ELECTRICAL MACHINES(EE 554)

Chapter-7(Fractional Kilowatt Motors)

Contents

Fractional Kilowatt Motors (6 hours)

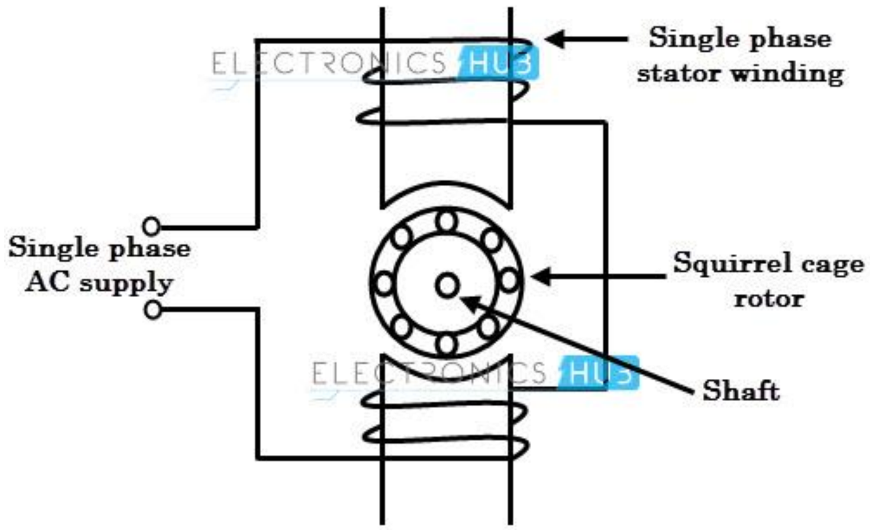
Fractional Kilowatt Motors(Single Phase Motors)

- Fractional horsepower motors are small motors that run with a power rating of less than one horsepower, or a fraction of a horsepower. But some of these motors have higher rating than a horsepower.
- Fractional kilowatt motors are built in smaller size and widely used in fans, air conditioners, mixtures, vacuum cleaner, washing machines, other kitchen equipment's, small farming appliances, tape recorder etc.
- In addition to this, single phase motors are reliable, cheap in cost, simple in construction and easy to repair.

Single phase Induction Motors

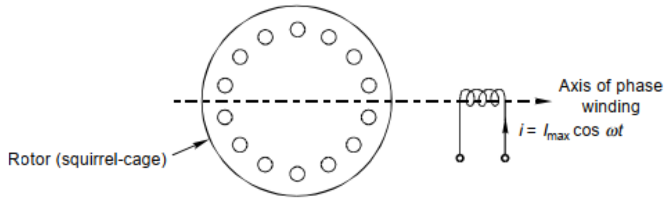
- A single phase induction motor is similar to a 3-phase induction motor with squirrel cage rotor in construction except that its stator is provided within single phase winding instead of a 3-phase winding.

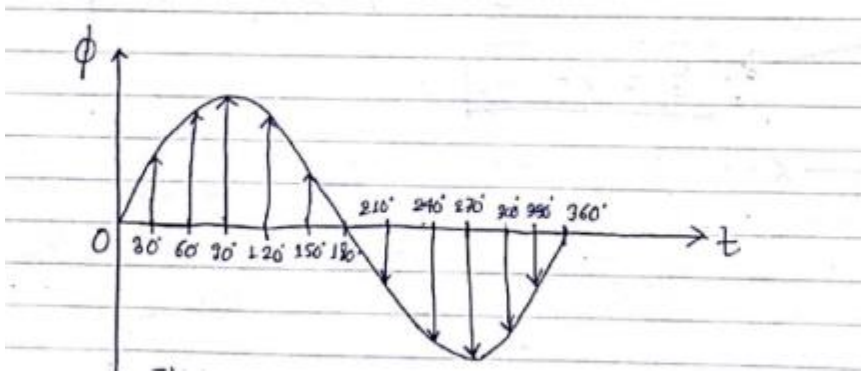
.



Principle:

- When the stator winding of the single-phase induction motor is energized by a single phase supply, a pulsating magnetic field is produced.
- The Pulsating field means that the field builds up in one direction falls to zero and then builds up in the opposite direction.

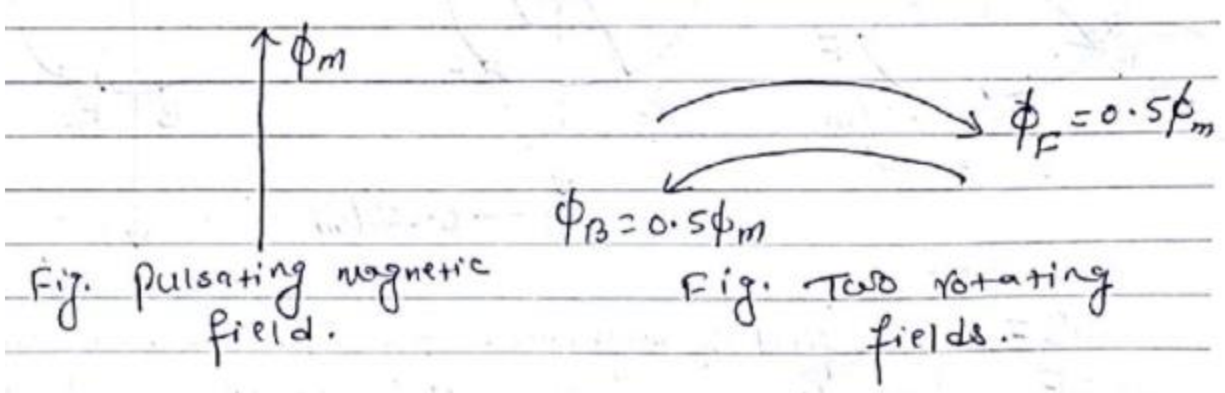




- The alternating current flowing through stator winding causes induced current in the rotor bars (of the squirrel cage rotor) according to Faraday's law of electromagnetic induction. This induced current in the rotor will also produce alternating flux. Even after both alternating fluxes are set up, the motor fails to start.
- Under these conditions, the motor does not develop any starting torque and hence the rotor of an induction motor will not start to rotate.
- Hence, a single phase induction motor is not self-starting. It requires some special starting means.
- However, if phase stator winding is excited and the rotor of the motor is rotated by an auxiliary means and the starting device is then removed, the motor continues to rotate in the direction in which it is started.
- This behavior of a single phase motor can be explained by double-field revolving theory.

Double Field Revolving Theory

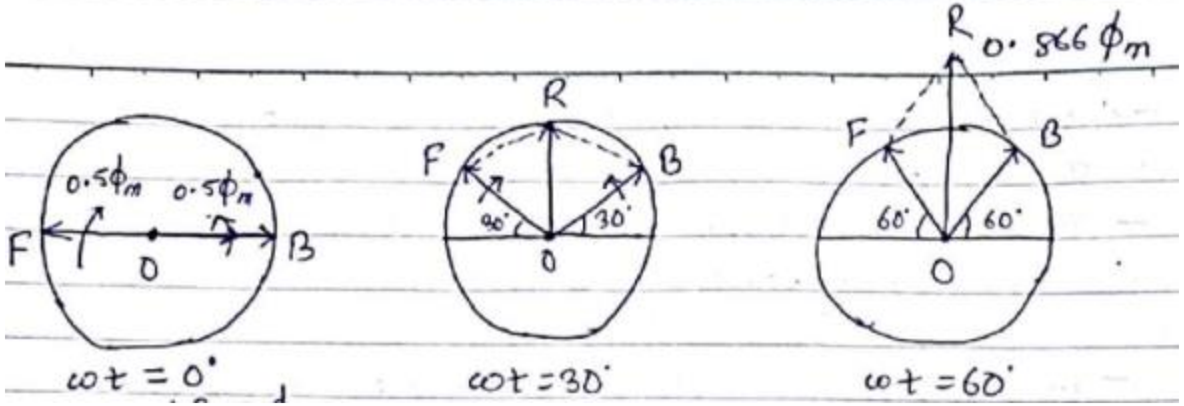
- The double-field revolving theory states that, any pulsating or alternating quantity (here, alternating flux) can be resolved into two components having magnitude half of the maximum magnitude of the alternating quantity, and both these components rotating in opposite direction.
- The induction motor responds to each of the magnetic fields separately and the net torque in the motor is equal to the sum of the torque due to each of the two magnetic fields.

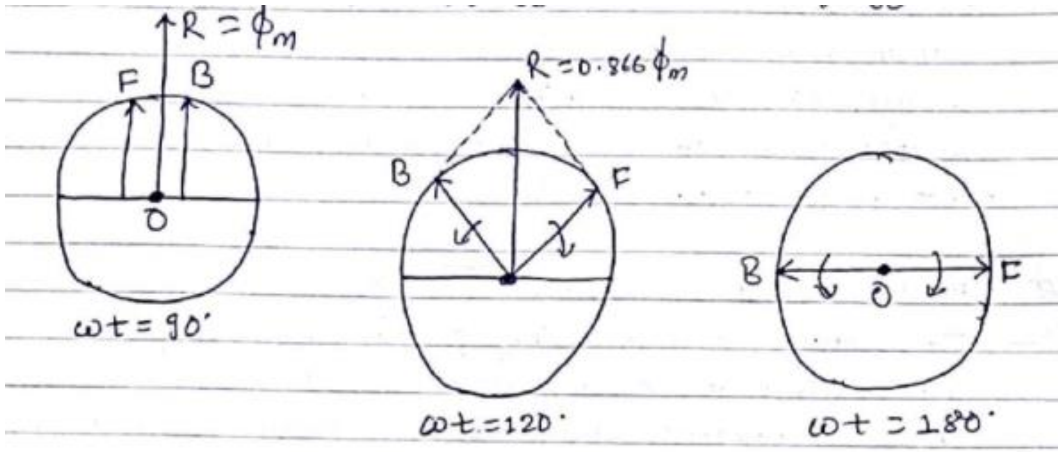


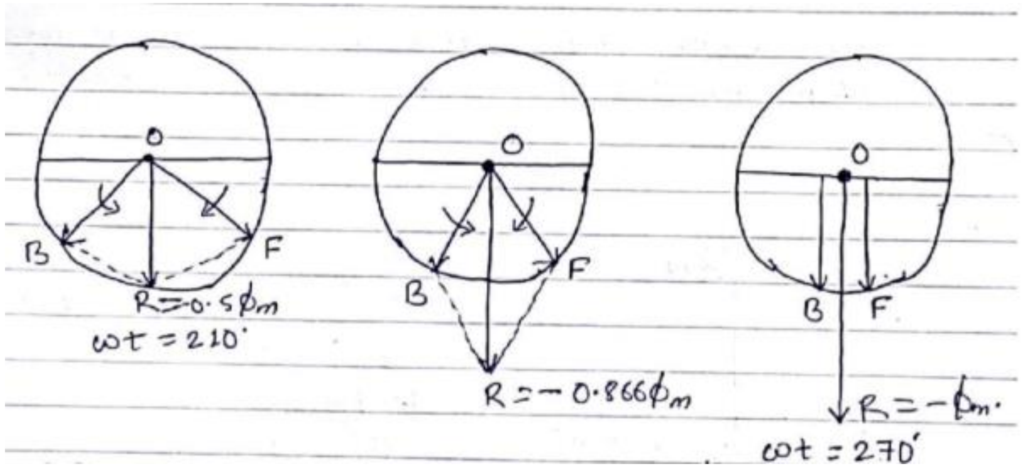
- If ϕ_m be the maximum magnitude of flux, then it can be resolved into two component having magnitude($\phi_m/2$) with two fluxes rotating in opposite direction.
- Let ,

OB= magnetic flux of ($\phi_m/2$) magnitude rotating in backward (Anticlockwise) direction
OF= magnetic flux of ($\phi_m/2$) magnitude rotating in forward (Clockwise) direction

At different values of rotation, the pulsating flux can be resolved into two rotating component having ($\phi_m/2$) magnitude as shown here.







- Hence, is it clear from above graphical analysis, as stated by double field revolving theory, the pulsating magnetic field produced by the single phase winding is equivalent to the phasor sum of two oppositely rotating magnetic fields, each having magnitude of 0.5 ϕ_m with a synchronous speed of N_s= 120f/P.
- The rotating magnetic field "OF" which rotates in clockwise direction is known as forward rotating magnetic field.
- The rotating magnetic field "OB" which rotates in anti-clockwise direction is known as back rotating magnetic field.
- The torques due to these two rotating fields can be expressed as T_b (Backward Torque) and T_f (Forward Torques).
- At standstill condition, T_b=T_f and hence net torque is zero. So motor can't start.

- But if rotated by some other means at starting, the two torques are unequal and resultant torque keeps the motor rotating in one direction.

- Based on the double field revolving theory, the torque speed characteristics of a single phase induction motor can be shown in figure.

- But in practice it is not possible to give initial torque to rotor externally hence some modifications are done in the construction of single phase induction motors to make them self starting.

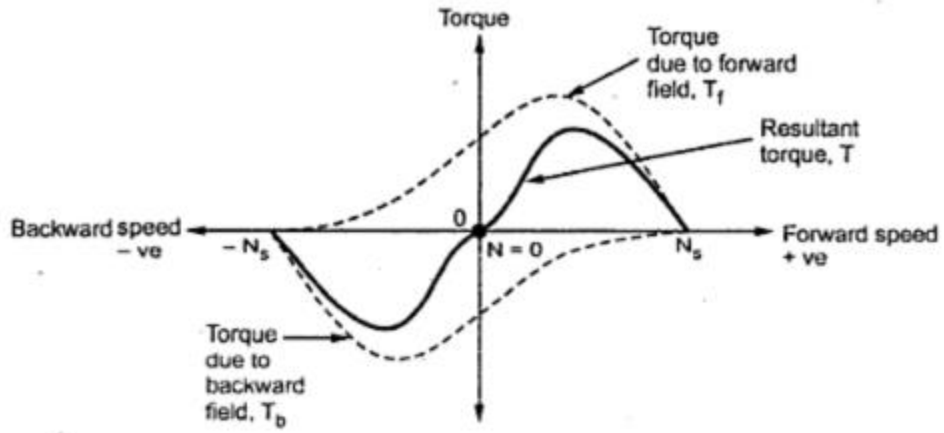


Fig: Torque-speed characteristics

Starting of Single phase starting motors

- From the above topic, we can easily conclude that the single-phase induction motors are not self-starting because the produced stator flux is alternating in nature and at the starting, the two components of this flux cancel each other and hence there is no net torque.
- The solution to this problem is that if we make the stator flux rotating type, rather than alternating type, which rotates in one particular direction only. Then the induction motor will become self-starting.
- For producing the rotating flux, we need an auxiliary winding which is phase shifted from the main winding.
- Now for producing this rotating magnetic field, we require two alternating flux, having some phase difference angle between them. When these two fluxes interact with each other, they will produce a resultant flux. This resultant flux is rotating in nature and rotates in space in one particular direction only and produces the starting torque in a particular direction.
- However, once the motor is running, it is capable of producing the torque with only the main winding.

Split Phase Induction Motor

- The Split Phase Motor is also known as a Resistance Start Motor.
- It has a single cage rotor, and its stator has two windings known as main winding and starting(Auxiliary) winding and both the windings are displaced 90 degrees in space.

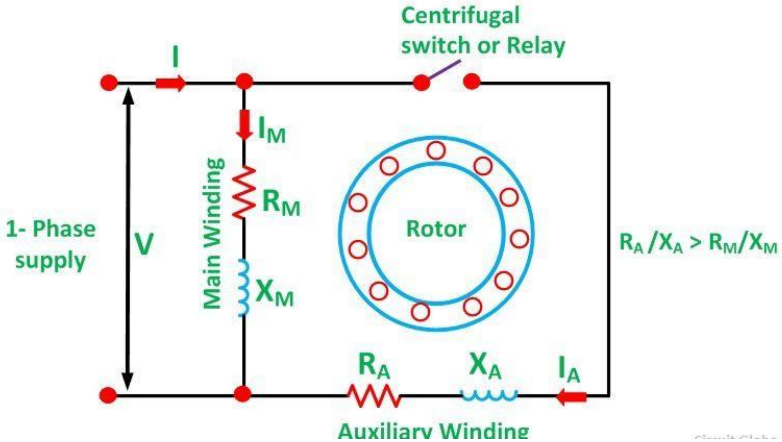


Fig.1. Split-phase Induction Motor

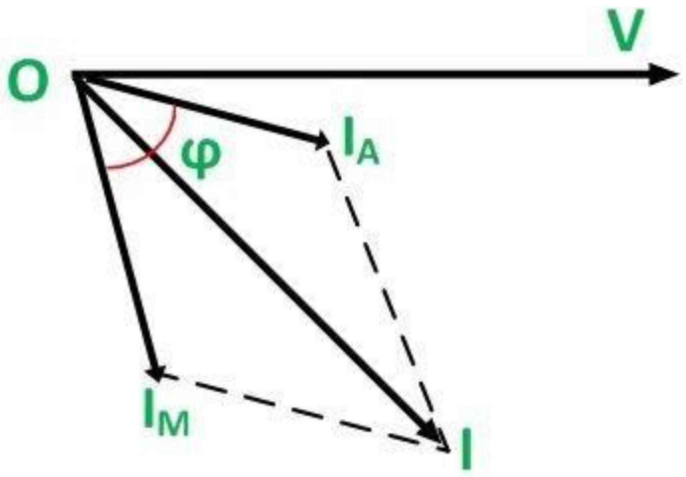


Fig.2. Phasor Diagram

- The main winding has very low resistance and a high inductive reactance whereas the starting winding has high resistance and low inductive reactance.
- The Connection Diagram of the motor is shown above. This auxiliary winding has higher resistance to reactance (R/X) ratio as compared to that in the main winding.
- The current (Ia) in the auxiliary winding lags the voltage (V) by an angle φ_a , which is small, whereas the current (Im) in the main winding lags the voltage (V) by an angle φ_m , which is nearly equal to 90.
- The phase angle between the two currents is (90° -φ), which should be at least 30° . This phase difference is enough to produce a rotating magnetic field and produces a small amount of starting torque.
- The switch, S (centrifugal switch) is in series with the auxiliary winding. It automatically cuts out the auxiliary or starting winding, when the motor attains a speed close to full load speed.
- The motor has a starting torque of 150-200% of full load torque, with the starting current as 5-7 times the full load current.
- The phasor diagram is shown in the figure above.

The torque-speed characteristics of split-phase single phase induction motor is shown here.

- The direction of the Resistance Start motor can be reversed by reversing the line connection of either the main winding or the starting winding. The reversal of the motor is possible at the standstill condition only.

- This type of motor is cheap and is suitable for easily starting loads where the frequency of starting is limited. This type of motor is not used for drives that require more than 1 KW because of the low starting torque. The various applications are as follows:
  - Used in the washing machine, and air conditioning fans.
  - The motors are used in mixer grinders, floor polishers.
  - Blowers, Centrifugal pumps.
  - Drilling and lathe machine.

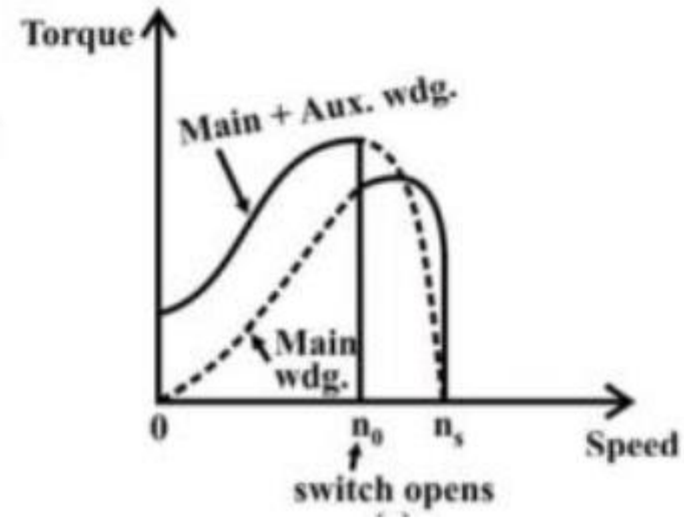


Fig 3: T-S characteristics of spit phase induction motor

Capacitor Start Motor

The schematic diagram of a capacitor-start motor is given in Fig.4.. The motor is so named because it uses the capacitor only for the purpose of starting. The capacitor value is usually so chosen as to give *a* = 90° elect. as shown in the phasor diagram of Fig. 5. The torque-speed characteristic with switching operation is shown in Fig. 6 which also shows that the starting torque is high. The starting torque is 3 to 4.5 times higher than does an equally rated split phase induction motor. It may be noted that
the capacitor need only be short-time rated. Because of the high VAR rating of the capacitor required, electrolytic capacitors must be employed. The range of capacitance is 250 *m*F or larger.

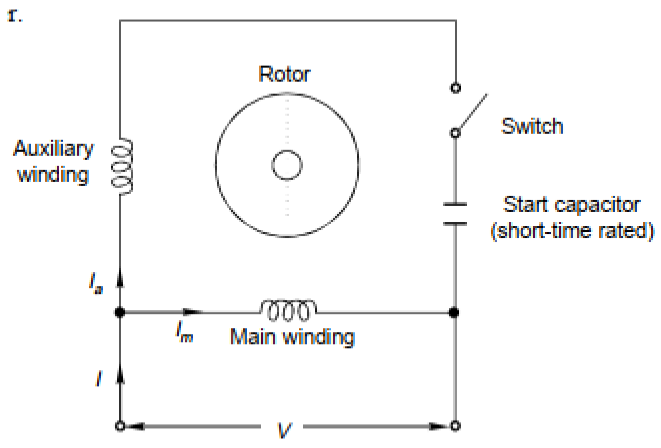


Fig 4: Capacitor start motor

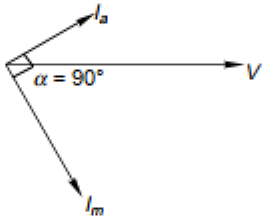


Fig 5: Phasor diagram

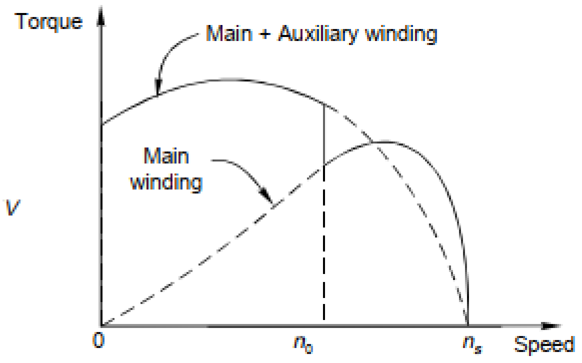


Fig 6: T-S characteristics of Capacitor start and run motor

Addition of a capacitor and accompanying switch naturally increases the cost of the motor and simultaneously reduces its reliability (because of the inclusion of extra components)

Capacitor start capacitor run motor

- Fig. 7 shows the schematic diagram of a capacitor start capacitor run motor. It is also known as two value capacitor method.

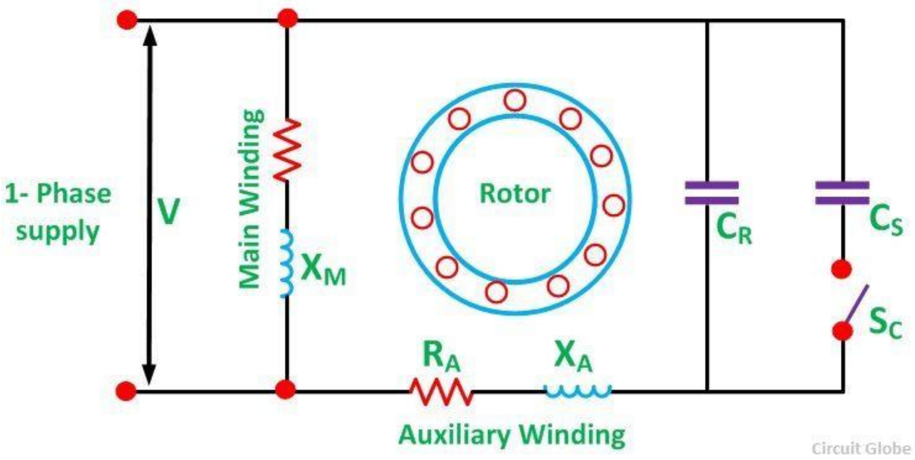


Fig 7: Capacitor start capacitor run motor

- There are two capacitors in this motor represented by C_S and C_R. In the starting, the two capacitors are connected in parallel. The capacitor Cs is the Starting capacitor is short time rated. It is almost electrolytic. A large amount of current is required to obtain the starting torque. Therefore, the value of the capacitive reactance X should be low in the starting winding. Since, $X_A = 1/2\pi f C_A$, the value of the starting capacitor should be large.

- The rated line current is smaller than the starting current at the normal operating condition of the motor. Hence, the value of the capacitive reactance should be large. Since, $X_R = 1/2\pi f C_R$, the value of the run capacitor should be small.
- As the motor reaches the synchronous speed, the starting capacitor Cs is disconnected from the circuit by a centrifugal switch Sc. The capacitor C_R is connected permanently in the circuit and thus it is known as RUN Capacitor. The run capacitor is long time rated and is made of oil-filled paper.

The figure below shows the Phasor Diagram of the Capacitor Start Capacitor Run Motor.

Fig(a) shows the phasor diagram when at the starting both the capacitor are in the circuit and ϕ > 90º. Fig (b) shows the phasor when the starting capacitor is disconnected, and ϕ becomes equal to 90º.

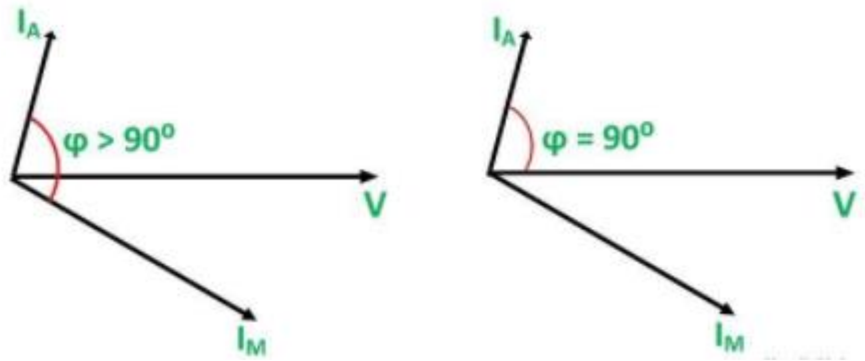


Fig (a) fig(b)

Fig 8: Phasor Diagram at starting

The torque-speed characteristic of a two-value capacitor motor is shown below:

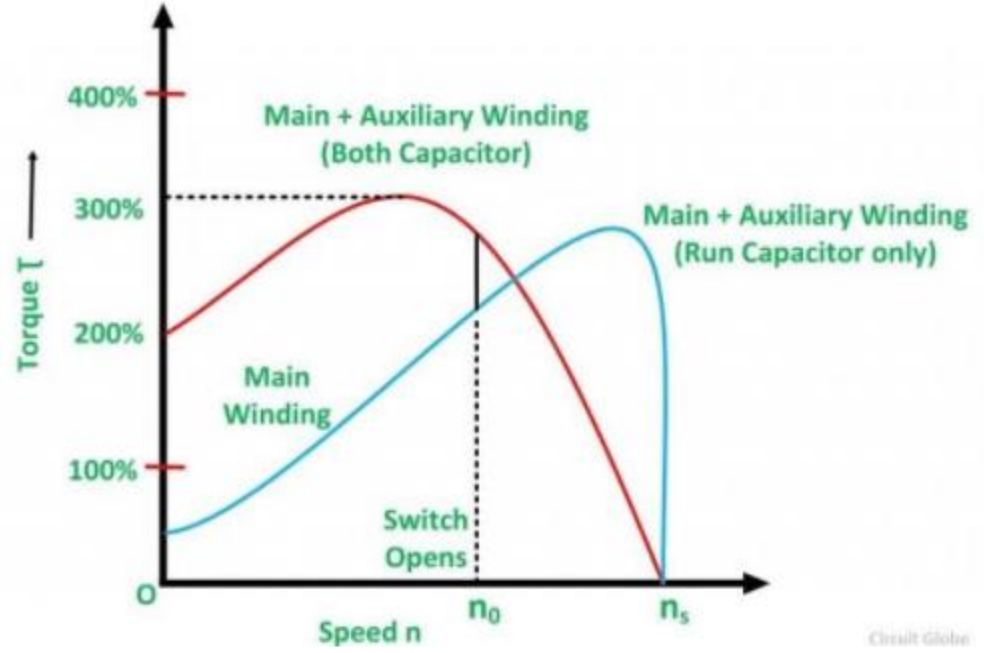


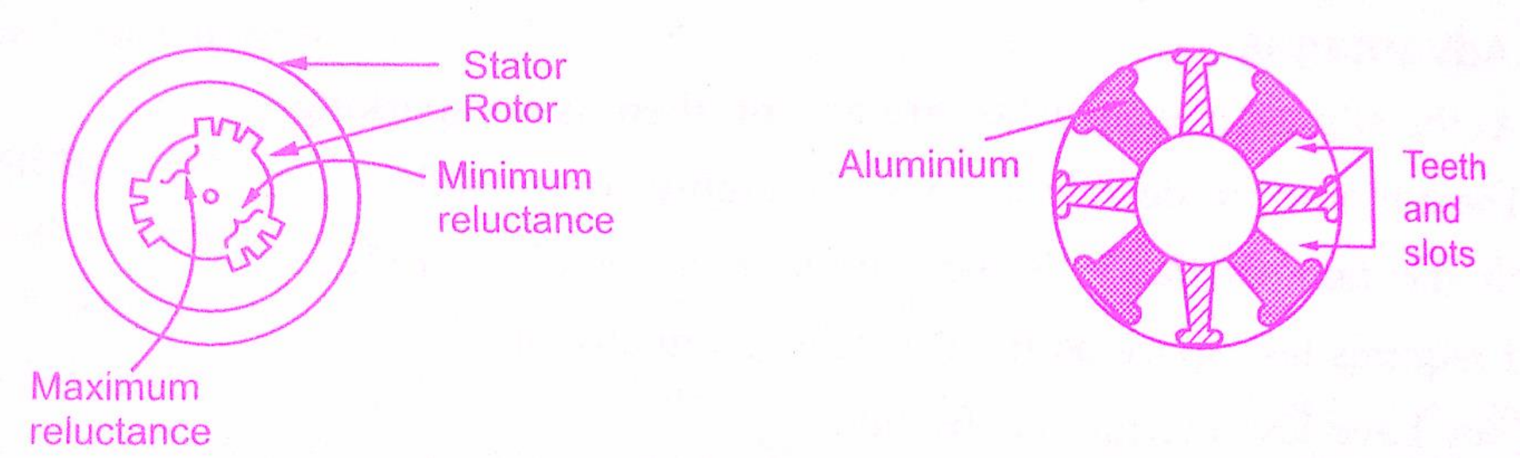
Fig 9: T-S characteristics of Capacitor start capacitor run motor

This type of motor is quiet and smooth running. They have higher efficiency than the motors that run on the main windings only. They are used for loads of higher inertia requiring frequent starts where the maximum pull-out torque and efficiency required are higher. The two value capacitor motors are used in pumping equipment, refrigeration, air compressors, etc.

Reluctance Motor

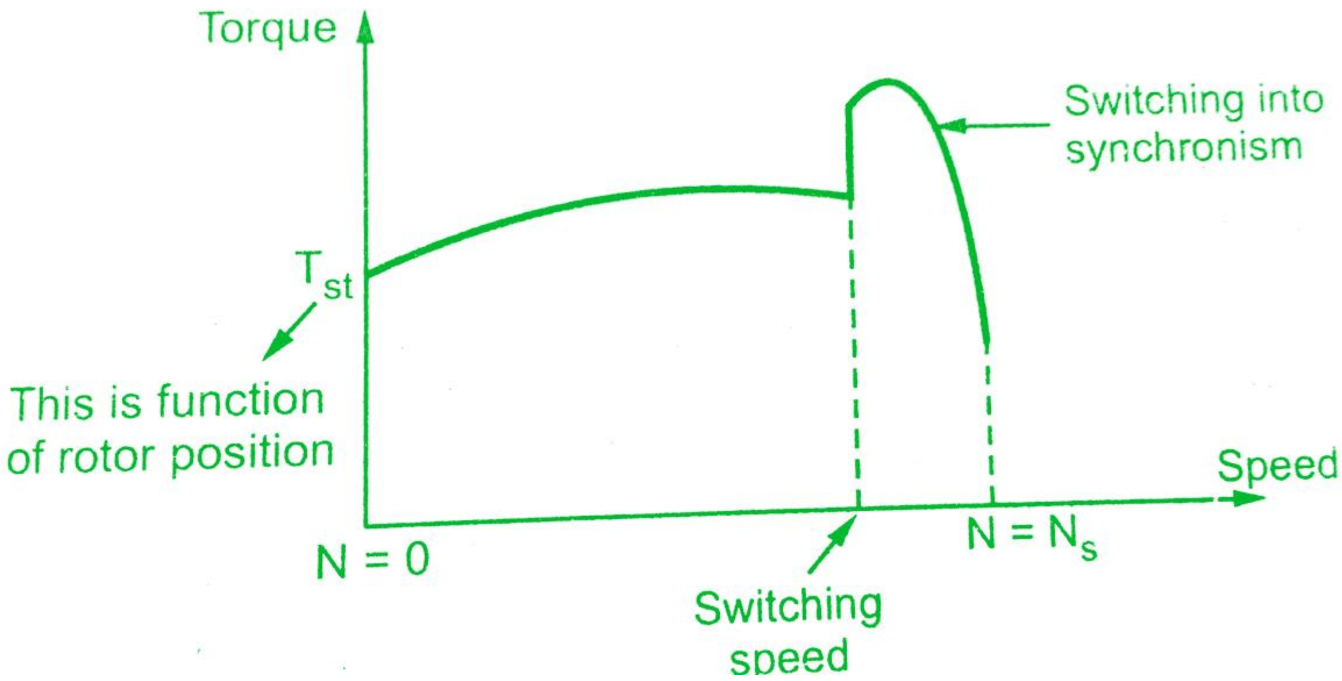
The reluctance motor has basically two main parts called stator and rotor. the stator has a laminated construction, made up of stampings. The stampings are slotted on its periphery to carry the winding called stator winding. The stator carries only one winding. This is excited by single-phase a.c. supply. The laminated construction keeps iron losses to a minimum. The stampings are made up of material from silicon steel which minimizes the hysteresis loss. The stator winding is wound for certain definite number of poles.
The rotor has a particular shape. Due to its shape, the air gap between stator and rotor is not uniform. No d.c supply is given to the rotor. The rotor is free to rotate. The reluctance i.e., the resistance of the magnetic circuit depends on the air gap. More the air gap, more is the reluctance and vice-versa. Due to the variable air gap between stator and rotor, when the rotor rotates, reluctance between stator and rotor also changes. The stator and rotor are designed in such a manner that the variation of the inductance of the windings is sinusoidal with respect to the rotor position.

The rotor carries the short-circuited copper or aluminum 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. Similarly, in the reluctance motor, rotor tries to align itself with the axis of rotating magnetic field in a minimum reluctance position. But due to rotor inertia, it is not possible when the rotor is standstill.



So rotor starts rotating near synchronous speed as a squirrel cage induction motor. 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. The resistance of the rotor must be very shall and the combined inertia of the rotor and the load should be small to run the motor as a synchronous motor.

The torque speed characteristics are shown in below figure. The starting torque is highly dependent on the position of the rotor.

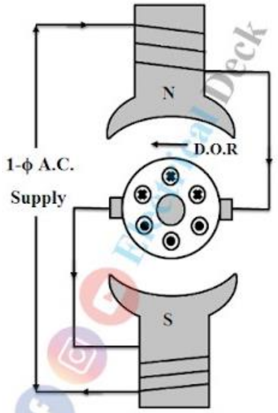


Applications of Reluctance Motor:
Reluctance motor is used in
- Signaling Devices
- Recording Instruments
- Clocks
- All timing devices
- Teleprinters

Alternating Current series motor(Universal Motors)

An ordinary d.c. series motor will run in the same direction regardless of the polarity of the supply. The direction of the torque depends upon the relative directions in space of flux and armature current. If the line terminals are reversed, both the field and armature current are reversed, the direction of torque remains unchanged. Therefore, the motor continues to rotate in the same direction.

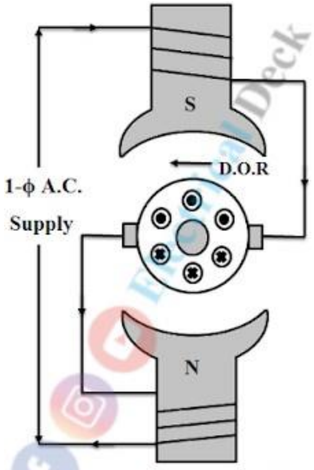
So when normal d.c. series motor is connected to an a.c. supply, both field and armature currents reverse simultaneously and unidirectional torque is produced in the motor.



Current Direction in First Half Cycle

Consider the case of a two-pole motor and let the alternating current be in its positive half, then the polarity of the field poles and the currents flowing through the armature conductors be as indicated in Figure. The armature conductors carry inward currents +ve under N-pole and outward currents -ve under S-pole. By applying Fleming's left-hand rule it will be seen that the torque developed in the armature will try to rotate in an anti-clockwise direction.

During the next instant, the alternating current goes through the negative half cycle Now the current through the field winding and armature will also change. It will be again seen that the armature will tend to rotate in the same direction because of the uniform torque produce by the two halves of the cycle.



Current Direction in Other Half Cycle

Thus a series motor can run on both the d.c. supply and a.c. supply. Such motors are called Universal Motors.

The performance of dc Series motor works on A.C. Supply is not satisfactory due to the following reasons,

1. The efficiency is low. This is because of the increase in core losses due to alternating flux.
2. The reactance of the field and armature winding increases as the supply given is alternating, which makes the machine run at a low power factor.
3. Considerable sparking at brushes will occur, Which increases the losses.

In order to overcome these difficulties, the following modifications are made in a d.c. series motor that is to operate satisfactorily on alternating current:

1. The field core is constructed of a material having low hysteresis loss. It is laminated to reduce eddy-current loss.
2. The field winding is provided with small number of turns. The field-pole area is increased so that the flux density is reduced. This reduces the iron loss and the reactive voltage drop.
3. The number of armature conductors is increased in order to get the required torque with the low flux.
4. In order to reduce the effect of armature reaction, thereby improving commutation and reducing armature reactance, a compensating winding is used. This winding is put in the stator slots as shown in figure below.

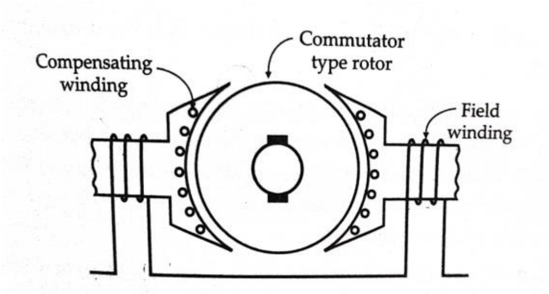


Fig: Series motor with conductive compensated winding

Construction of Universal Motors

- Construction of a universal motor is very similar to the construction of a DC machine.
- It consists of a stator on which field poles are mounted.
- field coils are wound on the field Poles and also compensating winding is placed on the pole.
- However, the whole magnetic path (states field circuit and also armature) is laminated.
- Lamination is necessary to minimize the eddy currents which induce while operating on AC.
- The rotary armature is of wound type having straight on skewed slots and commutator with brushes resting on it.
- The commutation on the AC is poorer than that for DC because of the current induced in the armature coils.
- For that reason, brushes used are having high resistance.

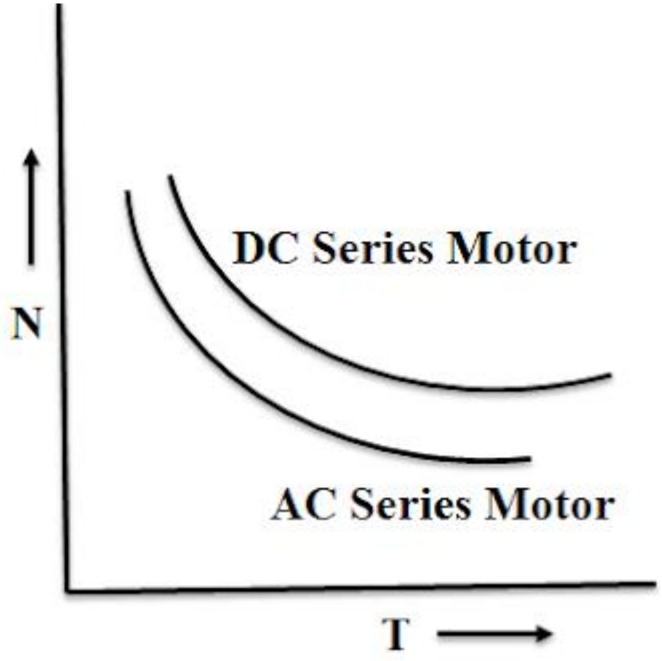


Fig: Torque-speed characteristics of Universal Series Motor

Special Purpose Machines

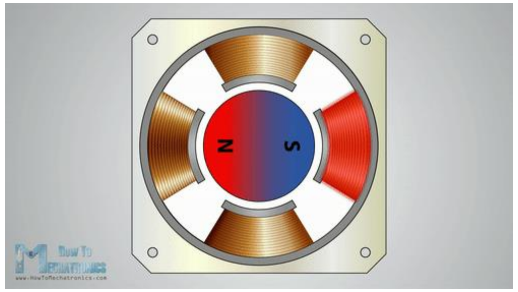
- AC or DC machines are used primarily for continuous energy.
- However, there are many special application where Continuous energy conversion is not required
- For example,

  robots require position control for the movement of the arm from one position to another.

  the printer of a computer requires that the paper move by steps in response to signals received from a computer.
- Such application requires a special motors of low power rating.

Stepper Motor:

- A stepper motor is an incremental motion machine i.e. the motor which turns in discrete movement(steps) in response to input electrical signal, are called the stepper motors.
- Stepper motor does not rotate continuously. Typical step sizes are 2^{o}, 2.5^{o}, 5°, 7.5° and 15° for each electrical pulse.
- It basically converts digital pulse inputs into analog output shaft motion.
- Typical application of stepper motors requiring incremental motion are printers, tape drivers, machine tools, X-Y recorders, robotics etc.



❖ Fig. 1 shows a simple application of a stepper motor in the Paper drive mechanism of a printer.

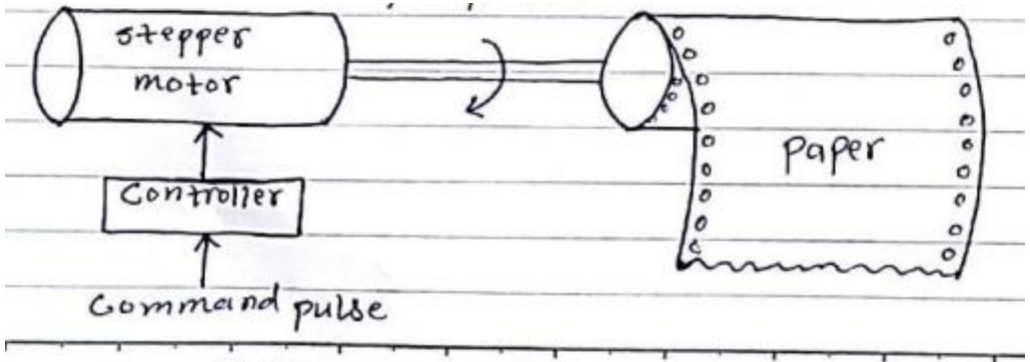


Fig 1. paper driving using stepper motor.

Two types of stepper motor are used:
i) Variable Reluctance type
ii) Permanent magnet type

i) Variable Reluctance Type:

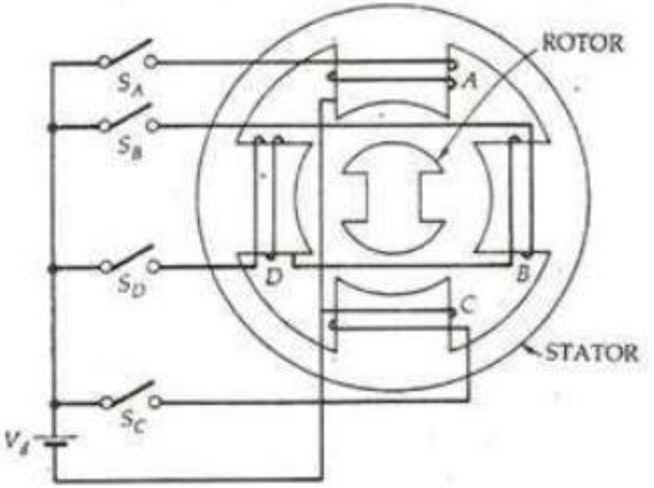


Figure shows a basic circuit configuration of a 4 phase 2 pole variable reluctance stepper motor.
When the stator phases are excited with dc current in proper sequence, the resultant air gap field steps around and the rotor follows the axis of air gap field by virtue of reluctance torque. This reluctance torque is generated because of the tendency of the ferromagnetic rotor to align itself along the direction of resultant magnetic field.

The rotor intact tries to align itself with the motor direction of the resultant magnetic field. Fig above shows the modes of stepper motor for a 45° step in the clockwise direction. The windings are excited in the sequence A, A+B, B, B+C and so on.

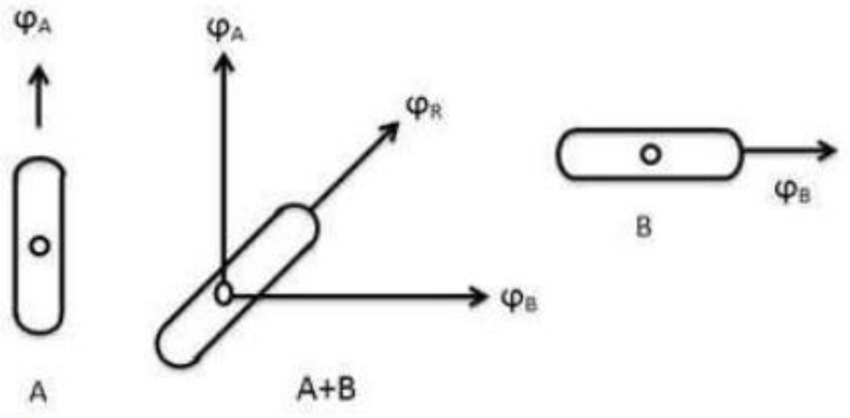


Fig: operating modes of stepper motor

When winding A is excited, the rotor aligns with axis of phase A. Next both windings A and B are excited which makes the resultant mmf axis move 45° in the clockwise direction. The rotor thus now aligns with this resultant mmf axis. In this way, the rotor can be rotated in steps of 45°.

The direction of rotation can be reversed by reversing the sequence of switching the windings A, A+ D, D, D+ C etc.

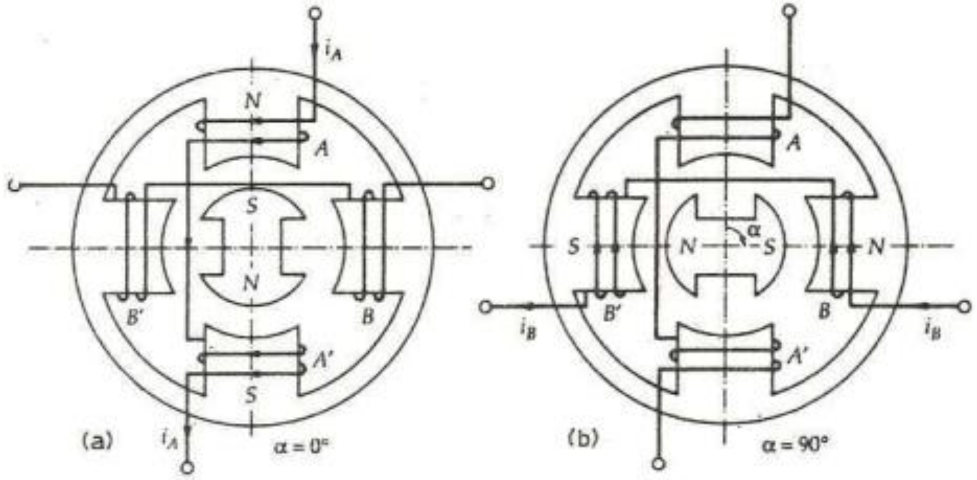
To achieve smaller steps, a multi-pole rotor and multiphase construction is required.

ii) Permanent magnet type stepper motor:

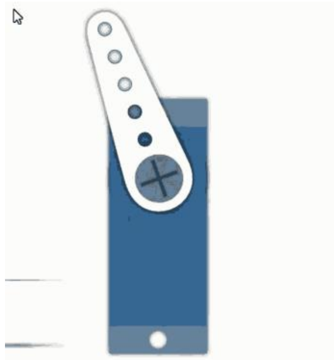
It has construction similar to variable reluctance motor. The fig below shows the alignment of the rotor if phase A winding is excited.

Now if the excitation is switched to phase B the rotor moves by a step of 90°. However, the direction in which the rotor will move is governed by the direction of current in B phase. Fig above illustrates the rotor position for positive current in phase A (A → A’). A switch over to positive current in phase B (B→B’) will produce a clockwise step.

If direction of currents B’ → B, the rotor will step in the anticlockwise direction. These motors are usually limited to steps range from 30°-90° only as it is difficult to make a permanent magnet rotor with large number of poles.



Servomotor:



- Servomotors are small power rating motors used for precise control of angular position.
- Servomotors are also called control motors.
- These motors are used in feedback control system as output actuators.
- The basic principle of operation of these motors is the same as that of other electromagnetic motor.
- However, their design, construction and mode of operation are different.
- Their power ratings vary from a fraction of a watt to few hundred watts.
- They have low rotor inertia and, therefore, they have high speed of response.
- Servomotors are widely used in radars, computers, robots, machine tools, tracking and guidance systems, process control.
- Both dc and ac (2-phase and 3-phase) Servomotors are being used presently.

DC servomotors

- DC servomotors are separately excited dc motors or permanent magnet dc motors.
- Fig.1 (a) shows a schematic diagram of a separately excited dc servomotor..
- The speed of dc servo motors is normally controlled by varying the armature voltage.
- The armature of a dc servomotor has a large resistance so that torque - speed characteristics are linear and have a large negative slope (torque reducing with increasing speed) as shown in Fig. 1(b).

The field is operated at well beyond the knee point of magnetizing saturation curve. In this portion of the curve, for huge change in magnetizing current, there is very small change in mmf in the motor field. This makes the servo motor is less sensitive to change in field current. Servomotors are usually controlled by the armature voltage.

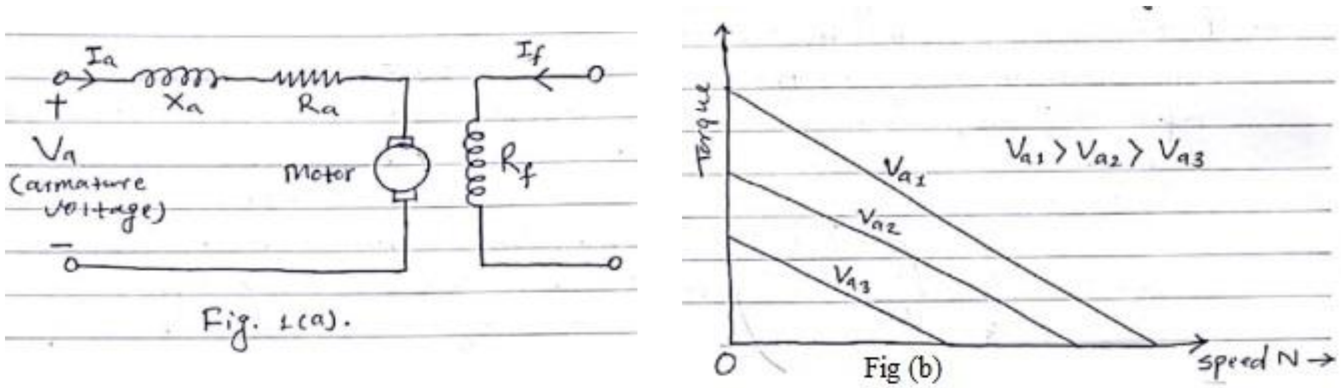
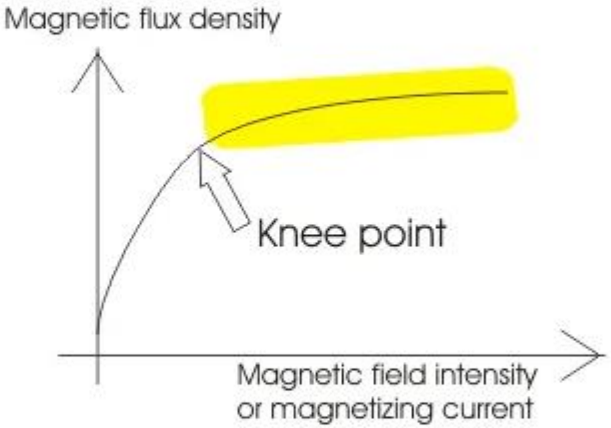


Fig.1. DC Servomotor
(a) Schematic Diagram (b) Torque-speed Characteristics

the general torque equation of DC motor is, torque $T \propto \varphi I_a$. Now if φ is large enough, for every little change in armature current I_a there will be a prominent changer in motor torque. That means servo motor becomes much sensitive to the armature current.



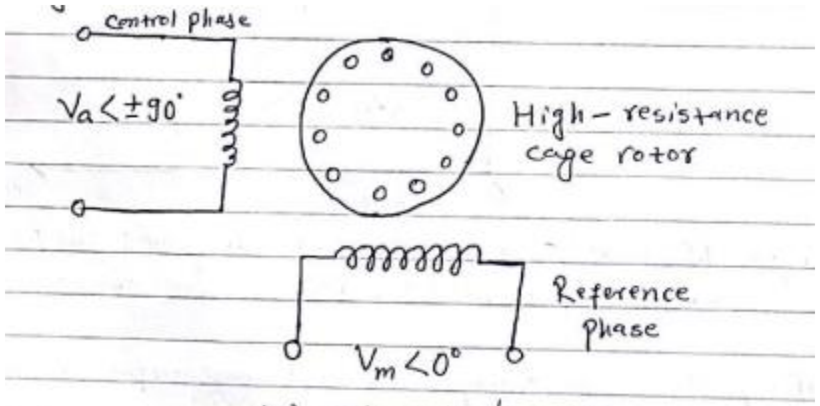
As the armature of DC motor is less inductive and more resistive, time constant of armature winding is small enough. This causes quick change of armature current due to sudden change in armature voltage. That is why dynamic response of armature controlled DC servo motor is much faster than that of field controlled DC servo motor. The direction of rotation of the motor can easily be changed by reversing the polarity of the voltage applied to armature.

AC Servomotors

- Most of the ac servomotors are of the two-phase squirrel cage induction type for low-power application.
- Recently, 3-Phase squirrel cage induction motors have been modified for application in high-power servo systems.

Two-phase AC servomotors

They are used for low power applications. They are robust in construction and have low inertia as compared to DC servomotors of same capacity. AC servomotors are generally, two phase squirrel cage induction motors as shown in the fig 1. The stator has two distributed windings displaced 90° electrical apart.

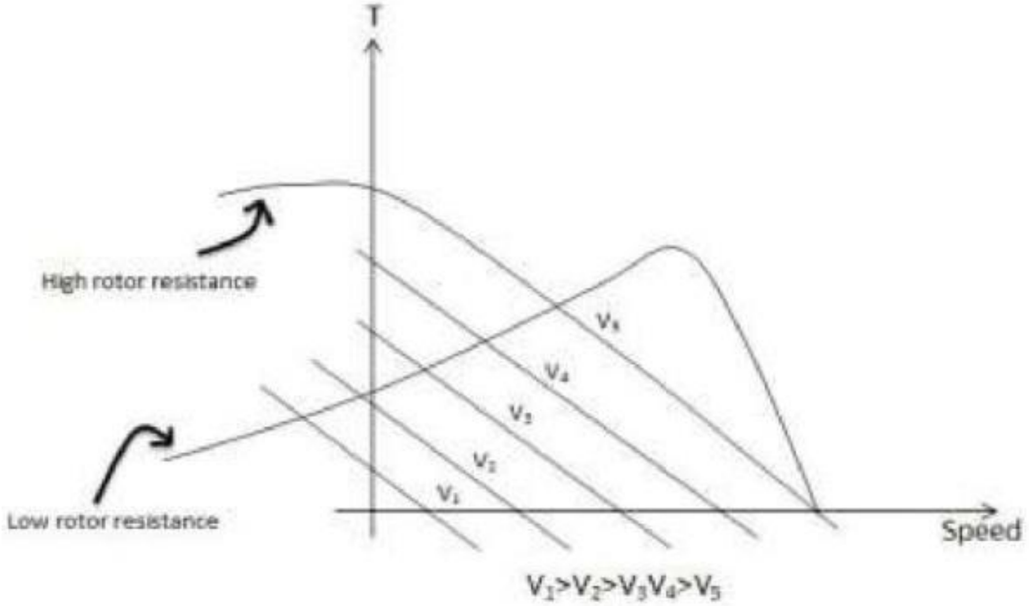


(a) schematic diagram.
Fig. 1 Two-phase ac servomotor.

One winding is called reference phase (fixed phase) and is supplied by a constant voltage source. The other winding is known as control phase and is supplied by a variable voltage source of same frequency as that supplied for reference voltage but displaced by 90^0 apart.

The speed and torque of the rotor are controlled by the phase difference between the control voltage and the reference phase voltage. The direction of rotation of the rotor can be reversed by reversing the phase difference, from leading to lagging(or vice-versa), between the control phase voltage and the reference phase voltage.

. For balanced two phase voltages, $|V_a| = |\ \ |V_m|$, the T-S curve of the motor is similar to that of three phase induction motor. For low rotor resistance, the characteristic is non-linear Such characteristic is unsuitable for applications of AC servomotors. However, if the rotor resistance is made high the T-S curve is essentially linear over a wide range of speed. To control the machine, it is operated with fixed voltage for the reference phase and variable voltage for the control phase.



Schrage Motor

Schrage motor is basically an inverted polyphase induction motor, with primary winding on the rotor and secondary winding on the stator. The primary winding on the rotor is fed through three slip rings and brushes at line frequency, secondary winding on the stator has slip frequency voltages induced in it. The speed and power factor of slip ring induction motor can be controlled by injecting ship frequency voltage in the rotor circuit. If resultant rotor voltage increases, current increases, torque increases and speed increases. Depending on the phase angle of injected voltage, power factor can be improved.

Construction and Operation

Schrage motor has three windings- Two in Rotor and One in Stator.

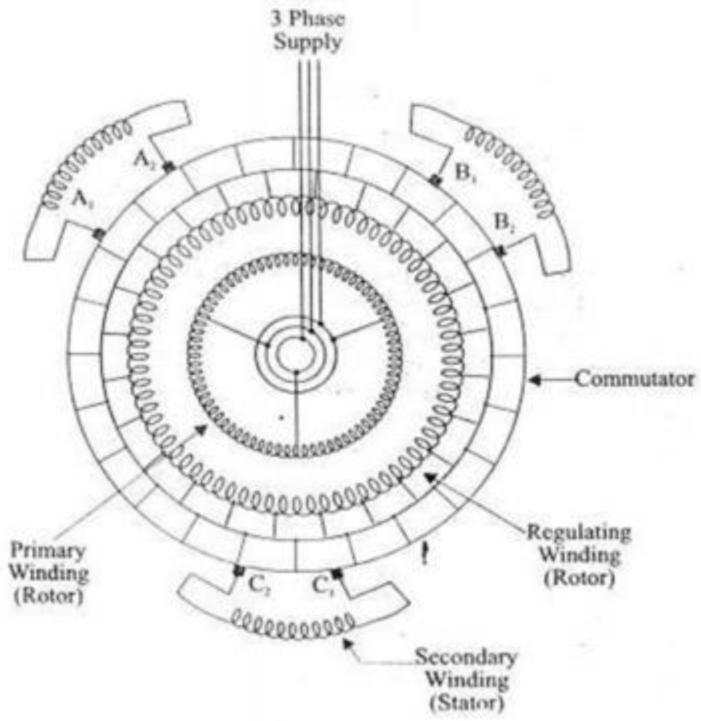
Primary winding: Placed on the lower part of the slots of the Rotor. Three phase supply at line frequency is fed through slip rings and brushes which generates working flux in the machine.

Regulating winding: Placed on the upper part of the slots of the Rotor. These are connected to commutator segments in a manner similar to that of D.C. machine Regulating windings are also known as tertiary winding/auxiliary winding/commutator winding.

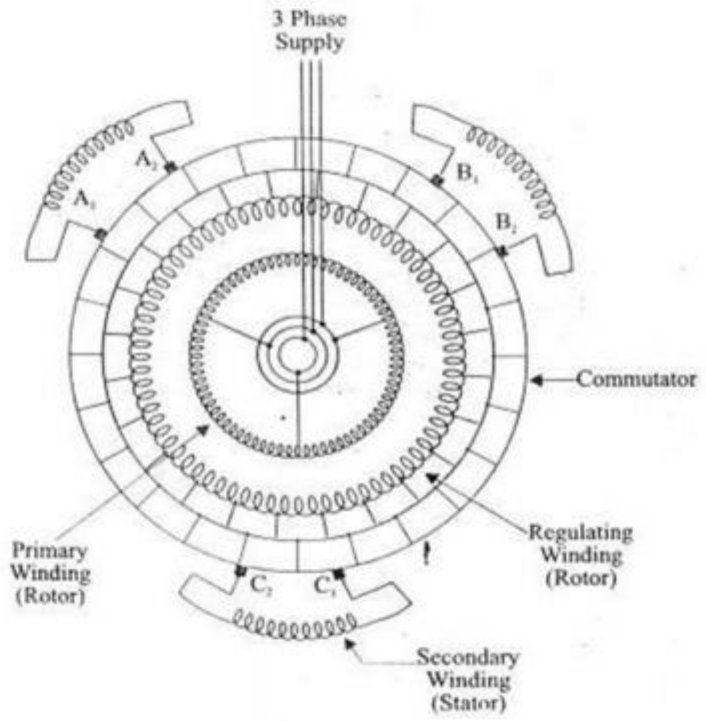
Secondary winding: Same as phase wound & located on stator. Each winding is connected toa pair of brushes arranged on the commutator Brushes are mounted on brush rockers. These are designed to move in opposite directions, relative to the center line of its stator phase.

Brushes A, B & C move together and are 120° apart.

Brushes A, B & C also move together and are 120° apart.



Now the primary energized with line frequency voltage. Transformer action occurs between primary and regulating winding. Induction motor action occurs between primary and secondary windings. Commutator acting as a frequency converter converts line frequency voltage of regulating winding to slip frequency voltage and feeds the same to secondary winding on the stator.



Voltage across the brush pairs A_1 - A_2, B_1-B_2 & C_1-C2 increases as brushes are separated.

Magnitude of voltage injected into the secondary winding depends on the angle of separation 'θ' of the brushes A_1 & A_2, B_1 & B_2, C_1 & C_2. ('θ'-Brush separation angle).

When primary is energized synchronously rotating field in clockwise direction is set up in the rotor core. Assume that the brushes are short circuited through commutator segment i.e. the secondary is short circuited. Rotor still at rest, the rotating field cuts the stationary secondary winding, induces an e.m.f. The stator current produce its own field. This stator field reacts with the rotor field thus a clockwise torque produced in the stator. Since the stator cannot rotate, as a reaction, it makes the rotor rotate in the counter clockwise direction.

Suppose that the rotor speed is N. rpm Rotor flux is rotating with Ns relative to primary & regulating winding. Thus the rotor flux will rotate at slip speed (N_1-N.) relative to secondary winding in stator with reference to space.

Advantages

A Schrage motor has the following advantages over an induction motor:

1. Since the external resistances are not required for speed control, the overall efficiency is improved.
2. Schrage motor provides a constant torque over a wide speed range and the power developed is proportional to speed.
3. Speed is easily increased or decreased over a wide range of 0.4 n_s to 1.4 n_s .
4. Speed is independent of load.

Disadvantages

1. A Schrage motor is costlier than an inductor motor of the same rating. The maintenance cost is also higher.
2. The moment of inertia of rotor is more than that of an induction motor of the same size.
3. Because of the third winding the losses are increased and the placement of the primary winding on the rotor limits the supply voltage, in turn limiting output.
4. Operating voltage has to be limited to 700 V because the power is to be supplied through slip rings.