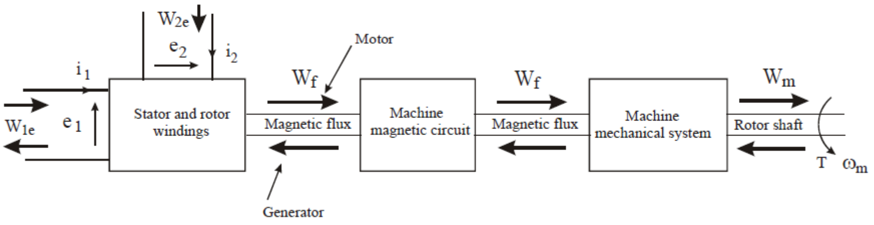
EEE 2015 ELECTRICS

AC Motors-Synchronous and Asynchronous

Electromechanical systems

For energy conversion between electrical and mechanical forms, electromechanical devices are developed, which can be divided into three categories:

1. Transducers (for measurement and control): These devices transform the signals of different forms. Examples are microphones, pickups, and speakers.
2. Force producing devices (linear motion devices): These type of devices produce forces mostly for linear motion drives, such as relays, solenoids (linear actuators), and electromagnets.
3. Continuous energy conversion equipment: These devices operate in rotating mode. A device would be known as a generator if it convert mechanical energy into electrical energy, or as a motor if it does the other way around (from electrical to mechanical).



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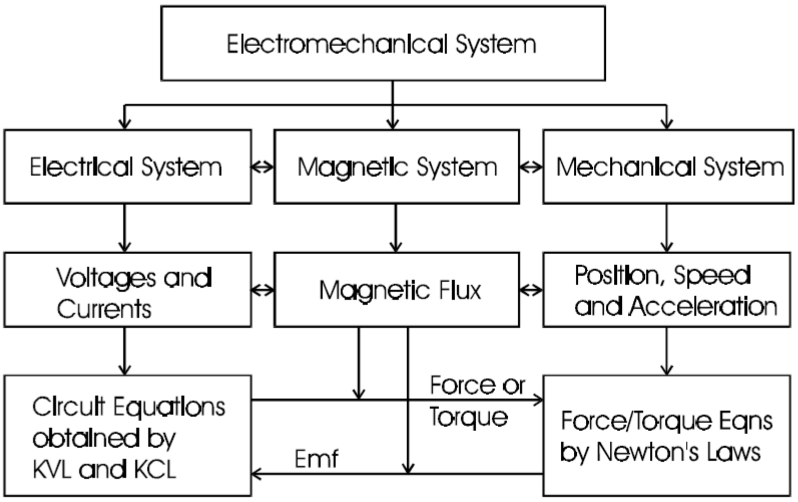
Electromechanical systems



Electromechanical System

Electrical System

Magnetic System

Mechanical System

Voltages and Currents

Magnetic Flux

Position, Speed and Acceleration

Circuit Equations obtained by KVL and KCL

Force or Torque

Emf

Force/Torque Eqns by Newton's Laws

Electric Motors

The electric motor is an electromechanical continuous energy conversion equipment that converts electrical energy into electrical energy mechanical energy. An electric motor utilizes three things to produce motion:

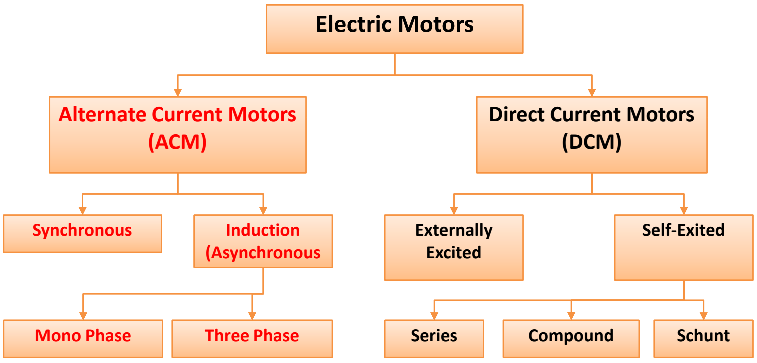
1. Current – In a brush motor when electricity is applied across the motor termination causes a current flows through a brush and commutator system into an electromagnetic armature that moves inside a fixed permanent magnet or fixed electromagnetic stator field. In brushless motor when electricity is applied across the motor termination, a current flows through a fixed stator field and is interacting with a moving permanent magnet or a moving induced magnetic field inside a rotor / armature.
2. Magnetic Flux - A motor can have a fixed wound coil or a permanent magnet stator and a moving wound coil armature or PM rotor that will have interacting magnetic flux fields to produce a force and motion.
3. Force - The amount of current that flows through the electromagnetic field is proportional to the amount of interacting electromagnetic field force required to achieve the opposing work load.

$$i(t)\rightarrow H(t)\rightarrow B(t)\Rightarrow F_{mag}=i(L\times B)/V_{ind}=L(v\times B)\rightarrow\theta:\text{rotation}$$

Magnetic field is static in DC Motors and rotary in AC Motors

AC Motors-Synchronous and Asynchronous

Electric Motors


Electric Motors
- **Alternate Current Motors (ACM)**
  - **Synchronous**
  - **Induction (Asynchronous**
    - **Mono Phase**
    - **Three Phase**
- **Direct Current Motors (DCM)**
  - **Externally Excited**
  - **Self-Exited**
    - **Series**
    - **Compound**
    - **Schunt**

Magnetic field is static in DC Motors and rotary in AC Motors

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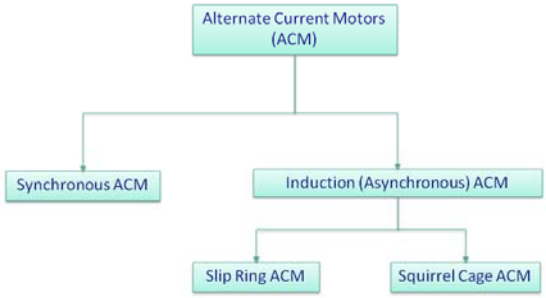
AC Motors-Synchronous and Asynchronous

Alternating Current Motors



The ACM's are simplier in structure and more economic than DCM's.
An ACM generates more power comparing with a DC motor that has the same weight.
Maintenance of ACM's is easier.
However, their speed control is harder. They can be connected to the AC source directly.
If accuracy in velocity or position control is needed, DCM's are used. But, ACM's are used more than DCM's in industry.

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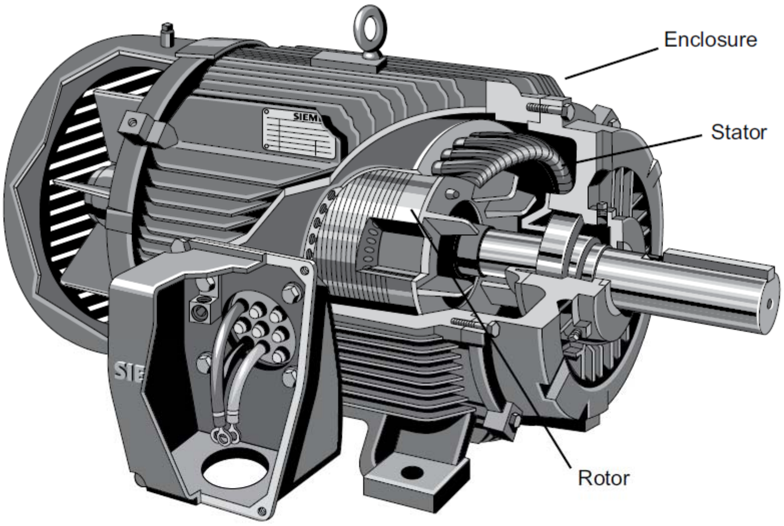
Motor Components

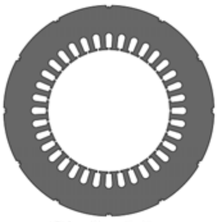
This AC motor has three main parts, rotor, stator, and enclosure. The stator and rotor do the work and the enclosure protects the stator and rotor.



Motor Components

Stator

The stator is the stationary part of the motor’s electromagnetic circuit. The stator core is made up of many thin metal sheets, called laminations. Laminations are used to reduce energy loses that would result if a solid core were used. Stator laminations are stacked together forming a hollow cylinder.


Stator Lamination


Stator Windings Partially Completed


Stator Windings Completed

Coils of insulated wire are inserted into slots of the stator core. When the assembled motor is in operation, the stator windings are connected directly to the power source. Each grouping of coils, together with the steel core it surrounds, becomes an electromagnet when current is applied.

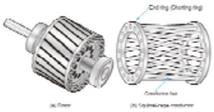
Motor Components

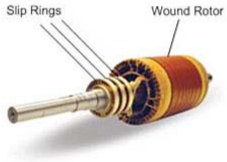
Rotor

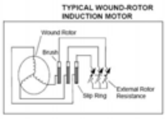
The rotor is the rotating part of the motor’s electromagnetic circuit.

There is no electrical power supplied to rotor conductors in induction motors. Electrical current in rotor flows because of the electromagnetic induction. There two common type of constructions for rotor used in a**n induction motor**.

1. Squirrel cage rotor
2. Wound Rotor







In synchronous motors, the rotor is an electromagnet and a DC power applied to it. In synchronous rotor construction it is common to use a combination of squiirrel cage and wound rotor.

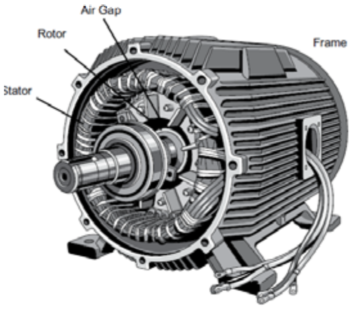
Motor Components

Enclosure

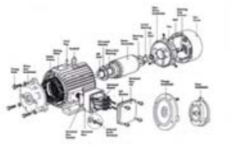
The enclosure consists of a frame (or yoke) and two end brackets (or bearing housings). The stator is mounted inside the frame.

The rotor fits inside the stator with a slight air gap separating it from the stator.

There is no direct physical connection between the rotor and the stator.



Partially Assembled Motor



The enclosure protects the internal parts of the motor from water and other environmental elements. The degree of protection depends upon the type of enclosure.

AC Induction (asynchronous) Motor

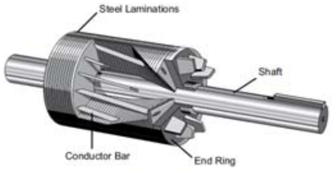
An induction or asynchronous motor is an AC electric motor in which the electric current in the rotor needed to produce torque is induced by electromagnetic induction from the magnetic field of the stator winding.

An induction motor therefore does not require mechanical commutation, separate-excitation or self-excitation for all or part of the energy transferred from stator to rotor

An induction motor's rotor can be either wound type or squirrel-cage type.

The squirrel cage rotor is so called because its construction is reminiscent of the rotating exercise wheels found in some pet cages.

Rotor Lamination



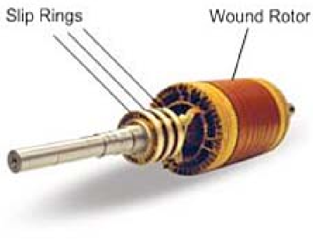
Cutaway View of Rotor

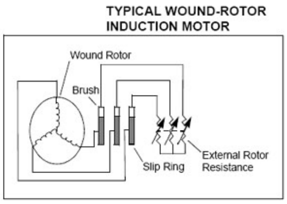
A squirrel cage rotor core is made by stacking thin steel laminations to form a cylinder. Rather than using coils of wire as conductors, **conductor bars** are die cast into the slots evenly spaced around the cylinder. Most squirrel cage rotors are made by die casting aluminum to form the conductor bars.

AC Induction (asynchronous) Motor

A major difference between the wound rotor motor and the squirrel cage rotor is that the conductors of the wound rotor consist of wound coils instead of bars.

These coils are connected through slip rings and brushes to external variable resistors. The rotating magnetic field induces a voltage in the rotor windings.



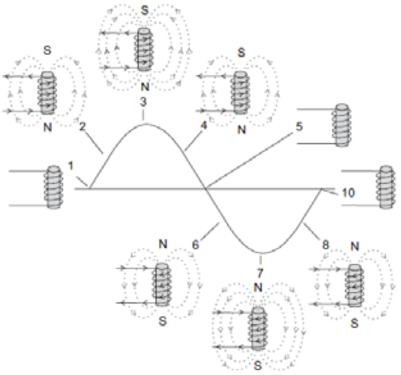


Increasing the resistance of the rotor windings causes less current to flow in the rotor windings, decreasing rotor speed. Decreasing the resistance causes more current to flow, increasing rotor speed.

Magnetic Field in Stator Coil

The magnetic field of an electromagnet has the same characteristics as a natural magnet, including a north and south pole. However, when the direction of current flow through the electromagnet changes, the polarity of the electromagnet changes. The polarity of an electromagnet connected to an AC source changes at the frequency of the AC source.

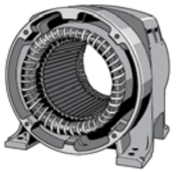
At time 1, there is no current flow, and no magnetic field is produced.
At time 2, current is flowing in a positive direction, and a magnetic field builds up around the electromagnet
At time 3, current flow is at its peak positive value, and the strength of the electromagnetic field has also peaked
At time 6, current is increasing in the negative direction. Note that the polarity of the electromagnetic field has changed. The negative half of the cycle continues through times 7 a nd 8, returning to zero at time 9.

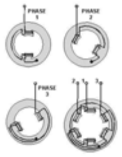


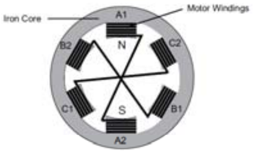
For a 60 Hz AC power supply, this process repeats 60 times a second.

Developing a Rotating Magnetic Field in Stator Coil

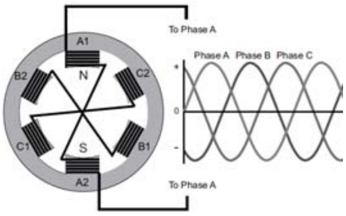
The stator of an AC motor is a hollow cylinder in which coils of insulated wire are inserted.

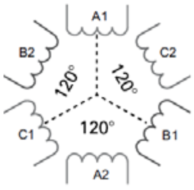






The coils are wound around the soft iron core material of the stator. Six stator windings are used, two for each of the three phases (two pole configuration).
When current is applied, each winding becomes an electromagnet, with the two windings for each phase operating as the opposite ends of one magnet.
The stator is connected to a three-phase AC power source. The A1 and A2 connected to phase A of the power supply. When the connections are completed, B1 and B2 will be connected to phase B, and C1 and C2 will be connected to phase C.
. **This corresponds to the 120° separation between each electrical phase.**





2-Pole Stator Winding

Developing a Rotating Magnetic Field in Stator Coil

t=0

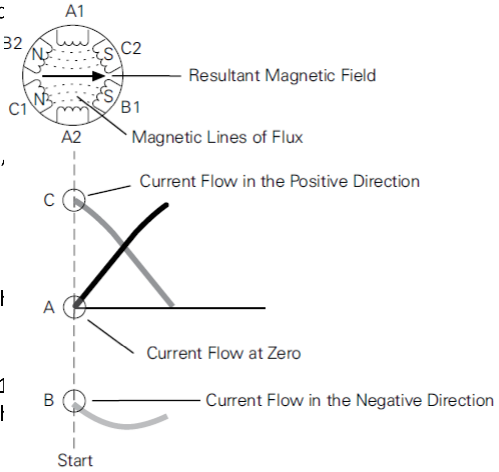
A has no current flow and its associated coils have no magnetic fielc Phase B has current flow in the negative direction and phase C has current flow in the positive direction.

Based on stator winding configuration, B1 and C2 are south poles and B2 and C1 are north poles.

Magnetic lines of flux leave the B2 north pole and enter the nearest soutl pole, C2.

Magnetic lines of flux also leave the C1 north pole and enter the nearest soutl pole, B1.

The vector sum of the magnetic fields is indicated by the arrow.



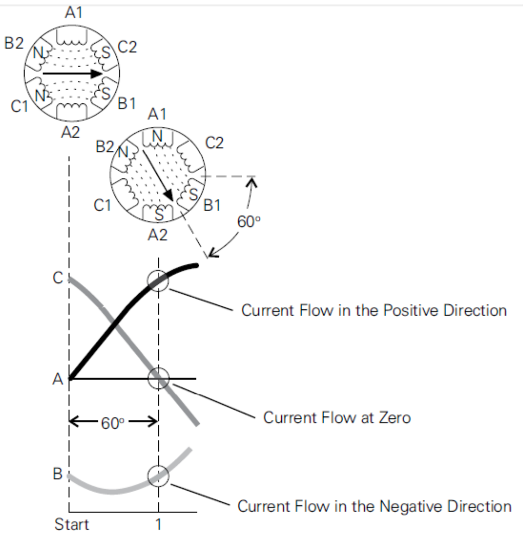
Developing a Rotating Magnetic Field in Stator Coil

t=t$_1$

The following chart shows the progress of the magnetic field vector as each phase has advanced 60°.

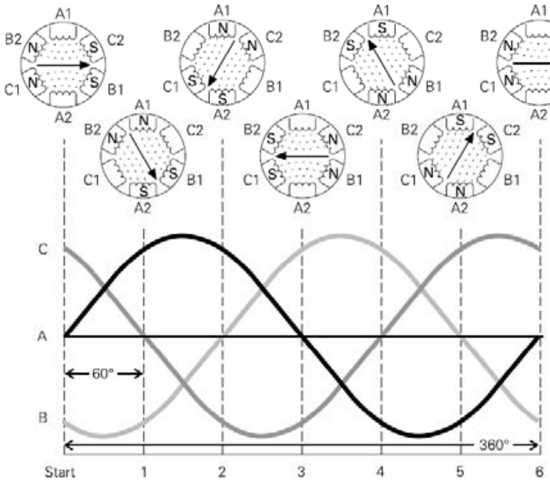
Note that at time 1 phase C has no current flow and no magnetic field is developed in C1 and C2. Phase A has current flow in the positive direction and phase B has current flow in the negative direction.

windings A1 and B2 are north poles and windings A2 and B1 are south poles. The resultant magnetic field vector has rotated 60° in the clockwise direction



Developing a Rotating Magnetic Field in Stator Coil

At the end of six such time intervals (it takes one period of applied AC voltage), the magnetic field will have rotated one full revolution or 360°.



This process repeats 50 times a second for a 60 Hz power source.

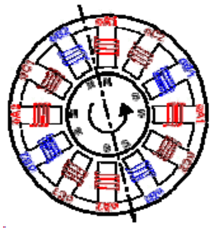
Synchronous Speed of an AC Motor

The speed of the rotating magnetic field is referred to as the **synchronous speed (NS)** of the motor.

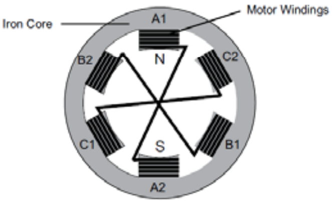
Synchronous speed is equal to 120 times the frequency (f_{AC}), divided by the number of motor poles (p).

$$n_S = \frac{120 f_{AC}}{p}$$

No. Poles	Synchronous Speed (no Load)	
	60 hz	50 hz
2 Pole	3600	3000
4 Pole	1800	1500
6 Pole	1200	1000
8 Pole	900	750



4 pole motor stator

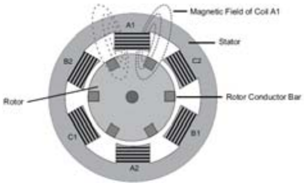


2 pole motor stator

Rotor Rotation

An induction motor **induces a current in its rotor so that a magnetic force can exist on rotor conductors**

When current is flowing in a stator winding, the electromagnetic field created cuts across the nearest rotor bars.



$$E_{rotor} = (V \times B_{stator}) L_{conductor}$$

When a conductor, such as a rotor bar, passes through a magnetic field, a voltage (emf) is induced in the conductor.

"V" is the relative velocity of the conductor with respect to stator magnetic field. This relative velocity terms is critical in operation of AC induction motors because the voltage can only be induced on rotor conductors if this velocity term is not zero.

So it is evident that the rotor and stator magnetic field have different angular speeds

The induced voltage causes current flow in the conductor. In a squirrel cage rotor, current flows through the rotor bars and around the end ring and produces a magnetic field round each rotor bar. In a wound rotor current flows through the external circuit, which is connected to slip rings

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Rotor Rotation

An induction motor **induces a current in its rotor so that a magnetic force can exist on rotor conductors**

A magnetic force acts on rotor conductors which, eventually, turns the rotor

$$F = (i_{rotor} \times B_{stator}) L_{conductor}$$

For a three-phase AC induction motor, the rotating magnetic field must rotate faster than the rotor to induce current in the rotor.

When power is first applied to the motor with the rotor stopped, this difference in speed is at its maximum and a large amount of current is induced in the rotor. (higher torque need)

After the motor has been running long enough to get up to operating speed, the difference between the synchronous speed of the rotating magnetic field and the rotor speed is much smaller.

This speed difference is called slip. Slip is expressed as a percentage of the synchronous speed

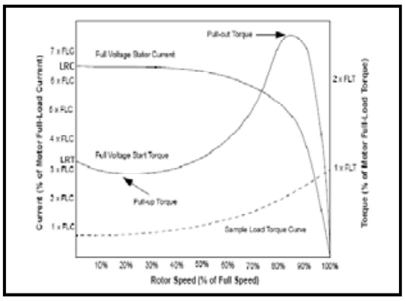
$$s = \frac{n_{sync} - n_{async}}{n_{sync}} 100$$

Slip is necessary to produce torque. Slip is also ddependent on load. An increase in load causes the rotor to slow down, increasing slip.

Operation of Indcution Motors

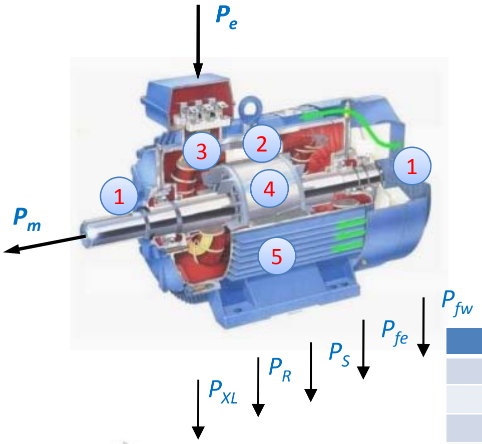
Approximate Electrical Motor Speed (RPM)				
No. Poles	Speed with Rated Load		Synchronous Speed (no Load)	
	60 hz	50 hz	60 hz	50 hz
2 Pole	3450	2850	3600	3000
4 Pole	1725	1425	1800	1500
6 Pole	1140	950	1200	1000
8 Pole	850	700	900	750

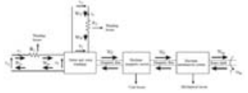
Slip Example
Curve
Explanation



Aynchronous Speed of Motors

Losses in Asynchronous Motors



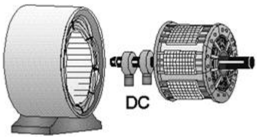


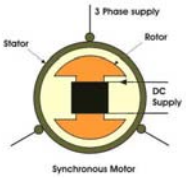
Losses	*Notation*
Friction and air flow losses	P_{fw}
Iron loss	P_{fe}
Loss of conductor (stator - copper)	P_S
Loss of conductor (rotor - alluminium)	P_R
Additinal load loss	P_{XL}

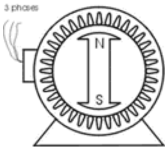
Losses	
Friction and Air Flow Losses	% 0,5 ~ 1,5
Iron loss	% 1,5 ~ 2,5
Conductor loss (stator)	% 2,5 ~ 4,0
Conductor Loss (rotor)	% 1,5 ~ 2,5
Additional load losses	% 0,5 ~ 2,5

Synchronous Motor

Remember that the rotating magnetic field rotates at a certain speed, that speed is called synchronous speed.







If an electromagnet/magnet is present in this rotating magnetic field, the electromagnet is magnetically locked with this rotating magnetic field and rotates with same speed of rotating field.

Synchronous motors is called so because the speed of the rotor of this motor is same as the rotating magnetic field.

$$n_s = \frac{120 f_{AC}}{p}$$

No. Poles	Synchronous Speed (no Load)	
	60 hz	50 hz
2 Pole	3600	3000
4 Pole	1800	1500
6 Pole	1200	1000
8 Pole	900	750

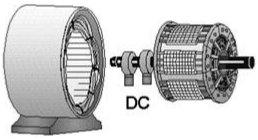
Synchronous Motor Operation

In start condition the magnetic field of the stator rotates so fast that the mechancial speed of rotor can not follow therefore an auxılary system should be integrated to rotor to gurantee proper operation.

That is a squirrel cage, in most of the motors rotor consistsi of both windings and conductor bars. The motor first starts as if it is an induction motor.

When the rotation speed of rotor approaches the synchronous speed the coil is powered via DC supply to form rotor electromagnet.

Eventually this electromagnet is locked with synchronous speed

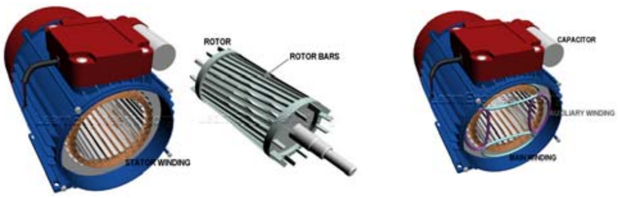


Mono Phase Induction Machine

Has only one stator coil. Uses only one phase.

Needs a unit to start to motor: Single phase induction motors require just one power phase for its operation.

Are used in applications needs 3 ~ 4 HP: They are commonly used in low power rating applications, in domestic as well as industrial use. (Fans, washing machines, household devices… etc.)



The principle of operation of single-phase induction motor can also be explained by double revolving field theory.

The single-phase supply given to the single-phase winding will produce pulsating field in the air gap. However, any pulsating field can be resolved into two components, equal in magnitude but oppositely rotating

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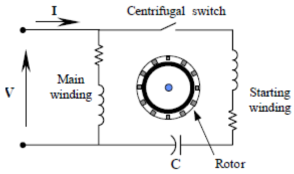
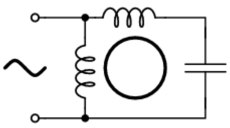
Mono Phase Induction Machine

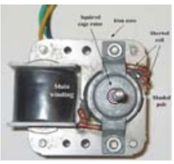
Starting methods for single-phase induction motors:

Single-phase split-phase motor

It shows the auxiliary winding also known as starting winding, in space quadrature with the main winding. The rotor is the squirrel-cage type. The starting winding is made of thin wire so that its impedance is different from that of the main winding. The two windings are connected in parallel to the ac supply. The phase difference between the two winding currents (about 30º) will be sufficient to produce a rotating magnetic field resulting in a starting torque.







Capacitor-start motors

If a capacitor is connected in series with the starting winding, the phase angle between the two winding currents will become more than 30º (about 80º) that is obtained in the split-phase motors. This increase in phase angle will increase the starting torque.

Shaded Pole motors