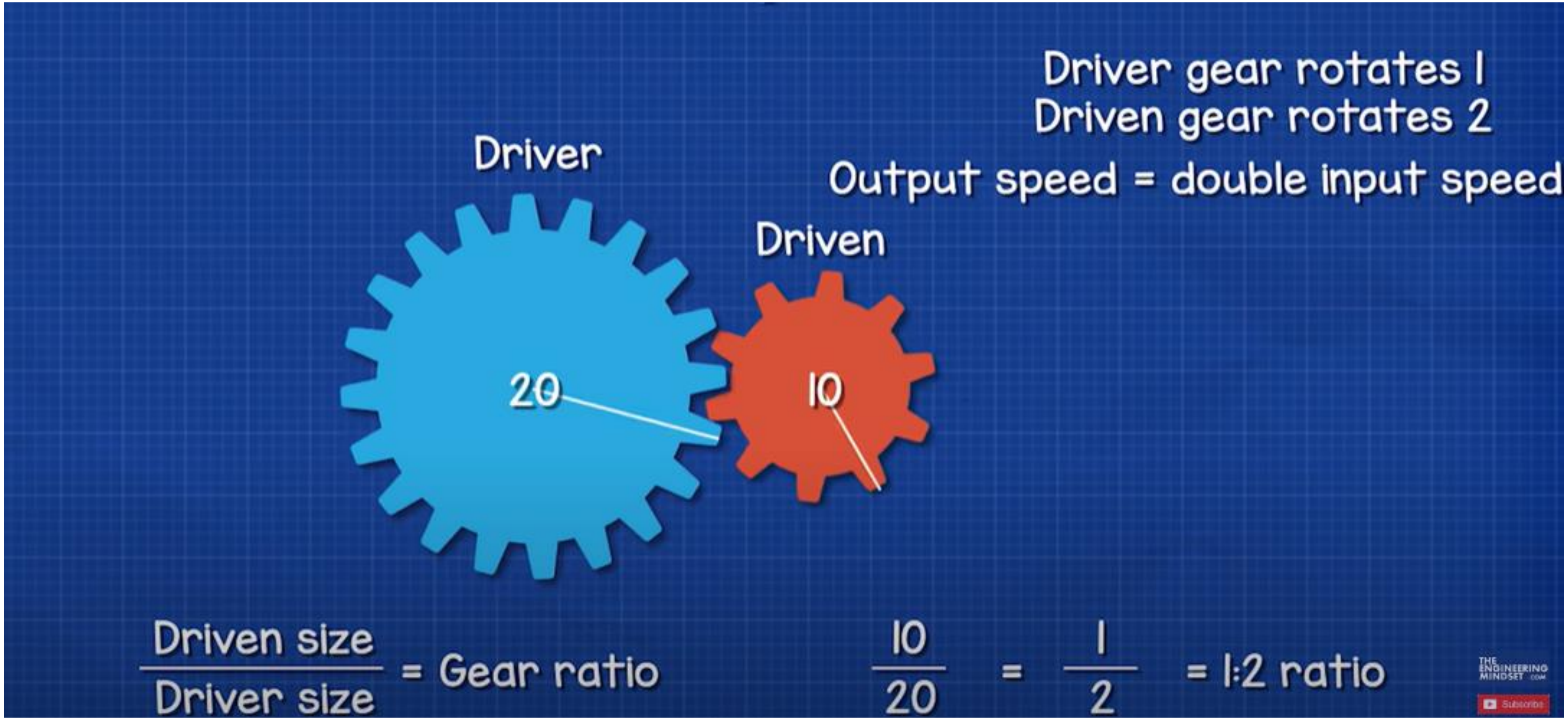
- The gear ratio is given as the ratio of no. of teeth of the driven gear and no. of teeth of the driver gear .



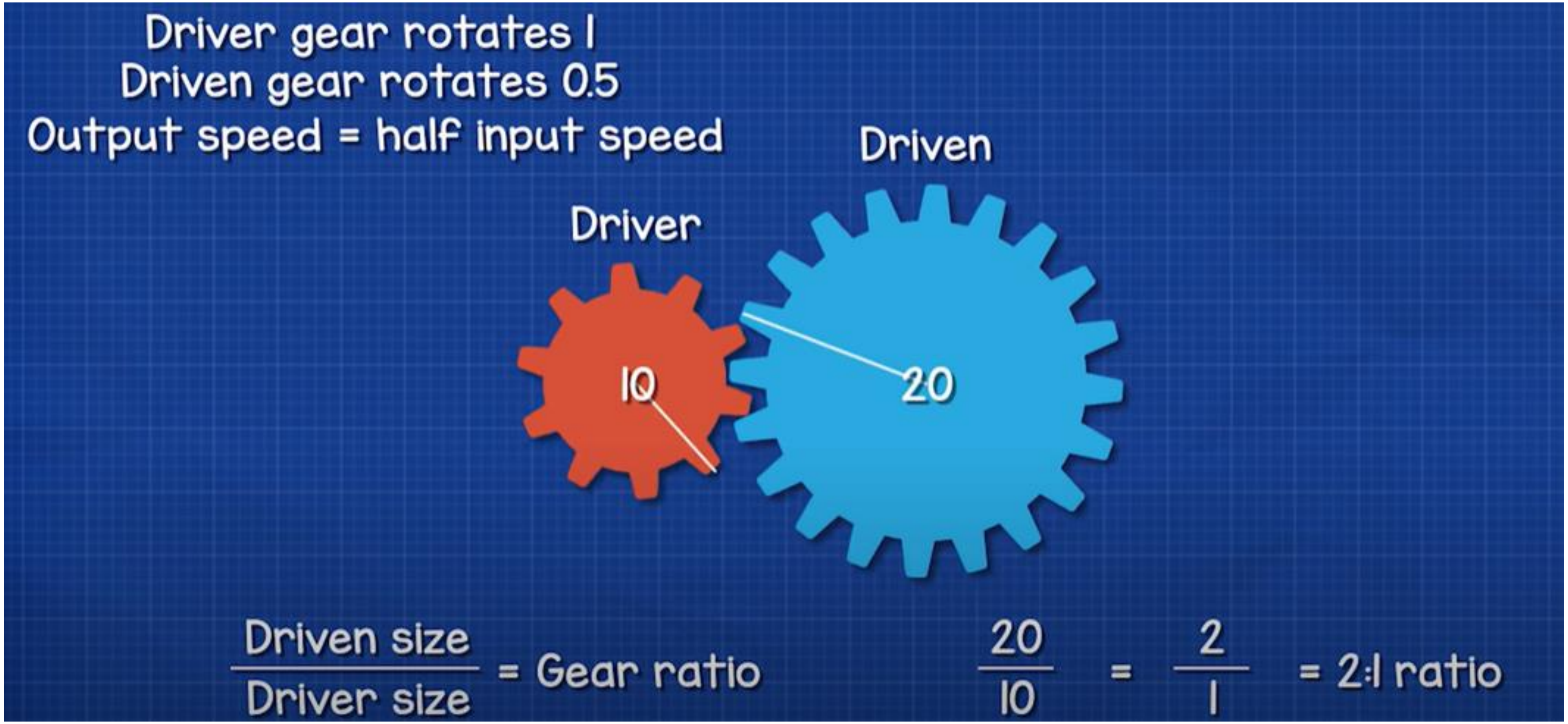
- When we have two gears with the same diameter, the gear ratio will be 1.(That means every time the driver gear completes one full rotation, the driven gear also completes one rotation and hence driven gear has the same speed as that of the driver gear.)



Gears

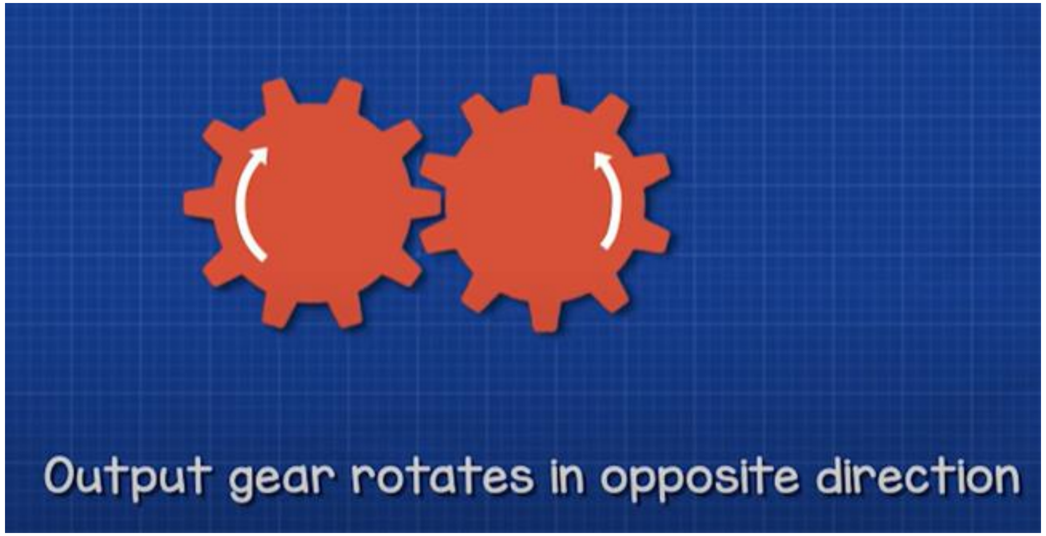

Driver gear rotates 1
Driven gear rotates 2
Output speed = double input speed
Driver
Driven
20
10
Driven size / Driver size = Gear ratio
10/20 = 1/2 = 1:2 ratio
THE ENGINEERING MINDSET .COM

Gears


Driver gear rotates 1
Driven gear rotates 0.5
Output speed = half input speed
Driven
Driver
10
20
Driven size / Driver size = Gear ratio
20 / 10 = 2 / 1 = 2:1 ratio

Gears

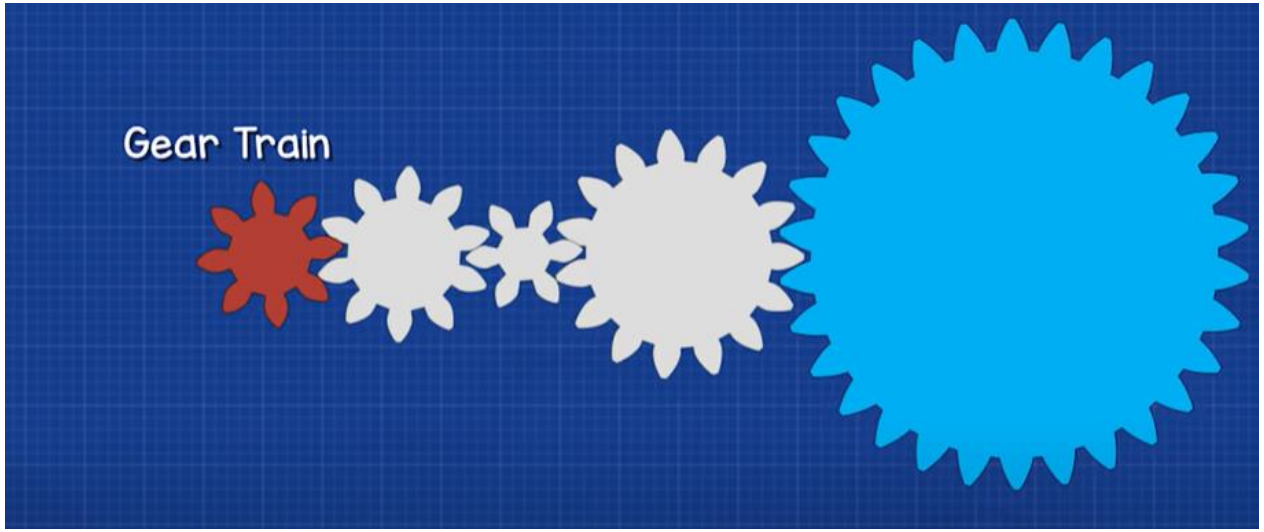
- It is important to note that:



Gears

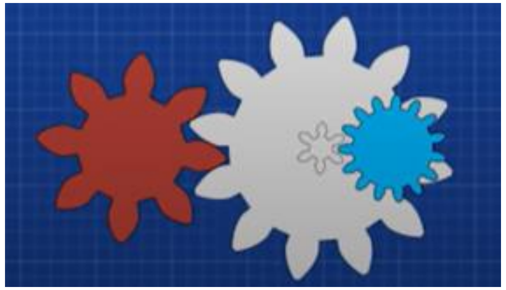
- In order to make the output rotate in the same direction as the input gear we need to insert an other gear in between input and output gears that creates a gear train. Middle gear is known as idler gear.

- We can add many gears to change the speed and output direction. But this will consume a lot of space.



Gears

- Instead we can **mount gears on same axis and create a compound gear train** . This will do the same job as gear train but it will occupy far less space.

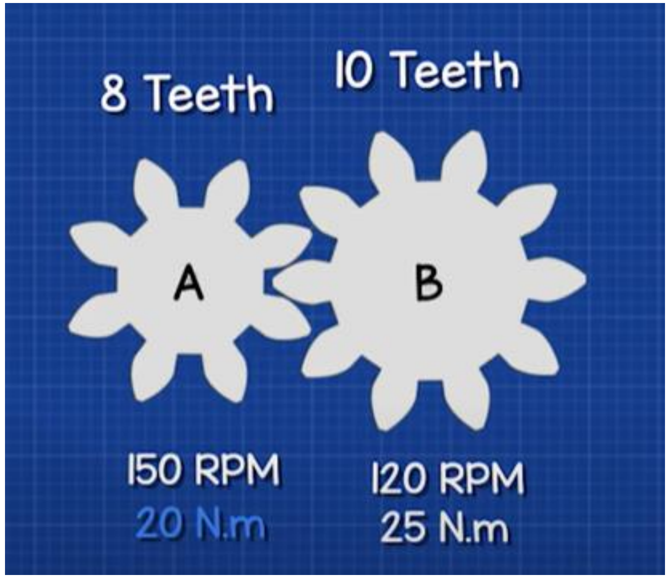


- **Calculation of RPM and torque of simple gear trains:**

- Here ratio indicates the **gear ratio** which is = **Teeth of output gear/teeth of input gear**

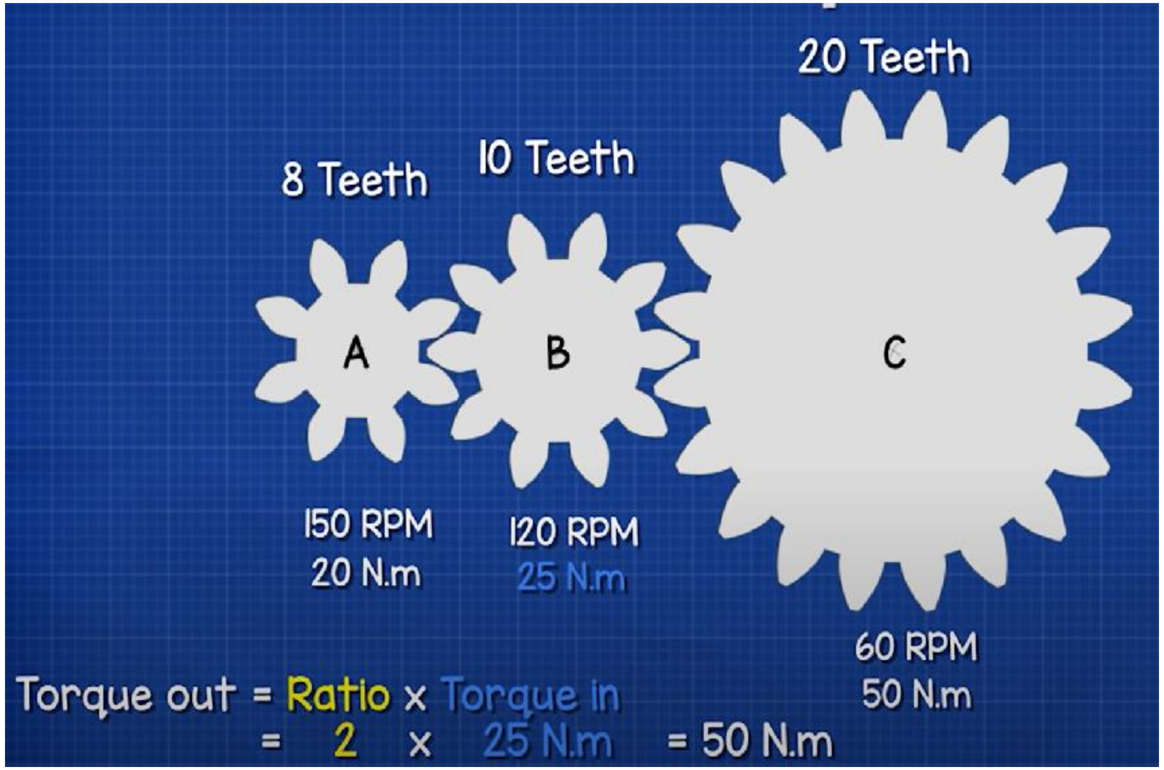
Gears

- Example



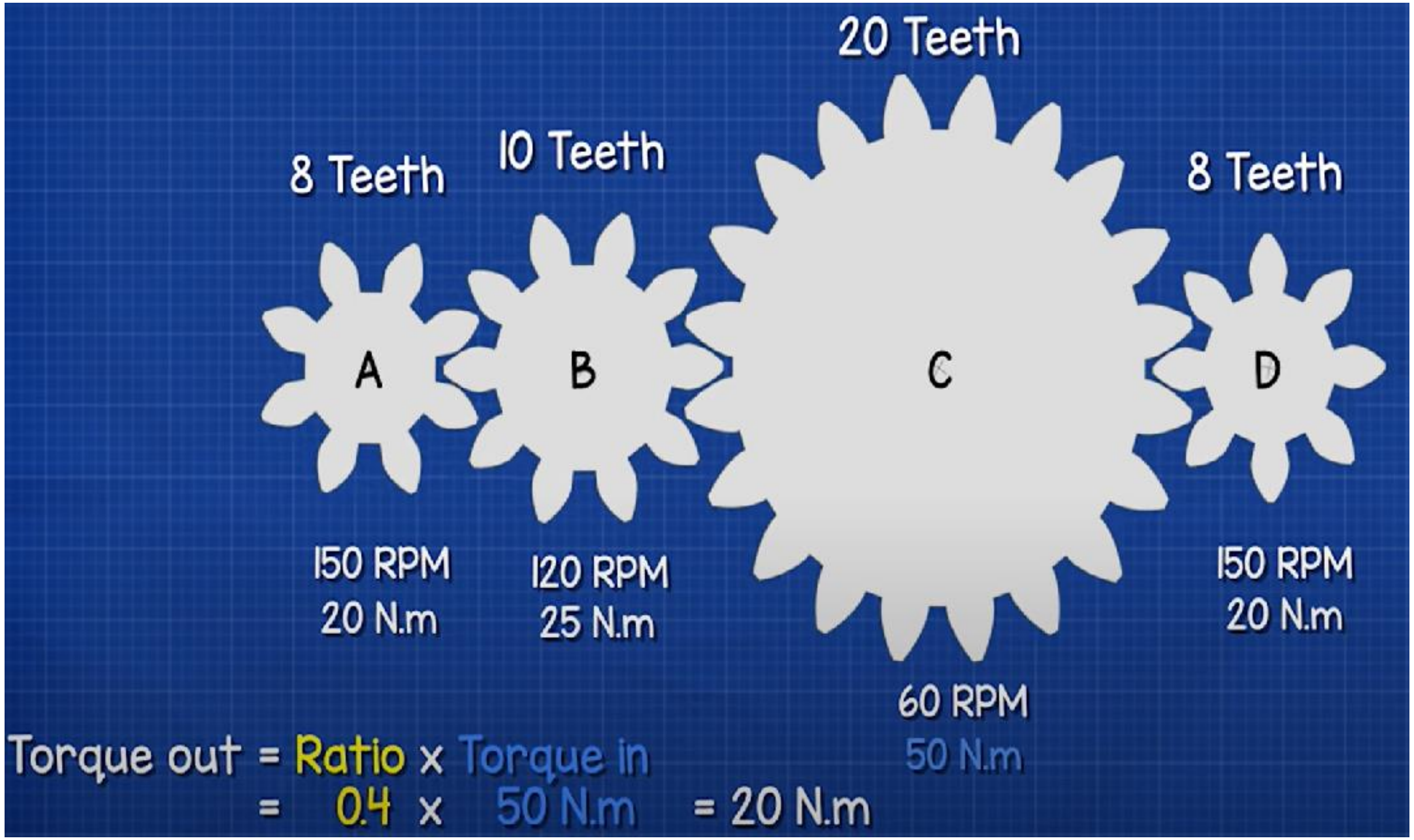
$$\text{RPM out} = \frac{150\ \text{RPM}}{1.25} = 120\ \text{RPM}$$

$$\text{Torque out} = \text{Ratio} \times \text{Torque in} = 1.25 \times 20\ \text{N.m} = 25\ \text{N.m}$$



$$\text{RPM out} = \frac{120\ \text{RPM}}{2} = 60\ \text{RPM}$$

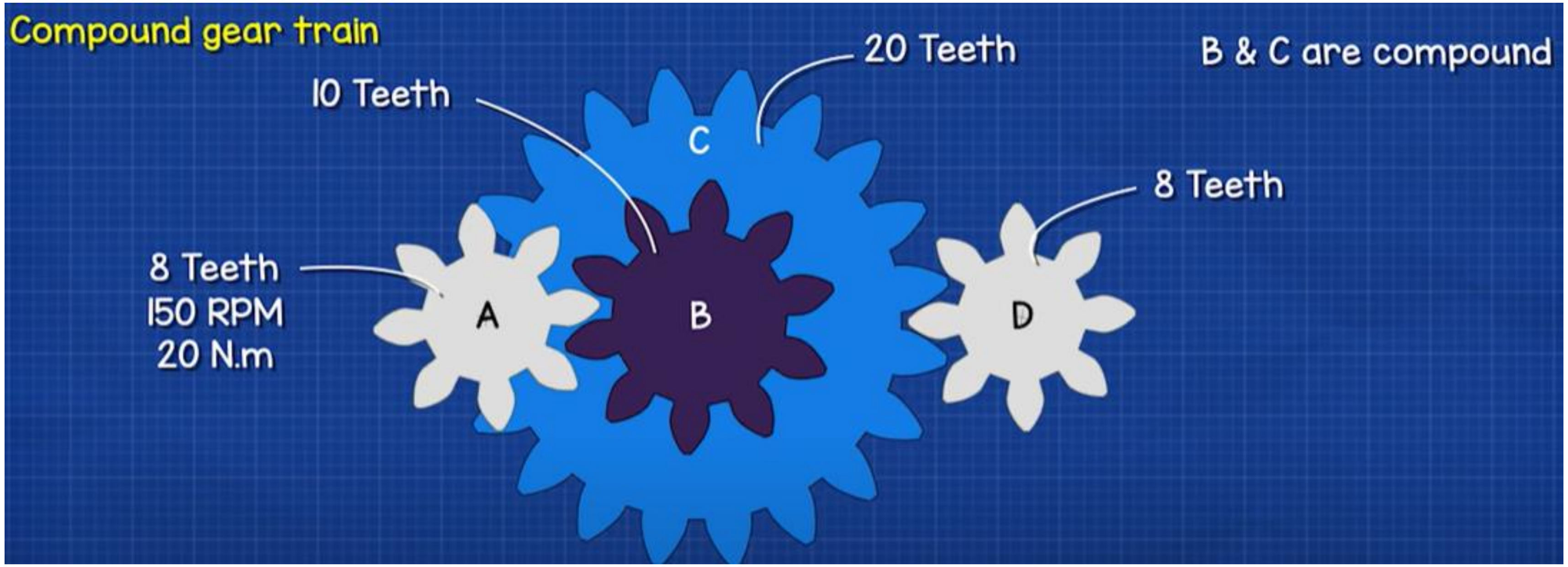
Gears

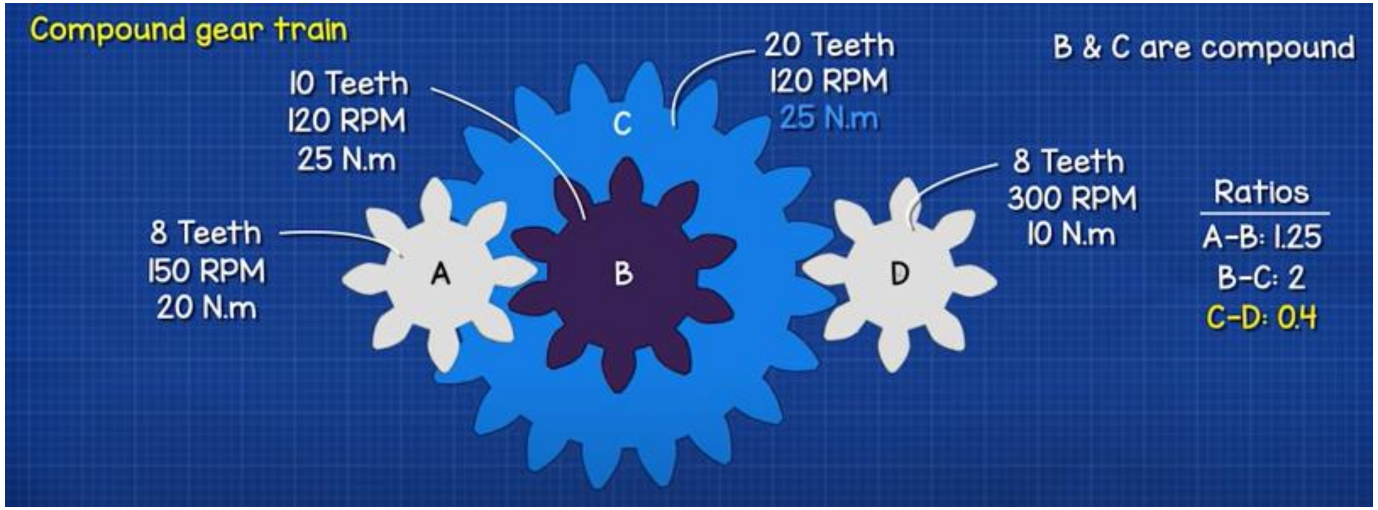


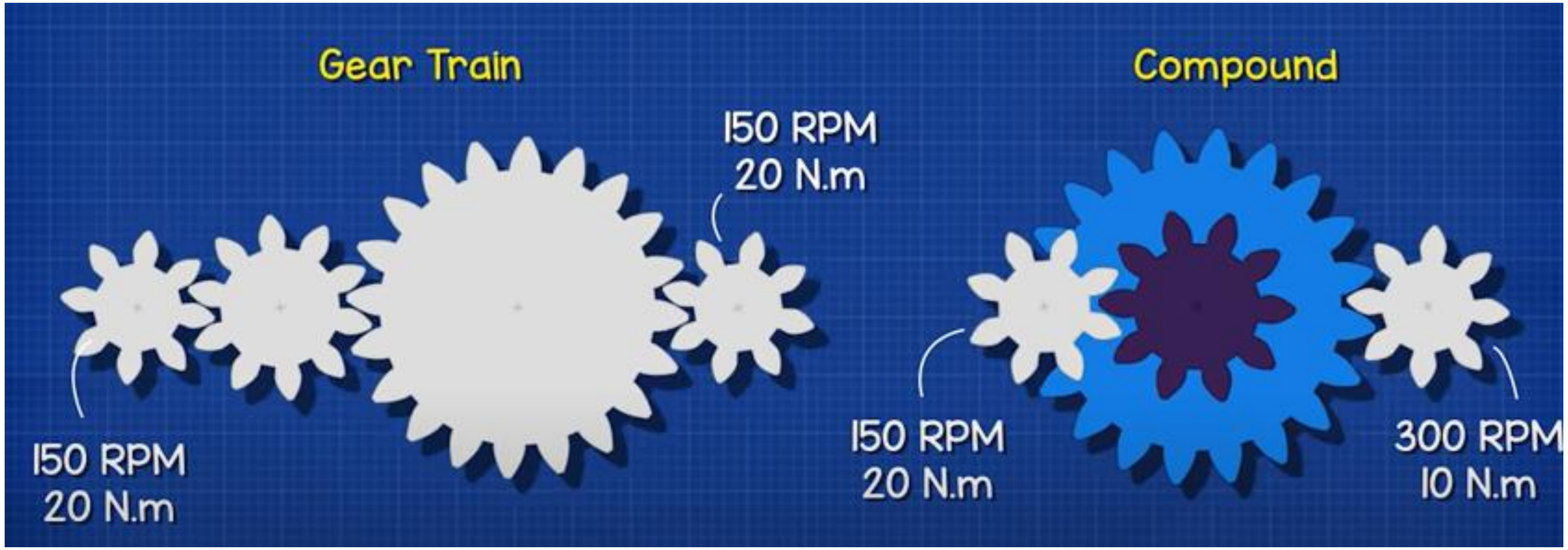
20 Teeth
10 Teeth
8 Teeth
8 Teeth
A
B
C
D
150 RPM
20 N.m
120 RPM
25 N.m
60 RPM
50 N.m
150 RPM
20 N.m
Torque out = Ratio x Torque in
= 0.4 x 50 N.m = 20 N.m

Gears

- Let us now consider the example of compound gear train:






Gear Train
150 RPM
20 N.m
150 RPM
20 N.m
Compound
150 RPM
20 N.m
300 RPM
10 N.m

Types of Gears

Types of Gears:

- Gears can be classified in various types according to construction of teeth, Use, the direction of motion transfer etc. but basically it is classified according to design of teeth.

1. Spur Gear:

- These gears are **used to transmit the power in same plane or when the driving and driven shafts are parallel to each other.** In this type of **gear teeth are cut parallel to the axis of the shafts so when is meshes with another spur gear it transmit the power in parallel shaft and when it connects with the helical gear it will transmit power at an angle from the driving axis.**

Spur Gear

Types of Gears

2. Helical Gear:

- On the helical gears **teeth are cut at an angle from the axis of it.** It has cylindrical roller with helicoid teeth. The main advantage of helical gears is that **they work with less noise and vibration** because the load is distributed on the full helix as compared to spur gears. It also has **less wear and tear** due to which they are widely used in industries. It also used for transmit power in parallel shaft but sometime they are used to transmit power in non-parallel shaft also. In the helical gears if the pinion (driving gear) is cut with right handed teeth then the gear (driven gear) is cut with left handed of in opposite direction.

Helical Gear

Types of Gears

3. Double Helical or Herringbone Gear:

- This gear has both right and left handed teeth on one gear. This gear is use to provide additional shear area on gear which further required **for higher torque transmission**. This is same as helical.

Double Helical Gear

4. Bevel Gear:

- This **gear is used to transmit power between perpendiculars**. The driving shaft and driven shaft makes a right angle with each other and both the axis of shaft meets each other at one point. This gear has helical or spiral teeth on a conical shaped geometry and meshes with the same gear.

Types of Gears

Bevel Gear

5. Rack and Pinion Gear:

- This gear is used in **steering system of automobile**. In this type of gear, teeth are cut on a straight rectilinear geometry know **as rack** and **one spur gear known as pinion**. This is used to transmit rotary motion to linear motion. It is seen as the infinite radius driven gear.

Rack and Pinion Gear

Types of Gears

6. Worm Gear:

- This type of gear is **used to transmit the power in nonintersecting shaft which makes right angle**. In this type of arrangement the driving gear is a screw gear and the driven gear is helical gear, spur gear or gear with spiral teeth as shown in figure.

Worm Gear

Robotic Sensors

- Sensors are used in robotic systems for a variety of functions . The most common use of sensors is to provide information about the status of links and joints of the manipulator as well as the working environment of the robot.
- Based on the functions the sensors in robots can be grouped into five basic categories:

1) Status sensors
2) Environment sensors
3) Quality control sensors
4) Safety sensors
5) Work cell control sensors

Robotic Sensors

- **Status sensors:** The primary **use of these sensors** on a robot is **to sense position , velocity, acceleration, torque/force at each joint of the manipulator for position and motion control**. These sensors form an **essential part of the internal closed loop control systems** and are called as internal/status sensors . Internal sensors give feedback on the status of the manipulator itself . The degree and accuracy that can be achieved by a manipulator depends on the resolution and accuracy of the internal sensors.
- **Environment sensors:** These sensors extract features of the objects in the work cell or surrounding environment of the robot. This knowledge is utilized by the computer controller to modify or adapt to a given situation. For example if the robot has to process several types of different parts each requiring a different sequence of actions by the robot such as adjusting the gripper orientation or applying exact gripper force it must determine the required parameters for each part. Sensors for these functions are generally placed in the environment external to the manipulator and are called environment sensors.

Robotic Sensors

- Environment sensors can be used to perform one or more of the following functions:

➢ Detect presence of workpiece

➢ Determination of position or orientation of workpiece present in the work cell

➢ Workpiece identification

➢ Determination of workpiece properties such as shape, size, and so on.

➢ Provide information about the manipulator-environment interaction forces and torques.

➢ Provide information about environment variables such as temperature, humidity and so on.

➢ An important sensing method is the vision system that might be employed to determine characteristics such as location, orientation ,shape , size and many other properties.

Robotic Sensors

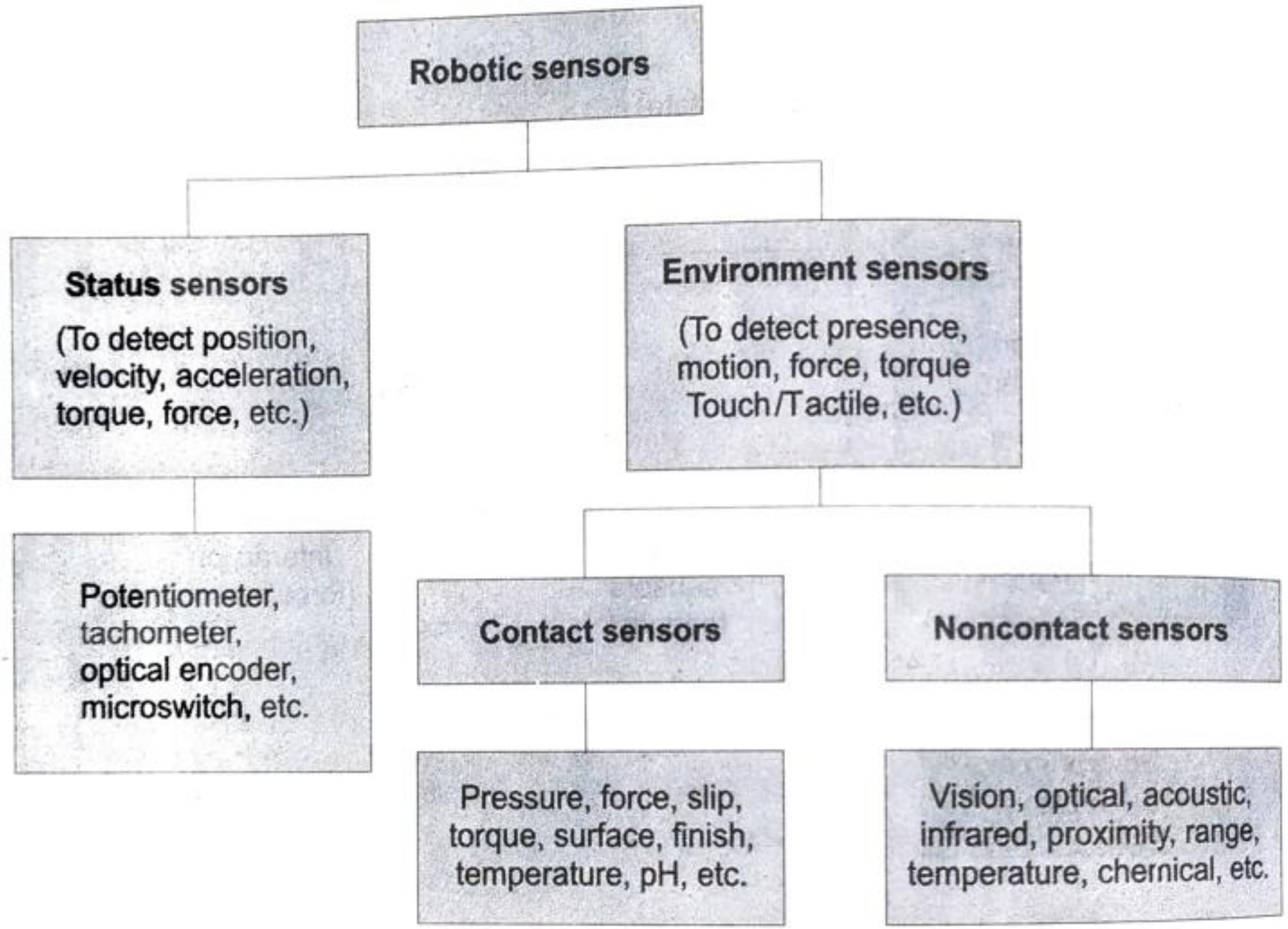
- **Quality Control Sensors: Inspection and quality control is an important function for robotic sensors. The external sensors used for environmental feedback can be used for detecting faults and failures in the finished product. Computer vision, ultrasonic sensors can be used for inspection.**

- **Safety Sensors:** An important function of the sensors in robotics is safety and hazard monitoring. The safety of the workers and other equipment in the work environment and that of the manipulator are important concerns . For example, if there is a power failure all the links of the manipulator may fall to zero gravity position instantaneously.

They may injure the humans in the vicinity or may damage the equipment of manipulator itself . A solution is to sense power failure and apply breaks to prevent the uncontrolled falling of links due to gravity.

Robotic Sensors

- **Work cell control sensors:** Another major use of sensors in robotics is to implement interlocks in work cycle. An interlock in the work cycle is a situation that requires sequencing of tasks such that completion of a task must be ensured before proceeding to the next task. For example , a part must arrive on the conveyor before the gripper of the manipulator can pick it. This kind of verification of interlocked tasks can be done by incorporating signals from a variety of sensors in the robot program.
- The signals from all the sensors on the manipulator and in the environment are fed to the computer controller which analyzes them and generate the control signals. The control signals are applied to the actuators to command and control the manipulator.


Robotic sensors
Status sensors
(To detect position, velocity, acceleration, torque, force, etc.)
Environment sensors
(To detect presence, motion, force, torque Touch/Tactile, etc.)
Potentiometer, tachometer, optical encoder, microswitch, etc.
Contact sensors
Noncontact sensors
Pressure, force, slip, torque, surface, finish, temperature, pH, etc.
Vision, optical, acoustic, infrared, proximity, range, temperature, chemical, etc.

Robotic Sensors

- Common sensors used for robotic applications are

1. touch/tactile sensors in the contact type
2. Proximity(to detect presence of an object),Range and physical property sensors in the non contact type.

- **Rotation sensors** are important in robotics to keep track of joint rotations and motion of end effector.
- **Proximity and touch** sensors are used in intelligent grasping of work piece and force-torque sensors provide feedback **for object manipulation and control** of its interaction with environment. For example these sensors can be useful to prevent slipping or damage of the object once grasped or to apply the right torque to tighten a nut.

Robotic Sensors

- **Acoustic sensors** are commonly used for proximity , distance measuring or navigation applications (indoor navigation).
- **Optic or light based sensors** are non contact sensors that work on the principle of detecting the change in the intensity of light sent and received. Optic sensors include infrared, Ultraviolet, and laser beam sensors. An infrared sensor based tracking system allows a full 3D-tracking within a space of few meters. Laser based scanning sensors can be used in navigation of autonomous guided vehicles.

Note : Infrared sensors detect the motion of an object within a region.

- **Pneumatic sensors** : Pneumatic sensors can be contactless devices or contact sensors which can be used as proximity sensors , pressure or force sensors.
- **Force/Torque sensors :** Force/Torque sensors are used to measure the joint torques . The interaction between robot and environment generates forces/torques that must be controlled to preserve the integrity of the task being performed. To measure these interaction forces, sensors are mounted between wrist and end effector and are known as wrist force torque sensors(WFTS).

Robotic Sensors

- **Optical Encoders** : For position sensing in robotics optical encoders are frequently used . Optical encoders covert linear or angular displacement into digital code or pulse signals.
- Optical encoders are of two types:
- Absolute encoders : They provide actual position relative to a fixed refernce position.
- Incremental encoders : These sense the position from the previous position.

Applications

Industrial Applications:

- OF the robots in the world 90% are found in industries. These robots are referred to as industrial robots . Of these 50% are used in automotive industries.
- Some of the tasks that robots can do in industries are:

➢ Handling Dangerous materials

➢ Assembling Products

➢ Spray finishing

➢ Polishing and cutting

➢ Repetitive , backbreaking and unrewarding tasks

➢ Tasks involving danger to humans or dangerous tasks

Applications

- Robotic applications in the industries today are primarily in four fields:

1. **Material Handling:** Operations involving picking the material , workpiece or tool from one place and placing it at the desired place are the material handling operations . These include material transfer and machine loading/unloading . Common material handling applications are in hazardous environment of foundry, die casting, plastic moulding and handling dangerous materials . The end effector for these applications is a suitable gripper to hold the material that may be radio-active or red-hot material.
2. **Operations:** Operations which current day robots perform are: arc welding, spot welding, spray painting etc.
3. **Assembly :** Assembly robots are common within manufacturing environment . They are capable of performing mundane and repetitive tasks with ease . An automotive factory is a great example of an industry that utilizes robotic assemblers.
4. **Inspection:** Inspection function is required in every stage of manufacturing from raw materials to finished products. Robots can be used **to inspect physical dimensions, surface finish and other characteristics of raw materials**, intermediate stages of parts , finished parts or finished products.

Robots have many potential applications, other than material handling, assembly, etc. in

- Pharmaceuticals industry.
- Textile industry.
- Chemical industry.
- Mining industry
- Construction industry.
- Energy sector.

Pharmaceuticals: packing drugs in boxes, stacking boxes , loading products in trays
Textile : Fabric printing and drawing, fabric printing, complex sewing
Chemical Industry: Operate in dangerous areas, Handling toxic materials
Mining industry: Laying explosives, excavation
Construction industry : Surveillance and inspection, Evaluation of progress of projects, Early detection of possible errors
Energy sector: For repairing pipelines and turbines and other infrastructure

Applications

Non Industrial Applications: The advances in robotic technology are not directed only for its use in industries . There has been a parallel growth of robotic technology in non-industrial environments. Different applications of robots in some diverse segments are :

Home Sector

Science fiction stories always considered robots as domestic slaves. This is going to be a reality in near future, though many of the current domestic applications are not much more than expensive toys. Some of the domestic applications possible are:

- Sweeping and cleaning.
- Cooking.
- Entertainment.
- Replacing pets.
- Garden maintenance.
- Security.

Health Care

The use of robots in human health care has a wide scope. Robotic technology is in use and is going to expand in health care for:

- Patient care and monitoring.
- Surgery.
- Rehabilitation—prosthetic limbs and robotic wheel chairs.

Microrobots can be injected into the human body to perform microsurgery.

Service Sector

Service robots can carry out diverse functions like:

- Traffic control.
- Fire fighting.
- Drive a vehicle.
- Sweep office rug, classrooms, streets etc.
- Manage shopping malls.
- Serve food in restaurant.
- Maintenance and repair.
- Disaster recovery.

Agriculture and Farms

Robot's use in agriculture and farming sector is very much limited today but is going to increase. They can be used to:

- Plough fields, sow seeds and transplant sapling etc.
- Pluck, sort and pack fruits.
- Breed livestock.
- Animal shearing.

Research and Exploration

With the help of robots, research in many inaccessible areas have been possible because of their greater capabilities to face hazardous environments and remote handling capabilities. These include:

- Space exploration.
- Under-sea exploration.
- Nuclear research.
- Geological exploration.

The list of tasks given above for different sectors can be expanded further to include following. A robot should

- Play football, cricket, etc.
- Knit a sweater.
- Change a tire, repair a puncture.
- Dispense gasoline.
- Dance.
- Play musical instruments.
- Polish diamonds.
- Make paintings.
- Talk and listen.

Software used for robot programming(https://www.automate.org/news/9-types-of-robotics-software-you-might-consider-for-your-robot)

- A “robotics software platform” is a software package which simplifies programming of several kinds of robotic devices by providing
- a unified programming environment;
- a set of reusable components;
- a debugging/simulation environment;
- a package of “drivers” for most wide-spread robotics hardware
- a package of common facilities such as computer vision, navigation or robotic arm control

Table 1 Robotic software platforms

Platform	Type	
Evolution Robotics ERSP	Platform	Commercial
Microsoft Robotics Studio	Platform	Commercial Free of charge for research and hobby
OROCOS	Machine and robot control libraries	Open source & free
Skilligent	Robot learning add-on	Commercial
URBI	Platform	Commercial
Webots	Simulation environment	Commercial
Player, Stage, Gazebo	Platform	Open Source & Free
iRobot AWARE	Platform	Commercial
OpenJAUS	Platform	Open source
CLARAty	Platform	Open source

Software used for robot programming

1.Offline Programming

- RoboDK , offline programming software provides a way for you **to program your industrial robot without needing to be physically connected to the robot at the time.** This means that you don’t need to take the robot out of production to program it. It reduces downtime, improves the quality of programming, and allows you to change between product lines quickly, amongst other benefits.

2. Simulators

Robot simulators come in many forms. Some only allow for simple 2D simulation of specific aspects of robotics whilst others include 3D simulation with complex physics engines and realistic environments.

- As well as being an offline programming tool, RoboDK is also a great simulator. It is simple enough to allow you to easily program your robot whilst being powerful enough to handle many different use cases.

3. Middleware:

Middleware is the “software glue” that helps robot builders to avoid reinventing the wheel when they are designing a new robotic system. Robot middleware provides a framework for running and managing complex robotic systems from a single unified interface. If you were building your own robotic system with multiple components or looking to coordinate multiple robots, you might use middleware .

Software used for robot programming

4**. Mobile Robot Planning :** Mobile robots are programmed in a different way from other robots which means using a different type of software too. For example, **path planners** are used to program the route that the robot will take through the environment while **obstacle avoidance** algorithms react to changes in the moment . Eg: **Mobile planner software.**

5. Real-Time Path Planning

Path planning software is used in many areas of robotics. Basic path planners, are simply used to speed up the programming phase for industrial robotics. Real-time path planning is much more complex and is based on **teaching–learning-based optimization (TLBO) USING AI.**

6. UAV (Drone) Control

A **growing type of robotic software is drone control**. This refers to any software which is used to program and coordinate unmanned aerial vehicles (UAVs/drones). DroneDeploy, PIX4D are examples of software used in drone control

(https://surveyinggroup.com/top-5-drone-mapping-softwares-that-you-will-need-on-your-project)

Software used for robot programming

7. Artificial Intelligence for Robots

- Artificial intelligence (AI) has been used with robotics for many years — almost as long as robotics have been around. However, there has **recently been a rising number of software solutions specifically for using AI with robots** in particular application areas. AI tends to be focused on specific aspects of applications, such as analyzing images collected in agricultural settings, filtering operational data in manufacturing environments, or coordinating swarms of mobile robots in logistics.
- https://www.infoq.com/news/2019/10/ros-smarter-hospitals-robotics/

Software used for robot programming

- **Programming languages used in Robotics:**

➢ **Pascal** is one of the first programming Languages which is the basis for several of the industrial robot languages.

➢ **Scratch** a visual programming language is another popular programming language for complete beginners as scratch programming is achieved by dragging around blocks and connecting them together.

➢ **LISP** is the world's second oldest programming language **. Part of ROS(Robotic Operating System)** are written in LISP and **Prolog** is a logical programming language used in AI.

➢ **Hardware Description languages(HDLs)** are used to program electronic Hardware without having to actually manufacture the silicon chip.(This language can be used in creating robotic electronics prototypes).

➢ **MATLAB** can be used for analysing data and developing control systems(Robotics toolbox is also available for MATLAB).

Software used for robot programming

- **C#** is the primary programming language of Microsoft Robotics Developer Studio
- **Java** is quite popular in some parts of robotics . It is one of the core languages of several modern AI including IBM’S Watson.
- **Python** is a popular language in robotics because of its ease of use and also is one of the programming languages used in ROS.
- **C/C++** are require languages in robotics because a lot of hardware libraries used in robotics use one of these programming languages . These libraries allow interaction with low level hardware.

Note: ROS is an open source middle wear suite containing a set of software frameworks for robot software development