What is a Squirrel Cage Induction Motor and Its Working

A machine that converts electrical energy into mechanical energy is called electric motor. These are simple in design, easily used, low cost, high efficiency, low maintenance, and reliable. Three-phase induction motors are one of the types and different from other types of electric motors. The main difference is that there is no electrical connection from the rotor winding to any source of supply. The required current and voltage in the rotor circuit are provided by induction from the stator winding. This is the reason to call is as an induction motor. This article describes the Squirrel cage induction motor, which is one of the types of three-phase induction motor.

What is Squirrel Cage Induction Motor?

Definition: Squirrel cage motor is one of the types of induction motors. In order to generate motion, it hardens electromagnetism. As the output shaft is connected to the rotor inner component which is looking like a cage. Hence it is called squirrel cage. The two-end caps i.e, circular in shape are joined by rotor bars. These are acted based on the EMF i.e, generated by the stator. This EMF is also generated outer housing that is made of laminated metal sheets and wire coiling. The two main parts of any type of induction motor are the stator and the rotor. The squirrel cage is a simple method of pulling an electromagnetic induction effect. A 4-pole squirrel cage induction motor is shown below.

Squirrel Cage Induction Motor

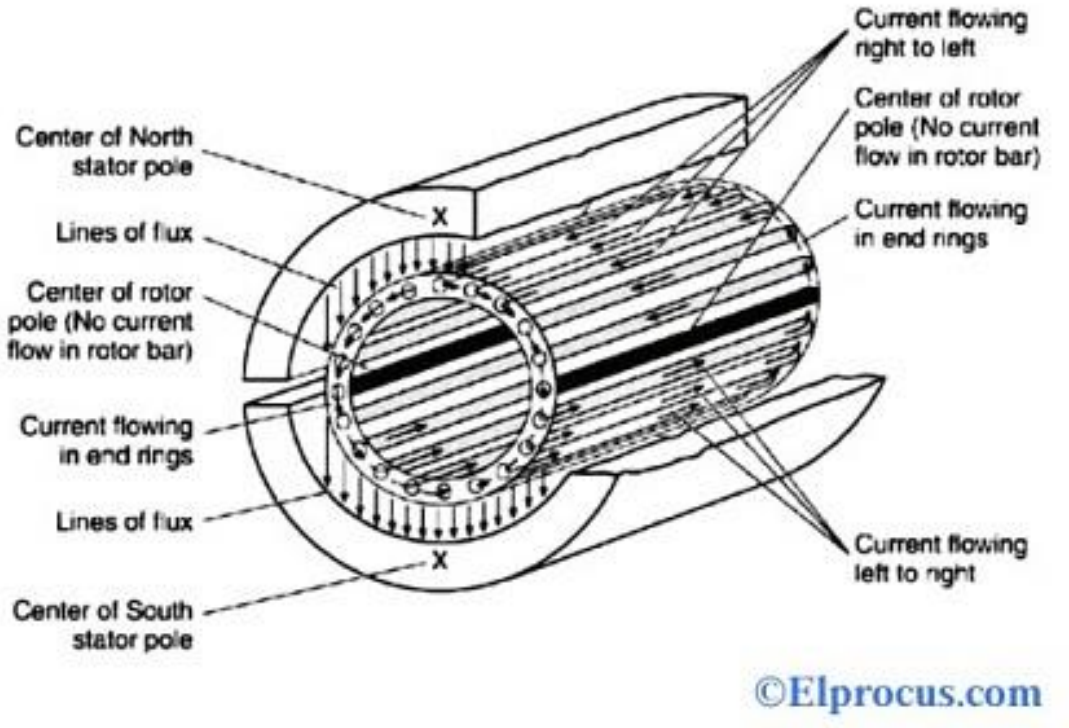
Squirrel Cage Induction Motor Working Principle

Squirrel induction motor working is based on the principle of electromagnetism. When the stator winding is supplied with a three-phase AC, it produces a rotating magnetic field (RMF) which has a speed called synchronous speed. This RMF causes voltage induced in the rotor bars. So, that short-circuit current flows through that. Due to these rotor currents, a self-magnetic field is generated which interacts with the stator field. Now, as per the principle, the rotor field starts opposing its cause. when the RMF catches the rotor moment, the rotor current drops to zero. Then there would be no relative moment between the rotor and RMF.

Hence, the zero tangential force is experienced by the rotor and reduces for a moment. After this reduction in the moment of the rotor, the rotor current is induced again by the reconstruction of relative motion between the RMF and the rotor. Hence the tangential force of the rotor for the rotation is restored and starts by following the RMF. In this case, the rotor maintains a constant speed, which is less than the speed of RMF and synchronous speed. Here, the difference between the speed of RMF and the rotor is measured in the form of slip. The final frequency of the rotor can be obtained by the multiplication of slip and supply frequency.

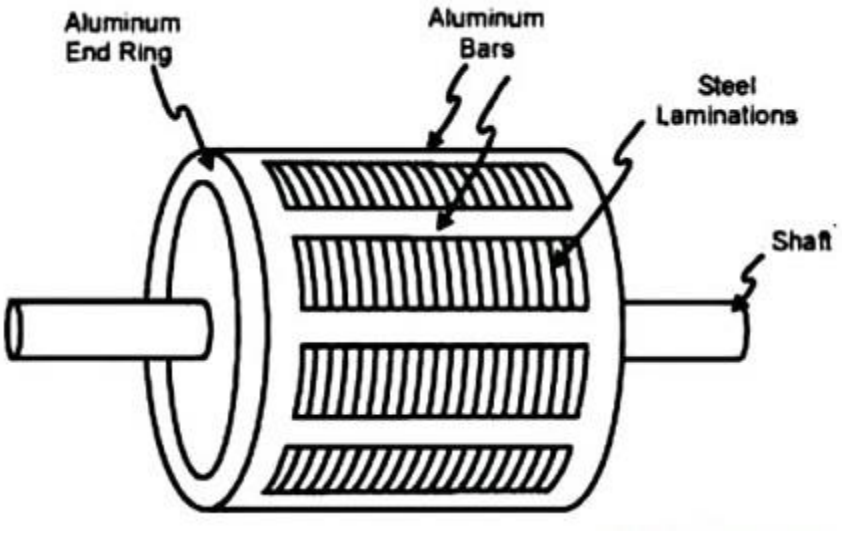
Squirrel Cage Induction Motor Construction

Parts that are required for the construction of squirrel cage induction motor are stator, rotor, fan, bearings. The stator consists of mechanically and electrically 120 degrees apart three-phase winding with metal housing and core. In order to provide the path of low reluctance for flux generated by AC current, the winding is mounted on the laminated iron core.



Motor Parts

Rotor converts given electrical energy into mechanical output. The shaft, a core, short-circuited copper bars are the parts of the rotor. In order to avoid hysteresis and eddy currents that are leading to power loss, the rotor is laminated. And I order to prevent cogging, conductors are skewed which also helps to give a good transformation ratio.



Motor Construction

A fan attached at the back of the rotor for heat exchange helps in maintaining under a limit of the temperature of the motor. For the smooth rotation, bearings are provided in the motor.

Difference between Squirrel Cage Induction Motor and Slip Ring Induction Motors.

Squirrel Cage Induction Motor	Slip Ring Induction Motor
The construction of squirrel cage induction simple and rugged.	Construction of slip ring induction motors needs slip rings, brushes, short-circuiting device, etc.
This type of motor has less overhang and better space factor in slots.	These motors have the highest overhang and poor space factor in slots.
Cost and maintenance are less.	The cost is more.
Higher efficiency (in case of machines, not designed for high starting torque)	Low efficiency and more copper losses.
Small copper losses and better power factor.	Poor power factor and can be improved at the start.
The cooling factor is better because of its bare end rings and the availability of more space for rotor fans.	The cooling factor is not quite efficient.
These motors have better speed regulation, simple starting and low staring torque with high starting current	Poor speed regulation when operated with external resistances in the rotor circuit. The motor needs slip rings, brush gear, short-circuiting device and starting resistors, etc. Possibility of increasing starting torque due to external resistances in the rotor circuit.
Power factor is poor at starting	The power factor can be improved.
There is no possibility of speed control.	Speed control is possible by the insertion of external resistors in the rotor circuit.
Explosion-proof against protection.	Explosion-proof against protection.

Classification of Squirrel Cage Induction Motor

In order to meet the industry requirements, three-phase squirrel cage induction motors in a range up to 150KW at various standard frequencies, voltages and, speeds. According to their electrical characteristics, of these motors are divided into 6 types as discussed below,

Class-A Design

These type motors have low resistance, reactance, slip, and higher efficiency at full load. The main disadvantage is high starting current which is 5 to 8 times of full-load current at rated voltage. These motors are widely used in small ratings for machine tools, centrifugal pumps, fans, blowers, etc.

Class B Design

These motors have high reactance and operate 5-150KW range. These motors can be replaced with class A motors for new installations because of its characteristics which are similar to Class A motors and have the same staring current. (around 5 times the full-load current at rated voltage).

Class C Design

These motors are known as double cage motors that high starting torque with the low starting current. Applications of class C motors are, driving air compressors, conveyors, reciprocating pumps, crushers, mixers, large refrigerating machines, etc.

Class D Design

These motors are squirrel cage motors with high resistance. Hence, they give high starting torque with the low starting current. These motors have low operating efficiency and limited to drive intermittent loads involved in high accelerating duty and high-impact loads such as punch presses, shears, bulldozers, small hoists, etc.

Class E Design

These motors operate with low starting torque, normal starting current, and also low slip at rated load.

Class F Design

These motors are operated with low starting torque, low starting current, and normal slip.

Advantages

The advantages of a squirrel cage induction motor include the following.

- Simple and rugged construction.
- The low initial as well as maintenance cost.
- Maintains constant speed.
- The overload capacity is high.
- Simple starting arrangement.
- High power factor.

- Low rotor copper loss.
- High efficiency.

Disadvantages

The disadvantages of a squirrel cage induction motor include the following.

- Motor
- High starting current
- Very sensitive to fluctuations in supply voltage
- Low power factor at light loads.
- Speed control is very difficult
- Very poor starting torque due to its low rotor resistance.

Applications

The applications of squirrel cage induction motor include the following.

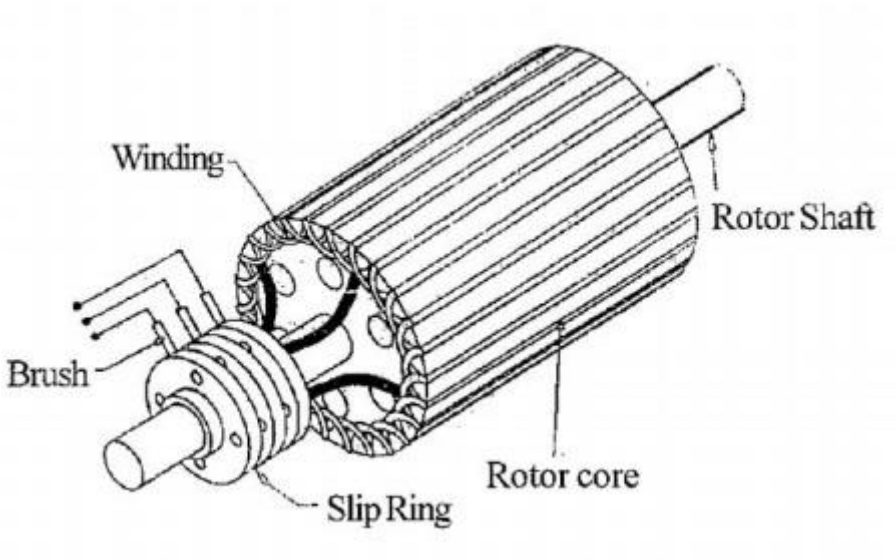
- Suitable for industrial drives of small power where speed control is not required such as for printing machinery, flour mills, and other shaft drives of small power.
- Centrifugal pumps, fans, blowers, etc
- In driving air compressors, conveyors, reciprocating pumps, crushers, mixers, large refrigerating machines, etc.
- Punch presses, shears, bulldozers, small hoists, etc.

What is Slip Ring Induction Motor and Its Working

An induction motor is an electrical device that converts electrical energy into mechanical energy. It is most widely used for industrial applications due to its self-starting attribute. Slip ring induction motor is one of the types of 3-phase induction motor and is a wound rotor motor type. Because of various advantages like low initial current, high starting torque, and improved power factor, it is used in applications that require high torque, cranes, and elevators. The rotor windings consist of more number of windings, higher induced voltage, and less current compared to the squirrel-cage rotor. The windings are connected to external resistance through slip rings, which helps to control the torque/speed of a motor.

What is a Slip Ring Induction Motor?

Definition: A slip ring induction motor is referred to as an asynchronous motor as the speed at which it operates is not equal to the synchronous speed of a rotor. The rotor of this type of motor is wound type. It comprises of a cylindrical laminated steel core and a semi-closed groove at the outer boundary to accommodate a 3-phase insulated winding circuit.



Slip Ring in Induction Motor

As seen in the figure above, the rotor is wound to match the number of poles on the stator. The three terminals of a rotor and three start terminals connecting through slip rings are connected to a shaft. The aim of the shaft is to transmit mechanical power.

Construction

Before we discuss the working principle of slip ring Induction motor, knowing the **slip ring induction motor construction** is important. So let's begin with the construction which includes two parts: Stator and Rotor.

- Stator
- Rotor

Stator

The stator of this motor comprises of various slots that are arranged to support the construction of a 3-phase winding circuit connecting to a 3-phase AC source.

Rotor

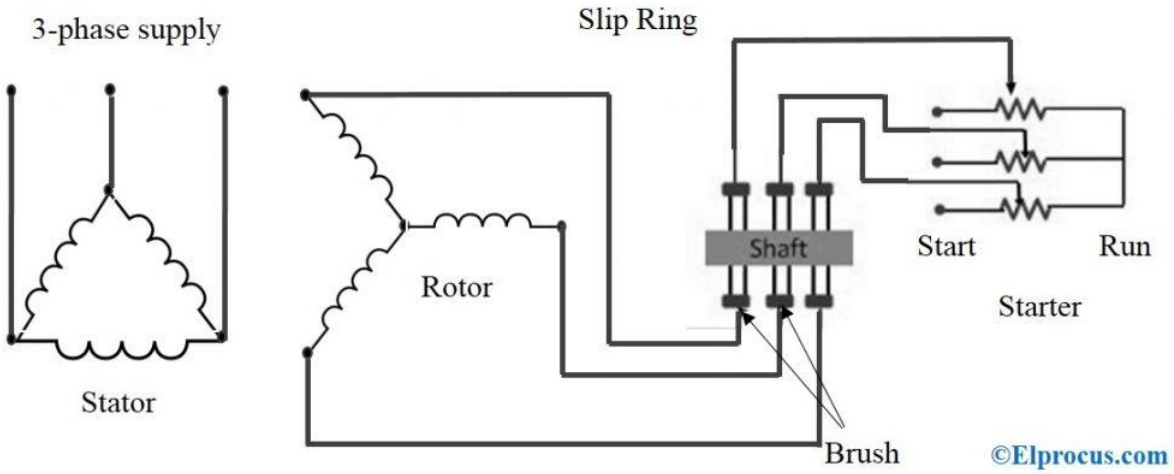
The rotor of this motor consists of a cylindrical core with steel laminations. Besides this, the rotor has parallel slots to accommodate 3-phase windings. The windings in these slots are arranged at 120 degrees to each other. This arrangement can reduce noise and avoid irregular pausing of a motor.

Working of Slip Ring Induction Motor

This motor runs on the principle of Faraday's law of electromagnetic induction. When a stator winding is excited with an AC supply, the stator winding produces magnetic flux. Based on faraday's law of electromagnetic induction, the rotor winding gets induced and generates a current of magnetic flux. This induced EMF develops torque that enables the rotor to rotate.

However, the phase difference between the voltage and current do not meet the requirements to generate high starting torque as torque developed is not unidirectional. The external resistance of high value is connected with the circuit to improve the phase difference of a motor.

As a result, inductive reactance and phase difference between I and V is reduced. Consequently, this reduction helps the motor to generate high stating torque. The **slip ring induction motor diagram** is shown below.



Slip Ring Induction Motor Connection Diagram

Why Slip Rings are used in an Induction Motor?

Slip is defined as the difference between the flux speed and the rotor speed. For an induction motor to produce torque, at least some difference should be there between stator field speed and rotor speed. This difference is called 'slip'. The Slip Ring" is an electromechanical device that aids in transmitting power and electrical signals from stationary to a rotating component.

What is DOL starter?

The word DOL means Directly On Line. The starter in which the motor is connected directly in line with the switch is called DOL starter.

It has only one contactor. There is no starting circuit to reduce the amount of starting current.

The simple DOL starter example is your home water pump, it has a motor which you can run directly without any method of soft starting. All you need is a switch to connect the motor to the electricity directly.

What is Star-Delta Starter?

Star delta starter is a starting method of larger induction motors, in this method the motor starts as a star connected then switches to delta after it starts.

This method does not connect the motor directly. It consists of two contactors. One contactor is used to start the motor with reduced voltage, i.e Start connection, and the other one, Delta contactor, is used to run the rated voltage of the motor.

The main differences between the DOL starter and star Delta starter are following.

Star Delta vs DOL table

DOL Starter	Star Delta Starter
Motor starts on its full starting torque	Starts motor on third of its starting torque
Motor starts at full starting current	Reduces starting current
Very simple and needs just one contactor	More complicated in design and needs 3 contactors
Suitable for high starting torque applications	Not good for applications with high starting torque
Lower cost, and requires less maintenance	Costs more, and requires more maintenance
Works for motors with Delta or Star connection	Motor must be designed to work on Delta connection
Full voltage is applied to the motor at the starting	The voltage is reduced to a lower value

Starting Current

- The DOL starter gives the highest possible current to start the motor. It doesn't reduce the starting current, which is a big disadvantage of DOL starter.
- While working with the DOL starter, values of 9 or 10 times of current the rated current exist, i.e motor starting current.

- **In case of star delta** starter, the starting current is reduced. It draws the star connection starting current which is about **30%** of the starting current provided by DOL. This is also a big advantage of star delta starter over the DOL.

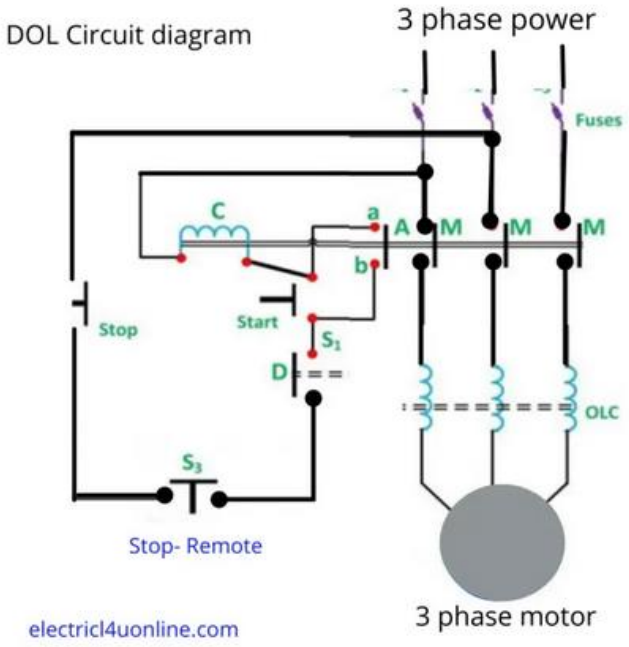
Starting Torque

When we talk about DOL starter vs star delta starter in terms of relative starting torque, we came to know that DOL starter gives the starting torque which is higher than the rated motor torque.

On the other hand a star delta starter reduces the starting torque of the motor.

Star delta starter is used when the application is not highly loaded during the start because, Star Delta does not provide the motor its full starting torque value.

Operating Principle and wiring diagram



DOL starter circuit

DOL principle and circuit

DOL starter circuit consists of, a contactor, overload relay, start button and a stop button.

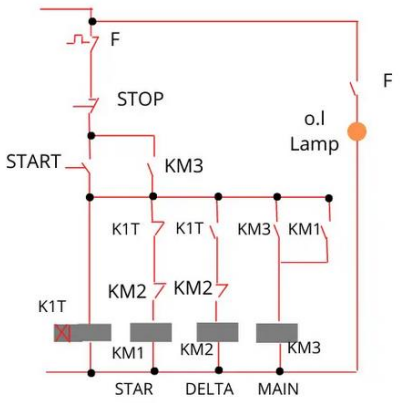
These components are used for the control and protection purposes.

In case of a fault condition, the contactor opens with the help of thermal overloaded relay.

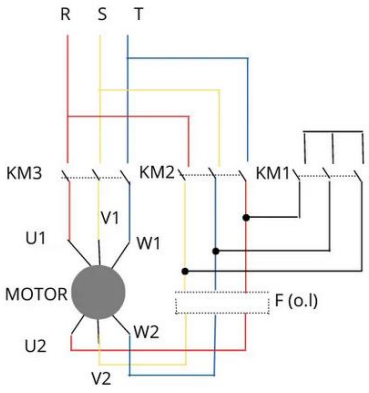
The contactor is also controlled by the start and stop buttons.

When the motor is working the contactors are electrically closed. To stop the motor, just press the stop button to de energize the contactor.

Star delta starter principle and wiring circuit



Star/Delta Control circuit



Star/Delta Power circuit

In case of star delta starter, the power supply source to the motor is connected to the delta connection from star with the help of wiring.

When the current passes the motor started in star configuration and then converted to the delta configuration.

In this process full voltage is applied to the motor when it is running and in this way full torque is obtained as an output.

The star delta starter is used to start the motor and when it gets the speed after starting it is converted to the delta.

Star connection starts the motor with less voltage and motor takes time to get the speed in this mode.

As we know the torque is proportional to the square of voltage that's why the starting torque also reduces in the star mod.

Wiring and Motor Terminals

In case of star delta starter the motor is connected in such a way that it can be switch-over from star to delta.

To complete this task the six ends of winding of motor are connected on the terminals. Then the starter switch of star delta starter performs its action of switching over the motor accordingly.

The working system of DOL starter is different. It requires only one set of cable from starter to the motor.

Starting time

Both types of starters also have great differences in case of starting times. **The starting time of star delta starter is larger than the DOL starter.**

Star delta starter takes the run up time of approximately 2 to 15 seconds. On the other hand the DOL starter takes the starting time of approximately 2 to 5 seconds.

circuit Component

- The formation of DOL starter is simple. It consists of only thermal overloaded relay and a main contactor. There is no further component or any circuit in it and all the working system is carried out by only these components.
- **Star delta starter** is not that simple in case of components. The components are consists of an overload relay, three contactors and a timer.

The timer is used to set the time in the start position. In order to use the star delta starter the motor should be delta connected during the normal run.

Significant Design Features

Star Delta starter

- Contactors have longer endurance due to wide voltage band.
- Reliable overload protection.
- Easy to install.
- Safe to use with smooth working

DOL starter

- Contactor should be wide.
- Easy and Quick mounting facility.
- Relay for reliable overload protection.
- Withstand wide voltage fluctuations.
- Screwed up earth wire for safety purposes.
- Manually reset facility after trip

Synchronous Machine

Synchronous Machine constitutes of both synchronous motors as well as synchronous generators. An AC system has some advantages over a DC system. Therefore, the AC system is exclusively used for the generation, transmission, and distribution of electric power. The machine which converts mechanical power into AC electrical power is called a **Synchronous Generator** or Alternator. However, if the same machine can be operated as a motor is known as **Synchronous Motor.**

Synchronous machine is an AC machine whose satisfactory operation depends upon the maintenance of the following relationship.

$$N_s = \frac{120f}{P} \dots\dots\dots (1) \quad \text{or}$$

$$f = \frac{PN_s}{120}$$

Where,

- N_s is the synchronous speed in revolution per minute (r.p.m)
- f is the supply frequency
- P is the number of poles of the machine.

When connected to an electric power system, a synchronous machine always maintains the above relationship shown in equation (1).

If the synchronous machine working as a motor fails to maintain the average speed (N_s) the machine will not develop sufficient torque to maintain its rotation and will stop. Then the motor is said to be **Pulled Out of Step.**

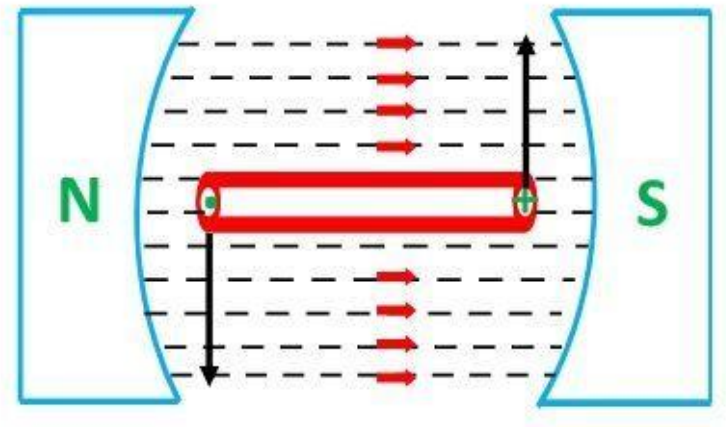
In case, when the synchronous machine is operating as a generator, it has to run at a fixed speed called Synchronous speed to generate the power at a particular frequency. As all the appliances or machines are designed to operate at this frequency. In some countries, the value of the frequency is **50 hertz**.

Basic Principles of Synchronous Machine

A synchronous machine is just an electromechanical transducer that converts mechanical energy into electrical energy or vice versa. The fundamental phenomenon or law which makes these conversions possible is known as the **Law of Electromagnetic Induction** and **Law of interaction.**

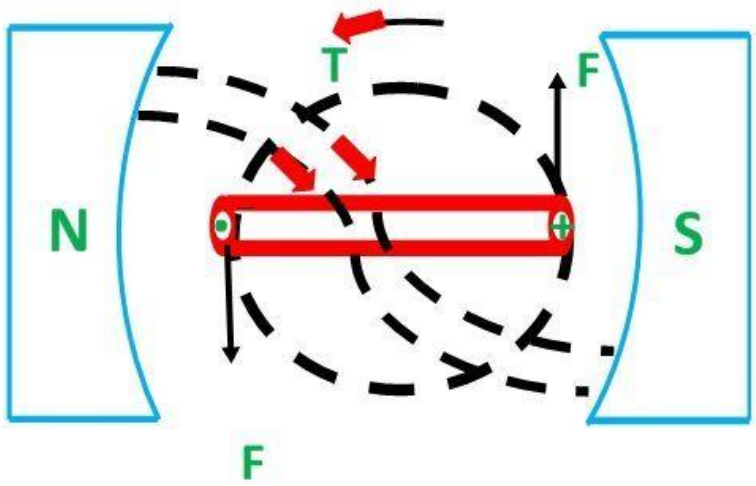
Law of Electro-Magnetic Induction

This law is also called Faraday's First Law of Electromagnetic Induction. This law relates to the production of emf, i.e.; emf is induced in a conductor whenever it cuts across the magnetic field as shown below:



Law of Interaction

This law relates to the production of force or torque, i.e., whenever a current-carrying conductor is placed in the magnetic field, by the interaction of the magnetic field produced by the current-carrying conductor and the main field, force is exerted on the conductor producing torque. The figure is shown below:



Three-Phase Synchronous Machine

- The machine which is used in the household appliance such as the small machine used in air coolers, refrigeration, fans, air conditioners, etc.
- However, large AC machines are three-phase type synchronous machines because of the following reasons.
- For the same size of the frame, three-phase machines have nearly 1.5 times the output than that of the single-phase machine.
- Three-phase power is transmitted and distributed more economical than single-phase power.
- Three-phase motors are self-starting (except synchronous motors).
- Three-phase motors have an absolute uniform continuous torque, whereas, single-phase motors have pulsating torque.

In a small synchronous machine, the fielding winding is placed on the stator, and the armature winding is placed on the rotor whereas for the large synchronous machine the field winding is placed on the rotor, and the armature winding is placed on the stator.

Construction of a Synchronous Machine

Construction of a Synchronous Machine, i.e. alternator or motor consists of two main parts, namely the stator and the rotor. The stator is the stationary part of the machine. It carries the armature winding in which the voltage is generated. The output of the machine is taken from the stator. The rotor is the rotating part of the machine. The rotor produces the main field flux.

The important parts of the Synchronous Machine are given below:

- Stator
- Rotor
- Miscellaneous

Stator Construction

The stationary part of the machine is called Stator. It includes various parts like stator frame, stator core, stator windings, and cooling arrangement. They are explained below in detail.

Stator Frame

It is the outer body of the machine made of cast iron, and it protects the inner parts of the machine.

Stator Core

The stator core is made of silicon steel material. It is made from a number of stamps that are insulated from each other. Its function is to provide an easy path for the magnetic lines of force and accommodate the stator winding.

Stator Winding

Slots are cut on the inner periphery of the stator core in which 3 phase or 1 phase winding is placed. Enameled copper is used as a winding material. The winding is star-connected. The

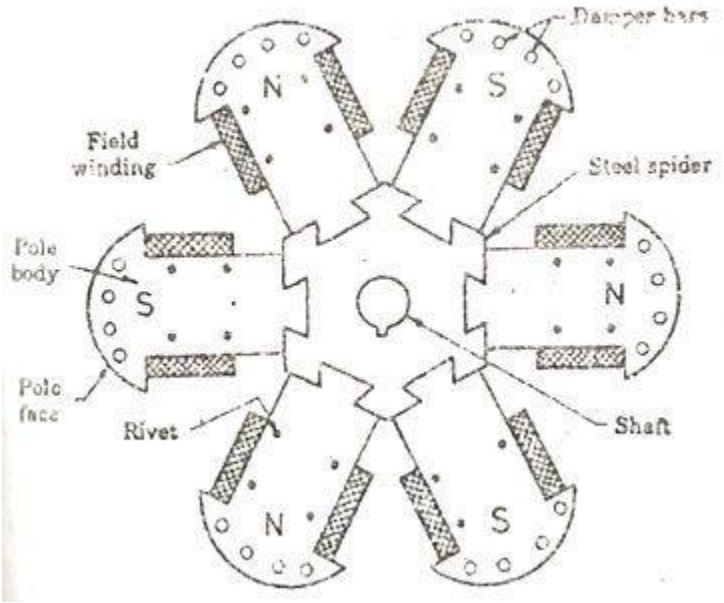
winding of each phase is distributed over several slots. When the current flows in a distributed winding it produces an essentially sinusoidal space distribution of EMF.

Rotor Construction

The rotating part of the machine is called Rotor. There are two types of rotor construction, namely the salient pole type and the cylindrical rotor type.

Salient Pole Rotor

The term salient means projecting. Thus, a salient pole rotor consists of poles projecting out from the surface of the rotor core. The end view of a typical 6 pole salient pole rotor is shown below in the figure:



Since the rotor is subjected to changing magnetic fields, it is made of steel laminations to reduce eddy current losses. Poles of identical dimensions are assembled by stacking laminations to the required length. A salient pole synchronous machine has a non-uniform air gap. The air gap is minimized under the pole centers and it is maximum in between the poles.

They are constructed for medium and low speeds as they have a large number of poles. A salient pole generator has a large diameter. The salient pole rotor has the following important parts.

Spider: It is made of cast iron to provide an easy path for magnetic flux. It is keyed to the shaft and at the outer surface, pole core and pole shoe are keyed to it.

Pole Core and Pole Shoe: It is made of laminated steel sheet material. The Pole core provides the least reluctance path for the magnetic field and the pole shoe distributes the field over the whole periphery uniformly to produce a sinusoidal wave.

Field Winding or Exciting Winding: It is wound on the former and then placed around the pole core. DC supply is given to it through slip rings. When direct current flows through the field winding, it produces the required magnetic field.

Damper Winding: At the outermost periphery, holes are provided in which copper bars are inserted and short-circuited at both sides by rings forming Damper winding.

Miscellaneous Parts

The miscellaneous parts are given below:

Brushes: Brushes are made of carbon, and they slip over the slip rings. A DC supply is given to the brushes. Current flows from the brushes to the slip rings and then to the exciting windings.

Bearings: Bearings are provided between the shaft and the outer stationary body to reduce the friction. They are made of high carbon steel.

Shaft: The shaft is made of mild steel. Mechanical power is taken or given to the machine through the shaft.