ROBOTICS AND AUTOMATION

Drives and Control System for Automation

UNIT-2

DC MOTOR

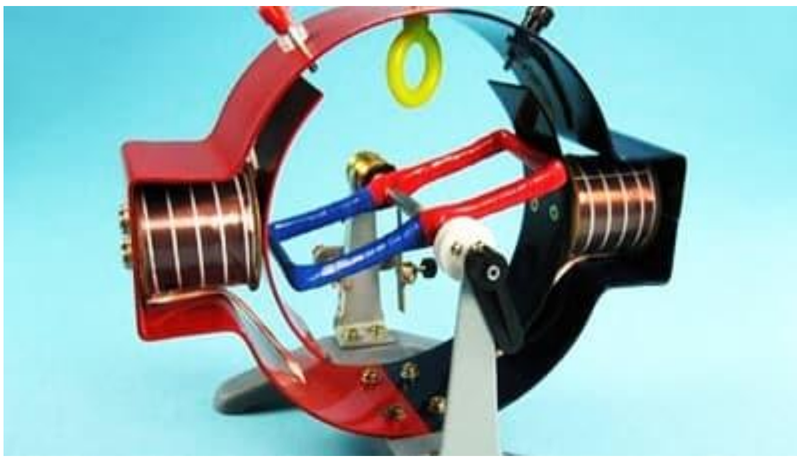
A DC motor is an electrical machine which **converts electrical energy into mechanical energy**.

WORKING PRINCIPLE OF DC MOTOR:

The working of DC motor is based on the principle that when a current carrying conductor is placed in a magnetic field, it experiences a mechanical force.

The direction of the mechanical force is given by **Fleming's Left-hand Rule** and its magnitude is given by **F = BIL** Newton.

The working of the AC motor (Induction motor and Synchronous Motor) is different from the DC motor.



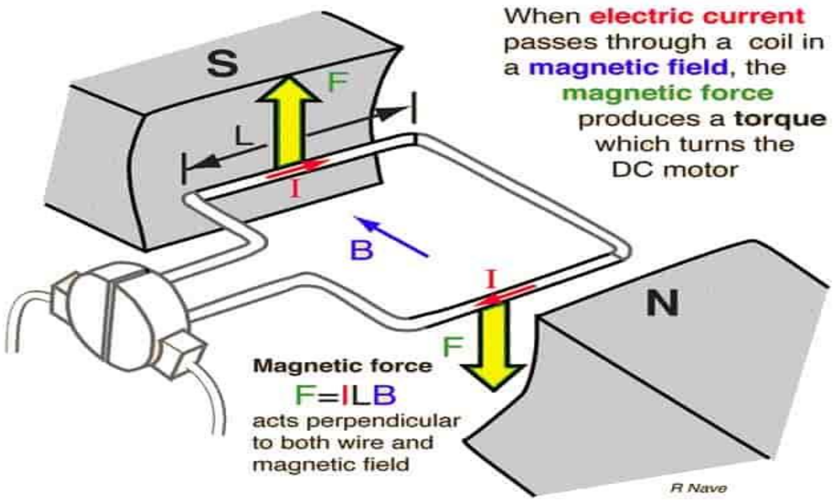
There is no basic difference in the construction of a DC generator and a DC motor. In fact, the same DC machine can be used interchangeably as a generator or as a motor.

Like generators, there are different types of DC motors which are also classified into shunt-wound**,** series-wound **and compound-wound dc motors**.

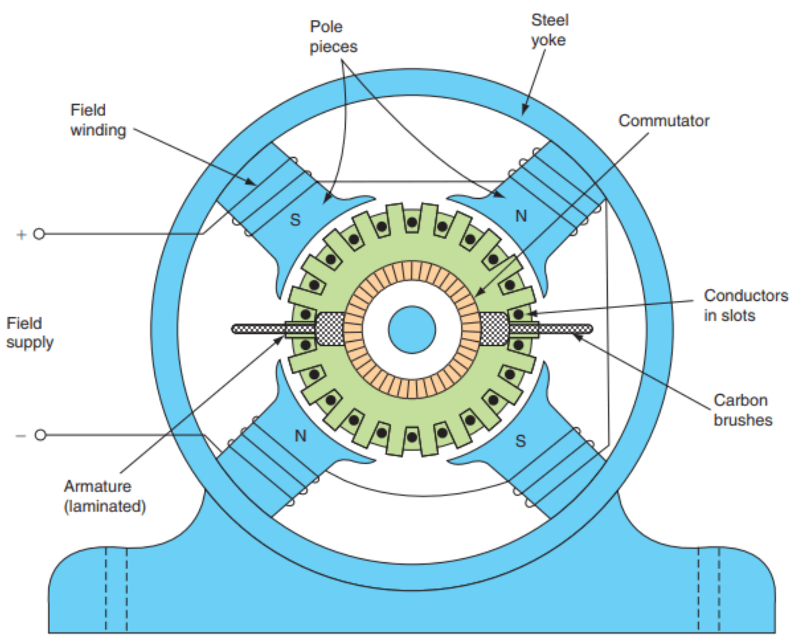
DC motors are seldom used in ordinary applications because all electric supply companies furnish alternating current.

However, for special applications such as in **steel mills, mines, and** electric trains, it is advantageous to convert alternating current into direct current in order to use dc motors. The reason is that the **speed/torque characteristics** of DC motors are much more superior to that of AC motors.

Therefore, it is not surprising to note that for industrial drives, DC motors are as popular as three phase induction motors.



Basically, there is no constructional difference between a DC motor and a DC generator. The same DC machine can be run as a generator or motor.



Cross-Section of a DC Machine

DC MOTOR ADVANTAGES AND DISADVANTAGES AND APPLICATIONS:

ADVANTAGES OF DC SERIES MOTORS:

- Starting torque of DC Series motor is comparatively higher than other motors so this kind of motors are widely used for traction applications
- Series wound motors can use for AC or DC supply so it's also known as universal motors.
- Compare with Shunt Motor DC series motor develop more power for the same construction size.

DISADVANTAGES OF DC SERIES MOTORS:

- Speed control and regulation of DC series motor are not good.
- It is necessary to have a load before starting the DC series motors. So Dc Series motors are not good to use where load does not apply to the initial stage.

APPLICATIONS OF DIRECT CURRENT MOTOR ADVANTAGES AND DISADVANTAGES

- Direct Current series motors are useful traction applications in electrical such as locomotives and trolley cars.
- DC Series Motors are also used for cranes and conveyor belt where higher starting torque is required.

DC SHUNT MOTORS

ADVANTAGES OF DC SHUNT MOTORS

- direct current machines can use for heavy industrial applications where torque and speed wider range.
- Shunt wound motor able to runs at a predetermined speed.
- The power supply of DC motor is any way cheap.

DISADVANTAGES OF DC SHUNT MOTORS

- Installation of DC machines is expensive compare with other types of machines.
- Since Shunt motors are constant speed motor, it would be a disadvantage where it's necessary to operate under variable speed.
- DC motors are unreliable at low speeds operations.
- The Size of DC motors is large compared with Alternative Current Motors.

APPLICATIONS OF DC SHUNT MOTORS

- This motors got great speed controlling characteristics so this type of motors are used in rolling mills.
- Use of lathe machines where constant speed is highly required.
- These motors are also widely used for fans, blowers, reciprocating and centrifugal pumps.

COMPOUND MOTORS

ADVANTAGES OF COMPOUND MOTORS

- Quick start and stop of the motor can do.
- Reversing and acceleration of the motor can do fast

DISADVANTAGES OF COMPOUND MOTORS

- Operation and maintenance cost of DC motors are expensive.

- DC motors unable to operate in hazard situation where spark occurs at the brush of the motor.
- In generally Every DC motor using brushes so the lifetime of such motors is less compared with AC motors.

APPLICATIONS OF COMPOUND MOTORS

- Compound motors are widely used in applications such as elevators, conveyor belts, air compressors, and punches.
- Can use for variable speed domestic appliances

CLASSIFICATION OF DIRECT CURRENT MOTORS AND ALTERNATING CURRENT MOTORS

First, we will focus on the various options you will find when looking for electric motors:

1. Direct current motors (DC motors)

These motors are classified based on the way their inductor coils are connected.Here we can find:

- Separately excited motor
- Series-wound motor
- Shunt-wound motor
- Compound motor

2. ALTERNATING CURRENT MOTORS (AC MOTORS)

Their classification is based on their rotation speed, number of input phases and the type of rotor. Based on their rotational speed, they may be classified as:

- **Synchronous**
- **Asynchronous(induction motor)**

Based on the number of input phases:

- **Single-phase:**
- **Three-phase:**
- **Two-phase**

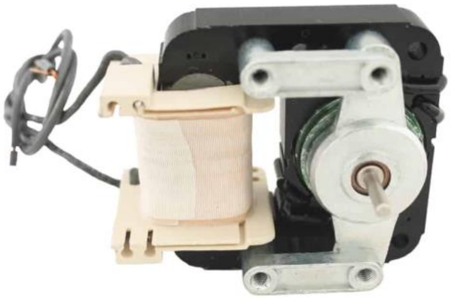
Based on the type of rotor:

- **Slip-ring motors**
- **Collector motors**
- **Squirrel cage motor**

WHAT ARE THE APPLICATIONS OF ALTERNATING CURRENT MOTORS?

- If we intend to vary the rotational speed, we will need to have a **frequency converter**, which makes the selection process harder.
- They are suitable for projects where a stable motion and fixed speed are not required.
- They are not suitable for applications that require very low speeds.

- If your application demands the highest performance and torque output, alternating current motors will be a good choice.
- Their price is another factor that may prompt you to choose this solution. Since their manufacturing is simpler, the price of these motors is lower than that of DC motors.
- Lastly, another aspect that sets them apart is that they may be single-phase and three-phase, while DC motors are only single-phase.



APPLICATION EXAMPLE

Industrial machinery such as **thread winding machines.** These applications require a **continuous motion and low torque**. Since industrial currents are used, alternating current motors are chosen in order to simplify this type of machinery, resulting in the use of less components.

When is it advisable to choose direct current motors?

- Applications that require great torque when starting the motor. Thanks to their high starting torque, **DC motors** are more than fitting. Since their torque is high, they overcome the inertia that may be exerted by the load to be moved during start-up.
- Whenever you require versatility. Using external applications using control electronics, it is possible to modify their current to decrease or increase the output torque and rotational speed. On the other hand, they offer good results both in low and high power applications.
- In cases where you need to power parts, machinery or devices that vary their power during operation.
- In projects where the load is more important than motion precision, these motors may offer you better results.

Application example

Window opening in farms, a successful deployment by CLR related to **technologies which improve productivity in the livestock industry**.
This project requires a high starting torque to start the motion of the window. The motion is controlled using electronic circuit boards in order to open them at a greater or lesser angle depending on the temperature.

Selection Criteria for DC or AC motors:

To Select a motor we require these specification:

- **TYPE OF START-UP**

  We should analyse the amount and characteristics of start-ups. There are machines that require a starting power that a motor may not be able to provide.

- **LOAD**

  Here we will consider its operation with or without a load. When bearing a load, the motor is dragging an object or bearing an external resistance (the load) which forces it to absorb mechanical energy. Therefore, in this case, the torque resistance results from internal and external factors. When a motor operates without a load, it does not pull any object, neither does it bear any sort of external resistance. The shaft rotates freely and any resistance results from internal factors.

- **TORQUE**

  This information specifies the motor's driving ability. This parameter will be key on any application where we intend to create a motion or displacement.

- **ELECTRICAL POWER USED BY THE MOTOR (IN KW)**

  When efficiency is a key factor for your project, you should calculate the electrical power used by the motor during its operation.

- **PERFORMANCE**

  You should analyse energy losses on the motor resulting from external (humidity, ambient temperature, material properties, etc.) and internal (material properties, brushed or brushless motors) factors.

- **VARIATIONS IN, AND PROGRESSION OF, THE ROTATIONAL SPEED**

  There are many aspects that may condition the rotational speed. If our application needs to work at various speeds, we should choose actuation solutions that are highly versatile.

There are many aspects to consider when selecting a motor, such as application, operational, mechanical, and environmental issues. Generally speaking, the choice is either an ac motor, a dc motor, or a servo/stepper motor. Knowing which one to use depends on the industrial application and if there are any special needs required.

A constant or variable torque and horsepower will be required for the motor depending on the type of load the motor is driving. The size of the load, the required speed, and acceleration/deceleration—particularly if it's fast and/or frequent—will define the torque and horsepower that is required. Requirements for controlling motor speed and position also need to be considered.

Environmental Issue:

Provide proper protection from surrounding.

Totally enclosed-non ventilated (TENV) **The 7 most common types of enclosures are:**

- Open drip proof
- Splash proof
- Totally enclosed-fan cooled (TEFC)
- Explosion proof
- Totally enclosed-air over (TEAO)

1. OPEN DRIP PROOF (ODP):

Allows air to circulate through the windings for cooling, but prevent drops of liquid from falling into motor within a 15 degree angle from vertical. Typically used for **indoor applications in relatively clean, dry locations**.

An **open drip proof** or **ODP motor** is a type of **motor** that typically runs cooler and does not overheat. Due to the fact that the chamber has **open** vents and air can flow directly over the windings, this **open drip proof motor** tends to be slightly more efficient because the windings are cooler.

2. Totally Enclosed Fan Cooled (TEFC)

Prevents the free exchange of air between the inside and outside of the frame, but does not make the frame completely air tight. A fan is attached to the shaft and pushes air over the frame during its operation to help in the cooling process.

The ribbed frame is designed to increase the surface area for cooling purposes.

The TEFC style enclosure is the most versatile of all. It is used on pumps, fans, compressors, general industrial belt drive and direct connected equipment.

3. Totally Enclosed Non-Ventilated (TENV)

Similar to a TEFC, **but has no cooling fan** and relies on convention for cooling. No vent openings, tightly enclosed to prevent the free exchange of air, but not airtight.

These are suitable for uses which are exposed to dirt or dampness, **but not very moist or hazardous (explosive) locations**.

TENV motors are used in a wide variety of smaller horsepower variable speed applications. It is particularly effective in environments where a fan would regularly clog with dust or lint.

The motor is constructed with a dust-tight, moderately sealed enclosure which rejects a degree of water. The motor radiates its entire excess heat through the body of the motor: Hence, the TENV motor has extra metal and extra fins to allow radiation of this heat.

The TENV motor is commonly built with special high temperature insulation, since the motor is designed to run hot. As such, care should be taken to avoid human contact with the body of the motor, as well as contact between inflammable objects and the motor.

Notice that this motor is not suitable for use in "washdown" or "Hazardous" enviroments.

4. **Totally Enclosed Air Over (TEAO)**

Dust-tight fan and blower duty motors designed for shaft mounted fans or belt driven fans. The motor must be mounted within the airflow of the fan.

5. **Totally Enclosed Wash down (TEWD)**

Baldor's Washdown Duty Motor for food processing, packaging, pharmaceuticals, or applications where motors are regularly exposed to high pressure wash down.

Designed **to withstand high pressure wash-downs** or other high humidity or wet environments. Available on TEAO, TEFC and ENV enclosures totally enclosed, hostile and severe environment motors:

Designed for use in extremely moist or chemical environments, but not for hazardous locations.

6. **EXPLOSION-PROOF ENCLOSURES (EXPL)**

SIEMENS's explosion proof motor for hazardous environments, such as in chemical plants, the oil industry, in gas works, in wood and plastic processing industry or in agriculture.

The explosion proof motor is a **totally enclosed machine** and is designed **to withstand an explosion of specified gas or vapor inside the motor casing** and prevent the ignition outside the motor by sparks, flashing or explosion.

These motors are designed for **specific hazardous purposes**, such as atmospheres containing gases or hazardous dusts. For safe operation, the maximum motor operating temperature must be below the ignition temperature of surrounding gases or vapors.

Explosion proof motors are designed, manufactured and tested under the rigid requirements of the **Underwriters Laboratories**.

7. **Hazardous Location (HAZ)**

Hazardous location motor applications are classified by the type of hazardous environment present, the characteristics of the specific material creating the hazard, the probability of exposure to the environment, and the maximum temperature level that is considered safe for the substance creating the hazard.

Motor load types

There are four types of industrial automation motor loads:

- Variable horsepower and constant torque
- Variable torque and constant horsepower
- Variable horsepower and variable torque
- Positional control or torque control.

Variable horsepower and constant torque applications include conveyors, cranes, and gear-type pumps. In these applications, the **torque is constant because the load doesn't change**. The required horsepower may vary depending on the application, which makes constant speed ac and dc motors a good choice.

An example of a variable torque and constant horsepower application is a machine rewinding paper. **The material speed remains constant, which means the horsepower doesn't change**. The load does change, however, as the roll diameter increases. In small systems, this is a good application for dc motors or a servo motor. Regenerative power also is a concern and should be considered when sizing the motor or choosing the energy control method. AC motors with encoders, closed-loop control, and full quadrant drives may be beneficial for larger systems.

Fans, centrifugal pumps, and agitators require variable horsepower and torque. As the motor speed increases, the load output also increases along with the required horsepower and torque. These types of loads are where much of the motor efficiency discussion begins with inverter duty ac motors using variable speed drives (VSDs).

Applications such as linear actuators, which need to move to multiple positions accurately, require tight positional or torque control and often require feedback to verify correct motor position. Servo or stepper motors are the best option for these applications, but a dc motor with feedback or an inverter duty ac motor with an encoder often is used for tight torque control in steel or paper lines as well as similar applications.

Different motor types

While there are two main motor classifications—ac and dc—there are over three dozen types of motors used in industrial applications.

While there are many motor types, there is a great deal of overlap in industrial applications and the market has pushed to simplify motor selection. This has narrowed practical choices for motors in most application. The six most common motor types, which fit the vast majority of applications, are brushless and brush dc motors, ac squirrel cage and wound rotor motors, and servo and stepper motors. These motor types fit the vast majority of applications with the other types used only in specialty applications.

Three main application types

The three main applications for motors are constant speed, variable speed, and position (or torque) control. Different industrial automation situations require different applications and questions and their own set of questions.

For example, a gearbox may be required if the top speed is less than the motor's base speed. This also may allow a smaller motor running at a more efficient speed. While there is a great deal of information online on how to size a motor, users must account for many factors because there are many details to consider. Calculating load inertia, torque, and speed requires the user to know about parameters such as total mass and size (radius) of the load as well as friction, gearbox losses, and the machine cycle. Changes in load, speed of acceleration or deceleration, and the application's duty cycle also must be considered or the motor may overheat.

After the motor type is selected and sized, users also need to consider environmental factors and motor enclosure types such as open frame and stainless housing for washdown applications.

Motor selection: 3 questions

Even after all those decisions have been made, the user needs to address these three questions before making a final decision.

1. Is it a constant speed application?

In a constant speed application, a motor often runs at an approximate speed with little or no concern about acceleration and deceleration ramps. This type of application is usually run using across-the-line on/off control. The control circuits often consist of a branch circuit fusing with a contactor, an overload motor starter, and a manual motor controller or soft starter.

Both ac and dc motors are suitable for constant speed applications. DC motors provide full torque at zero speed and have a large installed base. AC motors are also a good choice because they have a high power factor and require little maintenance. A servo or stepper motor's high performance characteristics, by comparison, would be considered overkill for a simple application.

2. Is it a variable speed application?

Variable speed applications usually require tight velocity and speed changes as well as defined acceleration and deceleration ramps. Reducing the motor speed in application, such as fans and centrifugal pumps often improves efficiency by matching the power consumed to the load instead of running at full speed and throttling or dampening the output. These are very important considerations for conveying applications, such as bottling lines.

Both ac and dc motors with the appropriate drives work well in variable speed applications. A dc motor and drive configuration was the only variable speed motor option for a long time and the components are developed and proven. Even now, dc motors are popular in variable speed, fractional horsepower applications and are useful in low-speed applications because they can provide full torque at low speed and constant torque across a wide range of motor speeds.

Maintenance can be a concern with dc motors, however, because many require brushes for commutation, and they wear out from being in contact with moving parts. Brushless dc motors eliminate this issue, but they are more expensive in upfront costs and the range of available motors is smaller.

Brush wear is not an issue with ac induction motors and a variable frequency drive (VFD) creates a useful choice for applications over 1 hp such as fan and pumping applications, which lead to improved efficiency. The type of drive chosen to run the motor can add some positional awareness. An encoder can be added to the motor if the application requires it, and a drive can be specified to use the encoder feedback. This setup can provide servo-like speed as a result.

3. Is position control required for the application?

Tight position control is accomplished through continuous verification of the motor's position as it moves. Applications such as positioning a linear actuator can use a stepper motor with or without feedback or a servo motor with inherent feedback.

A stepper is designed to accurately move to a position at a moderate speed and then hold the position. An open-loop stepper system offers strong positional control if properly sized. While there is no feedback, the stepper will move the exact number of steps unless it encounters a load disruption beyond its capacity. As the application's speed and dynamics increase, open-loop stepper control may not be able to meet system requirements, which requires an upgrade to a stepper with feedback or to a servo motor system.

A closed-loop system provides accurate, high-speed motion profiles and precise position control. A servo system will provide higher torque at high speeds compared to a stepper, and they also work better in high-dynamic load or complex-motion applications.

For high-performance motion with low-position overshoot, the reflected load inertia should be matched to the servo motor inertia as closely as possible. Up to a 10:1 mismatch will perform adequately in some applications, but a 1:1 match is optimal. Geared speed reduction is an excellent way to solve inertia mismatch problems as the reflected load inertia falls by the square of the gear ratio, but gearbox inertia must be included in the calculations.

Application, motor knowledge

Manufacturers offer a wide selection of motors for industrial applications. Stepper, servo, ac, and dc motors can meet most industrial automation requirements, but the ideal motor depends on the application. Whether it's a constant speed, variable speed, or position control application-users should work closely with the motor and drive the supplier to select the right motor for the application.

INDUCTION MOTOR (AC MOTOR):

An electrical motor is an electromechanical device which converts electrical energy into mechanical energy. In the case of three phase AC (Alternating Current) operation, the most widely used motor is a **3 phase induction motor**, as this type of motor does not require an additional starting device. These types of motors are known as self-starting induction motors.

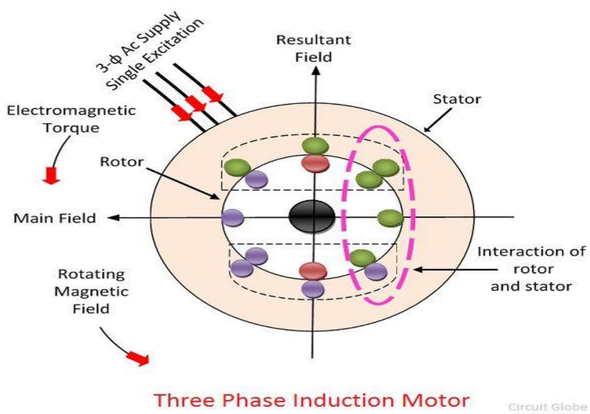
WORKING PRINCIPLE OF AN INDUCTION MOTOR:

The motor which works on the principle of electromagnetic induction is known as the induction motor. The electromagnetic induction is the phenomenon in which the electromotive force induces across the electrical conductor when it is placed in a rotating magnetic field.

The stator and rotor are two essential parts of the motor. The stator is the stationary part, and it carries the overlapping windings while the rotor carries the main or field winding. The windings of the stator are equally displaced from each other by an angle of 120°.

The induction motor is the single excited motor, i.e., the supply is applied only to the one part, i.e., stator. The term excitation means the process of inducing the magnetic field on the parts of the motor.

When the three phase supply is given to the stator, the rotating magnetic field produced on it. The figure below shows the rotating magnetic field set up in the stator.



In a DC motor, supply is needed to be given for the stator winding as well as the rotor winding. But in an **induction motor** only the stator winding is fed with an AC supply.

- Alternating flux is produced around the stator winding due to AC supply. This alternating flux revolves with synchronous speed. The revolving flux is called as "Rotating Magnetic Field" (RMF).
- The relative speed between stator RMF and rotor conductors causes an induced emf in the rotor conductors, according to the Faraday's law of electromagnetic induction. The rotor conductors are short circuited, and hence rotor current is produced due to induced emf. That is why such motors are called as **induction motors**.
(This action is same as that occurs in transformers, hence induction motors can be called as **rotating transformers**.)
- Now, induced current in rotor will also produce alternating flux around it. This rotor flux lags behind the stator flux. The direction of induced rotor current, according to Lenz's law, is such that it will tend to oppose the cause of its production.
- As the cause of production of rotor current is the relative velocity between rotating stator flux and the rotor, the rotor will try to catch up with the stator RMF. Thus the rotor rotates in the same direction as that of stator flux to minimize the relative velocity. However, the rotor never succeeds in catching up the synchronous speed. This is the **basic working principle of induction motor** of either type, single phase of 3 phase.
-

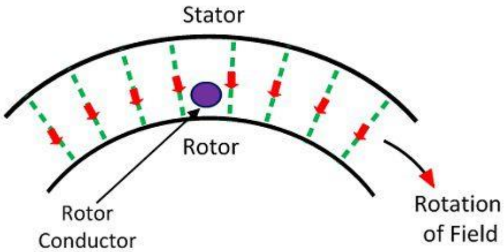
WHY ROTOR NEVER RUNS AT SYNCHRONOUS SPEED?

If the speed of the rotor is equal to the synchronous speed, no relative motion occurs between the rotating magnetic field of the stator and the conductors of the rotor. Thus the EMF is not induced on the conductor, and zero current develops on it. Without current, the torque is also not produced.

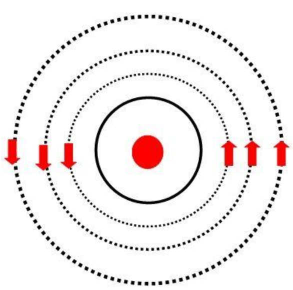
Because of the above mention reasons the rotor never rotates at the synchronous speed. The speed of the rotor is always less than the speed of the rotating magnetic field.

Alternatively, the method of the working principle of Induction Motor can also be explained as follows.

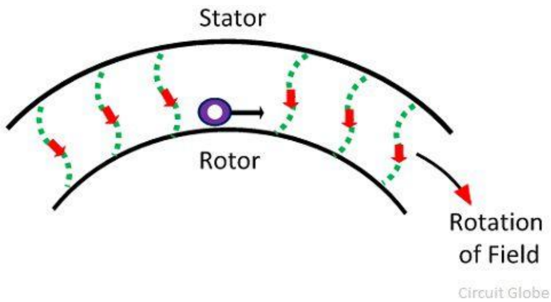
Let’s understand this by considering the single conductor on the stationary rotor. This conductor cuts the rotating magnetic field of the stator. Consider that the rotating magnetic field rotates in the clockwise direction. According to Faraday’s Law of electromagnetic induction, the EMF induces in the conductor.



 As the rotor circuit is completed by the external resistance or by end ring, the rotor induces an EMF which causes the current in the circuit. The direction of the rotor induces current is opposite to that of the rotating magnetic field. The rotor current induces the flux in the rotor. The direction of the rotor flux is same as that of the current.



 The interaction of rotor and stator fluxes develops a force which acts on the conductors of the rotor. The force acts tangentially on the rotor and hence induces a torque. The torque pushes the conductors of the rotor, and thus the rotor starts moving in the direction of the rotating magnetic field. The rotor starts moving without any additional excitation system and because of this reason the motor is called the self-starting motor.

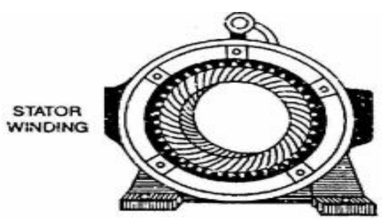


The operation of the motor depends on the voltage induced on the rotor, and hence it is called the induction motor.

CONSTRUCTION OF THREE PHASE INDUCTION MOTOR:

Figure 8.1 shows the **construction of three phase induction motor**. A **3 phase induction motor** has two main parts (i) stator and (ii) rotor. The rotor is separated from the stator by a small air-gap which ranges from 0.4 mm to 4 mm, depending on the power of the motor.

1. Stator :



It consists of a steel frame which encloses a hollow, cylindrical core made up of thin laminations of silicon steel to reduce hysteresis and eddy current losses. A number of evenly spaced slots are provided on the inner periphery of the laminations.[See Fig.(8.1)].The insulated connected to form a balanced 3-phase star or delta connected the circuit.

The **3-phase stator winding** is wound for a definite number of poles as per requirement of speed.Greater the number of poles, lesser is the speed of the motor and vice-versa.When 3-phase supply is given to the stator winding, a rotating magnetic field(See Sec. 8.3) of constant magnitude is produced.This rotating field induces currents in the rotor by electromagnetic induction.

2. Rotor:

The rotor, mounted on a shaft, is a hollow laminated core having slots on its outer periphery.The winding placed in these slots (called rotor winding) may be one of the following two types:

(i) Squirrel cage type (ii) Wound type

(i) Squirrel cage rotor: It consists of a laminated cylindrical core having parallel slots on its outer periphery.One copper or aluminum bar is placed in each slot. All these bars are joined at each end by metal rings called end rings.

This forms a permanently short circuited winding which is indestructible. The entire construction (bars and end rings) resembles a squirrel cage and hence the name. The rotor is not connected electrically to the supply but has current induced in it by transformer action from the stator.

Those induction motors which employ squirrel cage rotor are called squirrel cage induction motors. Most of **3 phase induction motors** use squirrel cage rotor as it has a remarkably simple and robust construction enabling it to operate in the most adverse circumstances.

However, it suffers from the disadvantage of a low starting torque. It is because the rotor bars are permanently short-circuited and it is not possible to add any external resistance to the rotor circuit to have a large starting torque.

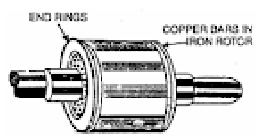


Fig.(8.2)

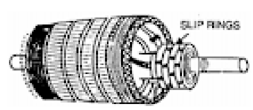


Fig.(8.3)

(ii) Wound rotor: It consists of a laminated cylindrical core and carries a **3-phase winding**, similar to the one on the stator [See Fig. (8.3)].The rotor winding is uniformly distributed in the slots and is usually star-connected. The open ends of the rotor winding are brought out and joined to three insulated slip rings mounted on the rotor shaft with one brush resting on each slip ring.

The three brushes are connected to a 3-phase star-connected rheostat as shown in Fig. (8.4).At starting, the external resistances are included in the rotor circuit to give a large starting torque. These resistances are gradually reduced to zero as the motor runs up to speed.

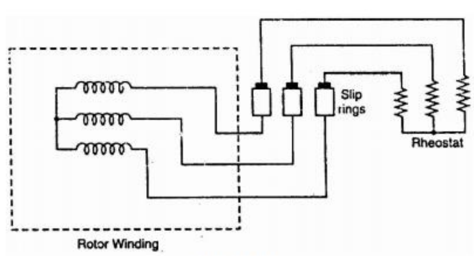


Fig.(8.4)

The external resistances are used during starting period only. When the motor attains normal speed, the three brushes are short-circuited so that the wound rotor runs like a squirrel cage rotor.

$$\therefore \quad \text{Cycles of current} = \frac{P}{2} \times \text{revolutions of field}$$

or $$\text{Cycles of current per second} = \frac{P}{2} \times \text{revolutions of field per second}$$

Since revolutions per second is equal to the revolutions per minute (N_s) divided by 60 and the number of cycles per second is the frequency f,

$$\therefore \quad f = \frac{P}{2} \times \frac{N_s}{60} = \frac{N_s P}{120}$$

or $$N_s = \frac{120\,f}{P}$$

The speed of the rotating magnetic field is the same as the speed of the alternator that is supplying power to the motor if the two have the same number of poles.Hence the magnetic flux is said to rotate at synchronous speed.

THREE PHASE INDUCTION MOTOR ADVANTAGES:

(i) It has simple and rugged construction.

(ii) It is relatively cheap.

(iii) It requires little maintenance.

(iv) It has high efficiency and reasonably good power factor.

(v) It has self starting torque.

THREE PHASE INDUCTION MOTOR DISADVANTAGES:

(i) it is essentially a constant speed motor and its speed cannot be changed easily.

(ii) its starting torque is inferior to dc shunt motor.

APPLICATIONS OF INDUCTION MOTORS:

- Wound rotor motors are suitable for loads requiring high starting torque and where a lower starting current is required.
- The Wound rotor induction motors are also used for loads having high inertia, which results in higher energy losses.
- Used for the loads which require a gradual buildup of torque.
- Used for the loads that require speed control.
- The wound rotor induction motors are used in conveyors, cranes, pumps, elevators and compressors, fan.
- The maximum torque is above 200 percent of the full load value while the full load slip may be as low as 3 percent. The efficiency is about 90 %.

Methods of Speed Control of a DC Motor

The basic principle of the DC motor is a device which converts DC energy into mechanical energy. When the current carrying armature is connected to the supply end though commutator segment, brushes are placed within the North South Poles of permanent or electromagnets. By using these electromagnets operating principle is depends on the Fleming's left hand rule to determine the direction of the force acting on the armature conductors of the DC motor.

Speed of a DC motor can be varied by varying flux, armature resistance or applied voltage. Different speed control methods for different DC shunt and series methods are there.

SPEED CONTROL OF SHUNT MOTORS

- Flux control method
- Armature and Rheostatic control method
- Voltage control method

1. Multiple voltage control
2. Ward Leonard system

SPEED CONTROL OF SERIES MOTORS

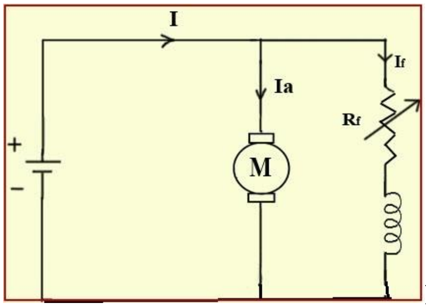
- Flux control method

1. Field diverter
2. Armature diverter
3. Trapped field control
4. Paralleling field coils

- Variable Resistance in series with motor
- Series -parallel control method

FLUX CONTROL METHOD

In this flux control method, speed of the motor is inversely proportional to the flux. Thus, by decreasing flux and speed can be increased vice versa. To control the flux , the rheostat is added in series with the field winding will increase the speed (N), because of this flux will decrease. So, the field current is relatively small and hence I2R loss is decreased. This method is quite efficient.



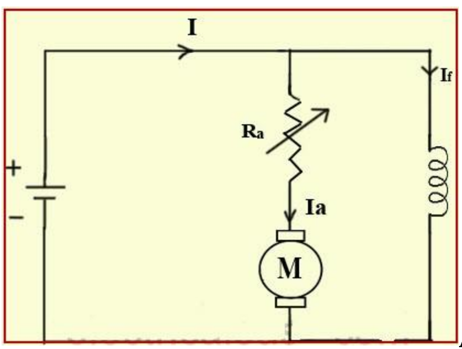
Flux Control Method

So in this method, the speed can be increased by reducing flux, it puts a method to reducing flux with this method, it puts a method to maximum speed as weakening of flux beyond the limits will adversely affect the commutator.

ARMATURE CONTROL METHOD

In the armature control method, the speed of the DC motor is directly proportional to the back emf (Eb) and Eb = V- IaRa. When supply voltage (V) and armature resistance Ra are kept constant, the Speed is directly proportional to armature current (Ia). If we add resistance in series with the armature, the armature current (Ia) decreases and hence speed decreases.

This armature control method is based on the fact that by varying the voltage across the required voltage. The motor back EMF (Eb) and Speed of the motor can be changed. This method is done by inserting the variable resistance (Rc) in series with the armature.



Armature Control Method

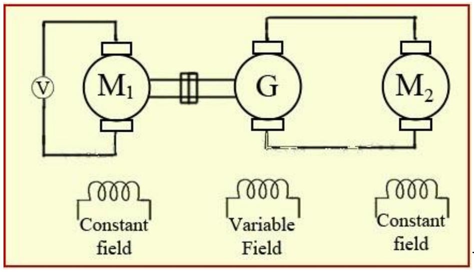
The basic equation of the armature control method, N is directly proportional to the V- ia (Ra+Rc) where Rc is controller resistance and Ra is the armature resistance. Due to the voltage back in the controller resistance the back EMF is decreased. Since N is directly proportional to the Eb.

VOLTAGE CONTROL METHOD OF DC MOTOR

Multiple Voltage Control: In this method, the shunt field is connected to a fixed exciting voltage, and the armature is supplied with different voltages. So the Voltage across armature is changed with the help of a suitable switchgear devises. Armature speed is approximately proportional to the voltage across the armature.

Ward-Leonard System: This Ward –leonard system is used where very sensitive speed control of the motor is required (e.g electric excavators, elevators, etc.). The arrangement of this system is as required in the figure shown below.

M2 is the motor, it controls the speed of the generator. M1 may be any AC motor or DC motor with constant speed. G is the generator directly coupled to M1. In this method the output from the generator G is fed to the armature of the motor M2 whose speed is to be controlled. The generator output voltage can be connected to the motor M2 and it can be varied from zero to its maximum value, and hence the armature voltage of the motor M2 is varied very smoothly. Hence very smooth speed control of motor can be obtained by this method.



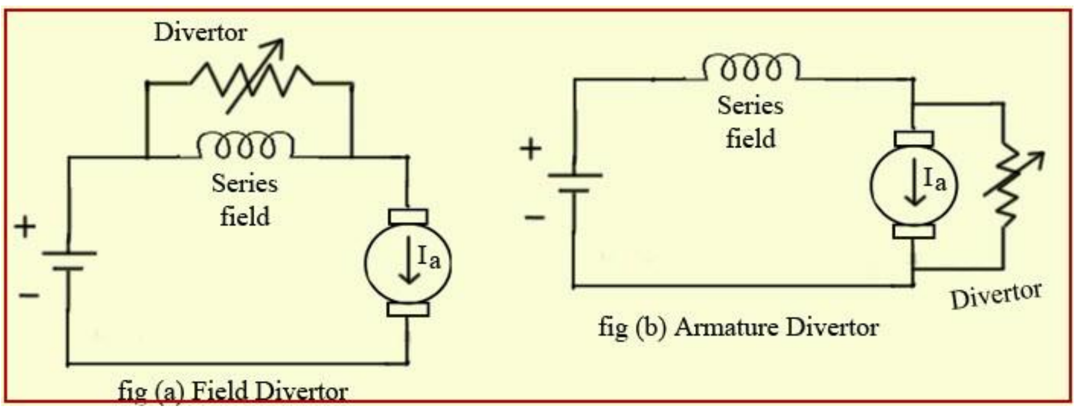
Ward Leonard System

SPEED CONTROL OF SERIES MOTOR

- **FLUX CONTROL METHOD**

Field Diverter : A Rheostart is connected parallel to the series field as shown in fig(a). This variable resistor is also called as a diverter, as desired value of the current can be diverted through this resistor and hence current through field coil can be decreased. Hence flux can be decreased to desired amount and speed(N) can be increased.

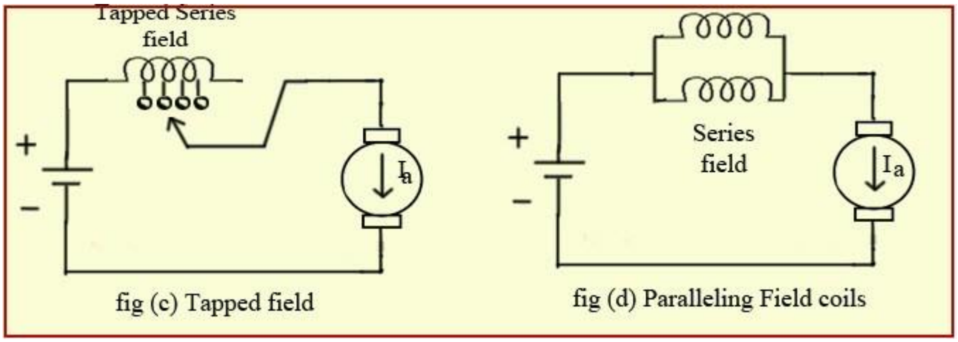
Armature Diverter : Rheostat (Divider) is connected across the armature of the coil as shown in fig (b). For a given constant load torque, if armature current is reduced, then flux must increase. As armature torque Ta α ØIa. This will result in an increase in current taken from the supply and hence flux Ø will increase and subsequently speed of the motor will decrease.



Field Armature

- **TAPPED FIELD CONTROL**

This tapped field control method is shown in fig (c). In this method, field coil is tapped dividing the number of turns. Thus we can select different value of Ø by selecting a different number of turns. In this method flux is reduced and speed is increased by decreasing the number of the turns of the series field winding. The switch S can be short circuit any part of the field winding, thus decreasing the flux and raising the speed (N) with full turns of coil.



Tapped Field Control

Paralleling Field Coils: This is used for fan motors several speed can be obtained by regrouping the field coils in series with the DC armature.

- **VARIABLE RESISTANCE IN SERIES WITH ARMATURE METHOD**

In this method, an introducing resistance (R) is series with the armature of motor. The voltage across the armature can be reduced. So the speed reduces in proportion with it. It is seen that for a 4 pole motor, the speed of the motor can be obtained easily.

Series-Parallel Control Method: This type of the method can be widely used in electric traction, where two or more mechanisms coupled series motors are employed. If required low speed motors are joined in series, and for higher speed motors are joined in parallel.

When motors are connected in series, the motors have the same current passing through them, although voltage across each motor is divided. When in parallel, the voltage across each motor is same, although current gets divided.

Speed control of three phase AC induction motor:

1. V / f control or frequency control
2. Controlling supply voltage
3. Adding rheostat in the stator circuit
4. Adding external resistance on rotor side

- **V / F CONTROL OR FREQUENCY CONTROL**

Whenever three phase supply is given to three phase induction motor rotating magnetic field is produced which rotates at synchronous speed given by

$$N_s = \frac{120f}{P}$$

In three phase induction motor emf is induced by induction similar to that of transformer which is given by

$$E \ or \ V = 4.44\phi K.T.f \ or \ \phi = \frac{V}{4.44KTf}$$

Where, K is the winding constant, T is the number of turns per phase and f is frequency. Now if we change frequency synchronous speed changes but with decrease in frequency flux will increase and this change in value of flux causes saturation of rotor and stator cores which will further cause increase in no load current of the motor . So, its important to maintain flux , φ constant and it is only possible if we change voltage. i.e if we decrease frequency flux increases but at the same time if we decrease voltage flux will also decease causing no change in flux and hence it remains constant. So, here we are keeping the ratio of V/f as constant. Hence its name is V/ f method. For controlling the speed of three phase induction motor by V/f method we have to supply variable voltage and frequency which is easily obtained by using converter and inverter set.

- **CONTROLLING SUPPLY VOLTAGE**

The torque produced by running three phase induction motor is given by

$$T \propto \frac{sE_2^2R_2}{R_2^2 + (sX_2)^2}$$

In low slip region $(sX)^2$ is very very small as compared to R_2. So, it can be neglected. So torque becomes

$$T \propto \frac{sE_2^2}{R_2}$$

Since rotor resistance, R_2 is constant so the equation of torque further reduces to

$$T \ \propto \ sE_2^2$$

We know that rotor induced emf $E_2 \propto V$. So, $T \propto sV^2$.

The equation above clears that if we decrease supply voltage torque will also decrease. But for supplying the same load, the torque must remain the same, and it is only possible if we increase the slip and if the slip increases the motor will run at a reduced speed. This method of speed control is rarely used because a small change in speed requires a large reduction in voltage, and hence the current drawn by motor increases, which cause overheating of the induction motor. For this we use VFD.

Adding Rheostat in Stator Circuit:

In this method of speed control of three phase induction motor rheostat is added in the stator circuit due to this voltage gets dropped .In case of three phase induction motor torque produced is given by $T \propto sV_2^2$. If we decrease supply voltage torque will also decrease. But for supplying the same load, the torque must remains the same and it is only possible if we increase the slip and if the slip increase motor will run reduced speed.

Adding External Resistance on Rotor Side:

In this method of speed control of three phase induction motor external resistance are added on rotor side. The equation of torque for three phase induction motor is

$$T \propto \frac{sE_2^2 R_2}{R_2^2 + (sX_2)^2}$$

The three-phase induction motor operates in a low slip region. In low slip region term $(sX)^2$ becomes very very small as compared to R_2. So, it can be neglected. and also E_2 is constant. So the equation of torque after simplification becomes,

$$T \propto \frac{s}{R_2}$$

Now if we increase rotor resistance, R_2 torque decreases but to supply the same load torque must remain constant. So, we increase slip, which will further result in the decrease in rotor speed. Thus by adding additional resistance in the rotor circuit, we can decrease the speed of the three-phase induction motor. The main advantage of this method is that with an addition of external resistance starting torque increases but this method of speed control of three phase induction motor also suffers from some disadvantages :

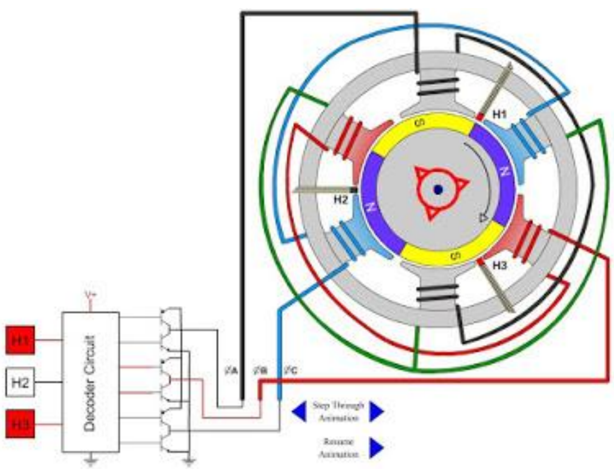
- The speed above the normal value is not possible.
- Large speed change requires a large value of resistance, and if such large value of resistance is added in the circuit, it will cause large copper loss and hence reduction in efficiency.
- Presence of resistance causes more losses.
- This method cannot be used for squirrel cage induction motor.

Injecting Slip Frequency EMF into Rotor Side:

When the speed control of three phase induction motor is done by adding resistance in rotor circuit, some part of power called, the slip power is lost as I^2R losses. Therefore the efficiency of three phase induction motor is reduced by this method of speed control. This slip power loss can be recovered and supplied back to improve the overall efficiency of the three-phase induction motor, and this scheme of recovering the power is called slip power recovery scheme and this is done by connecting an external source of emf of slip frequency to the rotor circuit. The injected emf can either oppose the rotor induced emf or aids the rotor induced emf. If it opposes the rotor induced emf, the total rotor resistance increases and hence the speed is decreased and if the injected emf aids the main rotor emf the total decreases and hence speed increases. Therefore by injecting induced emf in the rotor circuit, the speed can be easily controlled. The main advantage of this type of speed control of three phase induction motor is that a wide range of speed control is possible whether it is above normal or below normal speed.

BRUSH LESS DC OR BLDC MOTOR

A Brushless DC Motor, BLDC accomplishes commutation electronically using rotor position feedback to determine when to switch the current. The BLDC motor is electrically commutated by power switches instead of brushes. The structure of Brushless DC Motor, BLDC is shown in figure below.



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:

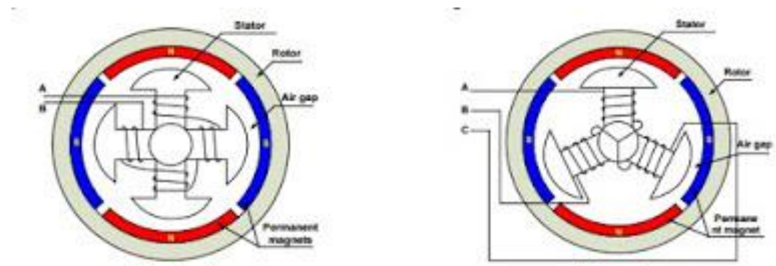
Like any other electric motor, a BLDC motor also has a stator and a rotor. Here we will consider Stator and Rotor each separately from construction point of view.

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 simplified cross section of a single-phase and a three-phase BLDC motor is shown in figure below. The rotor has permanent magnets to form two magnetic pole pairs, and surrounds the stator, which has the windings.

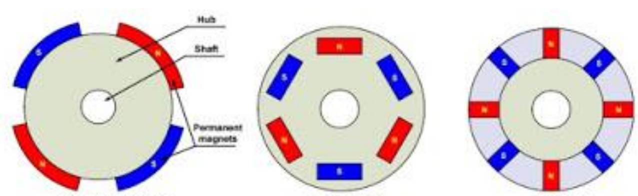


Single-phase   Three-phase

A single-phase motor has one stator winding wound either clockwise or counter-clockwise along each arm of the stator to produce four magnetic poles as shown in above figure.A three phase BLDC motor has three windings. Each phase turns on sequentially to make the rotor revolve.

ROTOR:

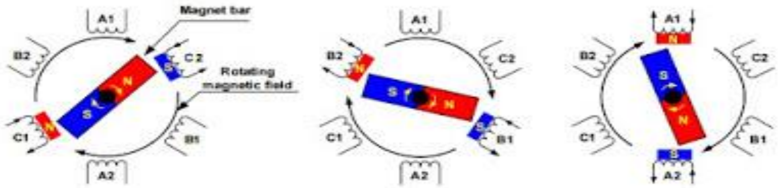
A rotor consists of a shaft and a hub with permanent magnets arranged to form between two to eight pole pairs that alternate between north and south poles. Figure below shows cross sections of three kinds of magnets arrangements in a rotor.



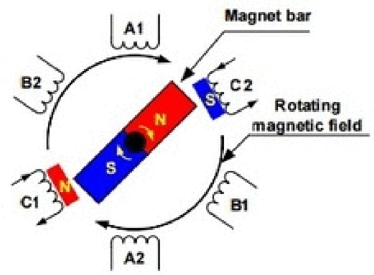
Surface-Mounted   Embedded   Inserted

HOW DOES A BRUSHLESS DC MOTOR WORK?

BLDC 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.

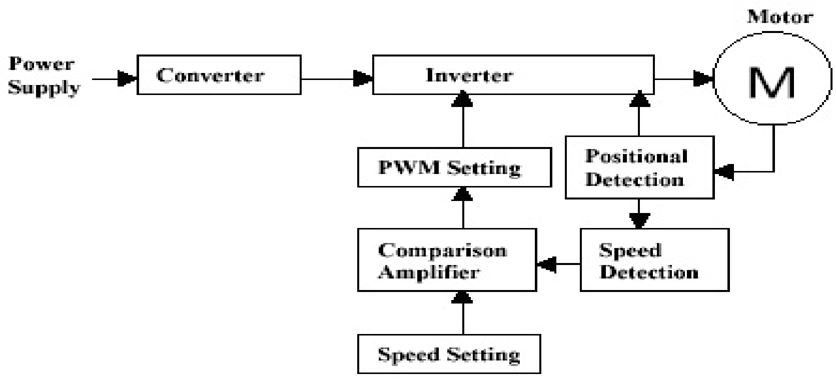


ADVANTAGE OF BLDC MOTOR:

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
- Greater dynamic response
- Better speed versus torque characteristics
- Higher speed range
- Longer life

Block Diagram of a Brushless DC Motor System



Block Diagram of a Brushless DC Motor System

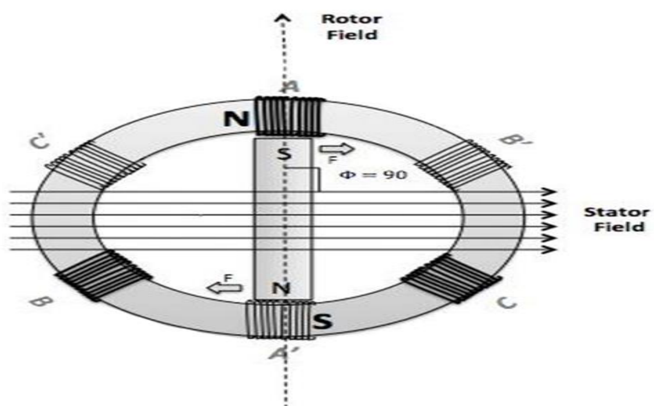
The switching sequence of the inverter is decided by the signal from the hall IC in the positional detection part of the block diagram, and the motor rotates.

Then, the signal from the hall IC is sent to the speed detector to become a speed signal, and it is compared with the speed setting signal in the comparison amplifier block, which then generates a deviation signal. The value of the motor input current is determined by the PWM setting block based on the deviation signal.

Brushless DC motor units have the following features.
1) It has high-efficiency because a permanent magnet rotor is used and secondary loss is small.
2) The rotor inertia can be reduced, and a high-speed response is obtained.
3) It is possible to downsize the motor because it is highly efficient.
4) Speed fluctuations with changing loads is low.

Applications:

The cost of the Brushless DC Motor has declined since its presentation, because of progressions in materials and design. This decrease in cost, coupled with the numerous focal points it has over the Brush DC Motor, makes the Brushless DC Motor a popular component in numerous distinctive applications. Applications that use the BLDC Motor include, yet are not constrained to:



As FOC control controls the direction of motor's stator magnetic field, it can keep the motor's stator magnetic field and the rotor magnetic field at 90° all the time, thus achieving a maximum torque output under a certain current. Advantages of FOC control include: small torque ripple, high efficiency, low noise and fast dynamic response. Disadvantages include: high hardware cost, higher requirement for the controller performance, and motor parameters need to be matched. Due to its distinct advantages, FOC control has gradually replaced the traditional control mode in many applications and won great favor in motion control field.

INDUSTRIAL APPLICATIONS
For industrial applications, brushless DC motors are primarily used in servo, actuation, positioning, and variable speed applications where precise motion control and stable operation

are critical for the satisfactory operation of the manufacturing or industrial process. They are commonly used as:

- Linear motors
- Servomotors
- Actuators for industrial robots
- Extruder drive motors
- Feed drives for CNC machine tools

LINEAR MOTORS

Linear motors produce linear motion without the need of a transmission system, such as a ball-and-lead screw, rack-and-pinion, cam, gears or belts, that would be necessary for rotary motors. Transmission systems are known to introduce less responsiveness and reduced accuracy. Direct-drive linear motors do not exhibit these shortcomings. In their simplest form, linear motors are essentially "unrolled rotary motors in which the poles of the stator have been laid in the direction of travel." There are many types of linear motors, ranging from stepper motors, dc brushed & brushless motors and AC synchronous motors. BLDC linear servomotors consist of a slotted stator with magnetic teeth and a moving actuator, which has permanent magnets and coil windings. To obtain linear motion, the motor controller excites the coil windings in the actuator causing an interaction of the magnetic fields thereby producing linear motion. As direct-drive linear motors, BLDC motors have the added advantages of maintenance-free operation with no mechanical connections, hysteresis or pitch cyclical error.

SERVOMOTORS

Servomotors are used for mechanical displacement, positioning or precision motion control based upon an input control and output feedback signal that establishes a tightly controlled, stable, closed loop operation. Servomotor drives are commonly used in machine tool servos, robotic actuator drives, among others. What sets servomotor applications apart from other types of motor control is their inherent high dynamic response, smooth torque production, high reliability and robust control even when there are wide variations in load inertia or motor parameters. In the past DC stepper motors were used as servomotors; however, since they are operate with open loop control, they typically exhibit torque pulsations. Brushless DC motors are more suitable as servomotors due to the feedback capability of the motor.

ACTUATORS FOR INDUSTRIAL ROBOTS

Permanent magnet DC motors primarily function as the actuators to move the joints of industrial robots for pick-and-place or tool positioning in assembly, welding and painting operations. (It merits noting that when heavy payloads are involved, hydraulic motors are typically used.) BLDC motors are preferred over brushed motors in robotic applications due to their compact size, power density, and maintenance-free characteristics. They also perform more reliably in less favorable or hazardous environments.

EXTRUDER DRIVE MOTORS

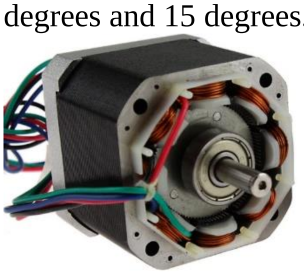
The function of the extruder drive & motor is to provide energy to turn the screw that compresses the polymer. DC drives are the most popular extruder drive due to their low cost and versatility. Since variations in screw speed can change the dimensions of the final extruded product, a precision motion control system is required to ensure product quality. Brushless DC drives have been frequently used in extruder drives because they offer full torque over the entire speed range with short-term speed errors as low as 0%.

FEED DRIVES FOR CNC MACHINE TOOLS
There are two drives used in CNC machine tools: spindle and feed drives. Spindle drives provide the motion and power for drilling, milling or grinding operation while feed drives function as axis drive motors and essentially replace the “manual hand wheel controls used in conventional machine tools.” While spindle drives use large DC shunt or AC squirrel cage induction motors, feed drives, on the other hand, typically use DC servomotors with an electronic controller. Brushless DC servomotors are used for their good heat dissipation, reduced rotor inertia and the advantage of maintenance free operation.

4.STEPPER MOTOR

Stepper Motor is a brushless electromechanical device which converts the train of electric pulses applied at their excitation windings into precisely defined step-by-step mechanical shaft rotation. The shaft of the motor rotates through a fixed angle for each discrete pulse. This rotation can be linear or angular.It gets one step movement for a single pulse input.
When a train of pulses is applied, it gets turned through a certain angle. The angle through which the stepper motor shaft turns for each pulse is referred as the step angle, which is generally expressed in degrees.

The number of input pulses given to the motor decides the step angle and hence the position of motor shaft is controlled by controlling the number of pulses. This unique feature makes the stepper motor to be well suitable for open-loop control system wherein the precise position of the shaft is maintained with exact number of pulses without using a feedback sensor.
If the step angle is smaller, the greater will be the number of steps per revolutions and higher will be the accuracy of the position obtained. The step angles can be as large as 90 degrees and as small as 0.72 degrees, however, the commonly used step angles are 1.8 degrees, 2.5 degrees, 7.5 degrees and 15 degrees.



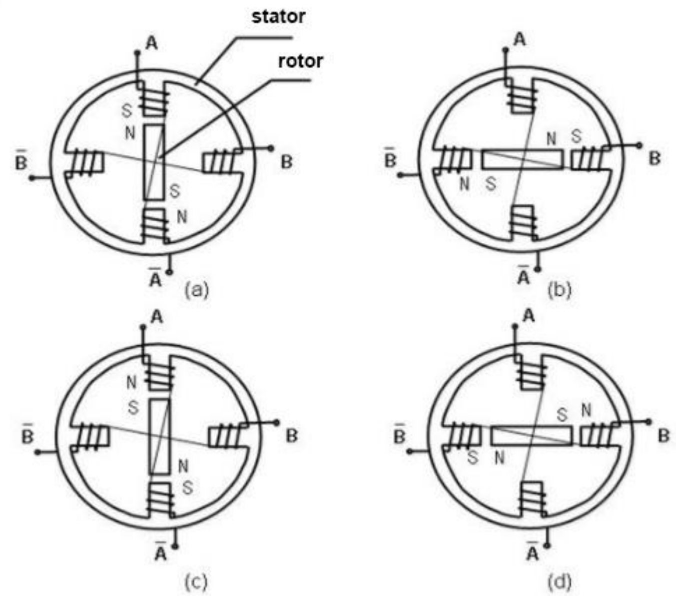
The direction of the shaft rotation depends on the sequence of pulses applied to the stator. The speed of the shaft or the average motor speed is directly proportional to the frequency (the rate of input pulses) of input pulses being applied at excitation windings. Therefore, if the frequency is low, the stepper motor rotates in steps and for high frequency, it continuously rotates like a DC motor due to inertia.
Like all electric motors, it has stator and rotor. The rotor is the movable part which has no windings, brushes and a commutator. Usually the rotors are either variable reluctance or permanent magnet kind. The stator is often constructed with multipole and multiphase windings,

usually of three or four phase windings wound for a required number of poles decided by desired angular displacement per input pulse.

Unlike other motors it operates on a programmed discrete control pulses that are applied to the stator windings via an electronic drive. The rotation occurs due to the magnetic interaction between poles of sequentially energized stator winding and poles of the rotor

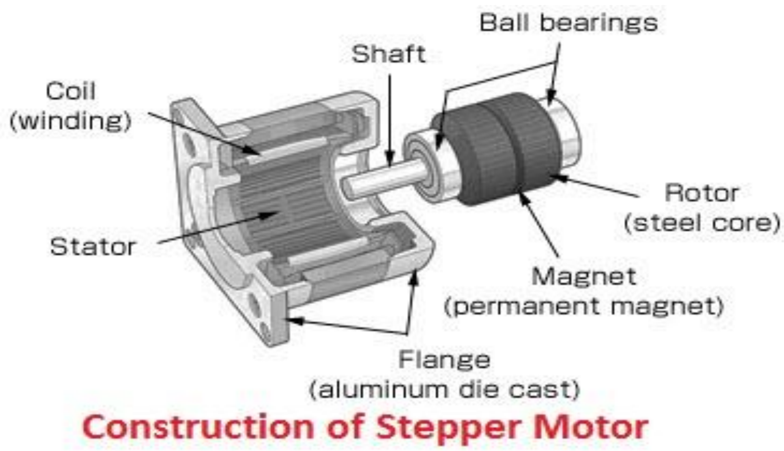
Stepper motor working principle:

How does a stepper motor work? The stepper motor rotor is a permanent magnet, when the current flows through the stator winding, the stator winding to produce a vector magnetic field. The magnetic field drives the rotor to rotate by an angle so that the pair of magnetic fields of the rotor and the magnetic field direction of the stator are consistent. When the stator's vector magnetic field is rotated by an angle, the rotor also rotates with the magnetic field at an angle. Each time an electrical pulse is input, the motor rotates one degree further. The angular displacement it outputs is proportional to the number of pulses input and the speed is proportional to the pulse frequency. Change the order of winding power, the motor will reverse. Therefore, it can control the rotation of the stepping motor by controlling the number of pulses, the frequency and the electrical sequence of each phase winding of the motor.



Construction of a Stepper Motor:

There are several types of stepper motors are available in today’s market over a wide range of sizes, step count, constructions, wiring, gearing, and other electrical characteristics. As these motors are capable to operate in discrete nature, these are well suitable to interface with digital control devices like computers.
Due to the precise control of speed, rotation, direction, and angular position, these are of particular interest in industrial process control systems, CNC machines, robotics, manufacturing automation systems, and instrumentation.

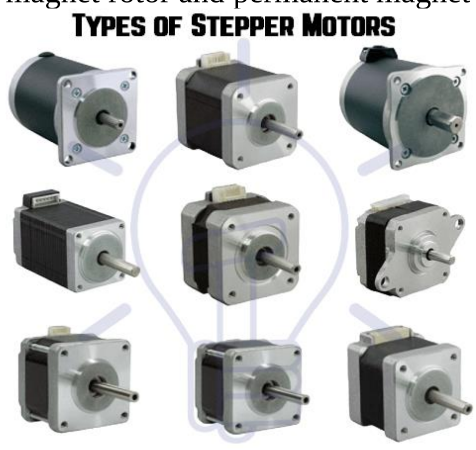


<u>TYPES OF STEPPER MOTORS:</u>

There are three basic **categories of stepper motors**, namely

- **Permanent Magnet Stepper Motor**
- **Variable Reluctance Stepper Motor**
- **Hybrid Stepper Motor**

In all these motors excitation windings are employed in stator where the number of windings refer to the number of phases.
A DC voltage is applied as an excitation to the coils of windings and each winding terminal is connected to the source through a solid state switch. Depends on the type of stepper motor, its rotor design is constructed such as soft steel rotor with salient poles, cylindrical permanent magnet rotor and permanent magnet with soft steel teeth. Let us discuss these types in detail.



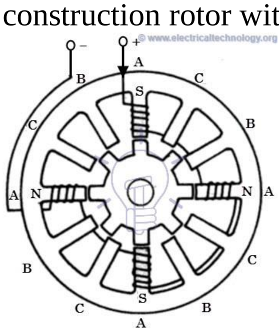
<u>VARIABLE RELUCTANCE STEPPER MOTOR</u>:

It is the basic type of stepper motor that has been in existence for a long time and it ensures easiest way to understand principle of operation from a structural point of view. As the name suggests, the angular position of the rotor depends on the reluctance of the magnetic circuit formed between the stator poles (teeth) and rotor teeth.


Variable Reluctance Stepper Motor

CONSTRUCTION OF VARIABLE RELUCTANCE STEPPER MOTOR:

It consists of a wound stator and a soft iron multi-tooth rotor. The stator has a stack of silicon steel laminations on which stator windings are wound. Usually, it is wound for three phases which are distributed between the pole pairs.
The number of poles on stator thus formed is equal to an even multiple of the number of phases for which windings are wounded on stator. In the figure below, the stator has 12 equally spaced projecting poles where each pole is wound with an exciting coil. These three phases are energized from of a DC source with the help of solid state switches.
The rotor carries no windings and is of salient pole type made entirely of slotted steel laminations. The rotor pole’s projected teeth have the same width as that of stator teeth. The number of poles on stator differs to that of rotor poles, which provides the ability to self start and bidirectional rotation of the motor.
The relation of rotor poles in terms of stator poles for a three phase stepper motor is given as, $N_r = N_s \pm (N_s / q)$. Here $N_s = 12$, and $q = 3$, and hence $N_r = 12 \pm (12 / 3) = 16$ or 8. An 8-pole construction rotor without any excitation is illustrated below.

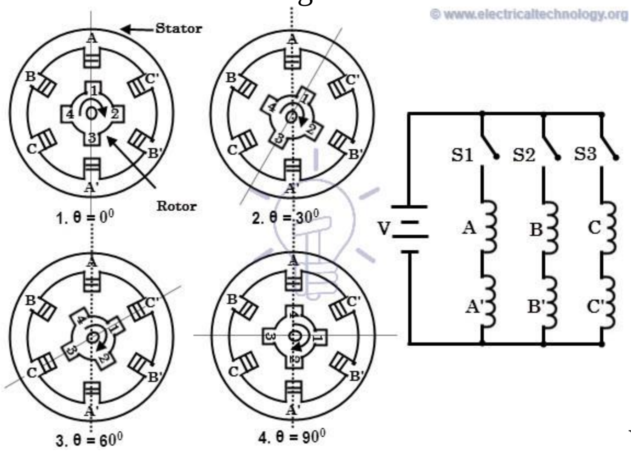


Construction of Variable Reluctance Stepper Motor

WORKING OF VARIABLE RELUCTANCE STEPPER MOTOR:

The stepper motor works on the principle that the rotor aligns in a particular position with the teeth of the excitation pole in a magnetic circuit wherein minimum reluctance path exist.
Whenever power is applied to the motor and by exciting a particular winding, it produces its magnetic field and develops its own magnetic poles.
Due to the residual magnetism in the rotor magnet poles, it will cause the rotor to move in such a position so as to achieve minimum reluctance position and hence one set of poles of rotor aligns with the energized set of poles of the stator. At this position, the axis of the stator magnetic field matches with the axis passing through any two magnetic poles of the rotor.
When the rotor aligns with stator poles, it has enough magnetic force to hold the shaft from moving to the next position, either in clockwise or counter clockwise direction.
Consider the schematic diagram of a 3-phase, 6 stator poles and 4 rotor teeth is shown in figure below. When the phase A-A’ is supplied with a DC supply by closing the switch -1, the winding

become a magnet which results one tooth become North and other South. So the stator magnetic axis lies along these poles.
Due to the force of attraction, stator coil North Pole attracts nearest rotor tooth of opposite polarity, i.e., South and South Pole attract nearest rotor tooth of opposite polarity, i.e., North. The rotor then adjusts to its minimum reluctance position where the rotor magnetic axis exactly matches with stator magnetic axis.



Working of Variable Reluctance Stepper Motor

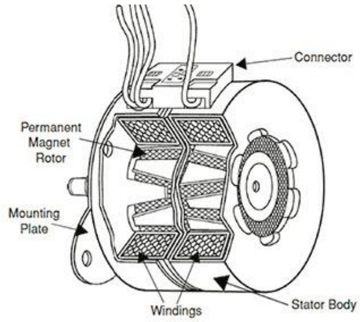
When the phase B-B’ is energized by closing switch -2 keeping phase A-A’ remain de-energized by opening switch-1, winding B-B’ will produce the magnetic flux and hence the stator magnetic axis shifts along the poles thus formed by it. Hence the rotor shifts to the least reluctance with magnetized stator teeth and rotates through an angle of 30 degrees in the clockwise direction.
When the switch-3 is energized after opening switch-2, the phase C-C’ is energized, the rotor teeth align with new position by moving through an additional angle of 30 degrees. By this way, the rotor moves clockwise or counterclockwise direction by successively exciting stator windings in a particular sequence. The step angle of this 3-phase 4-pole rotor teeth stepper motor is expressed as, 360/ (4 × 3) = 30 degrees (as step angle = 360 / Nr × q).
The step angle can be further reduced by increasing the number of poles on the stator and rotor, in such case motors are often wound with additional phase windings. This can also be achieved by a adopting different construction of stepper motors such as multistack arrangement and reduction gear mechanism.

PERMANENT MAGNET STEPPER MOTOR:
The permanent magnet design motor is perhaps the most common among several types of stepper motors. As the name implies, it adds permanent magnets to the motor construction. This type of stepper motors is also referred as **can-stack motor** or **tin-can motor**. The main advantage of this motor is its low manufacturing cost. This type of motor has 48-24 steps per revolution.


Permanent Magnet Stepper Motor

CONSTRUCTION PERMANENT MAGNET STEPPER MOTOR:

In this motor, the stator is of multipolar and its construction is similar to that of variable reluctance stepper motor as discussed above. It consists of slotted periphery on which stator coils are wound. It has projected poles on the slotted structure where the wound windings can be two or three or four-phase.
The end terminals of all these windings are bought out and connected to the DC excitation via solid state switches in the drive circuit.



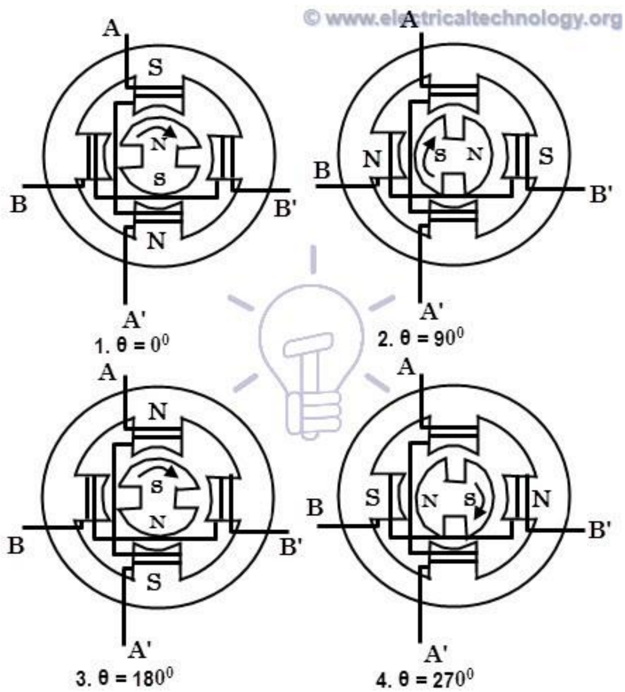
Permanent Magnet Stepper Motor Construction

Construction Permanent Magnet Stepper Motor

The rotor is made up of a permanent magnet material like a ferrite that can be in the shape of either cylindrical or salient pole, but usually it is of smooth cylindrical type. The rotor designed to have an even number of permanent magnetic poles with alternate North and South polarities.

WORKING OF PERMANENT MAGNET 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. Due to the force of attraction and repulsion between permanent magnet rotor poles and stator poles, the rotor starts moving up to the position for which pulses are given to the stator.
Consider a 2-phase stepper motor with two permanent magnetic rotor poles as shown in the figure below.



Working of Permanent Magnet Stepper Motor:

When the phase A is energized with a positive with respect to the A', the windings establish North and South poles. Due to the force of attraction, the rotor poles align with stator poles such that the magnetic pole axis of rotor adjusts with that of stator as shown in figure.
When the excitation is switched to B phase and switching off phase A, the rotor further adjusts to magnetic axis of phase B, and thus rotates through 90 degrees in clockwise direction.
Next, if the phase A is energized with a negative current with respect to A', the formation of stator poles causes the rotor to move through another 90 degrees in clockwise direction.
In the same way, if the phase B is excited with negative current by closing phase A switch, the rotor rotates through another 90 degrees in the same direction. Next, if the phase A is excited with positive current, the rotor comes to the original position thus making a 360 degrees complete revolution. This implies that, whenever the stator is excited, the rotor tends to rotate through 90 degrees in clockwise direction.
The step angle of this 2-phase 2-pole permanent magnet rotor motor is expressed as, 360/ (2 × 2) = 90 degrees. The step size can be reduced by energizing two phases simultaneously or a sequence of 1-phase ON and 2-phase ON modes with a proper polarity.

HYBRID STEPPER MOTOR:

It is the most popular type of stepper motor as it provides better performance than permanent magnet rotor in terms of step resolution, holding torque and speed. However, these motors are more expensive than PM stepper motors. It combines the best features of both variable reluctance and permanent magnet stepper motors. These motors are used in applications that require very small stepping angle such as 1.5, 1.8 and 2.5 degrees.

Hybrid Stepper Motor

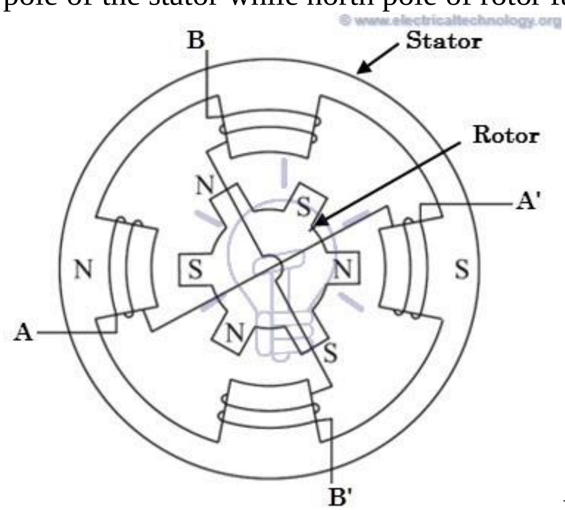
CONSTRUCTION OF HYBRID STEPPER MOTOR:

The stator of this motor is same as its permanent magnet or reluctance type counterpart. The stator coils are wound on alternate poles. In this, the coils of different phases are wound on each pole, usually two coils at a pole which is referred as a bifilar connection.

The rotor consists of a permanent magnet which is magnetized in axial direction to create a pair of magnetic poles (N and S poles). Each pole is covered with uniformly spaced teeth. The teeth are made up of soft steel and two section, of which on each pole are misaligned each other by a half-tooth pitch.

WORKING OF HYBRID STEPPER MOTOR:

This motor works similar to that of permanent magnet stepper motor. The figure above shows 2-phase, 4-pole, 6-tooth rotor hybrid stepper motor. When the phase A-A’ is excited with a DC supply, keeping B-B’ unexcited, the rotor aligns such that the south pole of the rotor faces north pole of the stator while north pole of rotor faces south pole of the stator.



Working of Hybrid Stepper Motor

Now, if the phase B-B’ is excited, keeping A-A’ switched off in such a way that upper pole becomes north and lower becomes south, then the rotor will align to a new position by moving through counterclockwise direction. If the phase B-B’ is oppositely excited such that the upper pole becomes south and lower becomes north, then the rotor will turn clockwise direction.

By a proper sequence of pulses to the stator, the motor will turn in desired direction. For every excitation, rotor will get locked into new position, and even if excitation is removed motor still maintains its locked condition due to the permanent magnet excitation. The step angle of this 2-phase, 4-pole, 6-tooth rotor motor is given as 360/ (2 × 6) = 30 degrees. In practice, hybrid motors are constructed with more number of rotor poles in order to get high angular resolution.

motor in half stepping is given below.

Step	Coil A	Coil B	Coil C	Coil D
1	ON	OFF	OFF	OFF
2	ON	ON	OFF	OFF
3	OFF	ON	OFF	OFF
4	OFF	ON	ON	OFF
5	OFF	OFF	ON	OFF
6	OFF	OFF	ON	ON
7	OFF	OFF	OFF	ON
8	ON	OFF	OFF	ON

ADVANTAGES OF STEPPER MOTOR:

- At standstill position, the motor has full torque. No matter if there is no moment or changing position.
- It has a good response to starting, stopping and reversing position.
- As there is no contact brushes in the stepper motor, It is reliable and the life expectancy depends on the bearings of the motor.
- The motor rotation angle is directly proportional to the input signals.
- It is simple and less costly to control as motor provides open loop control when responding to the digital input signals.
- The motor speed is directly proportional to the input pulses frequency, this way a wide range of rotational speed can be achieved.
- When load is coupled to the shaft, it is still possible to realize the synchronous rotation with low speed.
- The exact positioning and repeatability of movement is good as it has a 3-5% accuracy of a step where the error is non cumulative from one step to another.
- Stepper motors are safer and low cost (as compared to servo motors), having high torque at low speeds, high reliability with simple construction which operates at any environment.

DISADVANTAGES OF STEPPER MOTORS:

- Stepper motors having low Efficiency.
- It has low Accuracy.
- Its torque declines very quickly with speed.
- As stepper motor operates in open loop control, there is no feedback to indicate potential missed steps.
- It has low torque to inertia ratio means it can’t accelerate the load very quickly.
- They are noisy.

APPLICATIONS OF STEPPER MOTORS:

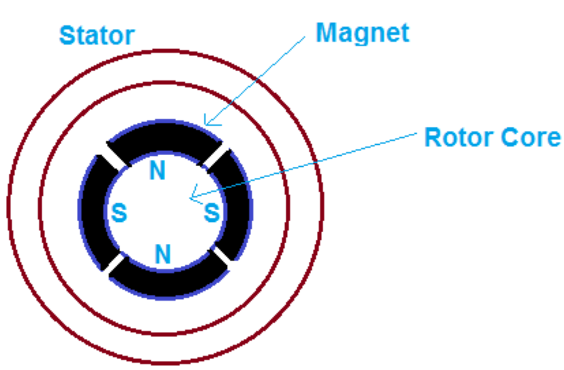
- Stepper motors are used in automated production equipments and automotive gauges and industrial machines like packaging, labeling, filling and cutting etc.
- It is widely used in security devices such as security & surveillance cameras.
- In medical industry, stepper motors are widely used in samples, digital dental photography, respirators, fluid pumps, blood analysis machinery and medical scanners etc.
- They are used in consumer electronics in image scanners, photo copier and printing machines and in digital camera for automatic zoom and focus functions and positions.
- Stepper motors also used in elevators, conveyor belts and lane diverters

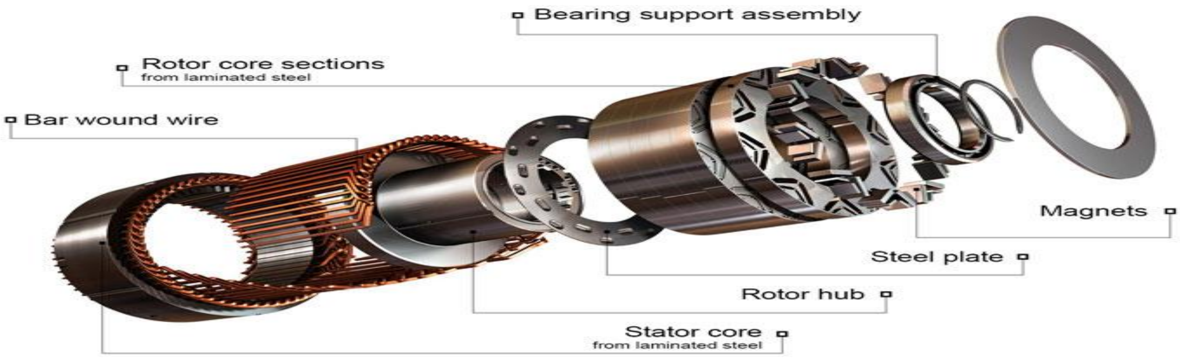
PERMANENT MAGNET SYNCHRONOUS MOTOR (PMSM):

The basic construction of PMSM is same as that of synchronous motor. The only difference lies with the rotor. **Unlike synchronous motor, there is no field winding on the rotor of PMSM. Field poles are created by using permanent magnet.** These Permanent magnets are made up of high permeability and high coercivity materials like Samarium-Cobalt and Neodium-Iron-Boron. Neodium-Iron-Boron is mostly used due to its ease of availability and cost effectiveness. Theses permanent magnets are mounted on the rotor core.

Based on the mounting arrangement of magnet on rotor core, Permanent Magnet Synchronous Motor (PMSM) can be categorized into two types: Surface Mounted PMSMs and Buried or interior PMSMs

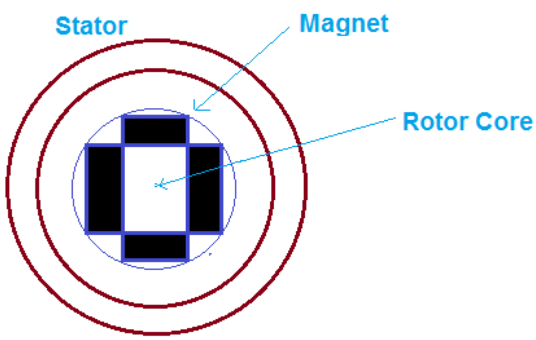
In **Surface Mounted PMSM**, permanent magnet is mounted on the rotor surface as shown in figure below.





This type of PMSM is not robust and therefore not suited for high speed application. Since the permeability of magnet and air gap is almost same, therefore this type of construction provides a uniform air gap. Therefore, there is no reluctance torque present. Thus the dynamic performance of this motor is superior and hence used in high performance machine tool drives and robotics.

In **Interior or Buried PMSM**, the permanent magnets are embedded into the rotor instead of mounting on the surface. This provides robustness and hence can be used in high speed applications. Due to presence of saliency, reluctance torque is present in this type of PMSM.



WORKING PRINCIPLE OF PERMANENT MAGNET SYNCHRONOUS MOTOR (PMSM):

The principle of operation of a synchronous motor is based on the interaction of the rotating magnetic field of the stator and the constant magnetic field of the rotor. The concept of the rotating magnetic field of the stator of a synchronous motor is the same as that of a three-phase induction motor.

The magnetic field of the rotor, interacting with the synchronous alternating current of the stator windings, according to the Ampere's Law, creates torque, forcing the rotor to rotate (more).

Permanent magnets located on the rotor of the PMSM create a constant magnetic field. At a synchronous speed of rotation of the rotor with the stator field, the rotor poles interlock with the rotating magnetic field of the stator. In this regard, the PMSM cannot start itself when it is connected directly to the three-phase current network (current frequency in the power grid 50Hz).

The working principle of permanent magnet synchronous motor is same as that of synchronous motor. When three phase winding of stator is energized from 3 phase supply, rotating magnetic field is set up in the air gap. At synchronous speed, the rotor field poles locks with the rotating magnetic field to produce torque and hence rotor continues to rotate.

As we know that synchronous motors are not self starting, PMSM needs to be started somehow. Since there is no winding on the rotor, induction windings for starting is not applicable for such motors and therefore variable frequency power supply for this purpose.

ADVANTAGES OF PERMANENT MAGNET SYNCHRONOUS MOTOR:

- Heat generated in stator is easy to remove.
- High torque per frame size.
- Reliability due to absence of brushes and commutator.
- Highest efficiency.
- Synchronous operation makes field orientation easy.
- Good high-speed performance.
- Precise speed monitoring and regulation possible.
- Smooth torque.

DRAWBACKS OF PERMANENT MAGNET SYNCHRONOUS MOTOR:

- Rotor position sensing required.
- Position sensor or sensorless technique is required for motor operation.
- Difficult to startup the motor using sensorless technique.

APPLICATIONS:

Permanent Magnet Synchronous Motor can be used as an alternative for servo drives. It is widely used in various industrial application viz. robotics, traction, aerospace etc.

AC Servo Motor:

Based on the construction there are two distinct types of AC servo motors, they are synchronous type AC servo motor and induction type AC servo motor.

Synchronous-type AC servo motor consist of stator and rotor. The stator consists of a cylindrical frame and stator core. The armature coil wound around the stator core and the coil end is connected to with a lead wire through which current is provided to the motor.

The rotor consists of a permanent magnet and hence they do not rely on AC induction type rotor that has current induced into it. And hence these are also called as brushless servo motors because of structural characteristics.

Synchronous-type AC servo motor
When the stator field is excited, the rotor follows the rotating magnetic field of the stator at the synchronous speed. If the stator field stops, the rotor also stops. With this permanent magnet rotor, no rotor current is needed and hence less heat is produced.Also, these motors have high efficiency due to the absence of rotor current. In order to know the position of rotor with respect to stator, an encoder is placed on the rotor and it acts as a feedback to the motor controller.

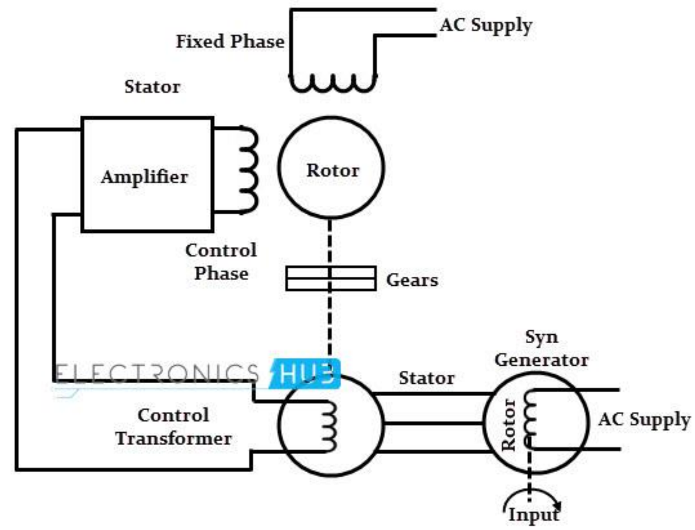
The **induction-type AC servo moto**r structure is identical with that of general motor. In this motor, stator consists of stator core, armature winding and lead wire, while rotor consists of shaft and the rotor core that built with a conductor as similar to squirrel cage rotor.

induction-type AC servo motor

The working principle of this servo motor is similar to the normal induction motor. Again the controller must know the exact position of the rotor using encoder for precise speed and position control.

WORKING PRINCIPLE OF AC SERVO MOTOR

The schematic diagram of servo system for AC two-phase induction motor is shown in the figure below. In this, the reference input at which the motor shaft has to maintain at a certain position is given to the rotor of synchro generator as mechanical input theta. This rotor is connected to the electrical input at rated voltage at a fixed frequency.



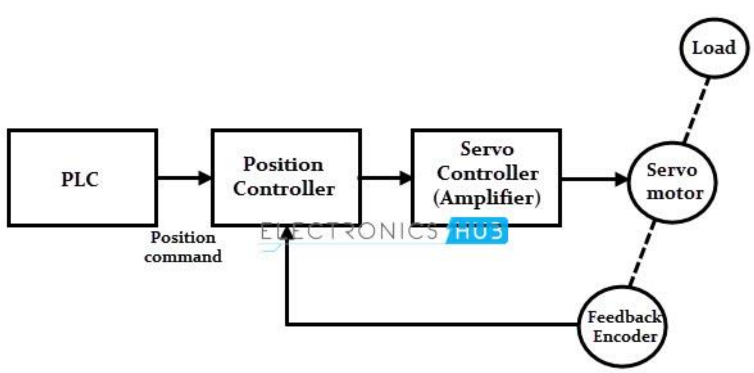
The three stator terminals of a synchro generator are connected correspondingly to the terminals of control transformer. The angular position of the two-phase motor is transmitted to the rotor of control transformer through gear train arrangement and it represents the control condition alpha.

Initially, there exist a difference between the synchro generator shaft position and control transformer shaft position. This error is reflected as the voltage across the control transformer. This error voltage is applied to the servo amplifier and then to the control phase of the motor.

With the control voltage, the rotor of the motor rotates in required direction till the error becomes zero. This is how the desired shaft position is ensured in AC servo motors.

Alternatively, modern AC servo drives are embedded controllers like PLCs, microprocessors and microcontrollers to achieve variable frequency and variable voltage in order to drive the motor.

Mostly, pulse width modulation and Proportional-Integral-Derivative (PID) techniques are used to control the desired frequency and voltage. The block diagram of AC servo motor system using programmable logic controllers, position and servo controllers is given below.



TYPES OF AC SERVO MOTORS

The AC servo motors are classified into different types which are

- Positional Rotation Servo Motor
- Continuous Rotation Servo Motor
- Linear Servo Motor

POSITIONAL ROTATION SERVO MOTOR:

The most common kind of servo motor is Positional rotation motor. The output of the shaft in motor rotates with 180 degrees. This type of motor mainly comprises includes physical stops that are placed in the gear mevjgchanism to prevent rotating outside to protect the rotation sensor. The applications of positional rotation servo motor include in robots, aircraft, toys, controlled cars, & many more applications.

CONTINUOUS ROTATION SERVO MOTOR:

Both common positional rotation servo motor and continuous rotation servo motor are same, except it can go in every direction without a fixed limit. The control signal alternately locates the static point of the servo to understand the direction as well as the speed of rotation. The variety of potential commands will cause the motor for rotating in the directions of clockwise otherwise anticlockwise as chosen by altering speed, based on the control signal. The application of continuous rotation servo motor includes a radar dish. For example, if you are traveling single on a robot otherwise you can employ one like a drive motor over a mobile robot.

LINEAR SERVO MOTOR:

The Linear servo motor is one kind of motor and it is similar to the positional rotation servo motor, however with extra mechanisms for changing the output from circular in the direction of back-and-forth. We cannot find these motors easily, although occasionally you can discover them at hobbyist stores everywhere they are used like actuators within advanced model airplanes. Thus, this is all about types of servo motors. This motor is a division of servomechanism and coupled with some type of encoder for providing positioning, speed feedback as well as some fault correcting apparatus which activates the supply signal. The basic characteristics to be required for any servo motor includes, the output torque of the motor must be proportional to the applied voltage. The torque direction which is expanded by the motor must be depending on the instantaneous polarity of the control voltage.

Advantages:

- If a heavy load is placed on the motor, the driver will increase the current to the motor coil as it attempts to rotate the motor. Basically, there is no out-of-step condition.
- High-speed operation is possible.

Disadvantages:

- Since the servomotor tries to rotate according to the command pulses, but lags behind, it is not suitable for precision control of rotation.
- Higher cost.
- When stopped, the motor’s rotor continues to move back and forth one pulse, so that it is not suitable if you need to prevent vibration
-

Applications of Servo Motor:

1. It is used in **robotic industry of position control**.
2. It is used in robotic arms.
3. It is used in press and cutting industry for the cutting and pressing the piece precisely.
4. It is used in conveyer belt for start and stop the conveyer belt at every position.
5. It is used in digital cameras for auto focusing.
6. It is used in **solar tracking system for tracking** the sun at every precise moment of time.
7. It is used in labeling and packing industry for labels the monogram and packing the things

Selection criteria of servo motor & Servo amplifier:

Selection of servo motor: While selecting a servo motor for a particular application various factors are to be considered.

1. Starting torque (N – m)

2. Maximum speed (steps/second)

3. Duty cycle

4. Required power

5. Load inertia

6. Speed control

7. Reversible motor

8. Time to accelerate

9. Time to decelerate

10. Size and weight consideration.

Servo systems provide amazing levels of speed, accuracy, and flexibility in automated equipment when the correct servo is chosen for the application. Unfortunately, choosing the wrong servo can lead to difficulty in tuning, poor accuracy, or underwhelming performance.

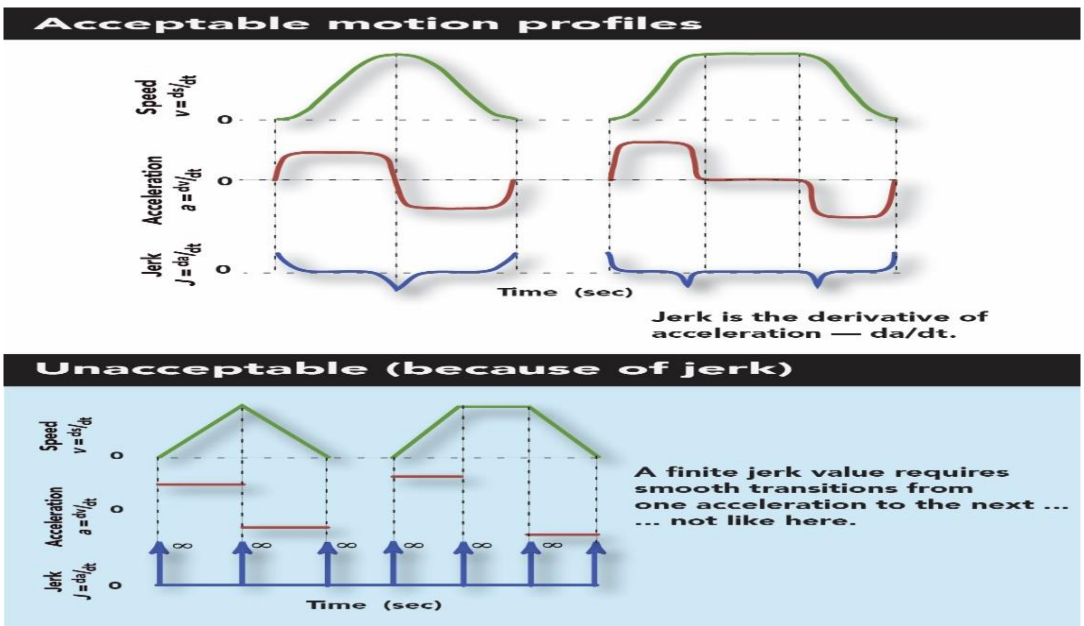
With so many different servos to choose from, how do you ensure that the right one was chosen? Fortunately, the process of choosing the right servo motor and drive, known as **sizing,** can be broken down into eight simple steps.

1. **DETERMINE REQUIRED VOLTAGE.**

The first and easiest factor to consider is the available power for the equipment. Servos are available in 100 VAC, 200 VAC, and 400 VAC models, and are compatible with single phase or three-phase power.

2. **DEFINE WHAT THE APPLICATION'S MOTION PROFILE LOOKS LIKE**.

For equipment that performs a repetitive operation, plot out the required motor speeds throughout the cycle. Be sure to allow for acceleration and deceleration time; servomotors are not magic, and cannot make step changes in speed. For non-repetitive operations such as milling, calculate the peak speed and acceleration required for the application.



3. **DETERMINE HOW MUCH TORQUE THE MOTION APPLICATION NEEDS**.

Torque is how much "muscle" it takes to rotate a mechanism, and comes from three different sources: **accelerating the mechanism's inertia, friction, and external forces such as pressing against an object or gravity**. This is the most difficult part to calculate accurately, but is also the most forgiving part of the selection process. Calculate the inertia of each component of the system and add the values. The formulas for calculating rotational inertia of various shapes are readily available on the Internet.

Multiply the acceleration by the load inertia to calculate the load's acceleration torque. Calculate friction forces for sliding loads, gravitational forces for vertical loads, and any external forces. Multiply each force by the radius it is acting on (known as the "moment") to calculate the torque.

Calculate the peak torque by adding up all the torque values in the worst-case scenario. This is typically when the fastest acceleration is occurring or when there is the most mass on the machine. Add up the torque values from external forces, gravity and friction to calculate the continuous torque requirement. Ideally, the continuous torque requirement would use a root-mean-squared (RMS) calculation, but this is tedious without the help of a software tool.

4. **CALCULATE THE MOTION SYSTEM'S OPTIMAL INERTIA RATIO.**

Calculating inertia ratio is often overlooked by newcomers to servo sizing, but is arguably the most important factor in determining the performance of a servo system. Inertia ratio is the ratio of the load's inertia divided by the motor's rotor inertia divided by the square of the gear reduction.

To use a boxing analogy, if torque is how strong the fighter is, inertia ratio is the weight class. Not only does the servo system need to have enough torque to move the load, it must have the ability to accurately control the load. In an ideal world, the mechanism would be mechanically rigid and torque from the motor would be transferred smoothly and without delay to the load. In the real world, couplings flex, belts and chains stretch, and gears have backlash.

These imperfections can be minimized but not completely eliminated. When the motor begins to move, the machine winds up like a spring, and begins to push back on the motor with some tiny delay. This spring effect is magnified with large inertia ratios.

Servo systems use the feedback from the built-in encoder and the PID algorithm in the amplifier to accurately position the motor, but this tiny spring delay can cause oscillations and loss of control if the loop gains are too high. Reducing the gain will stop the oscillation, but at the cost of responsiveness.

While basic servo drives may require inertia ratios of 3:1 or smaller, high performance servo drives have auto-tuning, vibration suppression, resonance filters, and disturbance compensation functions that allow up to a 30:1 inertia ratio without sacrificing performance. A ratio of 1:1 will give excellent performance, but usually results in an oversized motor. Ratios less than 1:1 waste power with no performance advantage.

5. **CHOOSE A SERVO MOTOR — TENTATIVELY.**

At this point, the key criteria for choosing a servo motor have been defined and it is time to browse the product selection guide to find the motor that matches these requirements.

Find a motor and drive that matches the supply voltage, has a rated speed, continuous torque, and peak torque rating that exceeds the values calculated above. Look at the motor's rotor inertia to find one that satisfies the inertia ratio requirement for the servo drive you are using.

Frequently, there may be several motors with similar torque and speed characteristics but different rotor inertias. If there is a motor that is a close match, you are finished. If not, gearing can be applied to match the motor and load more closely.

6. **DETERMINE WHAT KIND OF SERVO GEARING WILL WORK.**

Servomotors can produce their full rated torque from zero rpm up to many thousands of rpm. Few machines can take advantage of these speeds without gear reduction. Gear reduction matches the servo to the load in three ways; reducing the speed, increasing the torque, and lowering the inertia ratio. Speed is reduced proportional to the gear ratio, torque is increased proportional to the gear ratio, and most importantly, the inertia ratio is lowered by the square of the gear ratio. Gearbox manufacturers list the inertia of the servo-grade gearboxes, making it easy to include the gearbox inertia into the torque and inertia calculations.

7. **CHOOSE A MOTOR — FOR REAL THIS TIME.**

In Step 5 — tentative motor selection — most of the motors available likely were capable of far higher speeds than needed. Divide the motor speed by the required speed and round down to get a starting gear ratio. Then divide the required torque by the gear ratio to find the new required torque. This will narrow the choices down to just a couple of motors.

Next, find a motor with an acceptable inertia ratio. If two motors look equal, choose the one with the lower inertia ratio. Repeat this step a couple of times using motors with different rated speeds, as it's possible that more than one good solution exists.

8. **ROUND OUT THE DESIGN WITH A SERVO DRIVE AND OTHER POWER-TRANSMISSION COMPONENTS**.

Once the servomotor has been selected, choose a servo drive rated for the correct input voltage and with sufficient output current to drive the servo motor.

Servo drives can be controlled via several different interface types. These interfaces include pulse-and-direction digital control, analog control, and other servo networks. A servo network provides high-speed control and feedback, reduced wiring, and superior diagnostics capabilities compared to the other interfaces.

Finally, choose any options such as keyed motor shafts, shaft seals, holding brakes for vertical loads, or external braking resistors.

Selecting the best servo system for an application is a skill that improves with practice. When in doubt, it's a good idea to verify your results with the manufacturer or distributor.

Universal motor :

A **universal motor** is a special type of motor which is designed to run on either DC or single phase AC supply. These motors are generally DC series wound (armature and field winding are in series), and hence produce high starting torques. That is why, **universal motors** generally comes built into the device they are meant to drive. Most of the universal motors are designed to operate at higher speeds, exceeding 3500 RPM. They run at lower speed on AC supply than they run on DC supply of same voltage, due to the reactance voltage drop which is present in AC and not in DC.

field poles are mounted. field coils are wound on the field poles.
however, the whole magnetic path (stator field circuit and also armature) is laminated.
lamination is necessary to minimize the eddy currents which induce while operating on ac.

TYPES OF UNIVERSAL MOTOR:

There are two types of Universal Motor:

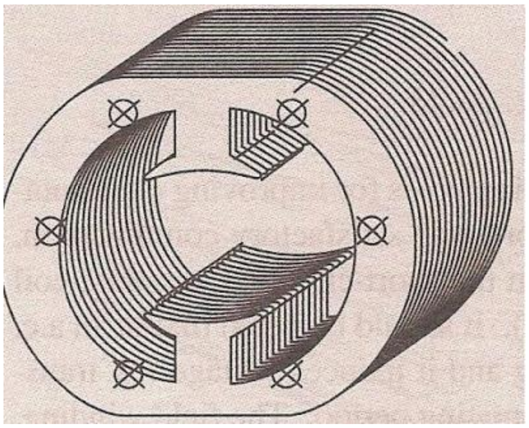
- Non-compensated Type with Concentrated Poles
- Compensated Type with Distributed Field.

CONSTRUCTION OF UNIVERSAL MOTOR:

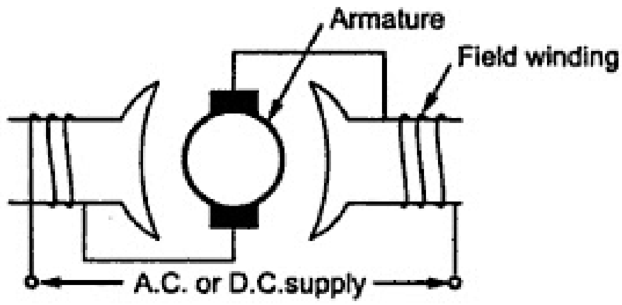
Construction of a universal motor is very similar to the construction of a DC machine. It consists of a stator on which field poles are mounted. Field coils are wound on the field poles.

NON-COMPENSATED UNIVERSAL MOTOR:

The Non-compensated motor has two salient poles and it is laminated as shown in figure below.



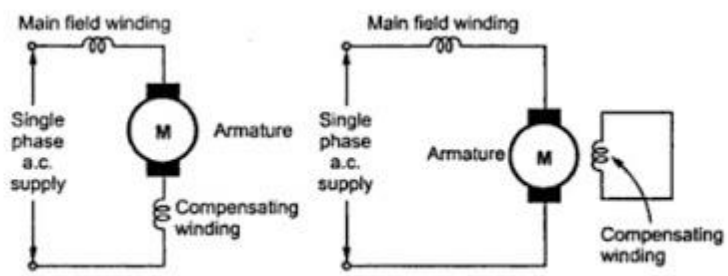
The armature is of wound type and the laminated core is either straight or skewed slots. The leads of the armature winding are connected to the commutator. High resistance brushes are used along with this type of motor to help better commutation. An equivalent Non-compensated type Universal Motor is shown in figure below.



COMPENSATED TYPE WITH DISTRIBUTED FIELD:

The compensated type Universal Motor consists of distributed field winding and the stator core is similar to that of split-phase motor. We know that split phase motors consist of an auxiliary winding in addition to main winding. Similar to the split phase motors, the compensated type also consists of an additional winding. The compensating winding helps in reducing the reactance voltage which is caused due to alternating flux, when the motor runs with the AC supply.

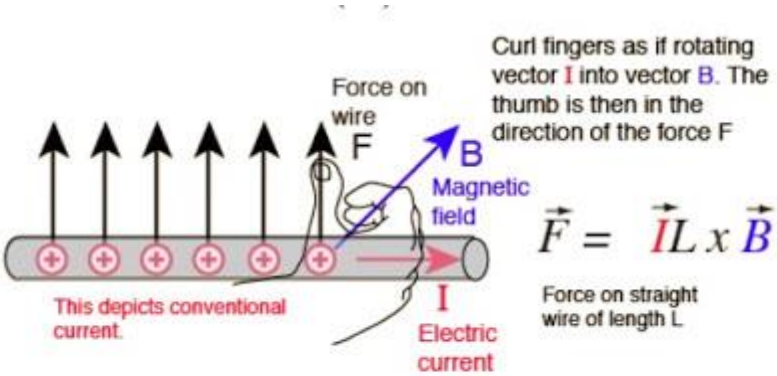
An equivalent Compensated type Universal Motor is shown in figure below.



Conductively compensated motor   Inductively compensated motor

WORKING PRINCIPLE OF UNIVERSAL MOTOR:

A universal motor works on either DC or single phase AC supply. When the universal motor is fed with a DC supply, it works as a DC series motor. When current flows in the field winding, it produces a magnetic field. The same current also flows from the armature conductors. When a current carrying conductor is placed in an electromagnetic field, it experiences a mechanical force. Due to this mechanical force, or torque, the rotor starts to rotate. The direction of this force is given by Fleming’s left hand rule.



Force on conductor, F=I(LxB)

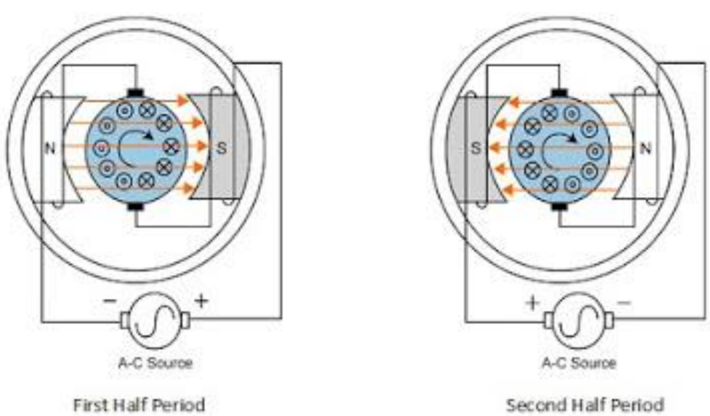
where I is the current flowing through the windings and L is active length of conductor.

Now the question is, how does a DC motor work on AC supply?

From the above image, the direction of the Resultant Force due to Current in the winding in presence of Magnetic field can be calculated. This Force called Lorentz Forece, is in the direction along which the Armature Coil rotates and hence the shaft.

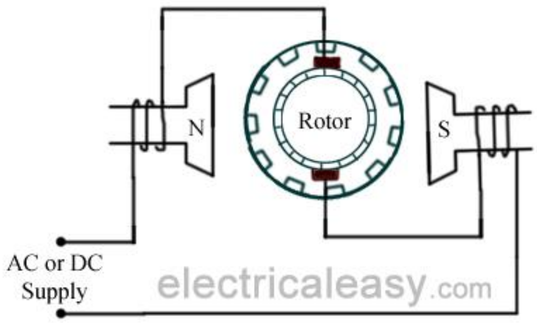
If the supply is DC, the polarity never reverses. So we get the field and the current in the same direction always and hence a net force in a particular direction on the conductors due to which the rotor rotates.

If the supply is AC, the polarity changes between +ve and –ve, 50 times per second. So, the direction of current as well as the Magnetic Field changes and hence we get the Resultant Force in different directions.



As in a DC Series motor, since the field is connected in series with the Armature, both the Current and Field Direction changes simultaneously and as a result, the Resultant Force always remains in the same direction, as can be seen from the direction (take the direction of I as the opposite to the original and B as the opposite to the original and using Fleming's left hand rule.) Thus, even if the polarity is changed, the motor continues to run in the same direction. The poles are laminated because they invariably run on AC and Eddy Currents are induced in it. Thus laminated poles reduces the Eddy Current.

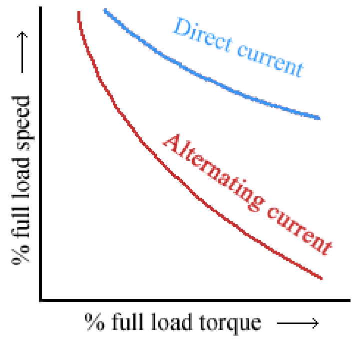
WORKING OF UNIVERSAL MOTOR:



A universal motor works on either DC or single phase AC supply. When the universal motor is fed with a DC supply, it works as a DC series motor. When current flows in the field winding, it produces an electromagnetic field. The same current also flows from the armature conductors. When a current carrying conductor is placed in an electromagnetic field, it experiences a mechanical force. Due to this mechanical force, or torque, the rotor starts to rotate. The direction of this force is given by Fleming's left hand rule.

When fed with AC supply, it still produces unidirectional torque. Because, armature winding and field winding are connected in series, they are in same phase. Hence, as polarity of AC changes periodically, the direction of current in armature and field winding reverses at the same time. Thus, direction of magnetic field and the direction of armature current reverses in such a way that the direction of force experienced by armature conductors remains same. Thus, regardless of AC or DC supply, universal motor works on the same principle that DC series motor works.

Speed/Load Characteristics



Speed/load characteristics of a universal motor is similar to that of DC series motor. The **speed of a universal motor** is low at full load and very high at no load. Usually, gears trains are used to get the required speed on required load. The speed/load characteristics are (for both AC as well as DC supply) are shown in the figure.

APPLICATIONS OF UNIVERSAL MOTOR

- Universal motors find their use in various home appliances like vacuum cleaners, drink and food mixers, domestic sewing machine etc.
- The higher rating universal motors are used in portable drills, blenders etc.

ELECTRIC DRIVE BLOCK DIAGRAM, TYPES AND APPLICATION

The first electric drive was invented in 1838 by B.S.Iakobi in Russia. He tested a DC motor which is supplied from a battery to push a boat. Although, the application of electric drive in industrial can happen after so many years like in 1870. At present, this can be observed almost everywhere. We know that the speed of an **electrical machine**(motor or generator) can be controlled by the source current's frequency as well as the applied voltage. Although, the revolution speed of a machine can also be controlled accurately by applying the electric drive concept. The main benefit of this concept is too controlling the motion can be optimized simply using the drive.

An Electric Drive can be defined as, a system which is used to control the movement of an electrical machine. This drive employs a prime mover such as a petrol engine, otherwise diesel, steam turbines otherwise gas, electrical & hydraulic motors like a main source of energy. These prime movers will supply the mechanical energy toward the drive for controlling motion

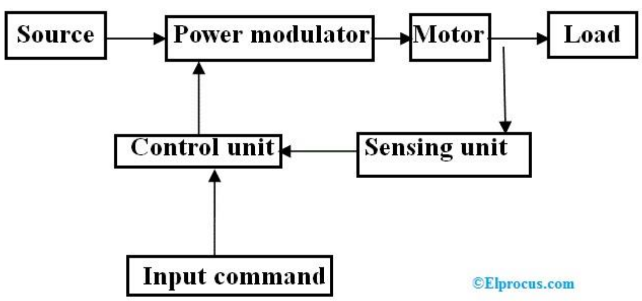
An electric drive can be built with an electric drive motor as well as a complicated control system to control the motor's rotation shaft. At present, the controlling of this can be done simply using the software. Thus, the controlling turns into more accurate & this drive concept also offers the ease of utilizing.

Electric Drive

The types of electrical drives are two such as a standard inverter as well as a servo drive. A standard inverter drive is used to control the torque & speed. A servo drive is used to control the torque as well as speed, and also components of the positioning machine utilized within applications that need difficult motion.

BLOCK DIAGRAM OF ELECTRIC DRIVE:

The block diagram of an electric drive is shown below, and the load in the diagram signifies different kinds of equipment which can be built with an electric motor such as washing machine, pumps, fans, etc. The electric drive can be built with source, power modulator, motor, load, sensing unit, control unit, an input command.



Electric Drive Block Diagram

POWER SOURCE

The power source in the above block diagram offers the necessary energy for the system. And both the converter and the motor interfaces by the power source to provide changeable voltage, frequency and current to the motor.

POWER MODULATOR

This modulator can be used to control the o/p power of the supply. The power controlling of the motor can be done in such a way that the **electrical motor** sends out the speed-torque feature which is necessary with the load. During the temporary operations, the extreme current will be drawn from the power source.

The drawn current from the power source may excess it otherwise can cause a voltage drop. Therefore the power modulator limits the motor current as well as the source.The power modulator can change the energy based on the motor requirement. For instance, if the basis is direct current & an induction motor can be used after that power modulator changes the direct current into **alternating current**. And it also chooses the motor's mode of operation like braking otherwise motoring.

LOAD

The mechanical load can be decided by the environment of the industrial process & the power source can be decided by an available source at the place. However, we can choose the other **electric components** namely electric motor, controller, & converter.

CONTROL UNIT

The control unit is mainly used to control the power modulator, and this modulator can operate at power levels as well as small voltage. And it also works the power modulator as preferred. This unit produces the rules for the safety of the motor as well as power modulator. The i/p control signal regulates the drive's working point from i/p toward the control unit.

SENSING UNIT

The sensing unit in the block diagram is used to sense the particular drive factor such as speed, motor current. This unit is mainly used for the operation of closed loop otherwise protection.

MOTOR

The electric motor intended for the specific application can be chosen by believing various features such as price, reaching the level of power & performance necessary by the load throughout the stable state as well as active operations.

CLASSIFICATION OF ELECTRICAL DRIVES

Usually, these are classified into three types such as group drive, individual drive, and multi-motor drive. Additionally, these drives are further categorized based on the different parameters which are discussed below.

- Electrical Drives are classified into two types based on supply namely AC drives & DC drives.
- Electrical Drives are classified into two types based on running speed namely Constant speed drives & changeable speed drives.
- Electrical Drives are classified into two types based on a number of motors namely Single motor drives & multi-motor drives.
- Electrical Drives are classified into two types based on control parameter namely stable torque drives & stable power drives.

ADVANTAGES OF ELECTRICAL DRIVES

The advantages of electrical drives include the following.

- These dries are obtainable with an extensive range of speed, power & torque.
- Not like other main movers, the requirement of refuel otherwise heat up the motor is not necessary.
- They do not contaminate the atmosphere.
- Previously, the motors like synchronous as well as induction were used within stable speed drives. Changeable speed drives utilize a dc motor.
- They have flexible manage characteristics due to the utilization of electric braking.

- At present, the AC motor is used within variable speed drives because of semiconductor converters development.

DISADVANTAGES OF ELECTRICAL DRIVE

The disadvantages of electrical drives include the following.

- This drive cannot be used where the power supply is not accessible.
- The power breakdown totally stops the entire system.
- The primary price of the system is expensive.
- The dynamic response of this drive is poor.
- The drive output power which is obtained is low.
- By using this drive noise pollution can occur.

APPLICATIONS OF ELECTRICAL DRIVES

The applications of electrical drives include the following.

- The main application of this drive is electric traction which means transportation of materials from one location to another location. The different types of electric tractions mainly include electric trains, buses, trolleys, trams, and solar-powered vehicles inbuilt with battery.
- Electrical drives are extensively used in the huge number of domestic as well as industrial applications which includes motors, transportation systems, factories, textile mills, pumps, fans, robots, etc.
- These are used as main movers for petrol or diesel engines, turbines like gas otherwise steam, motors like hydraulic & electric.

Thus, this is all about the fundamentals of electrical drives. From the above information, finally, we can conclude that a drive is one kind of electrical device used to control the energy which is sent to the electrical motor. The drive supplies energy to the motor in unstable amounts & at unstable frequencies, thus ultimately controls the speed and torque of the motor. Here is a question for you, what are the main parts of the electric drive.

Industrial Drives:

- DC Series Motor.
- DC Shunt Motor.
- Cumulative Compound Motor.
- Three phase Synchronous Motor.
- Squirrel Cage Induction Motor.
- Double Squirrel Cage Motor.
- Slip ring Induction Motor.
- Single phase Synchronous Motor.

Electric drives have inherent advantages over other prime movers. Special motors and control gears have been developed to suit every application. Induction motor is the veritable work horse of industry. Squirrel cage induction motor is used for all constant speed applications because of its low cost., rugged design and simple control gear. Wound rotor induction motor is used where one or more of the following consideration are involved:

(i) High starting torque

(ii) Low starting current

(iii) Speed control over a limited range

Synchronous motor is suitable for all constant speed application. It is generally more economical in rating above 100 kW particularly for slow speed drives because of high power factor, better efficiency and lower cost.

DC motors are invariably used where smooth and precise control over a wide range with or without quick speed reversals is needed. The type of electric drive and control gear for a particular application are determined by the following consideration:

(i) Duty ; whether heavy, medium light,

(ii) Starting torque,

(iii) Limitations on starting current,

(iv) Speed control range and its nature,

(v) Need for automatic control,

(vi) Environmental conditions.

Any production equipment used in a modem industry consists of three components. These are :

1. The prime mover along with its control equipment.

2. The motion transmitting device, and

3. The actual apparatus or equipment (load)

The function of the first two components is to impart motion to the production unit. The prime mover (which is an electric motor), the shaft transmitting motion, and the associated control equipment are together called the 'electric drive. The drive together with the load makes a complete drive system.

There are three types of industrial drives, indicating the trends in the form of advancement. These are the group drive, the individual drive and the multi-motor drive.

1.Industrial Drives > The group electric drivej n:

The group electric drive was used in the earlier days. It had a single motor of sufficient capacity to drive an entire group of machines used in a shop. The motor was connected to a line shaft and through the use of belts and pulleys all the machines were driven. This form of drive was very inefficient difficult to control, unsafe, and had many other objectionable features. This type of drive is not used now and is of historical interest only.

2. INDUSTRIAL DRIVES > IN THE INDIVIDUAL DRIVE:

In the individual drive there is one motor for each working machine. The electric motor is an integral part of the machine and can be specially designed to the needs of that machine.

3. INDUSTRIAL DRIVES > MULTI-MOTOR DRIVE:

The third type of drive is the multi-motor drive. This type of drive has more than one motor for each working machine. Examples are metal cutting machine tools, paper making machines and rolling mills, etc.

<u>INDUSTRIAL DRIVES CHARACTERISTICS OF DIFFERENT TYPES OF LOADS</u>:

In electric drives the driving equipment is an electric motor. One of the essential requirements in the selection of a particular type of motor for driving a machine is the matching of speed- torque characteristic of the driven unit and that of motor. Therefore, the knowledge of how the load torque varies with speed of the driven machine is necessary. Different types of load exhibit different speed-torque characteristics. However, most of the industrial loads can be classified into the following four general categories:

1. Constant torque type load;

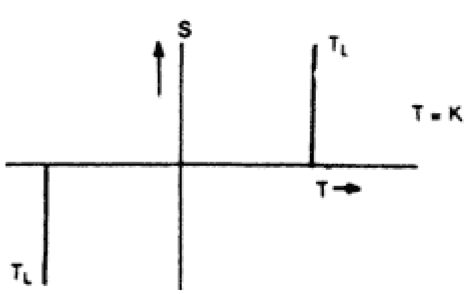
2. Torque proportional to speed (generator type load);

3. Torque proportional to square of the speed (fan type load);

4. Torque inversely proportional to speed (constant power type load)

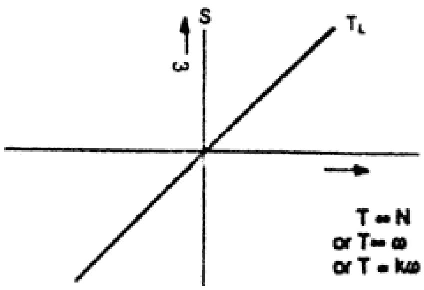
<u>Constant torque characteristic of industrial drive:</u>

Most of the working machines that have mechanical nature of work like shaping, cutting, grinding or shearing, require constant torque irrespective of speed. Similarly, cranes during hoisting and conveyers handling constant weight of material per unit time also exhibit this type of characteristic. The speed-torque characteristic of this type of load is given by T=K and is shown in the Figure.



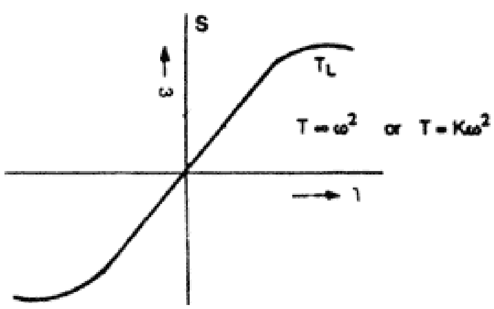
INDUSTRIAL DRIVE TORQUE PROPORTIONAL TO SPEED (GENERATOR TYPE LOAD):

Separately excited dc generators connected to a constant resistance load, eddy current brakes, and calendering machines have a speed-torque characteristic given by **T=Kω**. This type of characteristic is shown in Figure.



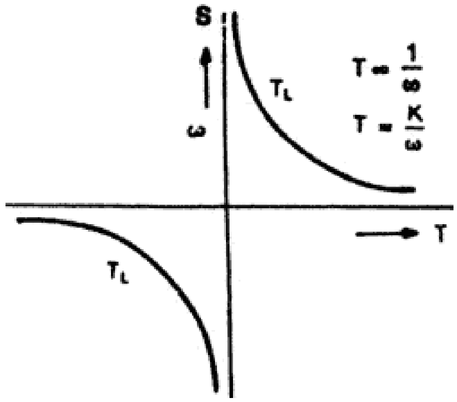
INDUSTRIAL DRIVE TORQUE PROPORTIONAL TO SQUARE OF THE SPEED (FAN TYPE LOAD):

Another type of load met in practice is the one in which load torque is proportional to the square, of the speed. The typical examples are : fans, rotary pumps, compressors and ship propellers. The speed-torque characteristic of this type of load is given by **$T=K\omega^2$** and is shown in Figure.

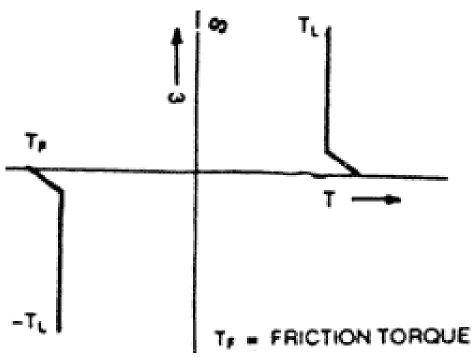


INDUSTRIAL DRIVE > TORQUE INVERSELY PROPORTIONAL TO SPEED (CONSTANT POWER TYPE LOAD):

Certain types of lathes, boring machines, milling machines, steel mill coiler, and electric traction load exhibit hyperbolic speed- torque characteristic. In such loads the torque is inversely proportional to speed or the load power remains constant. This type of characteristic is given by **T=K/ω** and shown in Figure.



Most of the loads require extra effort at the time of starting to overcome static friction. In power application it is known as breakaway torque and the control engineers call it 'stiction'. Because of stiction, the speed-torque characteristics of the loads are modified near the zero speed. For a constant torque type of load, the characteristic as modified due to stiction is shown in Figure.



Advantages of industrial drives over other prime movers

- The electrical drives are available in a wide range of torque, speed and power.
- It can operate in all four quadrants of speed torque plane.
- They can be started instantly and can immediately be fully loaded. i.e., there is no need to refuel or warm up the motor.
- They have flexible control characteristic and can be employed to automatically control the drive.
- They have flexible control characteristic and can be employed to automatically control the drive.
- Because of the following advantages, the mechanical energy already available from a non-electrical prime mover is sometimes first converted

into electrical energy by a generator and back to a mechanical energy of an electrical motor.

- Electrical link thus provides between the non-electrical prime mover and the load impact to the drive flexible control characteristic.

It may employ any of prime movers such as diesel or petrol engines, gas or steam turbines, steam engines, hydraulic motors and electric motors, for supplying mechanical energy for motion control.

MOTOR RATING AND HEATING OF MOTORS:

1. **Continuous Duty Motor**
2. **Electric Motor Cooling and Heating**
3. **Electric Motor Power Loss and Heating**
4. **Periodic Intermittent Duty**
5. **Short Time Intermittent Duty**

CONTINUOUS DUTY MOTOR:

There are two types of Continuous Duty Motor — continuous duty at constant load and continuous duty with variable load cycle. In the former the load torque remains constant for a sufficiently longer period corresponding normally to a multiple of time constant of the drive motor. The drive motor is therefore loaded for a sufficient amount of time continuously, till it attains thermal equilibrium.

While driving such a load a motor should have a rating sufficient to drive it without exceeding the specified temperature. The rating of the motor selected for this duty is called its **continuous rating** or **design rating**. By Continuous Duty Motor rating one means that it is the maximum load that the motor can give continuously over a period of time, without exceeding the temperature rise. Also, the motor selected should be able to withstand momentary overloads. Therefore, the selected motor may sometimes have a rating slightly greater than the power required by the load.

The load diagram and the temperature rise curve of the motor selected for the purpose are shown in Fig. 5.5. Centrifugal pumps, fans, conveyors and compressors are some types of loads where this type of Continuous Duty Motor at constant load is required.

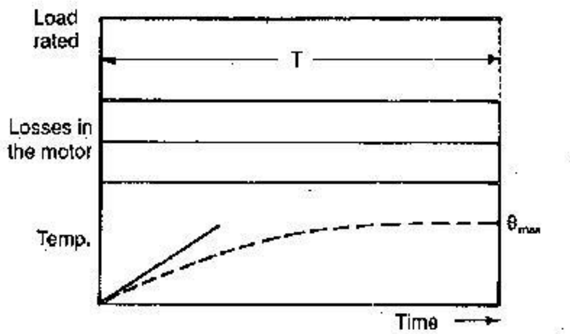


Fig. 5.5 *Pertaining to continuous duty of a motor delivering its rated load (constant)*

Selection of a motor for this class of duty is rather simple and straightforward. From the load characteristics or requirements one can determine the Continuous Duty Motor input required to the mechanical load. A suitable motor may be selected from the catalogue of series manufactured motors. These need not be checked again for thermal or overload capacities. The design rating normally takes care of heating and temperature rise and the motor normally has a short time overload capacity.

While selecting a motor for this type of duty it is not necessary to give importance to the heating caused by losses at starting even though they are more than the losses at rated load. This is because the motor does not require frequent starting. It is started only once in its duty cycle and the losses during starting do not have much influence on heating. However, sometimes it may be necessary to check whether the motor has sufficient starting torque, if the load has considerable amount of inertia.

For most types of loads where the torque and speed are known, the power output of the load

CONTINUOUS DUTY—VARIABLE LOAD

In this type of duty the load is not constant, but has several steps in one cycle. This cycle of loading repeats for a longer time. If the load variations are slight the motor of Continuous Duty Motor rating of the highest load may be chosen from the available catalog.

However, if the variations in the load cycle are large the machine undergoes a continuous change of temperature. However, after several cycles of operation the motor selected may attain a steady-state value. The thermal calculations of the motor are involved. The selection of a motor based on heating is rather involved and a difficult task. Therefore some simplified criteria may be evolved for selecting a motor for this duty.

If for such a load cycle a motor is selected according to the lowest load, it may not be able to drive the load satisfactorily; the temperature rise of the motor will be exceedingly high and it may not have sufficient capacity to drive the highest load. If the motor is selected according to the highest load, ii becomes overrated and may have poor efficiency. If it is an ac drive motor the pl. is also poor. The motor is underutilized.

The choice of the motor may be based on the average power or average current. At the outset, this method seems to be applicable. It has, however, a disadvantage in that it does not consider the variation of losses. The motor chosen will be smaller for the load cycle, and of insufficient capacity. This may have increased temperature due to overloads, where the losses increase. This happens if the load fluctuations are considerable. The method may give a satisfactory motor if the load fluctuations are relatively small.

However, a method based on average losses of the motor for the load cycle seems to be more appropriate for selecting a motor for a Continuous Duty Motor, variable load. A motor having its rated losses equal to the average of the losses of the motor for the variable load cycle is chosen to drive the load. In this case the final steady-state temperature rise of the motor under variable load is the same as the temperature rise of the motor with constant load. The motor therefore operates with permissible temperature rise.

The selection of a motor based on average losses requires an iterative procedure. A motor whose losses at its rated load are equal to or somewhat greater than the average losses is suitable for the job. However, it may be expected that the motor will have short time peaks of temperature and these may not be very detrimental to the life of the motor. The method does consider maximum temperature rise of the motor under variable load.

A typical load diagram for Continuous Duty Motor variable load is shown in Fig. 5.6. The following steps are involved in the choice of the motor.

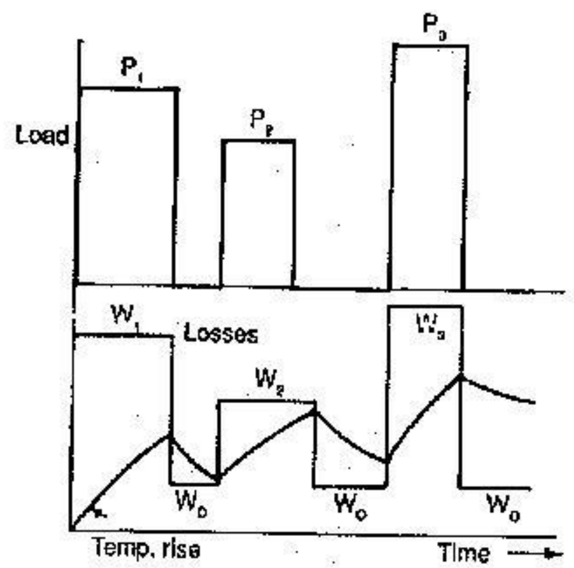


Fig. 5.6 *Heating of a motor having a typical variable load (one cycle of operations)*

1.The average power is determined. The foregoing discussion shows that a motor of this rating is of insufficient capacity. Therefore, a motor is selected from the catalogue, which has a rating 15 to 30% greater than the average

2.For the loads of the load cycle the loss diagram is determined using the efficiency curve of the motor.

3.The average losses are determined using the formula

$$W_{av} = \frac{W_k t_k}{t_k} \qquad (5.32)$$

4.These losses are compared to the rated losses of the motor (W_r). If W_r is equal to or somewhat greater than W_{av}, the motor selected is sufficiently good. If W_r is very much greater or less than W_{av}, the calculations are repeated for a new motor until a right motor is obtained.

5.A check on the overload capacity of the motor must be made. If the motor chosen does not satisfy the overload requirement as per the load cycle, a motor of higher capacity having the overload requirement may be chosen. The basis of heating is disregarded. The motor will however have the thermal rating**.**

Sometimes it is more convenient to base the selection of motor on equivalent current, torque or power. These equivalent values are the rms values.

ELECTRIC MOTOR POWER LOSS AND HEATING:

An Electric Motor Power Loss and Heating occurring in its various parts such as copper losses occurring in armature and field and eddy currents in the magnetic material used as a core, and mechanical losses due to friction and windage. These unavoidable Electric Motor Power Loss cause localized heating and are responsible for temperature rise of the motor. The heat flows from the point of origin to the external surface where it is dissipated to the surrounding cooling medium. Hence, heating and temperature rise of an electric machine are a function of the losses occurring in it.

Losses in an electric machine can be broadly classified into constant and variable losses. Constant losses remain independent of load current whereas variable losses vary as the square of the load, expressed as a fraction of the rated load. The losses occurring in a machine are

$$W = W_c + x^2 W_v \qquad (5.1)$$

where

W_c = constant losses

W_v = variable losses at full load

x = load on the motor expressed as a fraction of rated load.

If there is no cooling and the machine cannot dissipate heat to the external medium its temperature increases to a very high value. Hence, it must be provided with cooling to limit the maximum temperature rise to a permissible value, depending upon the class of insulation employed. The heat generated in the machine is dissipated to the surrounding cooling medium. However, a portion of heat is stored in the material itself causing a temperature rise. In the beginning all the heat is stored in the material and no heat is given to the medium. As the temperature rises, the component of heat stored decreases and the component of heat dissipated increases. Finally when the machine attains a steady temperature it can no longer store any more heat and all the heat generated is dissipated. Under these conditions the temperature remains constant, heat generated being equal to heat dissipated. The time taken by the motor to reach these final steady-state values depends upon the effectiveness of cooling. If a machine is well ventilated it reaches the steady-state quickly.

If the machine is switched off or its load is reduced it cools. It cools to the ambient temperature when it is switched of in the second case of temperature rise drops to a lower value, corresponding to the new load.

An electric machine is normally designed for a given temperature rise as decided by the class of insulation used. The design rating of the motor is called its continuous rating because the final steady-state temperature rise of the motor is within permissible limits if the machine delivers the power continuously over an extended period of time. In case a machine operates at a temperature higher than the specified one this result in thermal breakdown of the insulating materials. This may not occur as an immediate consequence, but deteriorates the quality of insulation used and reduces the life of the motor. The Classes of insulating materials and their permissible temperatures are given in Table 5.1.

Table 5.1 *Classes of insulating materials and permissible temperatures*

Class	Materials	Temperatures
Y	Cotton yarn, fabrics, fibrous materials of cellulose or silk, neither impregnated with nor immersed in a dielectric paper	90°C
A	The above materials but impregnated or immersed in a liquid dielectric	105°C
E	Certain synthetic organic films and other materials having the same thermal stability	120°C
B	Mica, asbestos, or glass fibre base materials with an organic binding agent	130°C
F	The above materials combined with suitable synthetic binding agent as well as impregnating one	155°C
H	Mica, asbestos or glass fibre combined with silicon binding and impregnating agents	180°C
C	Mica, ceramic materials, glass or quartz used without or with inorganic binding agents	exceeds 180° but is limited by the properties of the materials (physical, chemical or electrical)

An electric machine has sufficient overload capacity. The thermal restrictions as stated above do not allow a continuous overloading of the motor. This is because the losses rise more steeply than the power. The corresponding final steady-state temperature rise is also more. However, there is a time lag between the losses of the motor and resulting temperature rise. This allows a overloading of the motor for short periods limiting the final temperature rise to the permissible value.

Several classes of duty of an electric motors are possible. Before discussing these classes of duty and selecting a suitable motor rating for a given class of duty let us discuss in detail the heating and cooling of an electric motor under the influence of

PERIODIC INTERMITTENT DUTY:

The class of duty making use of the ability of electric motors to operate with overload is called **Periodic Intermittent Duty**. The load on the motor is a sequence of identical duty cycles as shown in Fig. 5.17. The drive motor is loaded at constant load for a period t_{on}. At the end of t_{on} the machine is switched off for a period of t_{off}. The machine heats during t_{on} and cools during t_{off}. The time t_{off} is insufficient for the machine to cool to ambient temperature. Also one cycle comprising t_{on} and t_{off} is insufficient for the motor fluctuation. The machine attains thermal equilibrium after a number of load cycles. The mean temperature attains a steady value. The load diagram for this class of duty is shown in Fig. 5.16 and the ratio $t_{on}/(t_{on}+t_{off})$ is called the **duty factor**. The effects of losses during starting on heating, are neglected.

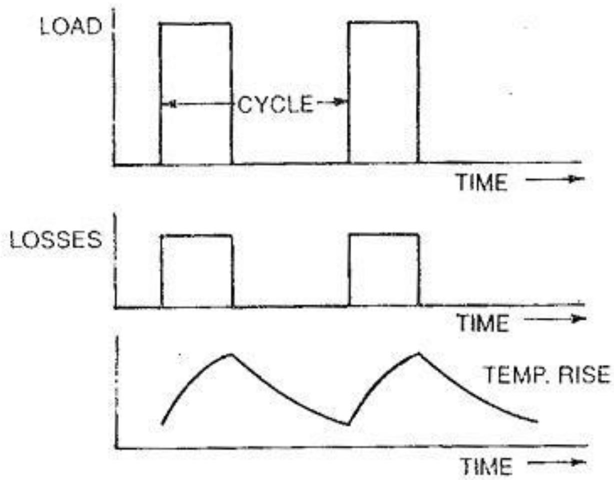


Fig. 5.16 *Periodic intermittent duty of a motor*

Such a class of duty may be identified when the losses during starting affect the motor heating and have to be considered. The load diagram for this Periodic Intermittent Duty is shown in Fig. 5.17. The Periodic Intermittent Duty includes starting period, period of constant load and rest period. The duty factor is given by $(t_{st}+t_{on})/(t_{st}+t_{on}+t_{off})$.. In this duty the motor stops during t_{off} by natural means and stopping does not include any additional losses. This takes place if t_{off} is sufficiently greater than the time required for stopping.

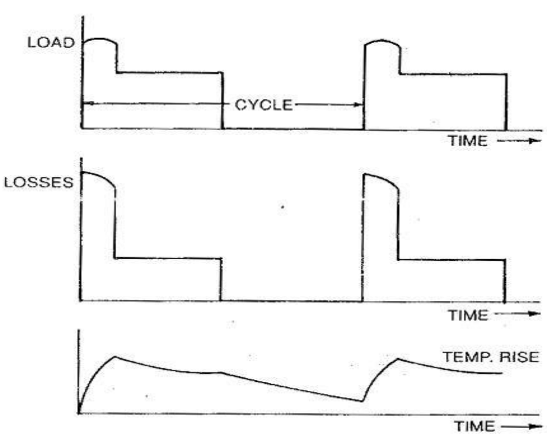


Fig. 5.17 *Periodic intermittent duty with starting*

When the machine has special methods of braking, the losses during braking must also be considered in the choice of motor rating. This is another sub class of duty. The Periodic Intermittent Duty contains a braking period besides a starting period, period of constant load and rest period as shown in Fig. 5.18. The duty factor ($t_{st} + t_{on} + t_{br} + t_{off}$).

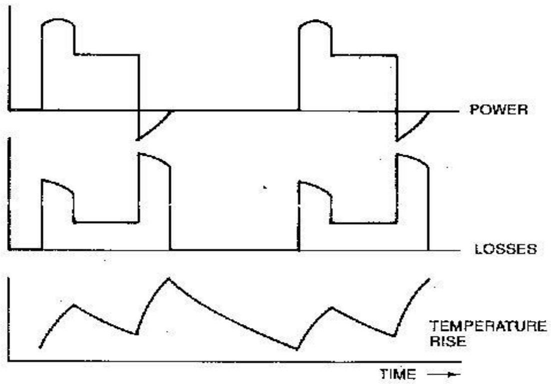


Fig. 5.18 *Load diagram for intermittent duty with starting and braking*

Let us consider the selection of a motor for duty factor having t_{on} and t_{off} (no starting and braking). The starting losses do not influence the heating. The load cycle and heating curve are as shown in Fig. 5.18. Here again a motor of rating equal to the constant load in the load cycle would prove uneconomical because it would have excess heating capacity. A motor of smaller capacity would be sufficient due to rest periods in between successive loadings, during which the machine has an opportunity to cool. A ratio (P/P_r) can be estimated for this class of duty also.

SHORT TIME INTERMITTENT DUTY:

Another class of duty for normally occurring loads is Short Time Intermittent Duty in which the load requires a constant power for a short interval of time and rests for sufficiently longer time. When a motor is used for this purpose, duration of the load on the motor is less than the heating time constant of the motor or the time required for obtaining thermal equilibrium. The period of rest is sufficient enough to cool the motor to the ambient temperature. The next cycle begins therefore from a cold condition. Such loads occur in some crane drives, household appliances, opening and closing of weirs, lockgates, bridges, etc. The load diagram for this Short Time Intermittent Duty is shown in Fig. 5.14.

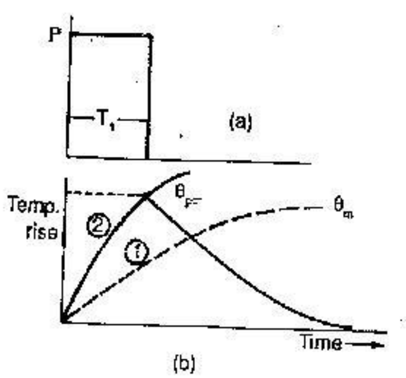


Fig. 5.14 *Short time duty of a motor (a) Load diagram (b) Temperature rise*
(1) Temperature rise of the motor for its continuous rated load < P.
(2) Temperature rise of the motor having load P (> rated load) for T_1

An electric motor, as has already been pointed out, will have steeply rising losses when it is overloaded. However there is a time lag between the losses taking place and temperature rise. Therefore, a given machine may be overloaded for a time till it reaches the permissible temperature rise and then switched off, allowing it to cool to the ambient temperature in the rest period. A machine of suitable rating is chosen such that it attains its permissible temperature rise during the period of application of load. When a machine is overloaded this way, the internal hot spot temperatures may reach a very high value. The simplified model gives a rough estimate of the motor rating.

A machine of smaller capacity may be advantageously used to drive these loads for short time. Considering the heating of the motor over a cycle

$$\theta = \theta_{max}(1 - e^{-t_1/\tau_1}) \qquad (5.42)$$

If a motor is selected having a rating equal to the amplitude of the power pulse represented by load the diagram, the temperature rise follows curve 1 of Fig. 5.14. From this it is very clear that at the end of duration of load t, when the motor is switched off its temperature rise is well below the permissible value. The motor is underutilised with regard to its thermal capacity. If, on the other hand, a motor of smaller capacity is chosen, when loaded to give an output corresponding to power pulse of load diagram, it is overloaded and has a temperature rise curve shown by curve 2 of Fig. 5.14. From the figure it is clear that the temperature of the motor rises rapidly towards another maximum value, as decided by the increased losses of the motor. In so doing it attains the permissible temperature rise at the end of t_1. The motor is switched off at this instant. The rating of the motor is called short time rating. The motors may have. 10 minute, 30 minute or 60 minute rating based on this criterion. The motor is thermally well utilised. A short time rating of an electric motor can be defined as the extrapolated overload rating of the motor which it can supply for the specified short time without getting overheated. Now a days the machines are being designed and manufactured for short duration having sufficient overload torque capability.

Using the temperature rise curve the short time rating of the given motor can be determined. Referring to Fig. 5.14 the machine having a continuous rating of P_r is used to drive the load P so that it reaches $\theta_{max}(\theta_{per})$ at the end of t_1 according to curve 2 of the figure. The temperature curve of the motor is curve 1, shown in Fig. 5.14. The curve 2 extends exponentially toward θ'_{max} which would be the maximum, temperature rise of the motor if the drive motor were loaded continuously with P.

BRAKING ,TYPES OF BRAKING | REGENERATIVE PLUGGING DYNAMIC BRAKING

The term braking comes from the term brake. We know that brake is an equipment to reduce the speed of any moving or rotating equipment, like vehicles, locomotives. The process of applying brakes can be termed as braking. Now coming to the term or question **what is braking**. First of all we can classify the term braking in two parts

1. Mechanical Braking
2. Electrical Braking

Mechanical braking is left out here because as it is an electrical engineering site, we should only focus on electrical braking here. In mechanical braking the speed of the machine is reduced solely by mechanical process but electrical braking is far more interesting than that because the

whole process is depended on the flux and torque directions. We will further see through the various **types of braking** but the main idea behind each type of barking is the reversal of the direction of the flux.
So, we can understand that when it is asked that **what is braking**? We can say that it is the process of reducing speed of any rotating machine. The application of braking is seen at almost every possible area, be it inside the motor used in factories, industrial areas or be it in locomotives or vehicles. Everywhere the use of mechanical and electrical brakes is inevitable.

TYPES OF BRAKING

Brakes are used to reduce or cease the speed of motors. We know that there are various types of motors available (DC motors, induction motors, synchronous motors, single phase motors etc.) and the specialty and properties of these motors are different from each other, hence this braking methods also differs from each other. But we can divide braking in to three parts mainly, which are applicable for almost every type of motors.

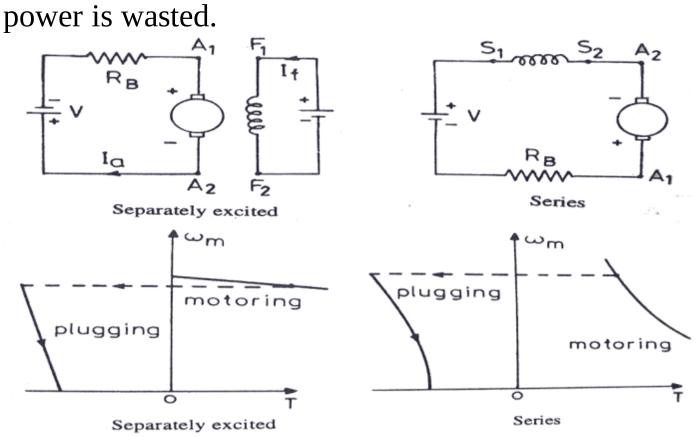
1. Regenerative Braking.
2. Plugging type braking.
3. Dynamic braking.

REGENERATIVE BRAKING:

Regenerative braking takes place whenever the speed of the motor exceeds the synchronous speed. This baking method is called regenerative baking because here the motor works as generator and supply itself is given power from the load, i.e. motors. The main criteria for regenerative braking is that the rotor has to rotate at a speed higher than synchronous speed, only then the motor will act as a generator and the direction of current flow through the circuit and direction of the torque reverses and braking takes place. The only disadvantage of this **type of braking** is that the motor has to run at super synchronous speed which may damage the motor mechanically and electrically, but regenerative braking can be done at sub synchronous speed if the variable frequency source is available.

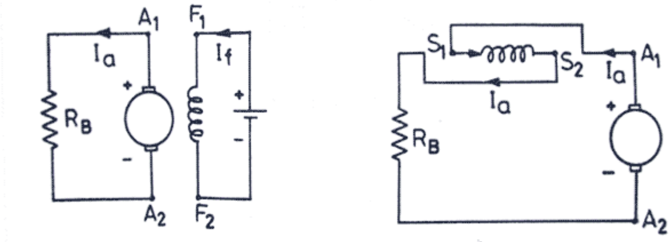
PLUGGING TYPE BRAKING

Another type of braking is **Plugging type braking**. In this method the terminals of supply are reversed, as a result the generator torque also reverses which resists the normal rotation of the motor and as a result the speed decreases. During plugging external resistance is also introduced into the circuit to limit the flowing current. The main disadvantage of this method is that here power is wasted.



<u>RHEOSTATIC BRAKING(DYNAMIC BRAKING)</u>

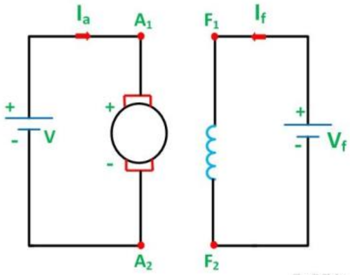
Another method of reversing the direction of torque and braking the motor is **dynamic braking**. In this method of braking the motor which is at a running condition is disconnected from the source and connected across a resistance. When the motor is disconnected from the source, the rotor keeps rotating due to inertia and it works as a self-excited generator. When the motor works as a generator the flow of the <u>current</u> and torque reverses. During braking to maintain the steady torque sectional <u>resistances</u> are cut out one by one.



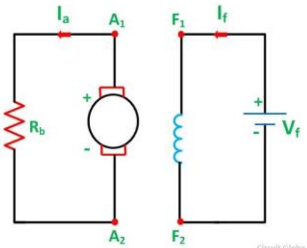
Separately excited motor　　Series motor

In **Dynamic Braking**, a braking resistor Rb is connected across the armature as soon as the DC motor is disconnected from the supply mains. The motor now works as a generator, producing the braking torque.For the braking operation in Dynamic Braking, the motor is connected in two ways.

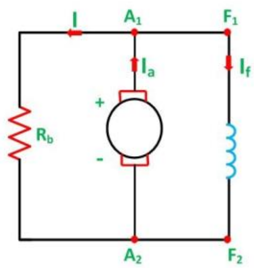
Firstly the separately excited or shunt motor can be connected either as a separately excited generator, where the flux is kept constant. The second way is that it can be connected to a self-excited shunt generator, with the field winding in parallel with the armature. The **connection diagram of Dynamic Braking** of separately excited DC motor is shown below. When the machine works in the **motoring mode**.



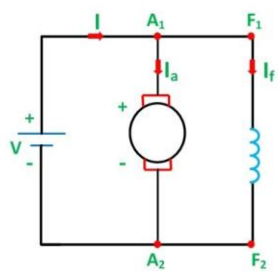
The connection diagram is shown below when braking with separate excitation is done.



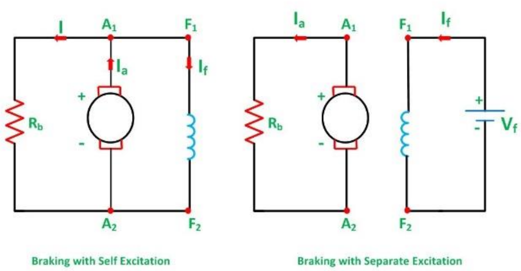
The connection diagram is shown below when braking with self-excitation is performed.



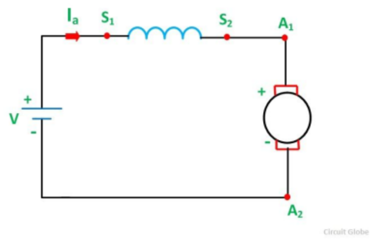
This method is also known as **Rheostatic Braking** because an external braking resistance R_b is connected across the armature terminals for electric braking. During an electric braking, the kinetic energy stored in the rotating parts of the machine and the connected load is converted into electric energy, when the motor is working as a generator. The energy is dissipated as heat in the braking resistance R_b and armature circuit resistance R_a.The connection diagram of Dynamic Braking of DC Shunt Motor is shown below.When the machine is working in the motoring mode.



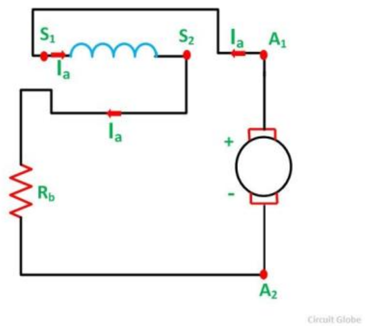
The connection diagram of shunt motor Braking with self and separate excitation is shown in the figure below.



For Dynamic Braking, the series motor is disconnected from the supply. A variable resistance R_b as shown in the figure below is connected in series, and the connections of the field windings are reversed.



Motoring



Braking with Self Excitation

The field connections are reversed so that the current through the field winding flows in the same direction as before i.e. from S_1 to S_2 so that the back EMF produces the residual flux. The machine now starts working as a self-excited series generator.

In self-excitation, the braking operation is slow. Hence, when a quick braking is required, the machine is connected in self-excitation mode. A suitable resistance is connected in series with the field to limit the current to a safe value.

The Dynamic or Rheostatic Braking is an insufficient method of braking because all the energy which is generated is dissipated in the form of heat in the resistance.

Requirements of Braking System:

1. Braking should be simple, robust and easy to operate.
2. It should require less maintenance
3. It should be fast and reliable.
4. The braking force must be capable of being controlled.
5. The braking should be inexhaustible. ie repeated quick application of brake be possible without needing any relaxation.
6. In case of emergency, it should make unfailing halt in the minimum possible distance.
7. Application of brakes should be very gradual and smooth to avoid damage to the goods and discomfort to passengers.
8. The system should apply brakes simultaneously overall the vehicles.