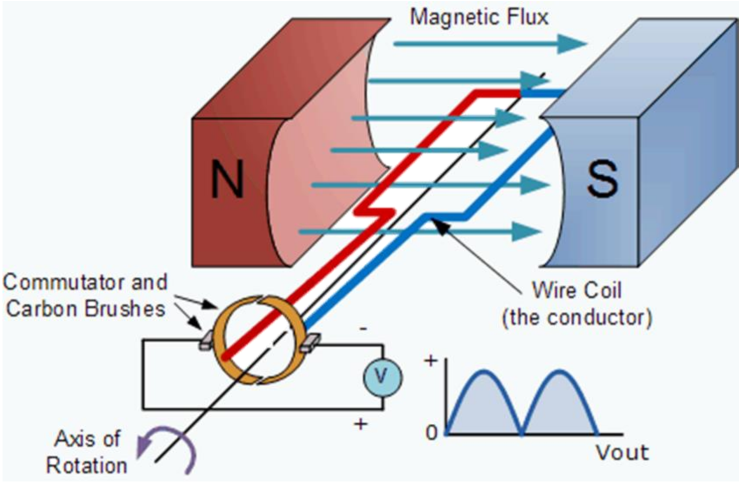
DC Machine Working Mechanisms

The working principle of a DC machine is when electric current flows through a coil within a magnetic field, and then the magnetic force generates a back EMF that rotates the dc motor.



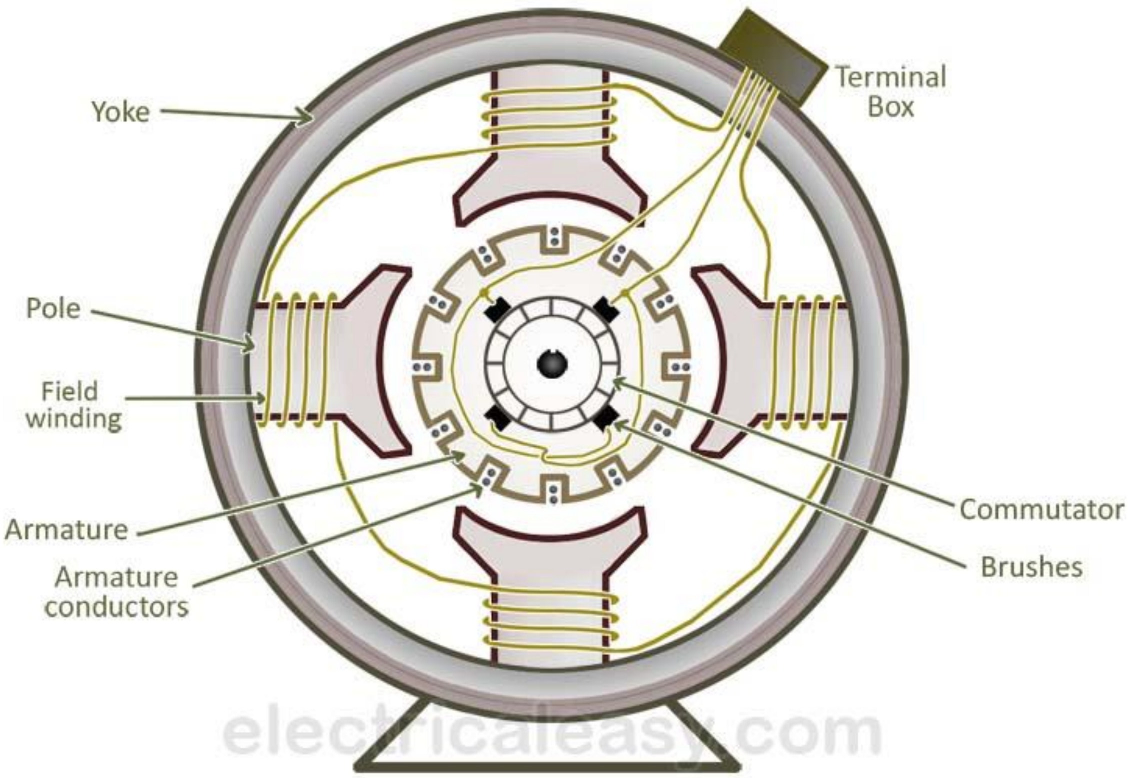
DC Machine Construction:

A DC generator is an electrical machine which converts mechanical energy into direct current electricity. Theoretically, a DC generator can be used as a DC motor without any constructional changes and vice versa is also possible. Therefore, a DC generator or a DC motor can be broadly termed as a DC machine. These basic constructional details are also valid for both DC Generator and DC motor. Hence, let's call this point as construction of a DC machine.

The above figure shows constructional details of a simple **4-pole DC machine**. A DC machine consists of two basic parts; stator and rotor. Basic constructional parts of a DC machine are described below.

1. **Yoke:** The outer frame of a dc machine is called as yoke. It is made up of cast iron or steel. It not only provides mechanical strength to the whole assembly but also carries the magnetic flux produced by the field winding.
2. **Poles and pole shoes:** Poles are joined to the yoke with the help of bolts or welding. They carry field winding and pole shoes are fastened to them. Pole shoes serve two purposes; (i) they support field coils and (ii) spread out the flux in air gap uniformly.

3. **Field winding:** They are usually made of copper. Field coils are former wound and placed on each pole and are connected in series. They are wound in such a way that, when energized, they form alternate North and South poles.
4. **Armature core:** Armature core is the rotor of a dc machine. It is cylindrical in shape with slots to carry armature winding. The armature is built up of thin laminated circular steel disks for reducing eddy current losses.
5. **Armature winding:** It is usually a former wound copper coil which rests in armature slots. The armature conductors are insulated from each other and also from the armature core. Armature winding can be wound by one of the two methods; lap winding or wave winding.
6. **Commutator and brushes:** The function of a commutator, in a dc generator, is to collect the current generated in armature conductors. They rest on commutator segments and slide on the segments when the commutator rotates keeping the physical contact to collect or supply the current.



EMF Equation for DC generator

Φ = Flux produced by each pole in weber (Wb)

P = number of poles in the DC generator.

Total flux produced by all the poles= $\Phi \times P$

Time taken to complete one revolution=60/N

N = speed of the armature conductor in rpm

Induced emf of one conductor is

$$e = \frac{d\phi}{dt} \quad and \; e = \frac{total\ flux}{time\ take}$$

$$e = \frac{\phi P}{\frac{60}{N}} = \phi P \frac{N}{60}$$

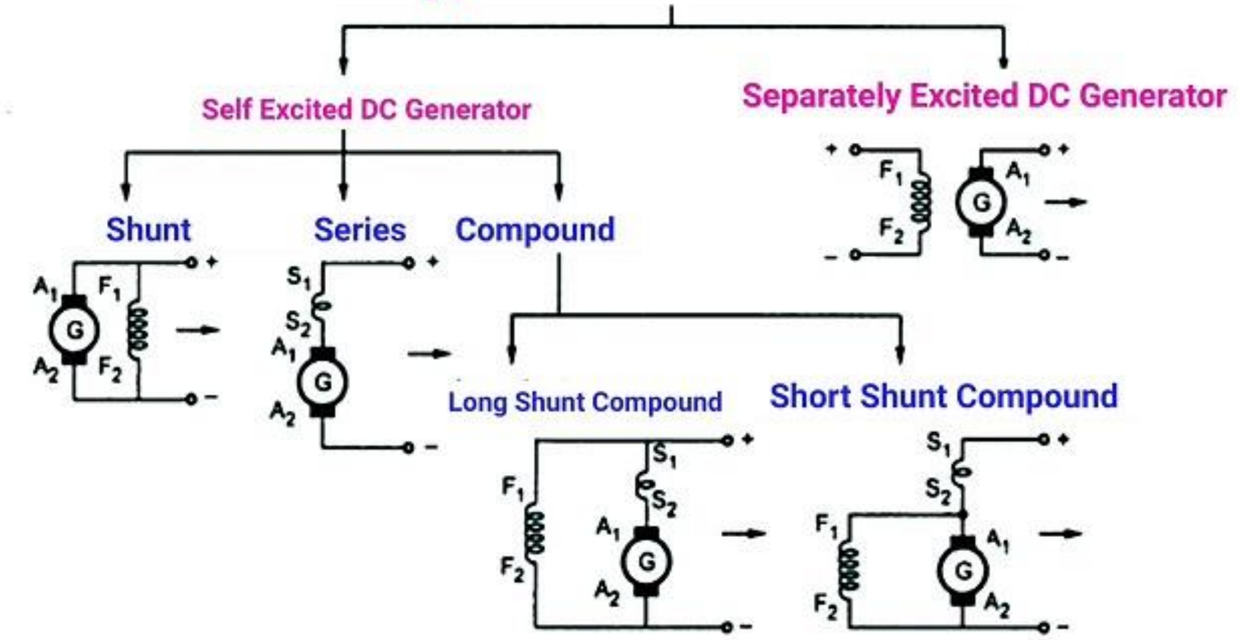
Z = total numbers of conductor
A = number of parallel paths

Induced emf of DC generator

E = emf of one conductor × number of conductor connected in series.

$$E_g = \frac{\phi Z N}{60} X \frac{P}{A} \; volt$$

Types of DC Generators



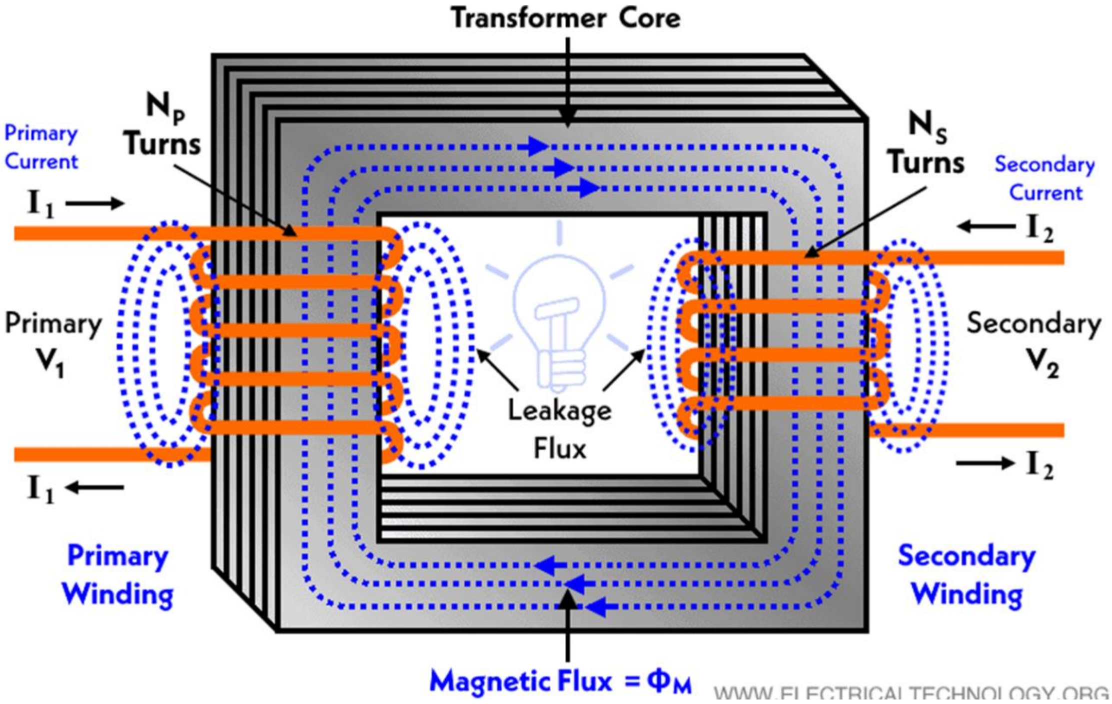
Basic Construction of Transformer

Electrical transformer is a static electrical machine which transforms electrical power from one circuit to another circuit, without changing the frequency. Transformer can increase or decrease the voltage with corresponding decrease or increase in current.

Basically, a transformer consists of two inductive windings and a laminated steel core. The coils are insulated from each other as well as from the steel core with minimum air-gap between them.

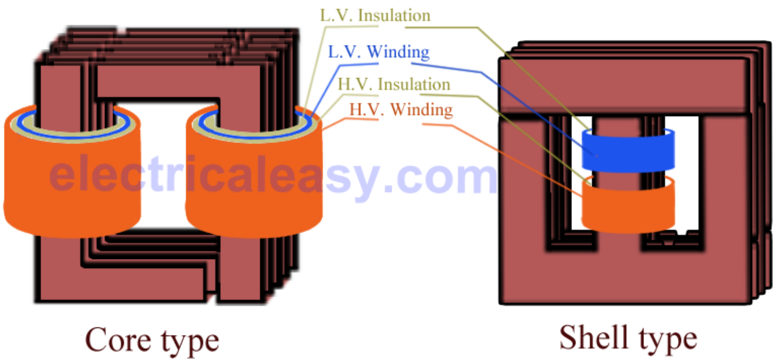
The steel used is having high silicon content and sometimes heat treated, to provide high permeability and low hysteresis loss. Laminated sheets of steel are used to reduce eddy current loss.

The sheets are cut in the shape as E,I and L. To avoid high reluctance at joints, laminations are stacked by alternating the sides of joint.



Types Of Transformers

Transformers can be classified on different basis of construction and voltage (A) On the basis of construction, transformers can be classified into two types as; (i) Core type transformer and (ii) Shell type transformer



(I) Core Type Transformer

In core type transformer, windings are cylindrical former wound, mounted on the core. The cylindrical coils have different layers and each layer is insulated from each other. Materials like paper, cloth or mica can be used for insulation.

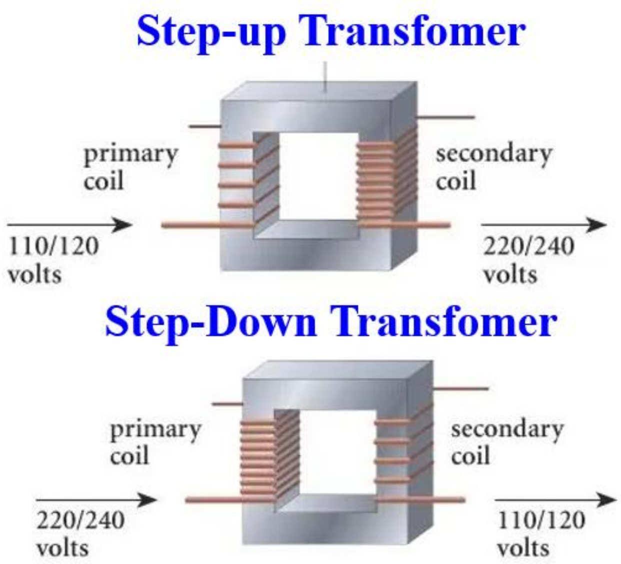
(II) Shell Type Transformer

The coils are former wound and mounted in layers stacked with insulation between them. A shell type transformer may have simple rectangular form or it may have a distributed form.

(B) **On the basis of Voltage:**

Step up transformer: Voltage increases (with subsequent decrease in current) at secondary.

Step down transformer: Voltage decreases (with subsequent increase in current) at secondary.



Working Principle of Transformer:

The **basic principle behind working of a transformer** is the phenomenon of mutual induction between two windings linked by common magnetic flux. The figure at right shows the simplest form of a transformer.

Basically a transformer consists of two inductive coils; primary winding and secondary winding. The coils are electrically separated but magnetically linked to each other. When, primary winding is connected to a source of alternating voltage, alternating magnetic flux is produced around the winding.

The core provides magnetic path for the flux, to get linked with the secondary winding. Most of the flux gets linked with the secondary winding which is called as 'useful flux' or main 'flux', and the flux which does not get linked with secondary winding is called as 'leakage flux'.

As the flux produced is alternating (the direction of it is continuously changing), EMF gets induced in the secondary winding. This emf is called 'mutually induced emf', and the frequency of mutually induced emf is same as that of supplied emf. If the secondary winding is closed circuit, then mutually induced current flows through it, and hence the electrical energy is transferred from one circuit (primary) to another circuit (secondary).

EMF Equation of a Transformer

Let, N_1 = No. of turns in primary

N_2 = No of turns in secondary

Φ_m = maximum flux in core in webers

$= B_m \times A$

f = frequency of AC input in Hz

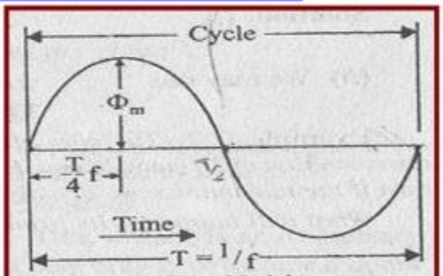


Fig. 32.14

As shown in **Fig. 32.14**, flux increases from its zero value to maximum value Φ_m in one quarter of the cycle i.e. in ($1/4f$) second .

So average rate of change of flux= $\dfrac{\Phi_m}{1/4f} = 4f\Phi_m$ wb/s or volt

Now rate of change of flux per turn means induced emf in volts.

So average emf turn $= 4f\Phi_m$ volt

If flux Φ varies *sinusoidally*, then rms value of induced emf is obtained by multiplying the average value with form factor.

$$\boxed{\text{Form factor} = \frac{\text{rms value}}{\text{average value}} = 1.11}$$

So rms value of emf/turn $= 1.11 \times 4f\Phi_m = 4.44f\Phi_m$ volt

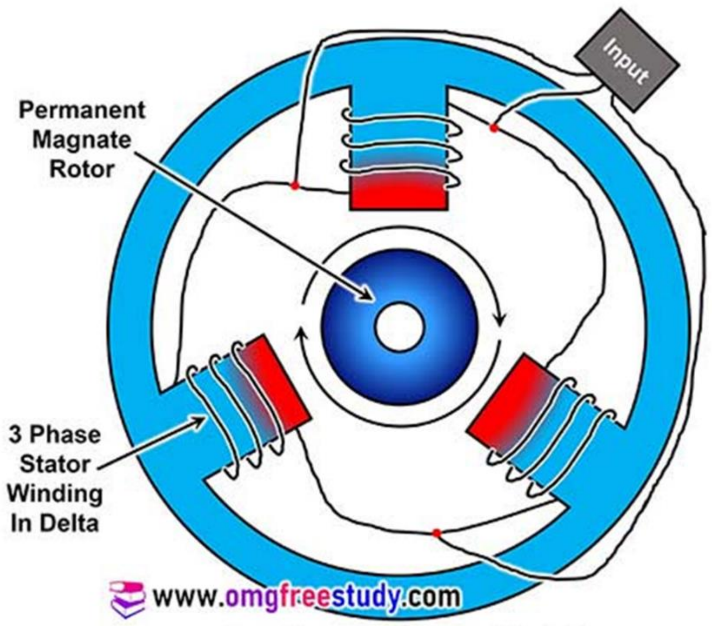
Brushless DC (BLDC) Motor:

A Brushless DC Electric Motor (BLDC) is an electric motor powered by a direct current voltage supply and commutated electronically instead of by brushes like in conventional DC motors.

In simple words, a BLDC has no brushes and commutator for having unidirectional torque rather integrated inverter / switching circuit is used to achieve unidirectional torque. That is why these motors are, sometimes, also referred as Electronically Commutated Motors.

Construction of a BLDC Motor:

Like any other electric motor, a BLDC motor also has a stator and a rotor. Here we will consider Stator and Rotor each separately from construction point of view.



Brushless DC Motor (BLDC)

BLDC Stator:

There are three types of the BLDC motor:

- Single-phase
- Two-phase
- Three-phase.

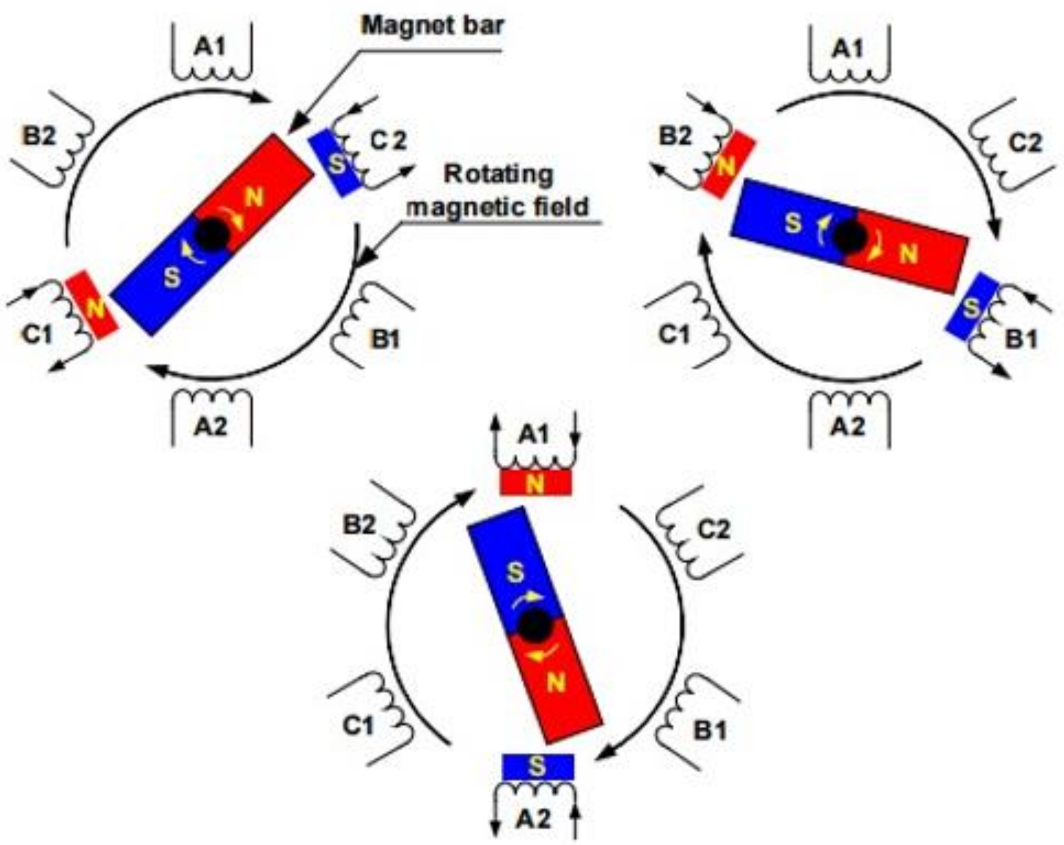
Stator for each type has the same number of windings. The single-phase and three-phase motors are the most widely used. The rotor has permanent magnets to form two magnetic pole pairs, and surrounds the stator, which has the windings.

Rotor:

A rotor consists of a shaft and a hub with permanent magnets arranged to form between two to eight pole pairs that alternate between north and south poles.

Working of BLDC Motor

Motor operation is based on the attraction or repulsion between magnetic poles. Using the three-phase motor as shown in figure below, the process starts when current flows through one of the three stator windings and generates a magnetic pole that attracts the closest permanent magnet of opposite pole.



The rotor will move if the current shifts to an adjacent winding. Sequentially charging each winding will cause the rotor to follow in a rotating field. The torque in this example depends on the current amplitude and the number of turns on the stator windings, the strength and the size of the permanent magnets, the air gap between the rotor and the windings, and the length of the rotating arm.

Advantage of BLDC Motor:

Compared with a brushed DC motor or an induction motor, the BLDC motor has many advantages:

- Higher efficiency and reliability
- Lower acoustic noise
- Smaller and lighter
- Better speed versus torque characteristics
- Higher speed range
- Longer life

Permanent Magnet Synchronous Motor (PMSM):

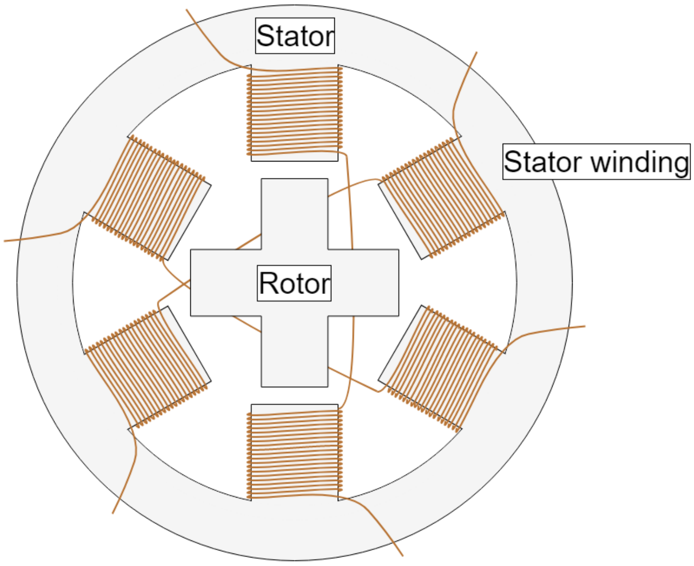
The (PMSM) is brushless and has very high reliability and efficiency. Due to its permanent magnet rotor, it also has a high torque with a small frame size and no rotor current. Instead of using winding for the rotor, permanent magnets are mounted to create a rotating magnetic field. As there is no supply of DC source, these types of motors are very simple and less cost.

The permanent magnet motors are AC synchronous motor whose field excitation is provided by permanent magnets and that has a sinusoidal back EMF waveform. The permanent magnets enable the PMSM to generate torque at zero speed. This motor delivers high-efficiency operations and requires a digitally controlled inverter.

Construction

The permanent magnet synchronous motors, like any rotating electric motor, are consisted of a rotor and a stator. The permanent magnet synchronous motor construction is similar to the basic synchronous motor, but the only difference is with the rotor. In this type of motor, the permanent magnets are mounted on the rotor and the rotor doesn't have any field winding.

The permanent magnets are used to create field poles. The permanent magnets used in the motor are made up of samarium-cobalt and medium, iron, and boron because of their higher permeability. The most widely used permanent magnet is neodymium-boron-iron because of its effective cost and ease of availability.



Working Principle

The principle of operation is based on the interaction of the rotating magnetic field of the stator and the constant magnetic field of the rotor. It depends on the rotating magnetic field that generates electromotive force at synchronous speed.

When the stator winding is energized by giving the 3-phase supply, a rotating magnetic field is created in between the air gaps. This produces the torque when the rotor field poles hold the rotating magnetic field at synchronous speed and the rotor rotates continuously. As these motors are not self-starting, it is necessary to provide a variable frequency power supply.

Advantages

- High power density
- Low rotor inertia makes it easy to control
- No torque ripple when the motor is commutated
- High and smooth torque
- High efficiency at high speeds
- Resistant to wear and tear
- Available in small sizes at different packages
- Easy maintenance and installation

Stepper Motor:

A stepper motor is an electric motor whose main feature is that its shaft rotates by performing steps, that is, by moving by a fixed amount of degrees. This feature is obtained thanks to the internal structure of the motor, and allows to know the exact angular position of the shaft by simply counting how may steps have been performed, with no need for a sensor. This feature also makes it fit for a wide range of applications.

Stepper Motor Types and Construction

The stepper motors have a stationary part (the stator) and a moving part (the rotor). On the stator, there are teeth on which coils are wired, while the rotor is either a permanent magnet or a variable reluctance iron core. The stepper motors have the same internal structure (or construction), as there are different rotor and stator configurations.

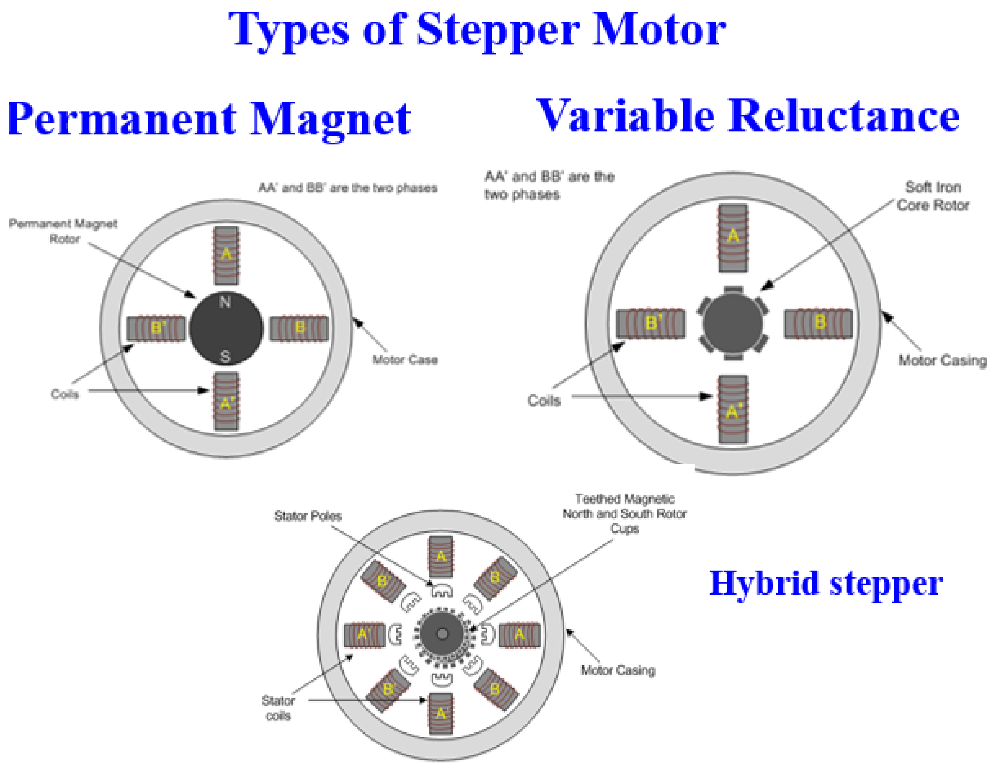
Rotor

For a stepper motor, there are basically three types of rotors:

Permanent magnet rotor: The rotor is a permanent magnet that aligns with the magnetic field generated by the stator circuit. This solution guarantees a good torque and also a detent torque. This means the motor will resist, even if not very strongly, to a change of position regardless of whether a coil is energized. The drawbacks of this solution is that it has a lower speed and a lower resolution compared to the other types. Figure shows a representation of a section of a permanent magnet stepper motor.

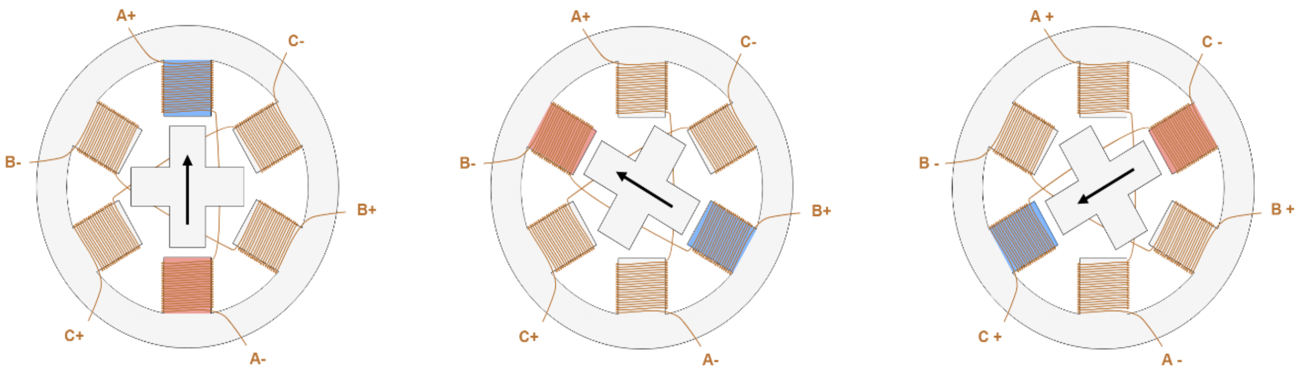
Variable reluctance rotor: The rotor is made of an iron core, and has a specific shape that allows it to align with the magnetic field. With this solution it is easier to reach a higher speed and resolution, but the torque it develops is often lower and it has no detent torque.

Hybrid rotor: This kind of rotor has a specific construction, and is a hybrid between permanent magnet and variable reluctance versions. The rotor has two caps with alternating teeth, and is magnetized axially. This configuration allows the motor to have the advantages of both the permanent magnet and variable reluctance versions, specifically high resolution, speed, and torque. This higher performance requires a more complex construction, and therefore a higher cost.



Basic working principle

The basic working principle of the stepper motor is the following: 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 different phases in sequence, the rotor can be rotated by a specific amount to reach the desired final position. 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 clockwise by 60° to align with the new magnetic field. The same happens when coil C is energized. In the pictures, the colours of the stator teeth indicate the direction of the magnetic field generated by the stator winding.



Step Angle

The step angle is the basis of the movement of a stepping motor.

The step angle depends on the total number of magnetic poles of the motor.

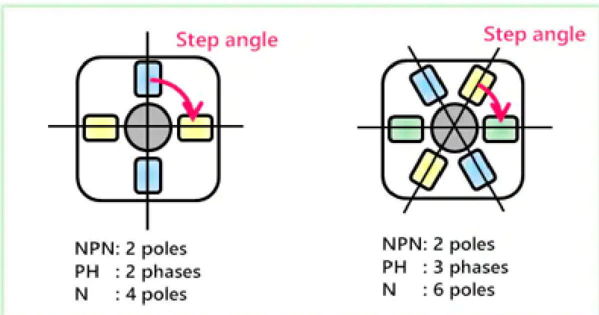
The step angle is determined by the formula:

Step angle = 360 degrees / N

where N = (NPH x PH)

NPH: Number of magnetic poles for each phase

PH: Number of phases



Advantages of The Stepper Motor:

- Maintenance Cost is low.
- High Repeatability.

- Excellent Low Speed Torque.
- Cost and Complexity is very low.
- Low efficiency.
- Torque Drops Rapidly with Increase in Speed.

Servo Motor

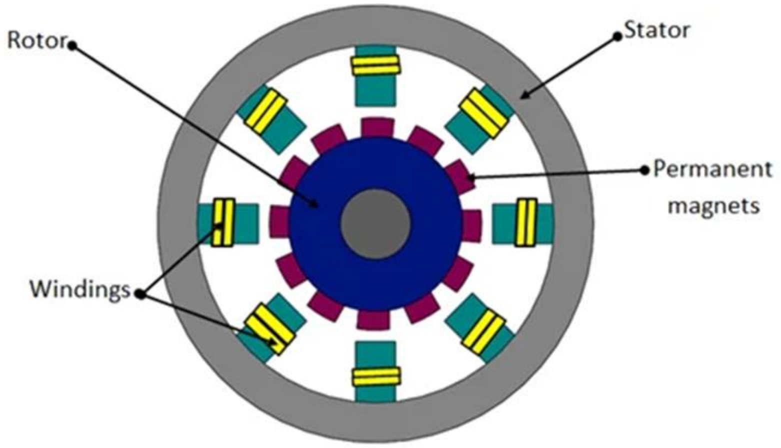
Servo motor is an electromagnetic device uses a negative feedback mechanism to converts an electric signal into controlled motion. Basically, servos behave like as actuators which provide precise control over velocity, acceleration, and linear or angular position. It consists of four things: DC motor, position sensor, gear train, and a control circuit. The gear mechanism connected with the motor provides the feedback to the position sensor.

If the motor of the servo is operated by DC then it is called a DC servo motor and if it is operated by AC then it is called as AC servo motor. The gear of the servo motor is generally made up of plastic but in high power servos, it is made up of metal.

Construction of Servo Motor

The Servo motor is DC motor which has 5 following parts:-

1. **Stator Winding**: This type of winding wound on the stationary part of the motor. It is also known as field winding of the motor.
2. **Rotor Winding**: This type of winding wound on the rotating part of the motor. It is also known as an armature winding of the motor.
3. **Bearing**: These are of two types, i.e, font bearing and back bearing which are used for the movement of the shaft.
4. **Shaft**: The armature winding is coupled on the iron rod is known as the shaft of the motor.
5. **Encoder**: It has the approximate sensor which determines the rotational speed of motor and revolution per minute of the motor.



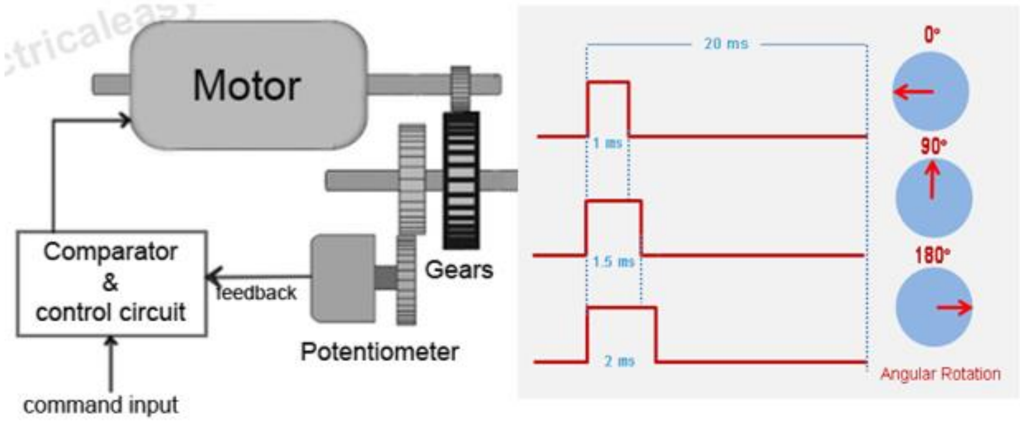
Working of Servo Motor

The servo motor works on the phenomenon of the automatic closed-loop system which composed of a comparator and a feedback path. It has one output and two inputs. In this, for producing an output signal, the comparator is used to compare the required reference signal and this output signal is sensed by the sensor.

The input signal for the motor is termed as a feedback signal. On the basis of the feedback signal, the motor starts working. Comparator signal is called a logic signal of the motor.

The motor would be ON for the desired time when the logical difference is higher and the motor would be OFF for the desired time when the logical difference is lower.

Basically, a comparator is used to decide that motor would be ON or OFF. Proper functioning of the motor can be done with the help of a good controller.

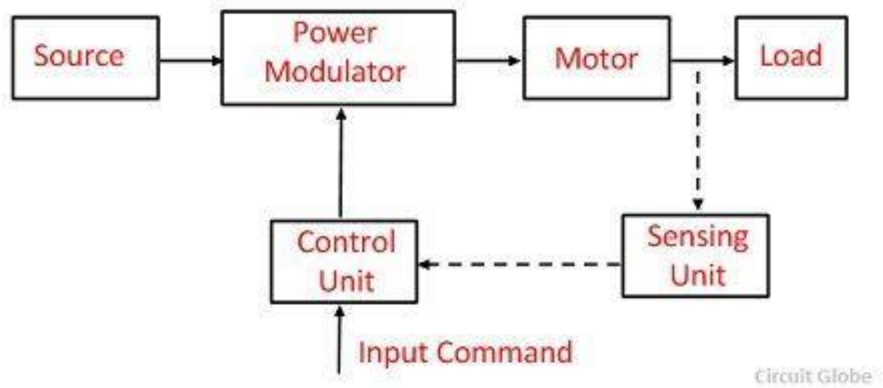


Electrical Drives:

The system which is used for controlling the motion of an electrical machine, such type of system is called an electrical drive. In other words, the drive which uses the electric motor is called electrical drive.

The electrical drive uses any of the prime movers like diesel or a petrol engine, gas or steam turbines, steam engines, hydraulic motors and electrical motors as a primary source of energy. This prime mover supplies the mechanical energy to the drive for motion control.

The block diagram of the electrical drive is shown in the figure below. The electrical load like fans, pumps, trains, etc., consists the electrical motor. The requirement of an electrical load is determined regarding speed and torque. The motor which suited the capabilities of the load is chosen for the load drive.



Parts of Electrical Drive

The main parts of the electrical drives are power modulator, motor, controlling unit and sensing units. Their parts are explained below in details.

Power Modulator – The power modulator regulates the output power of the source. It controls the power from the source to the motor in such a manner that motor transmits the speed-torque characteristic required by the load.

The power modulator converts the energy according to the requirement of the motor e.g. if the source is DC and an induction motor is used then power modulator convert DC into AC. It also selects the mode of operation of the motor, i.e., motoring or braking.

Control Unit – The control unit controls the power modulator which operates at small voltage and power levels. The control unit also operates the power modulator as desired. It also generates the commands for the protection of power modulator and motor. An input command signal which adjusts the operating point of the drive, from an input to the control unit.

Sensing Unit – It senses the certain drive parameter like motor current and speed. It mainly required either for protection or for closed loop operation.

Advantages of Electrical Drive

- The electric drive has very large range of torque, speed and power.
- Their working is independent of the environmental condition.
- The electric drives are free from pollution.
- The electric drives operate on all the quadrants of speed torque plane.
- The drive can easily be started and it does not require any refuelling.
- The efficiency of the drives is high because fewer losses occur on it.