UNIT II ELECTRICAL MOTORS

Review - Constructional details, principle of operation and performance characteristics of D.C. motors, single phase induction motor, three phase induction motor, synchronous motor, universal motor, servo motor, stepper motor and reluctance motor.

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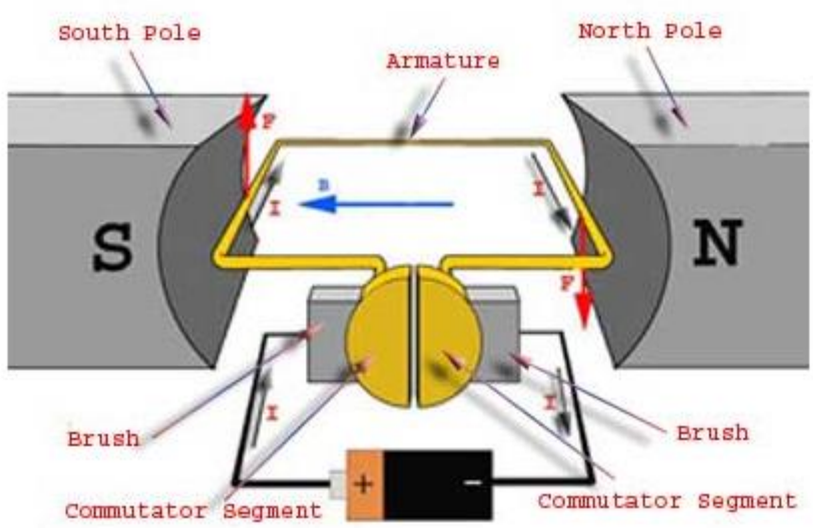
1.1 Constructional details, principle of operation and performance characteristics of D.C. motors

A DC motor in simple words is a device that converts electrical energy (direct current system) into mechanical energy. It is of vital importance for the industry today, and is equally important for engineers to look into the working principle of DC motor in details that has been discussed in this article. In order to understand the operating principle of DC motor we need to first look into its constructional feature.

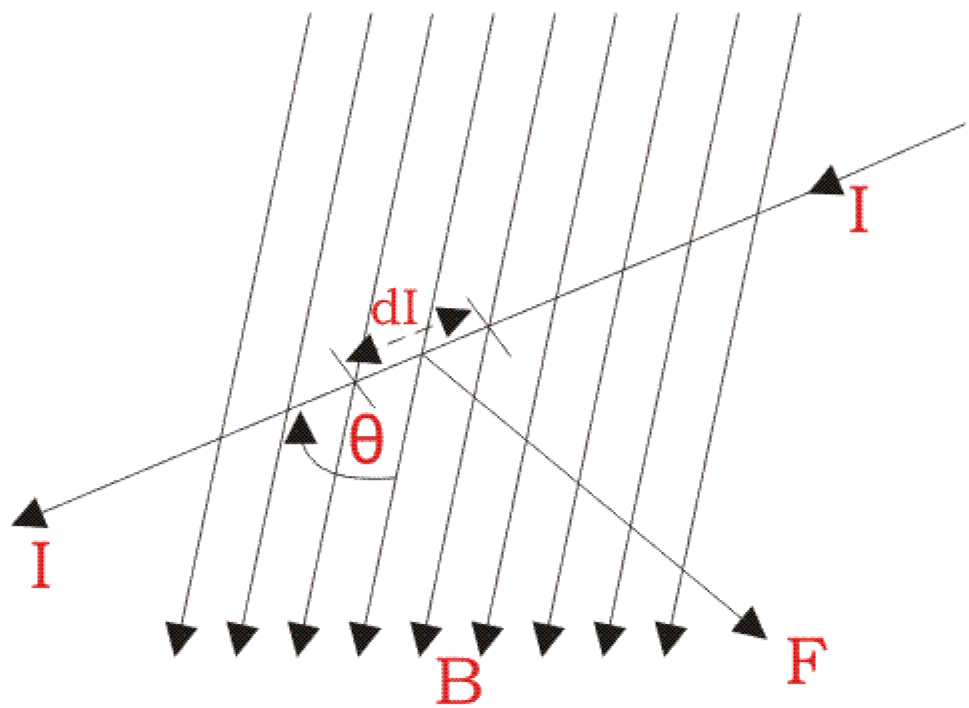


The very basic construction of a DC motor contains a current carrying armature which is connected to the supply end through commutator segments and brushes. The armature is placed in between north south poles of a permanent or an electromagnet as shown in the diagram above.

As soon as we supply direct current in the armature, a mechanical force acts on it due to electromagnetic effect of the magnet. Now to go into the details of the operating principle of DC motor its important that we have a clear understanding of Fleming's left hand rule to determine the direction of force acting on the armature conductors of DC motor.

If a current carrying conductor is placed in a magnetic field perpendicularly, then the conductor experiences a force in the direction mutually perpendicular to both the direction of field and the current carrying conductor. Fleming's left hand rule says that if we extend the index finger, middle finger and thumb of our left hand perpendicular to each other, in such a way that the middle finger is along the direction of current in the conductor, and index finger is along the direction of magnetic field i.e. north to south pole, then thumb indicates the direction of created mechanical force.

For clear understanding the principle of DC motor we have to determine the magnitude of the force, by considering the diagram below.



We know that when an infinitely small charge dq is made to flow at a velocity 'v' under the influence of an electric field E, and a magnetic field B, then the Lorentz Force dF experienced by the charge is given by:-

For the operation of DC motor, considering E = 0 i.e. it’s the cross product of dq v and magnetic field B.

Where dL is the length of the conductor carrying charge q.
From the 1st diagram we can see that the construction of a DC motor is such that the direction of current through the armature conductor at all instance is perpendicular to the field. Hence the force acts on the armature conductor in the direction perpendicular to the both uniform field and

current is constant.
So if we take the current in the left hand side of the armature conductor to be I, and current at right hand side of the armature conductor to be − I, because they are flowing in the opposite direction with respect to each other. Then the force on the left hand side armature conductor,
Similarly force on the right hand side conductor
Therefore, we can see that at that position the force on either side is equal in magnitude but opposite in direction. And since the two conductors are separated by some distance w = width of the armature turn, the two opposite forces produces a rotational force or a torque that results in the rotation of the armature conductor. Now let's examine the expression of torque when the armature turn crate an angle of α (alpha) with its initial position. The torque produced is given by,

Where, α (alpha) is the angle between the plane of the armature turn and the plane of reference or the initial position of the armature which is here along the direction of magnetic field. The presence of the term cosα in the torque equation very well signifies that unlike force the torque at all position is not the same. It in fact varies with the variation of the angle α (alpha).

1.2 Constructional details, principle of operation and performance characteristics of single phase induction motor

Single phase power system is widely used as compared to three phase system for domestic purpose, commercial purpose and to some extent in industrial purpose. As the single phase system is more economical and the power requirement in most of the houses, shops, offices are small, which can be easily met by single phase system. The single phase motors are simple in construction, cheap in cost, reliable and easy to repair and maintain. Due to all these advantages the single phase motor finds its application in vacuum cleaner, fans, washing machine, centrifugal pump, blowers, washing machine, small toys etc.The single phase ac motors are further classified as:

1. Single phase induction motors or asynchronous motors.
2. Single phase synchronous motors.
3. Commutator motors.

Stator:

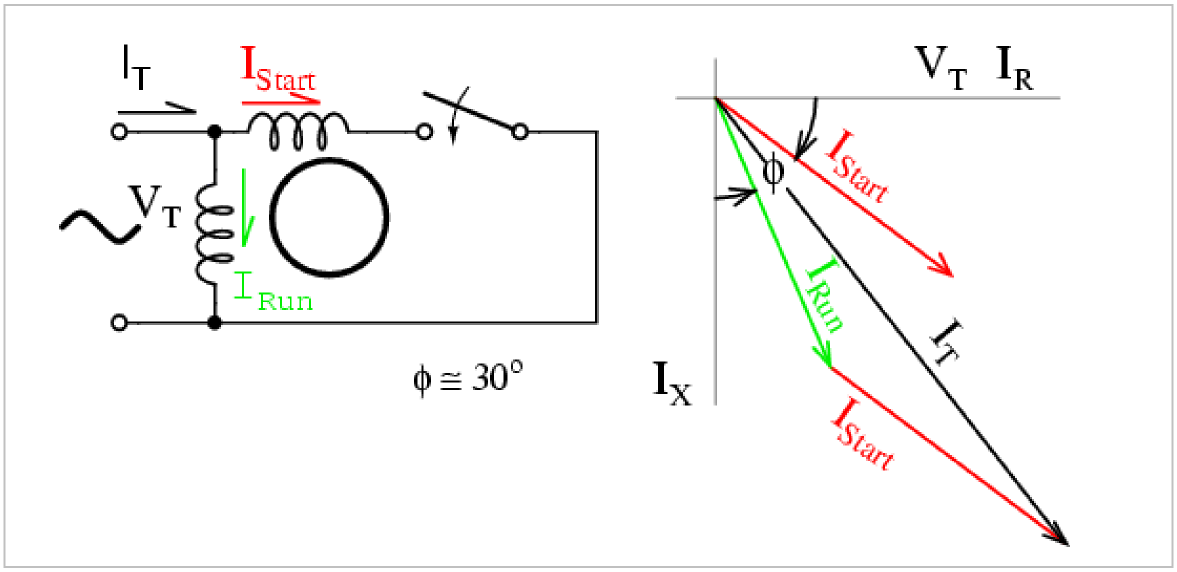
As its name indicates stator is a stationary part of induction motor. A single phase ac supply is given to the stator of single phase induction motor. Rotor: The rotor is a rotating part of induction motor. The rotor is connected to the mechanical load through the shaft. The rotor in single phase induction motor is of squirrel cage rotor type. The construction of single phase induction motor is almost similar to the squirrel cage three phase motor except that in case of asynchronous motor the stator have two windings instead of one as compare to the single stator winding in three phase induction motor.

The stator of the single phase induction motor has laminated stamping to reduce eddy current losses on its periphery. The slots are provided on its stamping to carry stator or main winding. In order to reduce the hysteresis losses, stamping are made up of silicon steel. When the stator winding is given a single phase ac supply, the magnetic field is produced and the motor rotates at a speed slightly less than the synchronous speed N_s which is given by

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

Where, f = supply voltage frequency, P = No. of poles of the motor. The construction of the stator of asynchronous motor is similar to that of three phase induction motor except there are two dissimilarity in the winding part of the single phase induction motor.

1. Firstly the single phase induction motors are mostly provided with concentric coils. As the number of turns per coil can be easily adjusted with the help of concentric coils, the mmf distribution is almost sinusoidal.
2. Except for shaded pole motor, the asynchronous motor has two stator windings namely the main winding and the auxiliary winding. These two windings are placed in space quadrature with respect to each other.



Rotor of Single Phase Induction Motor

The construction of the rotor of the single phase induction motor is similar to the squirrel cage three phase induction motor. The rotor is cylindrical in shape and has slots all over its periphery. The slots are not made parallel to each other but are bit skewed as the skewing prevents magnetic locking of stator and rotor teeth and makes the working of induction motor more smooth and quieter i.e less noise. The squirrel cage rotor consists of aluminum, brass or copper bars. These aluminum or copper bars are called rotor conductors and are placed in the slots on the periphery of the rotor. The rotor conductors are permanently shorted by the copper or aluminum rings called the end rings. In order to provide mechanical strength these rotor conductor are braced to the end ring and hence form a complete closed circuit resembling like a cage and hence got its name as squirrel cage induction motor. As the bars are permanently shorted by end rings, the rotor electrical resistance is very small and it is not possible to add external resistance as the bars are permanently shorted. The absence of slip ring and brushes make the construction of single phase induction motor very simple and robust.

Working Principle of Single Phase Induction Motor

NOTE: We know that for the working of any electrical motor whether its ac or DC motor, we require two fluxes as, the interaction of these two fluxes produced the required torque, which is desired parameter for any motor to rotate. When single phase ac supply is given to the stator winding of single phase induction motor, the alternating current starts flowing through the stator or main winding. This alternating current produces an alternating flux called main flux. This main flux also links with the rotor conductors and hence cut the rotor conductors. According to the Faraday's law of electromagnetic induction, emf gets induced in the rotor. As the rotor circuit is closed one so, the current starts flowing in the rotor. This current is called the rotor current. This rotor current produces its own flux called rotor flux. Since this flux is produced due to induction principle so, the motor working on this principle got its name as induction motor. Now there are two fluxes one is main flux and another is called rotor flux. These two fluxes produce the desired torque which is required by the motor to rotate.

Why Single Phase Induction Motor is not Self Starting?

According to double field revolving theory, any alternating quantity can be resolved into two components, each component have magnitude equal to the half of the maximum magnitude of the alternating quantity and both these component rotates in opposite direction to each other. For example - a flux, φ can be resolved into two components

$$\frac{\phi_m}{2} \; and \; -\frac{\phi_m}{2}$$

Each of these components rotates in opposite direction i. e if one φ_m / 2 is rotating in clockwise direction then the other φ_m / 2 rotates in anticlockwise direction. When a single phase ac supply is given to the stator winding of single phase induction motor, it produces its flux of magnitude, φ_m. According to the double field revolving theory, this alternating flux, φ_m is divided into two components of magnitude φ_m /2. Each of these components will rotate in opposite direction, with the synchronous speed, N_s. Let us call these two components of flux as forward component of flux, φ_f and backward component of flux, φ_b. The resultant of these two component of flux at any instant of time, gives the value of instantaneous stator flux at that particular instant.

$$i.e.\phi_r = \frac{\phi_m}{2} + \frac{\phi_m}{2} \; or \; \phi_r = \phi_f + \phi_b$$

Now at starting, both the forward and backward components of flux are exactly opposite to each other. Also both of these components of flux are equal in magnitude. So, they cancel each other and hence the net torque experienced by the rotor at starting is zero. So, the single phase induction motors are not self starting motors.

Methods for Making Single Phase Induction as Self Starting Motor

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 the stator flux is made rotating type, rather than alternating type, which rotates in one particular direction only. Then the induction motor will become self starting. 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. Once the motor starts running, the additional flux can be removed. The motor will continue to run under the influence of the main flux only. Depending upon the methods for making asynchronous motor as Self Starting Motor, there are mainly four types of single phase induction motor namely,

1. Split phase induction motor,
2. Capacitor start inductor motor,
3. Capacitor start capacitor run induction motor,
4. Shaded pole induction motor.
5. Permanent split capacitor motor or single value capacitor motor.

Comparison between Single Phase and Three Phase Induction Motors

6. Single phase induction motors are simple in construction, reliable and economical for small power rating as compared to three phase induction motors.
7. The electrical power factor of single phase induction motors is low as compared to three phase induction motors.
8. For same size, the single phase induction motors develop about 50% of the output as that of three phase induction motors.
9. The starting torque is also low for asynchronous motors / single phase induction motor.
10. The efficiency of single phase induction motors is less as compare it to the three phase induction motors.

Single phase induction motors are simple, robust, reliable & cheaper for small ratings. They are generally available up to 1 KW rating.

1.3 <u>Constructional details, principle of operation and performance characteristics of three phase induction motor</u>

In electrical motor is such an electromechanical device which converts electrical energy into a mechanical energy. In case of three phase AC operation, most widely used motor is Three phase induction motor as this type of motor does not require any starting device or we can say they are self starting induction motor.For better understanding the principle of three phase induction motor, the basic constructional feature of this motor must be known to us. This Motor consists of two major parts: Stator: Stator of three phase induction motor is made up of numbers of slots to construct a 3 phase winding circuit which is connected to 3 phase AC source. The three phase winding are arranged in such a manner in the slots that they produce a rotating magnetic field after 3Ph. AC supply is given to them. Rotor: Rotor of three phase induction motor consists of cylindrical laminated core with parallel slots that can carry conductors. Conductors are heavy copper or aluminum bars which fits in each slots & they are short circuited by the end rings. The slots are not exactly made parallel to the axis of the shaft but are slotted a little skewed because this arrangement reduces magnetic humming noise & can avoid stalling of motor.

<u>Working of Three Phase Induction Motor</u>

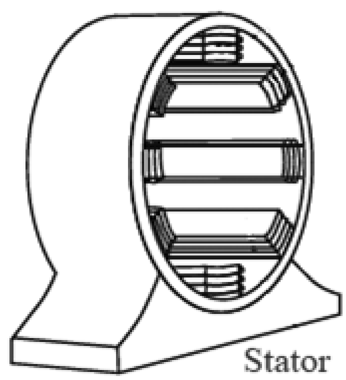
<u>Production of Rotating Magnetic Field</u>

The stator of the motor consists of overlapping winding offset by an electrical angle of 120°. When the primary winding or the stator is connected to a 3 phase AC source, it establishes a rotating magnetic field which rotates at the synchronous speed. Secrets Behind the Rotation: According to Faraday’s law an emf induced in any circuit is due to the rate of change of magnetic flux linkage through the circuit. As the rotor winding in an induction motor are either closed through an external resistance or directly shorted by end ring, and cut the stator rotating magnetic field, an emf is induced in the rotor copper bar and due to this emf a current flows through the rotor conductor. Here the relative speed between the rotating flux and static rotor conductor is the cause of current generation; hence as per Lenz's law the rotor will rotate in the same direction to reduce the cause i.e. the relative velocity.

Thus from the working principle of three phase induction motor it may observed that the rotor speed should not reach the synchronous speed produced by the stator. If the speeds equals, there would be no such relative speed, so no emf induced in the rotor, & no current would be flowing, and therefore no torque would be generated. Consequently the rotor can not reach the synchronous speed. The difference between the stator (synchronous speed) and rotor speeds is called the slip. The rotation of the magnetic field in an induction motor has the advantage that no electrical connections need to be made to the rotor. Thus the three phase induction motor is:

- Self-starting.
- Less armature reaction and brush sparking because of the absence of commutators and brushes that may cause sparks.
- Robust in construction.
- Economical.
- Easier to maintain.

Stator



The stator of a 3 phase IM (Induction Motor) is made up with number of stampings, and these stampings are slotted to receive the stator winding. The stator is wound with a 3 phase winding which is fed from a 3 phase supply. It is wound for a defined number of poles, and the number of poles is determined from the required speed. For greater speed, lesser number of poles is used and vice versa. When stator windings are supplied with 3 phase ac supply, they produce alternating flux which revolves with synchronous speed. The synchronous speed is inversely proportional to number of poles ($N_s = 120f / P$). This revolving or rotating magnetic flux induces current in rotor windings according to Faraday's law of mutual induction.

Rotor

Squirrel Cage Rotor

The rotor is a rotating part of induction motor. The rotor is connected to the mechanical load through the shaft. The rotor of the three phase induction motor are further classified as-

1. Squirrel cage rotor,
2. Slip ring rotor or wound rotor or phase wound rotor.

Depending upon the type of rotor used the three phase induction motor are classified as-

1. Squirrel cage induction motor
2. Slip ring induction motor or wound induction motor or phase wound induction motor

The construction of stator for both the kind of three phase induction motor remains the same and is discussed in brief in next paragraph. Stator of Three Phase Induction Motor The stator of the three phase induction motor consists of three main parts:

1. Stator frame
2. Stator core
3. Stator winding or field winding

Stator Frame: It is the outer most part of the three phase induction motor. Its main function is to support the stator core and the field winding. It acts as a covering and provide protection and mechanical strength to all the inner parts of the machine. The frame is either made up of die cast or fabricated steel. The frame of three phase induction motor should be very strong and rigid as the air gap length of three phase induction motor is very small, otherwise rotor will not remain concentric with stator which will give rise to unbalanced magnetic pull.

Stator Core : The main function of the stator core is to carry alternating flux. In order to reduce the eddy current losses the stator core is laminated. This laminated type of structure is made up of stamping which is about 0.4 to 0.5 mm thick. All the stamping are stamped together to form stator core, which is then housed in stator frame. The stampings are generally made up of silicon steel, which reduces the hysteresis loss.

Stator Winding or Field Winding : The slots on the periphery of stator core of the three phase induction motor carries three phase windings. This three phase winding is supplied by three phase ac supply. The three phases of the winding are connected either in star or delta depending upon which type of starting method is used. The squirrel cage motor is mostly started by star-delta stater and hence the stator of squirrel cage motor are delta connected. The slip ring three phase induction motor are started by inserting resistances so, the stator winding can be connected either in star or delta. The winding wound on the stator of three phase induction motor is also called field winding and when this winding is excited by three phase ac supply it produces rotating magnetic field.

1.4 Constructional details, principle of operation and performance characteristics of synchronous motor

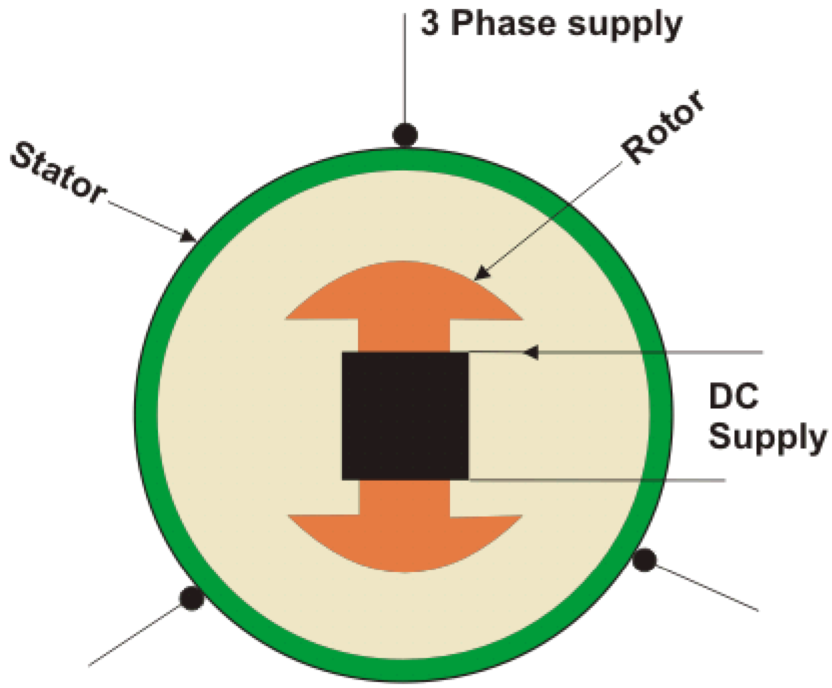
Electrical motor in general is an electro-mechanical device that converts energy from electrical domain to mechanical domain. Based on the type of input we have classified it into single phase and 3 phase motors. Among 3 phase motors, induction motors and synchronous motors are more widely used. When a 3 phase electric conductors are placed in a certain geometrical positions (In certain angle from one another) then an electrical field is generated. Now the rotating magnetic field rotates at a certain speed, that speed is called synchronous speed. Now if an electromagnet 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. It is basically a fixed speed motor because it has only one speed, which is synchronous speed and therefore no intermediate speed is there or in other words it’s in synchronism with the supply frequency. Synchronous speed is given by

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

Where, f = supply frequency and p = no. of poles

Construction of Synchronous Motor



Synchronous Motor

Normally it's construction is almost similar to that of a 3 phase induction motor, except the fact that the rotor is given DC supply, the reason of which is explained later. Now, let us first go through the basic construction of this type of motor.
From the above picture, it is clear that how this type of motors are designed. The stator is given is given three phase supply and the rotor is given DC supply.

Main Features of Synchronous Motors

1. Synchronous motors are inherently not self starting. They require some external means to bring their speed close to synchronous speed to before they are synchronized.
2. The speed of operation of is in synchronism with the supply frequency and hence for constant supply frequency they behave as constant speed motor irrespective of load condition
3. This motor has the unique characteristics of operating under any electrical power factor. This makes it being used in electrical power factor improvement.

<u>Principle of Operation Synchronous Motor</u>

Synchronous motor is a doubly excited machine i.e two electrical inputs are provided to it. It’s stator winding which consists of a 3 phase winding is provided with 3 phase supply and rotor is provided with DC supply. The 3 phase stator winding carrying 3 phase currents produces 3 phase rotating magnetic flux. The rotor carrying DC supply also produces a constant flux. Considering the frequency to be 50 Hz, from the above relation we can see that the 3 phase rotating flux rotates about 3000 revolution in 1 min or 50 revolutions in 1 sec. At a particular instant rotor and stator poles might be of same polarity (N-N or S-S) causing repulsive force on rotor and the very next second it will be N-S causing attractive force. But due to inertia of the rotor, it is unable to rotate in any direction due to attractive or repulsive force and remain in standstill condition. Hence it is not self starting.

To overcome this inertia, rotor is initially fed some mechanical input which rotates it in same direction as magnetic field to a speed very close to synchronous speed. After some time magnetic locking occurs and the synchronous motor rotates in synchronism with the frequency.

Methods of Starting of Synchronous Motor

1. Motor starting with an external prime Mover: Synchronous motors are mechanically coupled with another motor. It could be either 3 phase induction motor or DC shunt motor. DC excitation is not fed initially. It is rotated at speed very close to its synchronous speed and after that DC excitation is given. After some time when magnetic locking takes place supply to the external motor is cut off.
2. Damper winding: In case, synchronous motor is of salient pole type, additional winding is placed in rotor pole face. Initially when rotor is standstill, relative speed between damper winding and rotating air gap flux in large and an emf is induced in it which produces the required starting torque. As speed approaches synchronous speed, emf and torque is reduced and finally when magnetic locking takes place, torque also reduces to zero. Hence in this case synchronous is first run as three phase induction motor using additional winding and finally it is synchronized with the frequency.

Application of Synchronous Motor

1. Synchronous motor having no load connected to its shaft is used for power factor improvement. Owing to its characteristics to behave at any electrical power factor, it is used in power system in situations where static capacitors are expensive.
2. Synchronous motor finds application where operating speed is less (around 500 rpm) and high power is required. For power requirement from 35 kW to 2500 KW, the size, weight

and cost of the corresponding three phase induction motor is very high. Hence these motors are preferably used. Ex- Reciprocating pump, compressor, rolling mills etc.

1.5 Constructional details, principle of operation and performance characteristics of universal motor

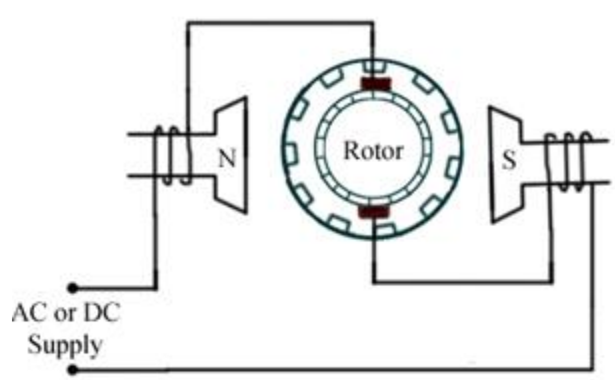
A universal motor is a special type of motor which is designed to run on either DC or single phase AC supply. These motors are generally series wound (armature and field winding are in series), and hence produce high starting torque (See characteristics of DC motors here). That is why, universal motors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

(i)compensated type and

(ii) uncompensated type

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. However, the whole magnetic path (stator field circuit and also armature) is laminated. Lamination is necessary to minimize the eddy currents which induce while operating on AC. The rotary armature is of wound type having straight or skewed slots and commutator with brushes resting on it. The commutation on 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.

Working of universal motor

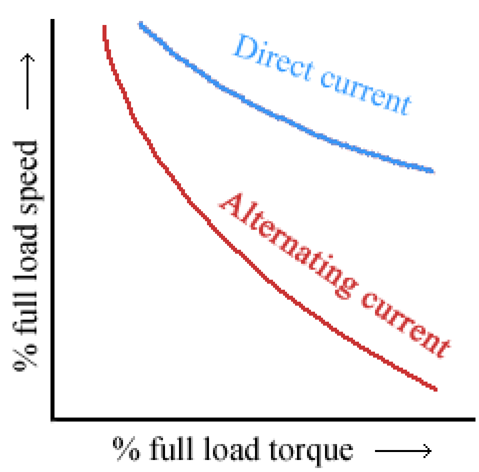


A universal motor works on either DC or single phase AC supply. When the universal motor is fed with a DC supply, it works as a DC series motor. (see working of a DC series motor here). When current flows in the field winding, it produces an electromagnetic field. The same current also flows from the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

When fed with AC supply, it still produces unidirectional torque. Because, armature winding and field winding are connected in series, they are in same phase. Hence, as polarity of AC changes periodically, the direction of current in armature and field winding reverses at the sametime.

Thus, direction of magnetic field and the direction of armature current reverses in such a way that the direction of force experienced by armature conductors remains same. Thus, regardless of AC or DC supply, universal motor works on the same principle that DC series motor works.

Speed/load characteristics



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

Applications of universal motor

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

1.6 Constructional details, principle of operation and performance characteristics of servo motor

A servo motor is an electrical device which can push or rotate an object with great precision. If you want to rotate and object at some specific angles or distance, then you use servo motor. It is just made up of simple motor which run through servo mechanism. If motor is used is DC powered then it is called DC servo motor, and if it is AC powered motor then it is called AC servo motor. We can get a very high torque servo motor in a small and light weight packages. Doe to these features they are being used in many applications like toy car, RC helicopters and planes, Robotics, Machine etc.

Servo motors are rated in kg/cm (kilogram per centimeter) most hobby servo motors are rated at 3kg/cm or 6kg/cm or 12kg/cm. This kg/cm tells you how much weight your servo motor can lift at a particular distance. For example: A 6kg/cm Servo motor should be able to lift 6kg if the load is suspended 1cm away from the motors shaft, the greater the distance the lesser the weight carrying capacity.

The position of a servo motor is decided by electrical pulse and its circuitry is placed beside the motor.

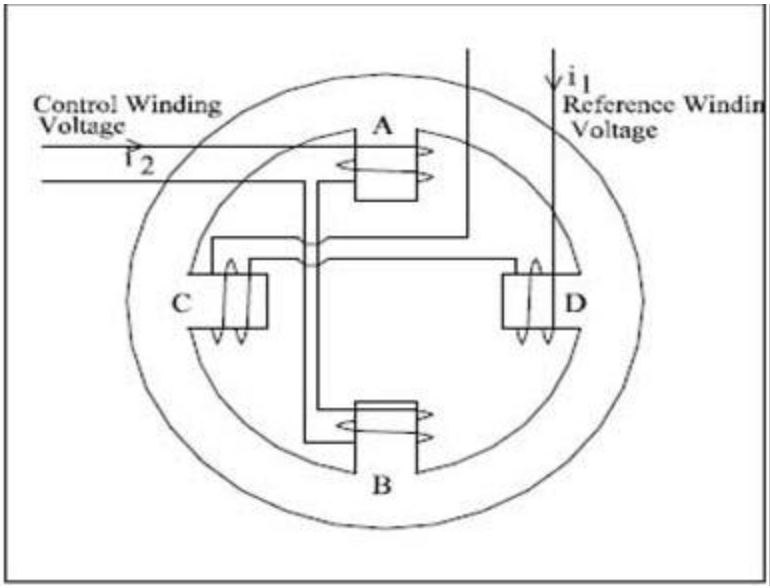
Servo Mechanism

It consists of three parts:

1. Controlled device
2. Output sensor
3. Feedback system

It is a closed loop system where it uses positive feedback system to control motion and final position of the shaft. Here the device is controlled by a feedback signal generated by comparing output signal and reference input signal.

Here reference input signal is compared to reference output signal and the third signal is produces by feedback system. And this third signal acts as input signal to control device. This signal is present as long as feedback signal is generated or there is difference between reference input signal and reference output signal. So the main task of servomechanism is to maintain output of a system at desired value at presence of noises.



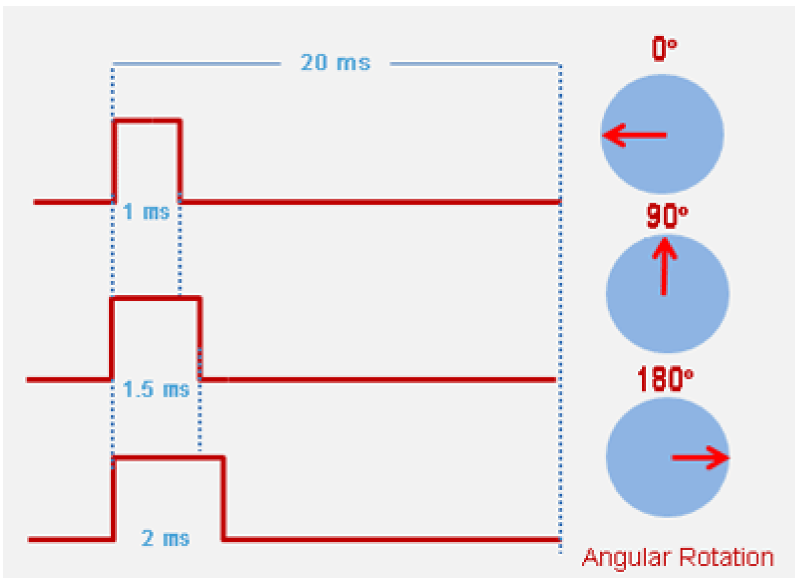
Working principle of Servo Motors

A servo consists of a Motor (DC or AC), a potentiometer, gear assembly and a controlling circuit. First of all we use gear assembly to reduce RPM and to increase torque of motor. Say at initial position of servo motor shaft, the position of the potentiometer knob is such that there is no electrical signal generated at the output port of the potentiometer. Now an electrical signal is given to another input terminal of the error detector amplifier. Now difference between these two signals, one comes from potentiometer and another comes from other source, will be processed in feedback mechanism and output will be provided in term of error signal. This error signal acts as the input for motor and motor starts rotating. Now motor shaft is connected with potentiometer and as motor rotates so the potentiometer and it will generate a signal. So as the potentiometer's angular position changes, its output feedback signal changes. After sometime the position of potentiometer reaches at a position that the output of potentiometer is same as external signal provided. At this condition, there will be no output signal from the amplifier to the motor input as there is no difference between external applied signal and the signal generated at potentiometer, and in this situation motor stops rotating.

Controlling Servo Motor:

All motors have three wires coming out of them. Out of which two will be used for Supply (positive and negative) and one will be used for the signal that is to be sent from the MCU.

Servo motor is controlled by PWM (Pulse with Modulation) which is provided by the control wires. There is a minimum pulse, a maximum pulse and a repetition rate. Servo motor can turn 90 degree from either direction form its neutral position. The servo motor expects to see a pulse every 20 milliseconds (ms) and the length of the pulse will determine how far the motor turns. For example, a 1.5ms pulse will make the motor turn to the 90° position, such as if pulse is shorter than 1.5ms shaft moves to 0° and if it is longer than 1.5ms than it will turn the servo to 180°.



Servo motor works on PWM (Pulse width modulation) principle, means its angle of rotation is controlled by the duration of applied pulse to its Control PIN. Basically servo motor is made up of DC motor which is controlled by a variable resistor (potentiometer) and some gears. High speed force of DC motor is converted into torque by Gears. We know that WORK= FORCE X DISTANCE, in DC motor Force is less and distance (speed) is high and in Servo, force is High and distance is less. Potentiometer is connected to the output shaft of the Servo, to calculate the angle and stop the DC motor on required angle.

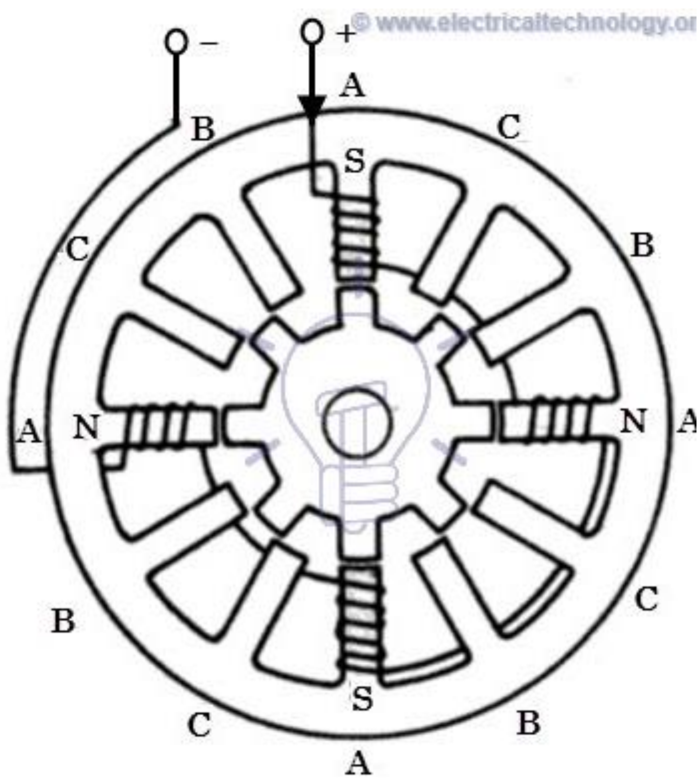
Servo motor can be rotated from 0 to 180 degree, but it can go up to 210 degree, depending on the manufacturing. This degree of rotation can be controlled by applying the Electrical Pulse of proper width, to its Control pin. Servo checks the pulse in every 20 milliseconds. Pulse of 1 ms

(1 millisecond) width can rotate servo to 0 degree, 1.5ms can rotate to 90 degree (neutral position) and 2 ms pulse can rotate it to 180 degree.

All servo motors work directly with your +5V supply rails but we have to be careful on the amount of current the motor would consume, if you are planning to use more than two servo motors a proper servo shield should be designed.

1.7 <u>Constructional details, principle of operation and performance characteristics of stepper motor</u>

It is a brushless electromechanical device which converts the train of electric pulses applied at their excitation windings into precisely defined step-by-step mechanical shaft rotation. The shaft of the motor rotates through a fixed angle for each discrete pulse. This rotation can be linear or angular.It gets one step movement for a single pulse input.



When a train of pulses is applied, it gets turned through a certain angle. The angle through which the stepper motor shaft turns for each pulse is referred as the step angle, which is generally expressed in degrees.

The number of input pulses given to the motor decides the step angle and hence the position of motor shaft is controlled by controlling the number of pulses. This unique feature makes the stepper motor to be well suitable for open-loop control system wherein the precise position of the shaft is maintained with exact number of pulses without using a feedback sensor.

If the step angle is smaller, the greater will be the number of steps per revolutions and higher will be the accuracy of the position obtained. The step angles can be as large as 90 degrees and as small as 0.72 degrees, however, the commonly used step angles are 1.8 degrees, 2.5 degrees, 7.5 degrees and 15 degrees.

The direction of the shaft rotation depends on the sequence of pulses applied to the stator. The speed of the shaft or the average motor speed is directly proportional to the frequency (the rate of input pulses) of input pulses being applied at excitation windings. Therefore, if the frequency is low, the stepper motor rotates in steps and for high frequency, it continuously rotates like a DC motor due to inertia.

Like all electric motors, it has stator and rotor. The rotor is the movable part which has no windings, brushes and a commutator. Usually the rotors are either variable reluctance or permanent magnet kind. The stator is often constructed with multipole and multiphase windings, usually of three or four phase windings wound for a required number of poles decided by desired angular displacement per input pulse.

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

There are several *types of stepper motors* are available in today’s market over a wide range of sizes, step count, constructions, wiring, gearing, and other electrical characteristics. As these motors are capable to operate in discrete nature, these are well suitable to interface with digital control devices like computers.

Due to the precise control of speed, rotation, direction, and angular position, these are of particular interest in industrial process control systems, CNC machines, robotics, manufacturing automation systems, and instrumentation.

There are three basic categories of stepper motors, namely permanent magnet stepper motor, variable reluctance stepper motor and hybrid stepper motor. In all these motors excitation windings are employed in stator where the number of windings refer to the number of phases.

A DC voltage is applied as an excitation to the coils of windings and each winding terminal is connected to the source through a solid state switch. Depends on the type of stepper motor, its rotor design is constructed such as soft steel rotor with salient poles, cylindrical permanent magnet rotor and permanent magnet with soft steel teeth

1.8 Constructional details, principle of operation and performance characteristics of reluctance motor

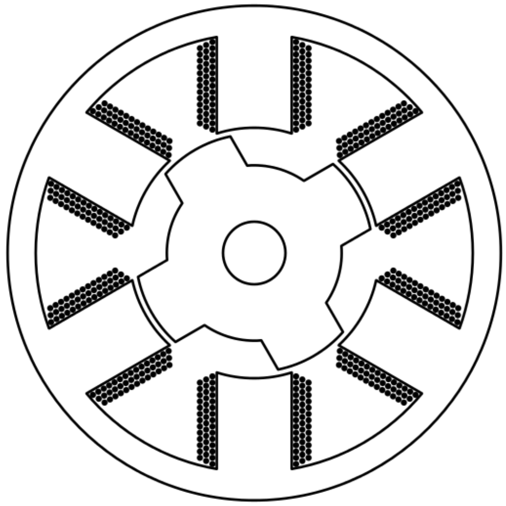
A reluctance motor is a type of electric motor that induces non-permanent magnetic poles on the ferromagnetic rotor. The rotor does not have any windings. Torque is generated through the phenomenon of magnetic reluctance.

There are various types of reluctance motors:

- Synchronous reluctance
- Variable reluctance
- Switched reluctance
- Variable reluctance stepping.

Reluctance motors can deliver very high power density at low cost, making them ideal for many applications. Disadvantages are high torque ripple (the difference between maximum and minimum torque during one revolution) when operated at low speed, and noise [1] caused by torque ripple. Until the early twenty-first century their use was limited by the complexity of designing and controlling them. These challenges are being overcome by advances in the theory, by the use of sophisticated computer design tools, and by the use of low-cost embedded systems for control, typically based on microcontrollers using control algorithms and real-time computing to tailor drive waveforms according to rotor position and current or voltage feedback. Before the development of large-scale integrated circuits the control electronics would have been prohibitively costly.

- The stator consists of a single winding called main winding. But single winding can not produce rotating magnetic field. So for production of rotating magnetic field, there must be at least two windings separated by certain phase angle.
- Hence stator consists of an additional winding called auxiliary winding which consists of capacitor in series with it.



- Thus there exists a phase difference between the currents carried by the two windings and corresponding fluxes.
- Such two fluxes react to produce the rotating magnetic field. The technique is called split phase technique of production of rotating magnetic field.
- The speed of this field is synchronous speed which is decided by the number of poles for which stator winding is wound.
- The rotor carries the short circuited copper or aluminium bars and it acts as 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 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 small and the combined inertia of the rotor and the load should be small to run the motor as a synchronous motor