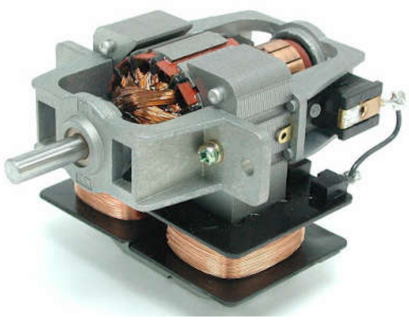
36.17 Universal Motor

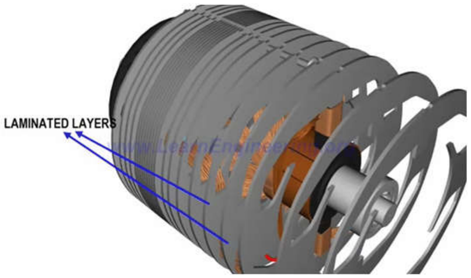
B. L. Theraja, A. K. Theraja, “A Textbook of ELECTRICAL TECHNOLOGY in SI Units **Volume II**, AC & DC Machines,” S. Chand & Company Ltd.

Universal Motors

Definition: A universal motor is defined as a motor which may be operated either on DC or single-phase AC supply at approximately the same speed and output. Universal motor is also called ac series motor.

A DC series motor can be operated as a universal motor by some modification such as entire magnetic circuit is laminated, turns of series field winding is reduced, high-resistance leads (brushes) are used.





Working Principal of Universal Motors

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.

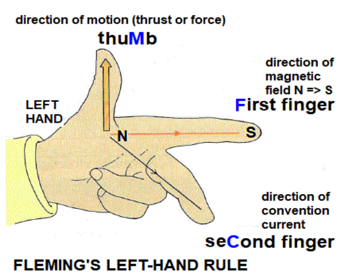
Due to this mechanical force, or torque, the rotor starts to rotate. The direction of this force is given by Fleming's left hand rule.

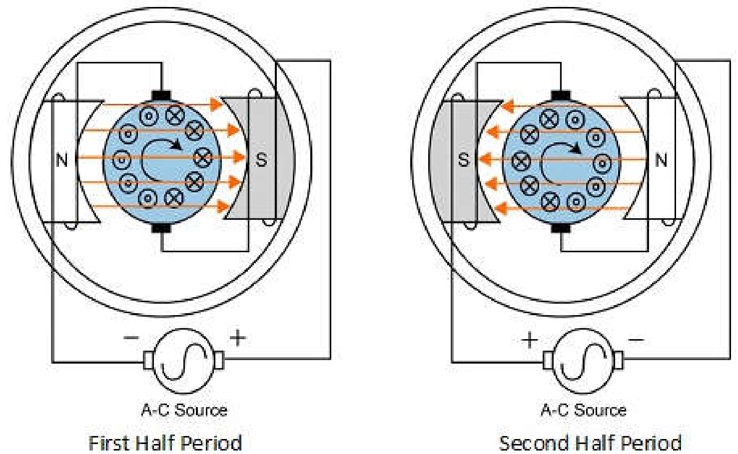
If the supply is DC, the polarity never reverses. So, we get the field and the current in the same direction always and hence a net force in a particular direction on the conductors due to which the rotor rotates.

If the supply is AC, the polarity changes between +ve and –ve. So, the direction of current and the Magnetic Field changes.

Since the field is connected in series with the Armature, both the armature current and field direction changes simultaneously and as a result, the resultant force always remains in the same direction.

Thus, even if the polarity is changed, the motor continues to run in the same direction.





https://www.youtube.com/watch?v=0PDRJKz-mqE

Characteristics of Universal Motors

- The speed of a universal motor varies just like that of a DC. series motor *i.e.* low at full-load and high on no-load (about 20,000 r.p.m. in some cases).
- In fact, on no-load the speed is limited only by its own friction and windage load.
- Fig. 36.48 shows typical torque characteristics of a universal motor both for DC. and AC supply.

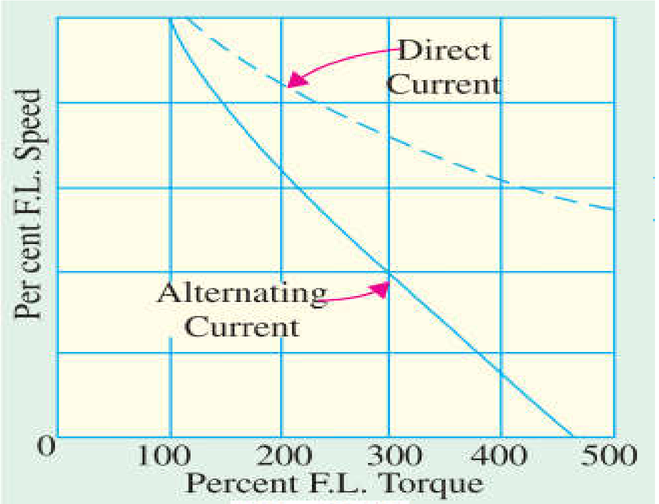
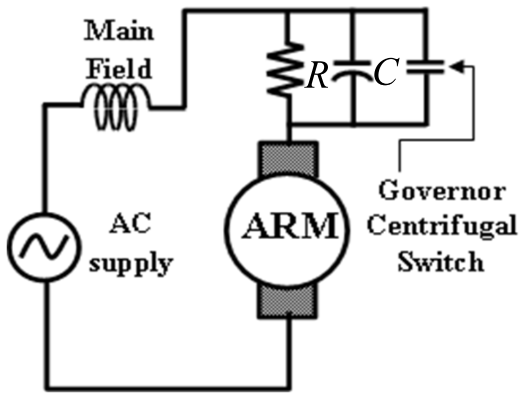


Fig. 36.48

Purpose of Governor Universal Motors

A governor (which is control the speed) may be used to maintain reasonable speeds since it is dangerous to operate at high no load speed. This governor consists of a ***centrifugal switch*** mounted on the shaft of the motor. The tension of the ***springs*** of the switch is adjusted so that the switch contacts open at a ***predetermined speed*** and thus place a ***resistor in series with the armature***, thereby reducing the speed. When the speed falls because of loading, the switch contacts close, thereby shorting out the series resistor, thus again raising the speed. The connections are shown in **Fig. 22.3**. The ***capacitor*** is placed across the governor contacts ***to reduce sparking***.



Advantages of Universal Motors

- High speed from above 3600 rpm to 25000 rpm
- High power output in small physical sizes to use in portable tools.
- High torque at low and intermediate speeds to carry a particularly severe load.
- Variable speed by adjustable governor by line voltage or especially by modern pulse technique.

Disadvantages of Universal Motors

- Increased service requirement due to use of brushes and commutators. The life of these parts is limited in severe service.
- Relatively high noise level at high speeds.
- Moderate to severe radio and television interference due to brush sparking.
- Requirement for careful balancing to avoid vibration.
- Requirement for reduction gearing in most portable tools.

Applications of Universal Motors

The universal motors have high-speed (and corresponding small size) and large starting torque. They can, therefore, be used to drive:

(***a***) High-speed vacuum cleaners

(***b***) Sewing machines

(***c***) Electric shavers, hair driers

(***d***) Drills

(***e***) Drink and food mixer, blender

(***f***) Machine tools etc.

Induction Motor
Chapter 34

B. L. Theraja, A. K. Theraja, "A Textbook of ELECTRICAL TECHNOLOGY in SI Units **Volume II**, AC & DC Machines," S. Chand & Company Ltd.

Construction of Induction Motor

An induction motor consists of two main parts:

(*a*) Stator (*b*) Rotor

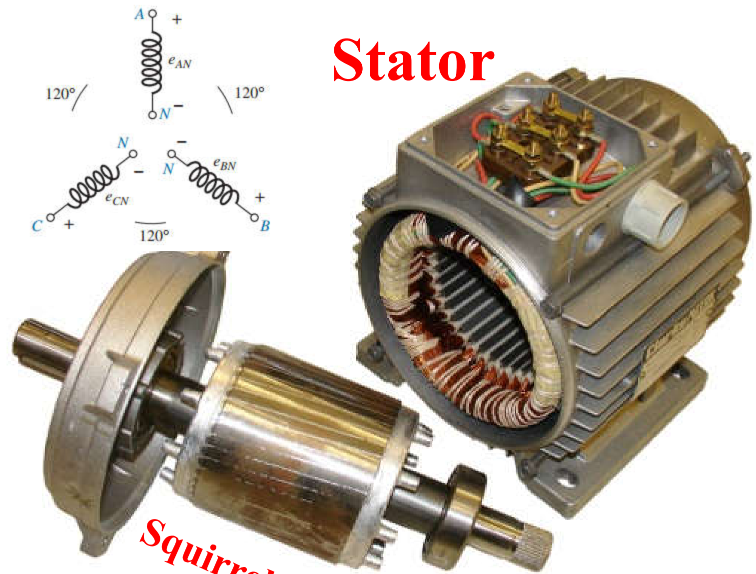
Stator

The stator carries a three-phase winding and is fed from a three-phase supply. It is wound for a definite number of poles, the exact number of poles being determined by the requirements of speed. Greater the number of poles, lesser the speed and ***vice versa***.

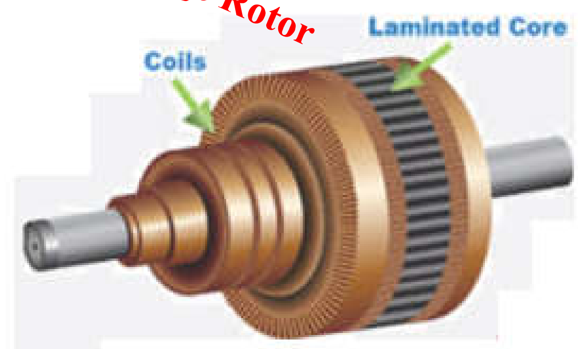
Rotor: The rotor of an induction is two type:

Squirrel-Cage Rotor: The squirrel-cage rotor consists of a cylindrical laminated core with parallel slots for carrying the rotor conductors. The rotor conductors are heavy bars of copper, aluminium or alloys. The rotor bars are permanently short-circuited by the two end-rings.

Phase-wound or Wound Rotor: This type of rotor is provided with three-phase double layer windings consisting of coils. One layer of winding permanently shorted, another layer winding connected with 3-slip rings to control externally from rotor side. The rotor is wound for as many poles as the number of stator poles.



Squirrel-Cage Rotor



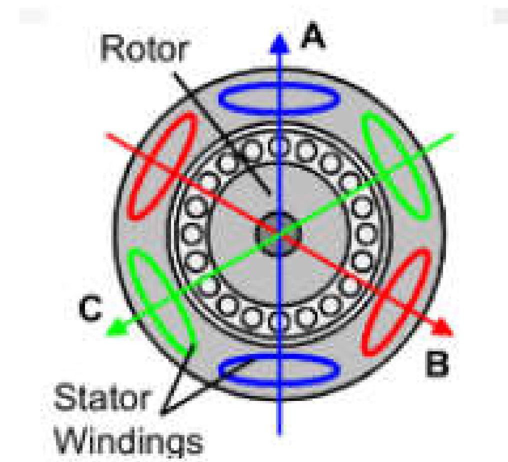
Phase-Wound or Wound Rotor

Working Principal of an Induction Motor

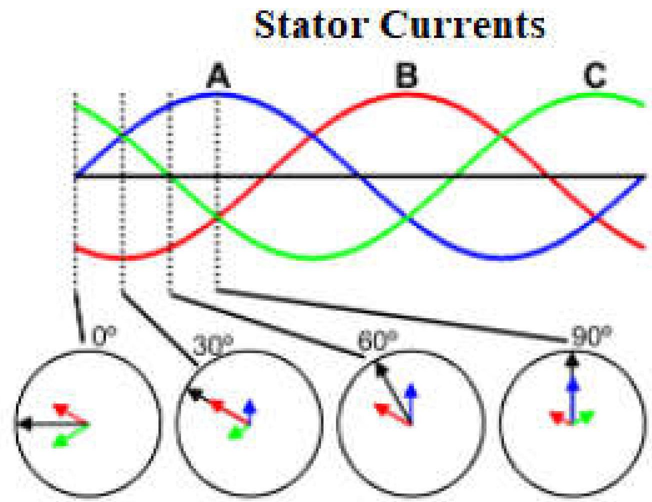
- When 3-phase stator winding is energized from a 3-phase supply, a rotating magnetic field is set up which rotates round the stator at synchronous speed [$N_s = 120f/P$].
- The rotating field cuts the rotor conductors. Due to the relative speed between the rotating flux and the stationary rotor, emfs are induced in the rotor conductors. Since the rotor circuit is short-circuited, currents start flowing in the rotor conductors.
- Since the current-carrying rotor conductors are placed in the magnetic field produced a mechanical force acts on the rotor conductors. The sum of the mechanical forces on all the rotor conductors produces a torque which tends to rotating the rotor in the same direction as that of stator field and tries to catch it.

Induction motor starts to run immediately supply the power. That's why three phase induction motor is a ***self-starting motor***.

The working principle of an induction motor is almost similar to a transformer except that the secondary side is rotating that's why an induction motor is also called ***rotating transformer***.



Motor Cross Section View



Synchronous Speed (N_s): The speed of rotating flux which is produced due to the supply of three-phase voltage in the stator of an induction motor is called synchronous speed.

$$N_s = \frac{120f}{P} \text{ [rpm]}$$

Slip Speed (N_{sl}) : The difference between synchronous speed (N_s) and the actual rotor speed (N) is called slip speed.

$$N_{sl} = N_s - N \text{ [rpm]}$$

Slip (s): The per-unit value of slip speed with respect to synchronous speed is called slip.

$$s = \frac{N_{sl}}{N_s} = \frac{N_s - N}{N_s} \qquad N = (1-s)N_s \qquad N_{sl} = sN_s$$

Under Running Condition

Frequency of Rotor Current (f_r): $f_r = sf$

Rotor Induced Voltage (E_r): $E_r = sE_2$

Rotor Reactance (X_r): $X_r = sX_2$

At standstill ($N = 0$) condition the value of slip, $s = 1$.

$$f_r = f \qquad E_r = E_2 \qquad X_r = X_2$$

If in an induction motor the rotor speed equal to the synchronous speed, no voltage will be induced in the rotor. No current and flux will be produced by the rotor circuit as well as the rotor will be rotated. So, the rotor speed of an induction motor is always less than the synchronous speed. That's why induction motor is also called ***asynchronous motor***.

Example 34.3. *A 4-pole, 3-phase induction motor operates from a supply whose frequency is 50 Hz. Calculate :*

(i) *the speed at which the magnetic field of the stator is rotating.*

(ii) *the speed of the rotor when the slip is 0.04.*

(iii) *the frequency of the rotor currents when the slip is 0.03.*

(iv) *the frequency of the rotor currents at standstill.*

Solution. **(i)** Stator field revolves at synchronous speed, given by

$$N_s = 120\, f/P = 120 \times 50/4 = \mathbf{1500\ r.p.m.}$$

(ii) rotor (or motor) speed, $N = N_s(1-s) = 1500(1-0.04) = \mathbf{1440\ r.p.m.}$

(iii) frequency of rotor current, $f' = sf = 0.03 \times 50 = 1.5\ \text{r.p.s} = \mathbf{90\ r.p.m}$

(iv) Since at standstill, $s = 1$, $f' = sf = 1 \times f = f = \mathbf{50Hz}$

Example 34.4. *A 3-ϕ induction motor is wound for 4 poles and is supplied from 50-Hz system. Calculate* **(i)** *the synchronous speed* **(ii)** *the rotor speed, when slip is 4% and* **(iii)** *rotor frequency when rotor runs at 600 rpm.*

Solution. (*i*) $N_s = 120\,f/P = 120 \times 50/4 = 1500$ rpm

(*ii*) rotor speed, $N = N_s(1-s) = 1500\,(1-0.04) =$ **1440 rpm**

(*iii*) when rotor speed is 600 rpm, slip is

$$s = (Ns - N)/N_s = (1500 - 600)/1500 = 0.6$$

rotor current frequency, $f' = sf = 0.6 \times 50 =$ **30 Hz**

Single Phase Induction Motor

Chapter 36

B. L. Theraja, A. K. Theraja, "A Textbook of ELECTRICAL TECHNOLOGY in SI Units **Volume II**, AC & DC Machines," S. Chand & Company Ltd.

A single-phase induction motor is, more or less, similar to a polyphase induction motor, except that: (*i*)

(*i*) its stator is provided with a single-phase winding and

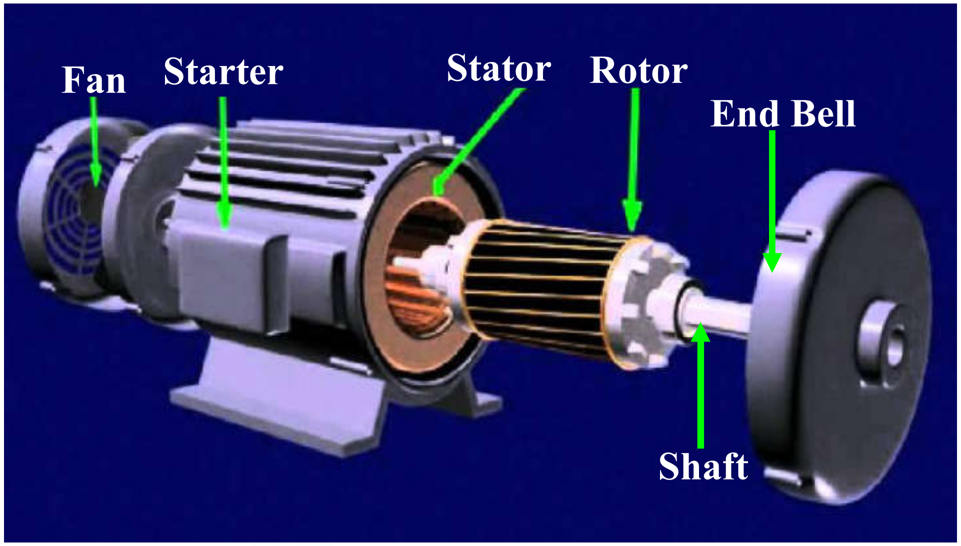
(*ii*) a centrifugal switch is used in order to cut out a winding, used only for starting purpose.

It has ***distributed stator winding*** and a ***squirrel-cage rotor***.

When fed from a single-phase supply, its stator winding produces an alternating flux which is ***not a synchronously rotating flux***.

An alternating or pulsating flux acting on a *stationary,* squirrel-cage rotor cannot produce rotation. That is why a single-phase motor is not ***self-starting***.

However, if the rotor of such a machine is given an initial start by hand (or small motor) or otherwise, *in either* direction, then immediately a torque arises and the motor accelerates to its final speed.



This peculiar behavior of the motor has been explained in two ways:

(*a*) **Two-field or double-field revolving theory**

(*b*) **Cross-field theory**

36.4 Making Single-Phase Induction Motor Self-Starting

To make a single-phase induction motor self-starting, the stator is provided with an extra winding known as ***starting*** (or ***auxiliary***) winding, in addition t the ***main*** (or ***running***) winding.
Two winding are connected in parallel across the supply and they are spaced 90° electrically apart.

It is arranged that the phase difference between the currents in the two stator windings is very large (ideal value is 90°). Hence, the motor behaves like a two-phase motor. These two currents produce a revolving flux and hence make the motor self starting.

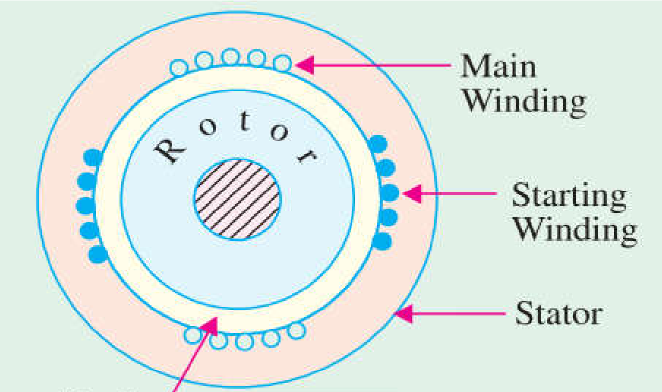


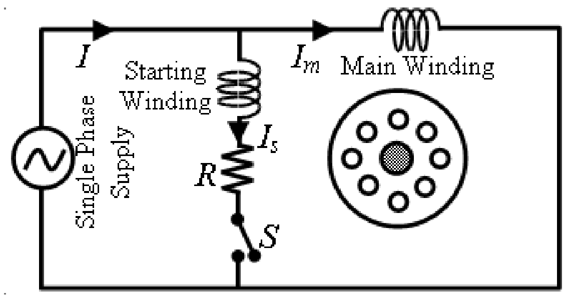
Fig. 36.4

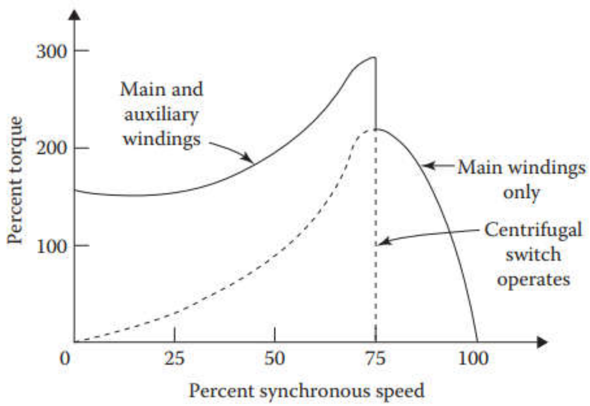
Classification of Single-Phase Induction Motor

Single-phase induction motors are categorized based on the methods used to start them. Each starting method differs in cost and in the amount of starting torque it produces.

1. Split-Phase (or resistance-start) Motor
2. Capacitor-Start Motor
3. Capacitor-Run Motor
4. Capacitor-Start Capacitor-Run Motor
5. Shaded-Pole Motor

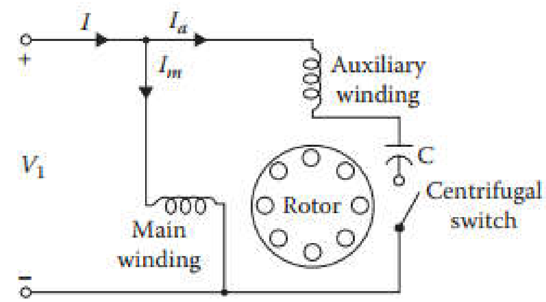
Split-Phase (or resistance-start) Motor

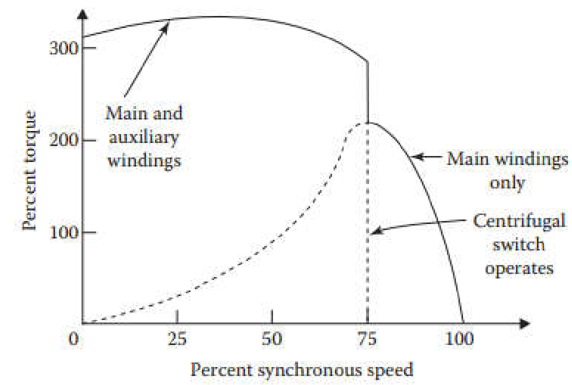




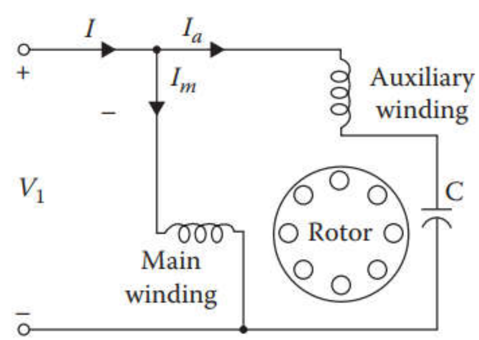
The auxiliary winding may be disconnected automatically by the operation of a centrifugal switch at about 75% of synchronous speed. Once the motor is started, it continues to run in the same direction.

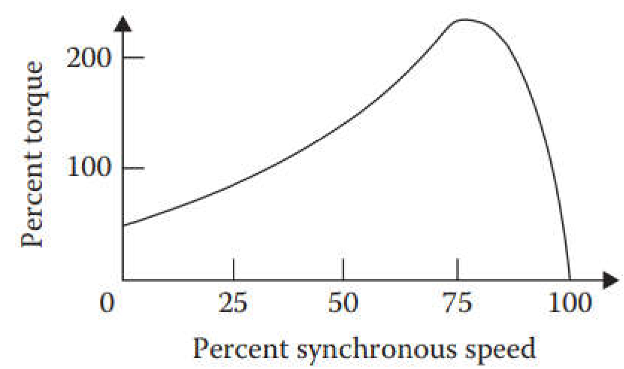
Capacitor Start Motor





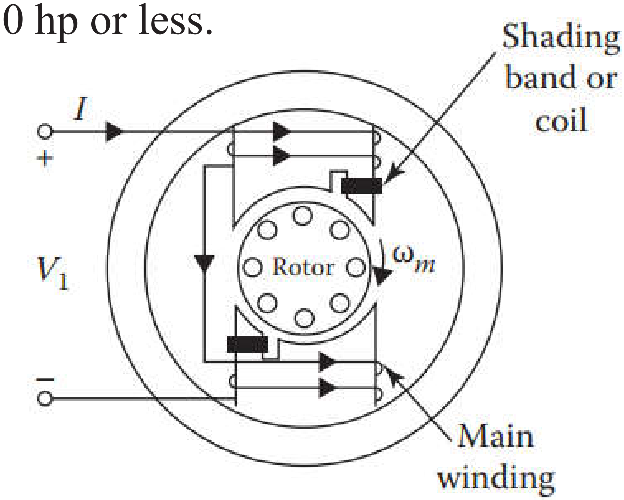
Capacitor Run Motor



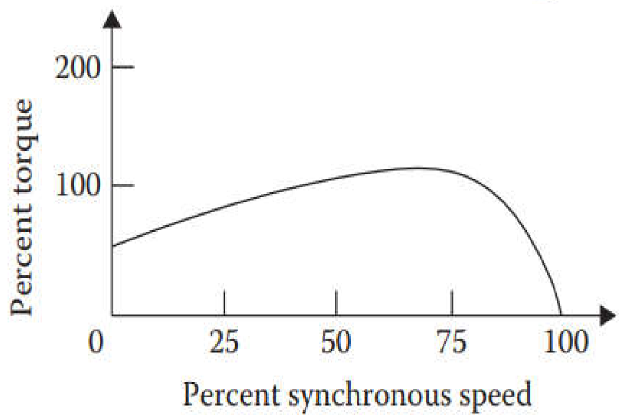


Shaded-Pole Motor

The shaded-pole induction motor is used widely in applications that require 1/20 hp or less.



As shown in the following figure, the motor has a salient-pole construction, with one-coil-per-pole main windings, and a squirrel-cage rotor.
One portion of each pole has a shading band or coil.
The shading band is simply a short-circuited copper strap (or single-turn solid copper ring) wound around the smaller segment of the pole piece.
The current induced in the shading band causes the flux in the shaded portion of the pole to lag the flux in the unshaded portion of the pole.



Therefore, the flux in the unshaded portion reaches its maximum before the flux in the shaded portion.
The result is like a rotating field moving from the unshaded to the shaded portion of the pole, and causing the motor to produce a slow starting torque.
The shaded-pole motor is rugged, cheap, small in size, and needs minimum maintenance.
It has very ***low starting torque, efficiency, and power factor***, and is used in ***turntables, motion-picture projectors, small fans, and vending machines***.

Synchronous Generator [Alternator]

Chapter 37

B. L. Theraja, A. K. Theraja, “A Textbook of ELECTRICAL TECHNOLOGY in SI Units **Volume II**, AC & DC Machines,” S. Chand & Company Ltd.

Synchronous Generator Or Alternator

Almost whole of the world, all ***three-phase power*** is generated by synchronous machines operated as generators. Synchronous generators are also called **alternators** and are large machines producing electrical power at hydro, nuclear, or thermal power plants.

Synchronous generators rated in excess of **1000 MVA** are quite commonly used in generating stations.

The term ***synchronous*** refers to the fact that these machines ***operate at constant speeds and frequencies***.

A given synchronous machine can operate as a ***generator*** or as a ***motor***.

Such machines are used as motors in constant-speed drives in ***industrial applications*** and also for ***pumped-storage stations***.

In small sizes with only fractional horsepower, they are used in ***electric clocks***, ***timers***, ***record players***, and in other applications which ***require constant speed***.

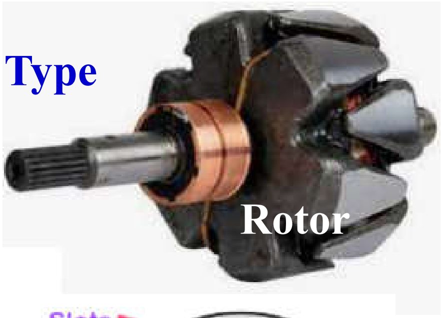
Construction of a Synchronous Generator Or an Alternator

In a synchronous machine, the **armature winding** is on the **stator** and the **field winding** is on the rotor.

Stator: The stator consist of a cast-iron frame, which supports the armature core, having ***slots on its inner periphery*** for housing the armature conductors.

Rotor: Rotor consists of electromagnet which have the same number of poles as the stator winding. The rotor winding is supplied from ***an external dc source*** (or converted induced emf in alternator dc voltage using rectifier) through slip rings and brushes. There are two types rotor constructions as follows:

(*i*) **Salient (or projecting) Pole Type** , and (*ii*) **Smooth Cylindrical or Non-salient pole Type**



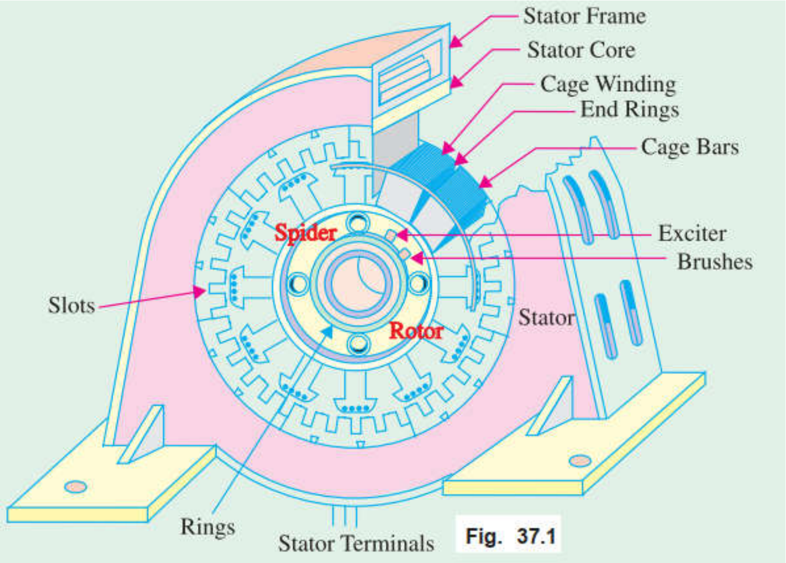
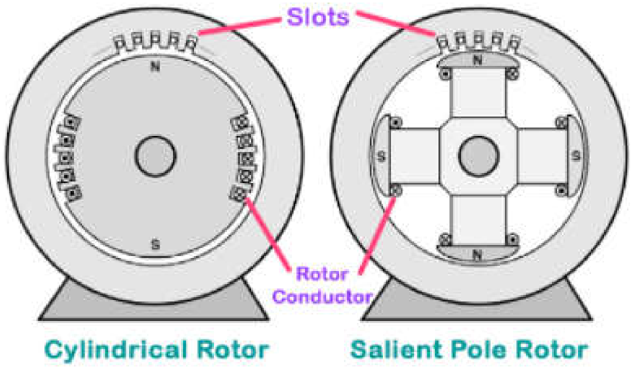


Fig. 37.1



Working Principal of a Synchronous Generator Or an Alternator

When the rotor rotates by applying the mechanical energy, the stator conductors (being stationary) are cut by the magnetic flux, hence they have induced emf produced in individual winding.

Because the magnetic poles are alternately *N* and *S*, they induce an emf and hence current in armature conductors, which first flows in one direction and then in the other.
Hence, an alternating emf is produced in the stator conductors:

(*i*) whose frequency depends on the number of *N* and *S* poles moving past a conductor in a one second, and
(*ii*) whose direction is given by Fleming's Right-hand rule

37.6 Speed and Frequency of an Alternator

The frequency of an alternator can relate with the speed as follows:

$$\text{Frequency}: \quad f = \frac{P}{2} \times \frac{N(\text{rpm})}{60} = \frac{PN(\text{rpm})}{120} \ \text{Hz} \quad \text{or} \quad f = \frac{P}{2} N(\text{rps}) \ \text{Hz}$$

where, P = total number of magnetic poles

N = rotating speed of the rotor

f = frequency of generated emf in Hz

It is clear from the above that for slower engine driven alternators, their number of poles is much greater as compared to that of the turbo-generators, which run at very high speeds.

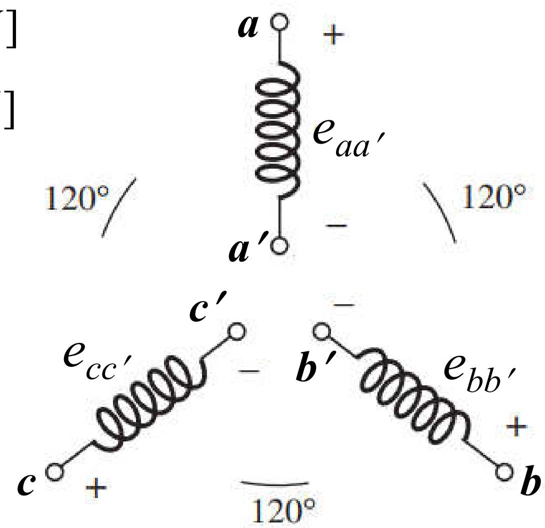
Equation of Induced EMF

The three-phase induced emf in an alternator can be given by:

$$e_{aa'} = E_{\max}\sin\omega t = \sqrt{2}E_{ph}\sin\omega t \quad [\text{V}]$$

$$e_{bb'} = E_{\max}\sin(\omega t - 120^\circ) = \sqrt{2}E_{ph}\sin(\omega t - 120^\circ) \quad [\text{V}]$$

$$e_{cc'} = E_{\max}\sin(\omega t + 120^\circ) = \sqrt{2}E_{ph}\sin(\omega t + 120^\circ) \quad [\text{V}]$$



where, $E_{ph} = 4.44k_c k_d f\Phi T = 4.44k_w f\Phi T$

$$E_{\max} = \sqrt{2}E_{ph}$$

E_{ph} = RMS value of per phase voltage

Φ = Flux/pole [Wb]

T = Number of coils or turns/phase

$f = (PN_s/120)$ Frequency in Hz

N_s = Rotor speed in rpm

$k_w = k_c k_d$ = winding factor

k_c or k_p = Pitch or chord factor [see 37.11]

k_d = Distribution factor [see 37.12]

Example: A 3-phase, 16 poles alternator has star-connected winding with 240 turns coil in each phase. The flux per pole is 0.03 Wb and the speed is 375 rpm. Its stator winding factor is 0.96. Find (***i***) the frequency, (ii) the rms value of phase voltage and line voltage of this generator, and (***iii***) the three phase voltages as a function of time.

Solution: Given, $P = 16$, $T = 240$, $\Phi = 0.03$ Wb. $N_s = 375$ rpm and $k_w = 0.96$.

$$(\boldsymbol{i})\ f = \frac{PN}{120} = \frac{16\times 375}{120} = 50\text{ Hz}$$

$$(\boldsymbol{ii})\ E_{ph} = 4.44 k_w f \Phi T = 4.44\times 0.96\times 50\times 0.03\times 240 = 1534.46\text{ V}$$

$$E_L = \sqrt{3}E_{ph} = \sqrt{3}\times 1534 = 2657.76\text{ V}$$

$$(\boldsymbol{iii})\ E_{\max} = \sqrt{2}E_{ph} = \sqrt{2}\times E_{ph} = \sqrt{2}\times 1534.46 = 2170\text{ V} \qquad \omega = 2\pi f = 2\times 3.14\times 50 = 314\text{ rad/s}$$

$$e_{aa'} = 2170\sin 314t\ \text{ V}$$

$$e_{bb'} = 2170\sin(\omega t - 120^\circ)\ \text{ V}$$

$$e_{cc'} = 2170\sin(\omega t + 120^\circ)\ \text{ V}$$

Practice Problem: A 3-phase, 16 poles alternator has star-connected winding with 96 turns coil in each phase. The flux per pole is 5×10^{-2} Wb and the speed is 450 rpm. Its stator pitch factor is 0.966 and distribution factor is 0.96. Find (***i***) the frequency, (ii) the rms value of phase voltage and line voltage of this generator, and (***iii***) the three phase voltages as a function of time.

Synchronous Motor

Some characteristic features of a synchronous motor:

1. **It runs either at synchronous speed or not at all**.
2. **It is not inherently self-starting**.
3. **It is capable of being operated under a wide range of power factors, both lagging and leading**.

38.1 Synchronous Motor - General

A synchronous motor is electrically identical with an alternator or AC generator.

A given alternator (or synchronous machine) can be used as a motor, when driven electrically.

Some characteristic features of a synchronous motor are as follows:

1. **It runs either at synchronous speed or not at all** *i.e.* while running it maintains a constant speed. The only way to change its speed is to vary the supply frequency (because N_S=120f/P).

2. **It is not inherently self-starting**. It has to be run up to synchronous (or near synchronous) speed by some means, before it can be synchronized to the supply.

3. **It is capable of being operated under a wide range of power factors, both lagging and leading**. Hence, it can be used for power correction purposes, in addition to supplying torque to drive loads.

38.2 Working Principal of Synchronous Motor

When a 3-phase winding is fed by a 3-phase supply, then a magnetic flux of constant magnitude but *rotating* at synchronous speed, is produced.

Consider a two-pole stator of **Fig. 38.2**, in which are shown two stator poles (marked N_S and S_S) rotating at synchronous speed say, in clockwise direction.

Since the two similar poles, N (of rotor) and N_S (of stator) as well as S and S_S will repel each other, the rotor tends to rotate in the anti-clockwise direction.

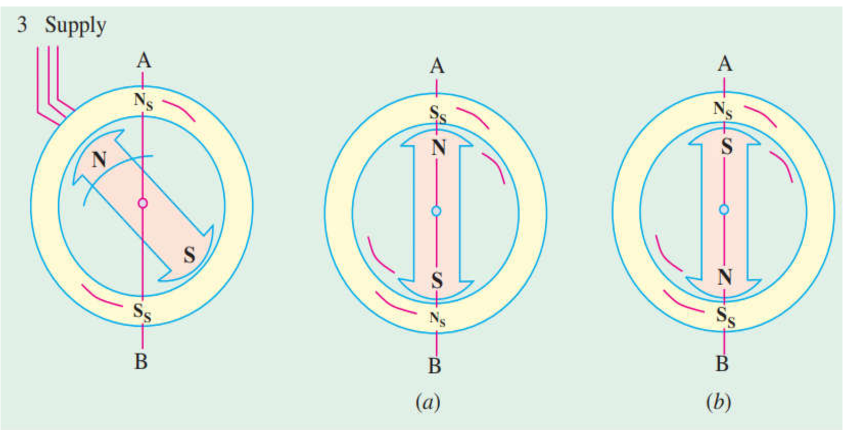


Fig. 38.2 Fig. 38.3 Fig. 38.3

But half a period latter, stator poles, having rotated around, interchange their position *i.e.* N_S is at position B and S_S at point A. under these conditions, N_S attracts S and S_S attracts N and rotor tends to rotate clockwise.

Hence, we find that due to continuous and rapid rotation of stator poles, the rotor is subjected to torque which tends to move it first in one direction and then in the opposite direction.

Owing to its large inertia, the rotor cannot instantaneously respond to such quickly reversing torque, with the result that it remains stationary.

Now, consider the condition shown in **Fig. 38.3**(a) where the stator and rotor poles are attracting each other.

Suppose that the rotor is not stationary, but it is rotating clockwise, with such a speed that turns through one pole-pitch by the time the stator poles interchange their positions, as shown in Fig. 38.3(b).

Here, again the stator and rotor poles attract each other.

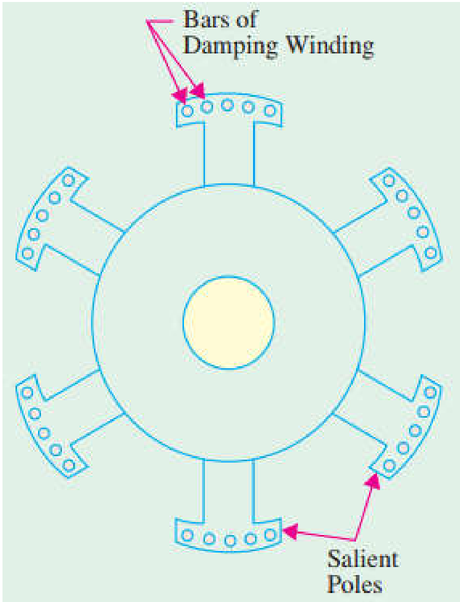
It means that if the rotor poles also shift their positions along with the stator poles, then they will continuously experience a unidirectional torque *i.e.* clockwise torque, as shown in Fig. 38.3.

38.3 Method of Staring of Synchronous Motor

There are several methods to start the synchronous motor such as:

(***a***) Auxiliary drive (induction motor or dc motor)

(***b***) Induction start (using damper winding), etc



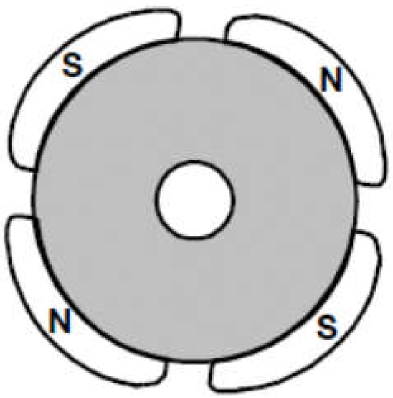
Permanent Magnet Synchronous Motor (PMSM)

B. L. Theraja, A. K. Theraja, “A Textbook of ELECTRICAL TECHNOLOGY in SI Units **Volume II**, AC & DC Machines,” S. Chand & Company Ltd.

Definition: A permanent magnet synchronous motor (PMSM) is a motor that uses permanent magnets to produce the air gap magnetic field rather than using electromagnets.

Construction: The permanent magnet synchronous motor construction is similar to the basic synchronous motor, ***but the only difference is with the rotor***. The rotor doesn't have any field winding, but the permanent magnets are used to create field poles.
Based on the mounting of the permanent magnet on the rotor, the construction of a permanent magnet synchronous motor is divided into two types.

Surface-mounted PMSM: In this construction, the magnet is mounted on the surface of the rotor. It is suitable for high-speed devices like robotics and tool drives. No reluctance torque. Less robust motor.



Buried PMSM or Interior PMSM: In this type of construction, the permanent magnet is embedded into the rotor. It is suitable for high-speed applications and gets robustness. Reluctance torque is due to the saliency of the motor.

Working Principal:

The permanent magnet synchronous motor working principle is similar to the synchronous motor. It depends on the rotating magnetic field that generates electromotive force at synchronous speed. When the stator winding is energized by giving the 3-phase supply, a rotating magnetic field is created in between the air gaps.

This produces the torque when the rotor field poles hold the rotating magnetic field at synchronous speed and the rotor rotates continuously. These motors are not self-starting motors, it is necessary to provide a variable frequency power supply.

Advantages:

The advantages of PMSM are:

- Provides higher efficiency at high speeds
- Available in small sizes at different packages
- Maintenance and installation is very easy than an induction motor
- Capable of maintaining full torque at low speeds.
- High efficiency and reliability
- Gives smooth torque and dynamic performance

Disadvantages:

The disadvantages of PMSM are:

- These type of motors are very expensive when compared to induction motors
- Somehow difficult to start-up because they are not self-starting motors.

Applications:

The PMSMs applications are:

Air conditioners, Refrigerators, AC compressors

Washing machines, which are direct-drive

Automotive electrical power steering

Large power systems to improve leading, and lagging power factor

Machine tools, Control of traction

Data storage units, Servo drives

Industrial applications like robotics, aerospace, and many more.

Reluctance Motor

B. L. Theraja, A. K. Theraja, “A Textbook of ELECTRICAL TECHNOLOGY in SI Units **Volume II**, AC & DC Machines,” S. Chand & Company Ltd.

Definition: A reluctance motor is a synchronous motor similar in construction to an induction motor, in which the member carrying the secondary circuit has the salient poles, without dc excitation. It starts as an induction motor but operates normally at synchronous speed.

Construction: A reluctance motor consists of:

(*i*) **A stator** carrying a single-phase winding along with an auxiliary winding to produce a synchronous-revolving magnetic field.

(*ii*) **A squirrel-cage rotor** having unsymmetrical magnetic construction. This is achieved by symmetrically removed some of the teeth from the squirrel-cage rotor to produce salient poles on the rotor as shown in the following figure. The rotor carries the short-circuited copper or aluminium bars and it acts as a squirrel cage rotor of an induction motor. If an iron piece is placed in a magnetic field, it aligns itself in a minimum reluctance position and gets locked magnetically.

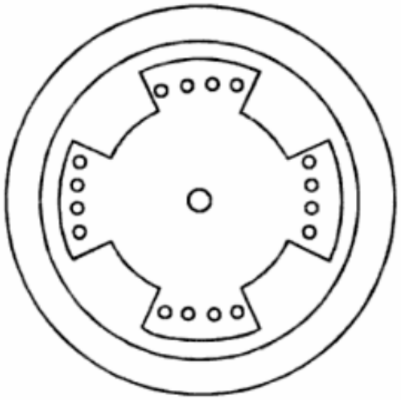
Working Principal:

When power supply to stator rotating magnetic field is produced. The speed of this field is synchronous speed.

Rotor start to rotate like an induction motor due short-circuited copper or aluminium bars on the rotor.

When the rotor speed is about synchronous, stator magnetic field pulls rotor into synchronism i.e. minimum reluctance position and keeps it magnetically locked.

Then rotor continues to rotate with a speed equal to synchronous speed. Such a torque exerted on the rotor is called the *reluctance torque*. Thus finally the reluctance motor runs as a synchronous motor.



Advantages:

The reluctance motor has following advantages:

- No dc supply is necessary for rotor
- Constant speed characteristics
- Robust construction
- Less maintenance

Disadvantages:

The reluctance motor has following disadvantages:

- Less efficiency
- Poor power factor
- Need to very low inertia rotor
- Less capacity to drive the loads

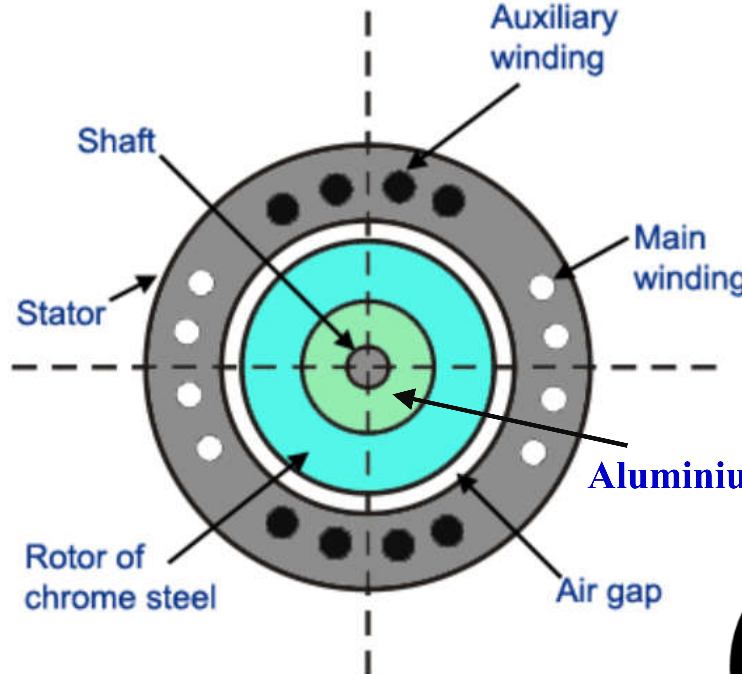
Application:

Reluctance Motor is used in signaling devices, control apparatus, automatic regulators, recording instruments, clock and all kinds of timing device, teleprinter, gramophone etc.

Hysteresis Motor

Definition: A hysteresis motor is a synchronous motor having ***cylindrical rotor*** starts by virtue of the hysteresis losses induced in its hardened steel secondary member by the revolving filed of the primary and operates normally at synchronous speed and runs on hysteresis torque because of the retentivity of the secondary core.
It is a single-phase motor whose operation depends upon the hysteresis effect i.e., magnetization produced in a ferromagnetic material lags behind the magnetizing force.

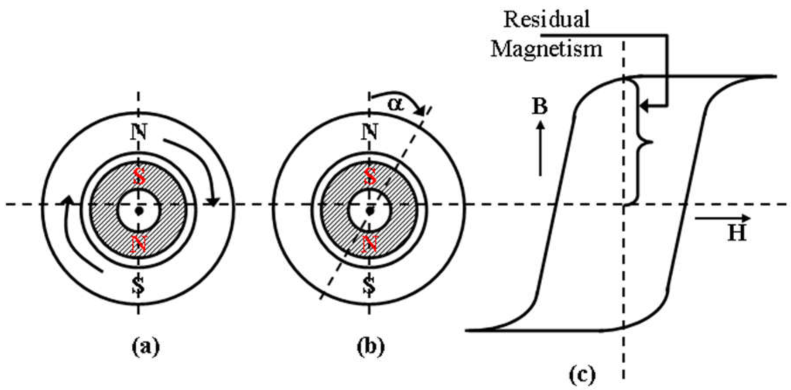
Construction: A reluctance motor consists of:
(***i***) **A stator** carrying a single-phase winding along with an auxiliary winding to produce a synchronous-revolving magnetic field. Shaded pole also can be used to produce revolving magnetic field.
(***ii***) **A rotor** of hysteresis motor is made of magnetic material (such as chrome, cobalt steel or alnico or alloy) that has high hysteresis loss due to large area of hysteresis loop.
Magnetic cylindrical portion of the rotor is assembled over shaft through ***arbor of non-magnetic material like brass***.



Working Principal:

When power is supply to stator, a rotating magnetic field is produced. The speed of this field is synchronous speed. The rotor, initially, starts to rotate due to eddy-current torque and hysteresis torque developed on the rotor. Once the speed is near about the synchronous, the stator pulls rotor into synchronism and eddy-current loss is vanishes.

Due to the hysteresis effect, rotor pole axis lags behind the axis of rotating magnetic field as shown in the following Figures. When the stator field moved forward, due to high residual magnetism (i.e. retentivity) the rotor pole strength remains maintained. So higher the retentivity, higher is the hysteresis torque. The high retentivity ensures the continuous magnetic locking between stator and rotor.



Advantages:

The advantages of hysteresis motor are:

1. No mechanical vibrations.
2. Operation is quiet and noiseless.
3. Suitability to accelerate inertia loads.
4. Possibility of multispeed operation by employing gear train.

Disadvantages:

The disadvantages of hysteresis motor are:

1. The output is about one-quarter that of an induction motor of the same dimension.
2. Low efficiency, power factor, torque
3. Available in very small sizes

Applications:

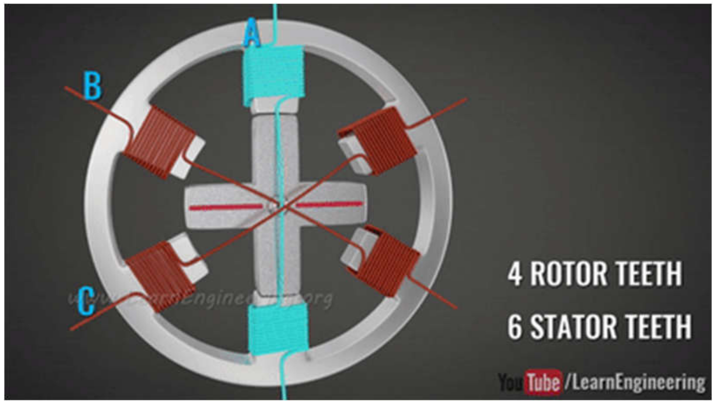
Due to noiseless operation it is used in sound recording instruments, sound producing equipments, high quality record players, electric clocks, teleprinters, timing devices etc.

Stepper Motor
Chapter 39

B. L. Theraja, A. K. Theraja, “A Textbook of ELECTRICAL TECHNOLOGY in SI Units **Volume II**, AC & DC Machines,” S. Chand & Company Ltd.

39.2 Stepper Motor

- Stepper motors (often referred as stepping or step motors) are operate on **discrete control pulses received and rotate in discrete (angular rotation) steps**.
- A stepper motor **rotates in fixed steps of a certain number of degrees**.
- Stepping motors are ideally suited for situations where either **precise positioning or precise speed control or both are required**.
- The stepper motor is **quite robust and reliable**.
- Since it rotates of discrete angular intervals or steps, one step being taken each time a command pulse is received, the stepper motor **well-suited for open-loop position control**.
- Develop torque of this type of motor is from 1 μNm to 40 Nm
- The output power ranges from 1 W to maximum of 2500 W.



Step Angle (β):

The angle through which the motor shaft rotates each command pulse is called the step angle (β). Smaller the step angle, greater the number of steps per revolution and higher the resolution or accuracy of positioning obtained. The step angles can be as small as 0.72° or as large as 90°.
The common step size are 1.8°, 2.5°, 7.5° and 15°.

$$\beta = \frac{(N_s - N_r)}{N_s N_r} \times 360°$$

$$\beta = \frac{360°}{m N_r}$$

N_s : Number of Stator poles (teeth)
N_r : Number of Rotor poles (teeth)
m : Number of stator phases

Resolution:

Resolution is the number of steps needed to complete one revolution of the rotor shaft.

$$\text{Resolution} = \frac{\text{No. of steps}}{\text{revolution}} = \frac{360°}{\beta}$$

Mathematical Expression of Shaft Speed (n):

$$n = \frac{\beta \times f}{360} \text{ rps} = \text{Pulse Frequency Resolution}$$

f : Stepping frequency)or pulse rate) in pulses per second (pps)

Slewing:

Operation of a stepper motor at high speed is called slewing.
A stepper motor has ability to operate at very high stepping rates (upto 20,000 steps per second).
When the pulse rate is high, the shaft seems continuous.

Example 39.1: A hybrid VR stepping motor has a 8 main poles which have been castleated to have 5 teeth each. If rotor has 50 teeth, calculate the steeping angle.

Solution: Given, $N_s = 8 \times 5 = 40$; $N_r = 50$;

$$\beta = \frac{(50-40)}{50 \times 40} \times 360° = 1.8°$$

Example 39.2: A stepper motor has a steep angle of 2.5°. Determine (***a***) the resolution, (***b***) the number of steps required for the shaft to make 25 revolutions, and (***c***) the shaft speed, if the steeping frequency is 3600 rps.

Solution:

(***a***) Resolution = 360°/β = 360°/2.5° = 144 steps/revolution

(***b***) Steps for 25 revolutions = 144 × 25 = 3600 steps

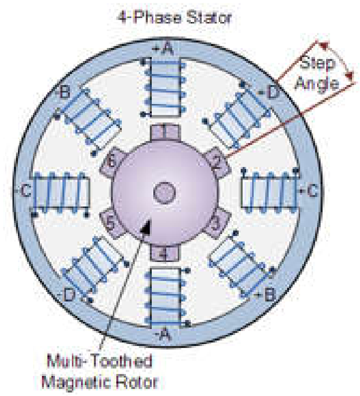
(***c***) Shaft speed: $n = \frac{\beta \times f}{360} = \frac{2.5 \times 3600}{360} = 25$ rps

Example 39.1.1: For the following stepping motor, calculate the steeping angle.

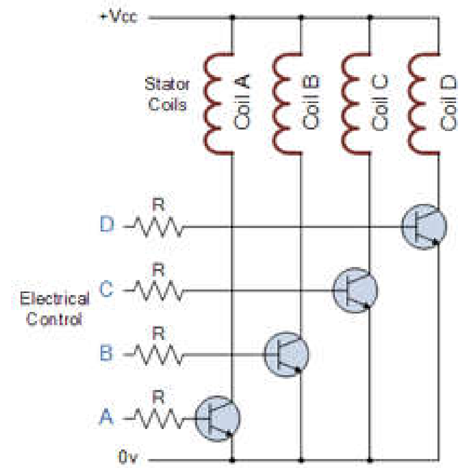
Solution: Given, $N_s = 8$; $N_r = 6$; and $m = 4$

$$\beta = \frac{N_s - N_r}{N_s N_r} \times 360° = \frac{(8-6)}{8 \times 6} \times 360° = 15°$$

$$\beta = \frac{360°}{mN_r} = \frac{360°}{4 \times 6} = 15°$$



Construction



Control circuit

Advantages of Stepper Motor:

- Stepper motor control is pretty simple. The motor does need a driver, but does not need complex calculations or tuning to work properly. In general, the control effort is lower compared to other motors. With microstepping, you can reach high position accuracy, up to approximately 0.007°.
- Due to their internal structure, stepper motors do not require a sensor to detect the motor position. Since the motor moves by performing "steps," by simply counting these steps, you can obtain the motor position at a given time.
- Simplicity of construction and low maintenance cost are other advantages.
- Very reliable since there are no contact brushes in the motor.
- Stepper motors offer good torque at low speeds, are great for holding position, and also tend to have a long lifespan.

Disadvantages of Stepper Motor:

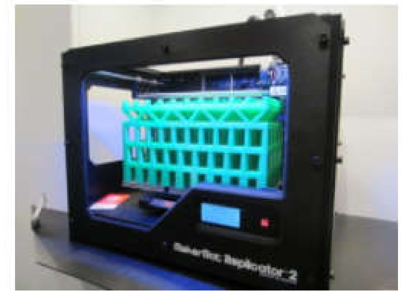
- It requires more amount of current than a normal dc motor.
- Not easy to operate at extremely high speeds.
- They can miss a step if the load torque is too high. This negatively impacts the control, since there is no way to know the real position of the motor. Using microstepping makes stepper motors even more likely to experience this issue.
- These motors always drain maximum current even when still, which makes efficiency worse and can cause overheating.
- Stepper motors have low torque and become pretty noisy at high speeds.
- Finally, stepper motors have low power density and a low torque-to-inertia ratio.

Applications of Stepper Motor:

- Stepper motors are used for in motion-controlled positioning system as it is easy to produce precise position control with the help of computer-controlled stepper motors.
- They are widely used in biomedical equipment where precise and accurate position control is needed.
- Stepper motors are also present in disc drivers, computer printers and scanners, intelligent lighting, camera lenses.
- Stepper motors are preferred in robotics because of their precision characteristic.
- Because of its high reliability and precision, 3D cameras, X Y Plotters, CNC and some other camera platforms also impart stepper motors.

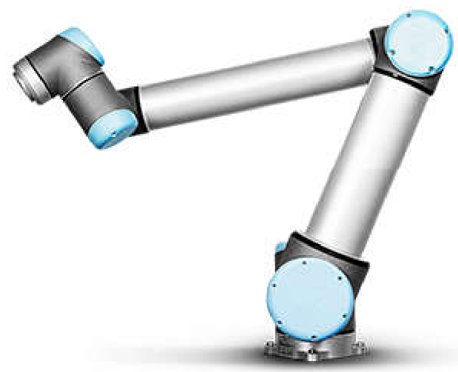

Video Cameras: Pan, Tilt, Zoom, Focus

ATM Machines: Bill Movement, Tray Elevators


3D Printers: XY Table Drive, Media Drive

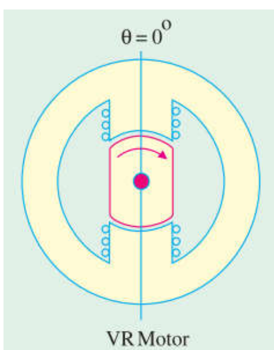
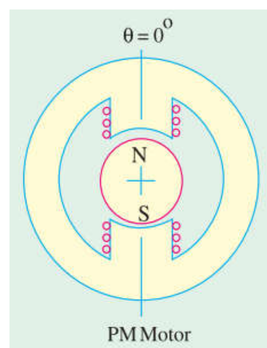
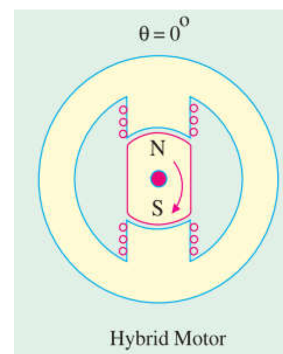

Printers: Printheads, Paper Feed, Scan Bar


Engraving Machines: XY Table Motion


Robots: Arms, End Effectors

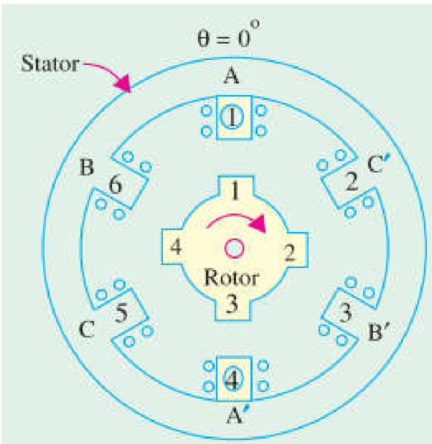

CNC machines

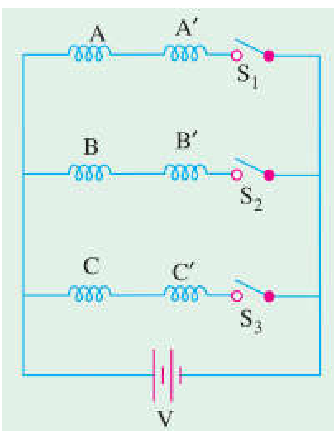
Types of Stepper Motors

	Variable Reluctance Steeper Motor	Permanent Magnet Stepper Motor	Hybrid Stepper Motor
Stator:	All of there types of stepper motor, Stator poles are created by wounding the wires/coils.		
Rotor:	Rotor poles are made of a ferromagnetic materials	Rotor poles are made of permanent magnet	Rotor poles are made of permanent magnet
Reluctance:	Varies with the angular position of the rotor.	Not varied due to the cylindrical shape rotor	Varies with the angular position of the rotor.
Direction of Rotation:	Independent of the polarity of the stator current	Dependent of the polarity of the stator current	Independent of the polarity of the stator current
	 Salient pole rotor	 Non-salient *i.e.* cylindrical pole rotor	 Salient pole rotor

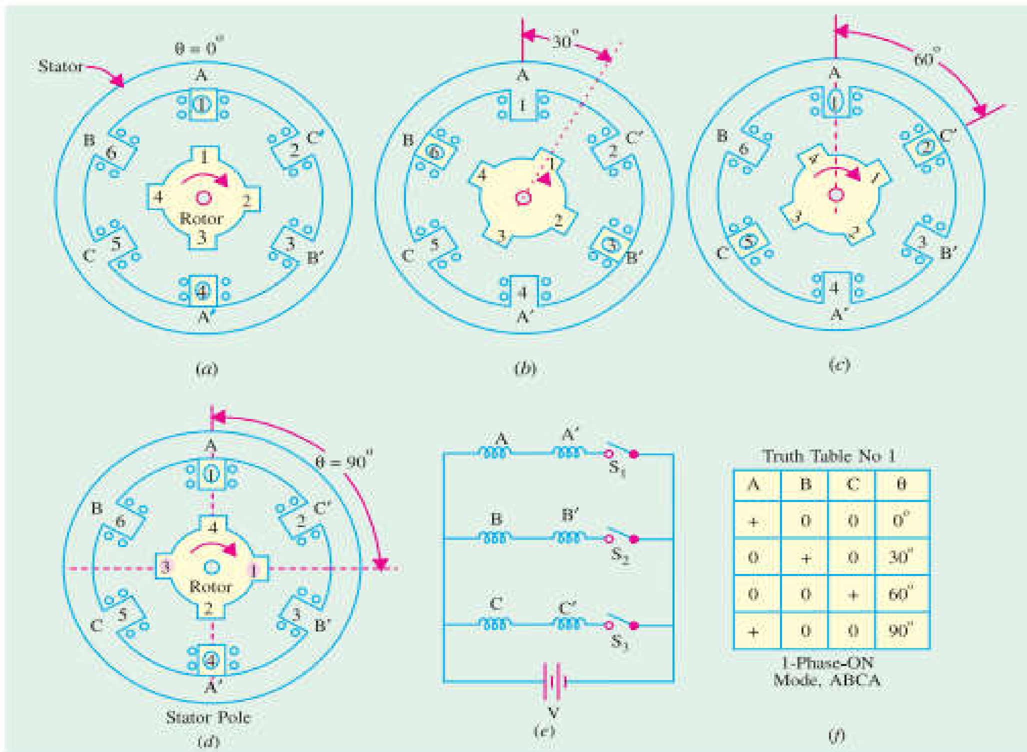
Operation of Variable Reluctance Stepper Motors

39.4 Full Step Operation





One (1)–Phase ON



Truth Table No 1

A	B	C	θ
+	0	0	0°
0	+	0	30°
0	0	+	60°
+	0	0	90°

1-Phase-ON Mode, ABCA

Fig. 39.2

Two (2)–Phase ON

Truth Table No. 2

A	B	C	
+	+	0	15°
0	+	+	45°
+	0	+	75°
+	+	0	105°

2 Phase-ON Mode
AB, BC, CA, AB

Half Step or One (1)–Phase ON and Two (2)–Phase ON Operation

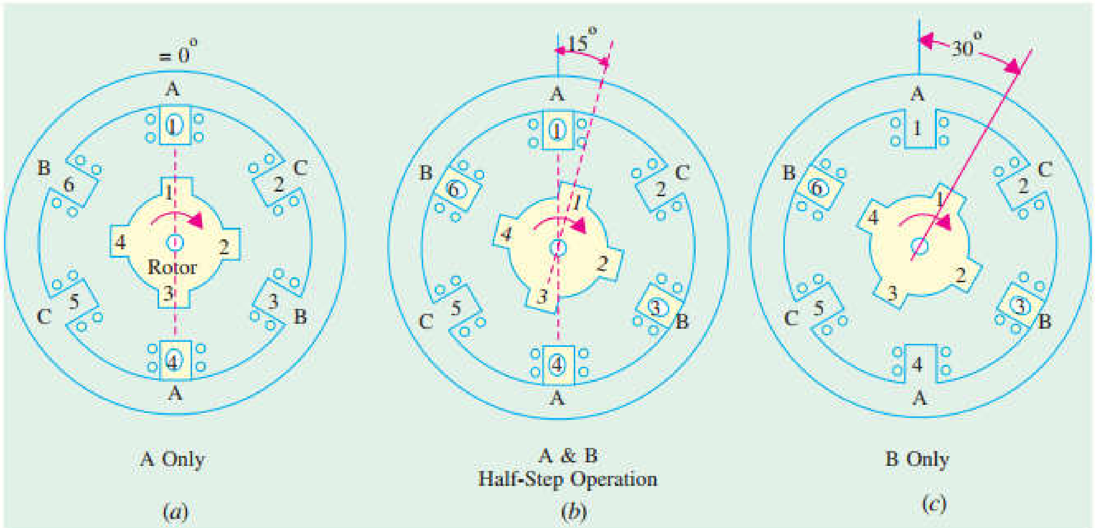


Fig. 39.4

Truth Table No. 3

	A	B	C		
A	+	0	0	0°	
	+	+	0	15°	AB
B	0	+	0	30°	
	0	+	+	45°	BC
C	0	0	+	65°	
	+	0	+	75°	CA
A	+	0	0	90°	

Half-Stepping Alternate
1-Phase-On &
2-Phase-on Mode
A, AB, B, BC, C, CA, A

Micro/Mini Stepping Operation

In this operation two-phase mode is used but the two current deliberately made unequal.

The current of Phase H is held constant while that in phase B is increased in very small increments until maximum current is reached.

The current in phase A is then reduced to zero using same very small increments. In this way, the resultant step becomes very small.

39.22 Servo Motor

Servomotors are also called control motors and have high-torque capabilities.

They are **not used for continuous energy conversion** but **only for precise speed and precise position control at high torques**.

They generally operate at very low speeds or sometimes zero speed.

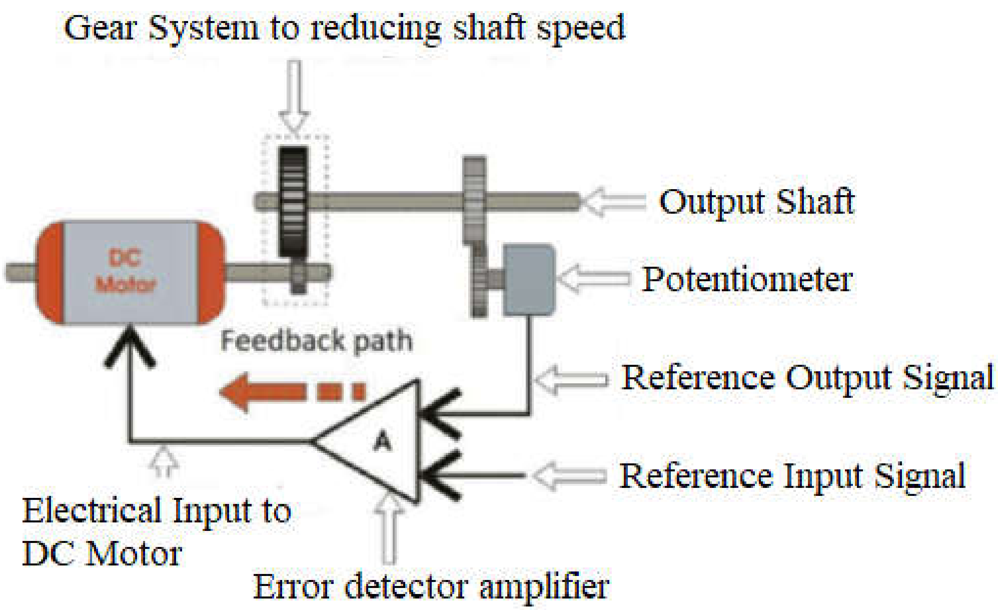
Their power ratings vary from a fraction of a watt up to a few 100 W.

They find wide applications in **robotics, radio-controlled cars, radar, tracking and guidance systems, process controllers, computers and machine tools**.

Servomotors differ in application capabilities from large industrial motors in the following respects:

1. They produce high torque at all speeds including zero speed.
2. They are capable of holding a static (*i.e.* no motion) position.
3. They do not overheat at standstill or lower-speeds.
4. Due to low-inertia, they are able to reverse directions quickly.
5. They are able to accelerate and decelerate quickly.
6. They are able to return to a given position time after-time without any drift.

The main difference of servo motor from other motors is that more electrical wires come out of them for power as well as for control.



A **servomechanism**, or **servo** is an automatic device which uses error-sensing feedback to correct the performance of a mechanism.

DC Servo Motor

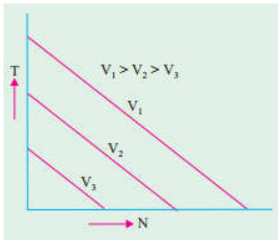
DC servomotor mainly either self-excited or permanent magnet dc motor.

The speed dc servo motor is controlled by varying the armature voltage where armature resistance have large resistance for linear and negative slope torque-speed characteristics.

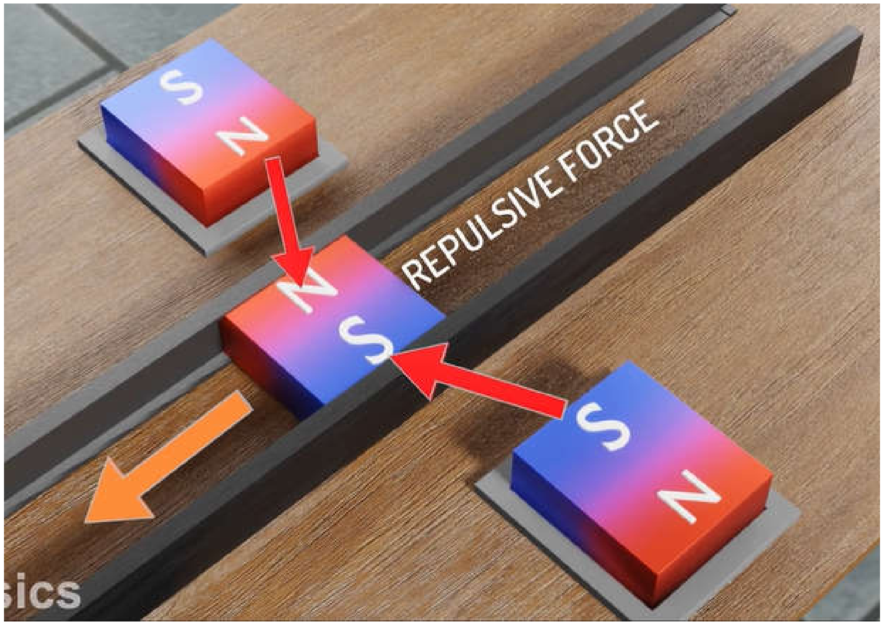
AC Servo Motor

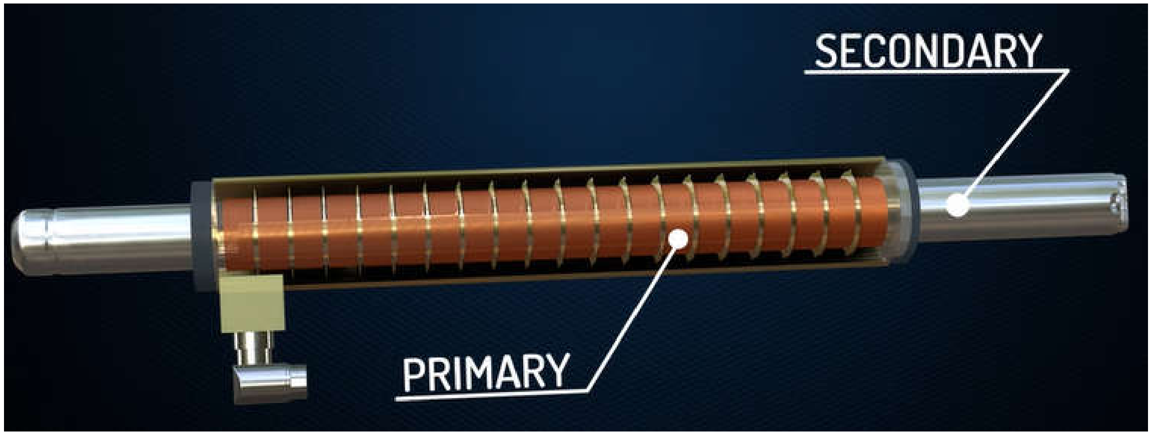
Most of the AC servomotors are of the two-phase squirrel-cage induction type and are used for low power applications.

Recently, three-phase induction motors have been modified for high power servo systems which had so far been using high power dc servomotors.



Linear Motor





Definition: Linear Electric Motors belong to the group of special electrical machines that convert electrical energy into mechanical energy of linear (translator) motion along its length instead of producing a torque (rotation

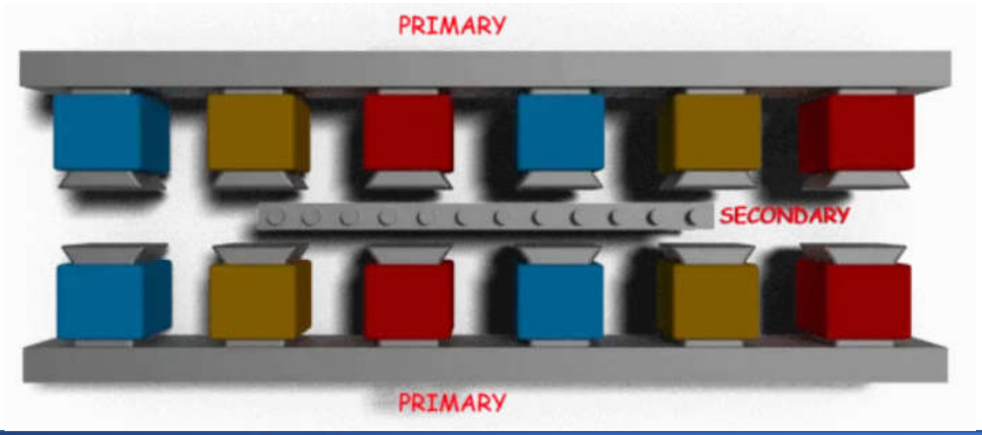
Classification: Linear Electric motors can be classified as follows

- Induction motors
- DC motors
- Synchronous motors including reluctance and stepper motors
- Oscillatory motors
- Hybrid motors

Working Principle:

When the primary of a Linear Induction Motor (LIM) gets excited by a balanced three-phase power supply, a flux starts traveling along the entire length of the primary.

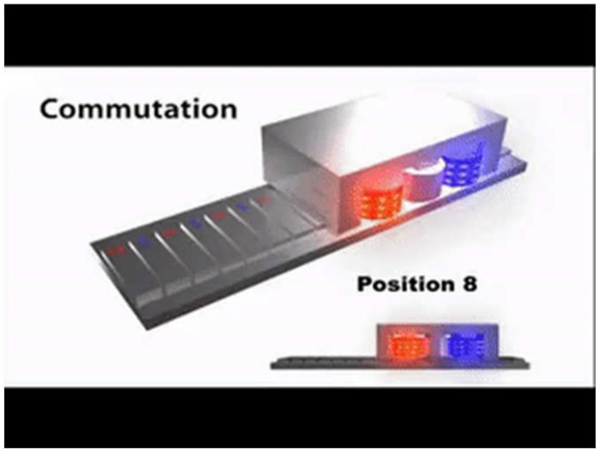
Electric current gets induced in the conductors of the secondary due to the relative motion between the traveling flux and the conductors. Then the induced current interacts with the traveling flux wave to produce linear force or thrust.



Advantages of Linear Motor:

The linear motor has following advantages:

- Low maintenance cost due to the absence of rotating parts.
- No limitation of maximum speed due to centrifugal forces.
- No overheating of the rotor.
- Simpler in construction
- Better power to weight ratio.
- Low initial cost



Disadvantages of Linear Motor: :

The linear motor has following disadvantages:

- High Air-gap
- Poor magnetic flux utilization
- Linear motor power consumption is for carrying high load with high acceleration.
- High vibration
- Large amount of heat produced due to high power consumption
- Not self-locking

Application of Linear Motor:

- CNC Machine
- People movers (Elevators)
- Automatic sliding doors in electric trains.
- Metallic conveyor belts.
- Electromagnetic Pumping of liquid metal, material handling in cranes, etc.
- High-speed rail traction
- Trolley cars (for internal transport in workshops)
- Rapid transportation
- Baggage handling
- Crane drives
- Theme park rides
- Flexible manufacturing systems
- Stage and curtain movement