Automation in Manufacturing
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Week – 06
Electrical drives
Lecture – 02
DC and AC Motors

In this lecture, we will be learning the Direct Current Motors and Alternating Current Motors.

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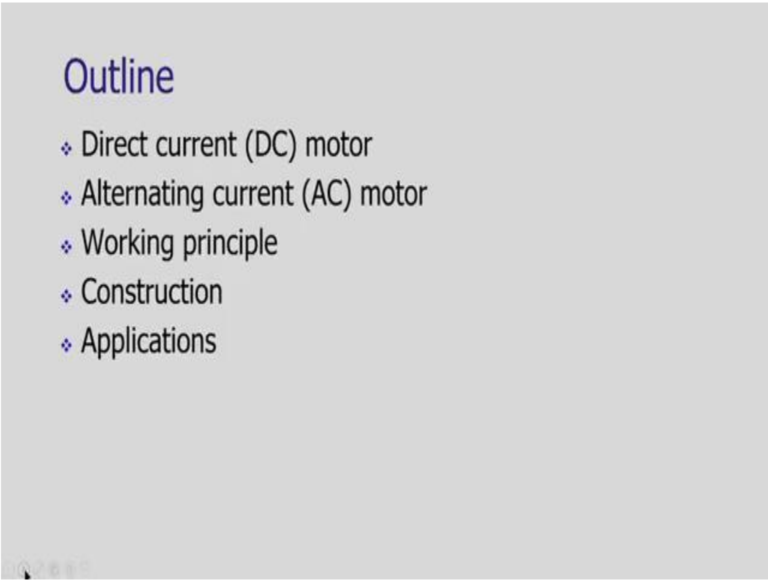

Let us look at the outline of this lecture. At start of the lecture, we will see the direct current motor, its principle of operation, construction and its applications. DC motor is the fundamental motor. It is a very important part of an automated system. Then we will see the alternating current motor, its constructional details, principle of operation and the applications. At then we will conclude, and then we move ahead for the next part of our study.

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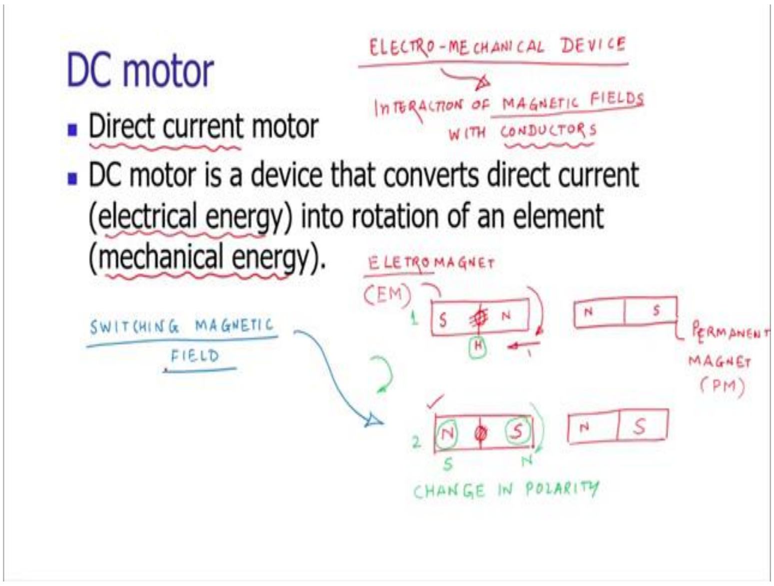

DC motor is Direct Current motor. Direct voltage is applied to this electromechanical device the required mechanical energy is obtained. DC motor basically converts the electrical energy into rotation of a mechanical element.

The electrical energy is converted into the mechanical energy. In product lifecycle, there are various manufacturing related functions which require the mechanical energy.

The basic function is transformation the production. The transformation of raw material into the finished product or semi-finished product. Assembly of the semi-finished product to get the final work. The quality control or the inspection of the in process products or the finished product, then the mechanical energy is required for packaging, for painting and then dispatching it to the market.

DC motor is an electromechanical device. In this device, basically the interaction of the magnetic fields is obtained with the conductors. These magnetic fields are generated by using the electrical energy, and then the mechanical energy is produced due to the interaction between the magnetic fields with the conducting elements of the device.

DC motor is an electromechanical device which converts electrical energy into the mechanical energy. The DC motor is most common type of electromechanical device being used in domestic as well as industrial applications. DC motor is capable of producing continuous motion, and the DC motor speed can be controlled easily.

The principle is very simple. Consider we are having a magnet. This is a permanent magnet. If we take another magnet and let us consider this magnet is electromagnet. This material or this element is getting the magnetic properties when it is energized due to the electricity.

In this situation as we know that the similar kind of polesrepel each other, there would be repulsion if we hinge this electromagnet then instead of having the repulsion and the linear motion away from the permanent magnet, the north pole will rotate bound this hinge. This will rotate and the south pole which will get attracted towards this north; and due to this the rotated position of the electromagnet something is obtained like this.

Now, if the polarity of supply of electricity to this electromagnet is changed, the south pole will be converted into north pole, and the north pole will be converted into south pole. Due to the change in polarity, again two similar poles near to each other are obtained. Due to the repulsion of the similar poles, we get the force acting on the electromagnet, but it is hinged, so that force will be converted into the torque. This is step number 1, and this is step number 2. The step number 1 and 2 will be repeated in sequence. And in this way the clockwise motion about H is obtained.

By having a switching mechanism of magnetization, the rotation of the mechanical element can be obtained. And that rotational mechanical energy can be utilized for a variety of application. Thus the crucial factor in the electric motor is switching magnetic field, generation of switching magnetic field.

The switching magnetic field is responsible for rotation of this element about the point H. The various types of motors which are invented and developed in the industry are based upon the various methods or various types of application of the switching magnetic field. The purpose is same to convert electrical energy into mechanical energy, but the mode of switching the magnetic field is different.

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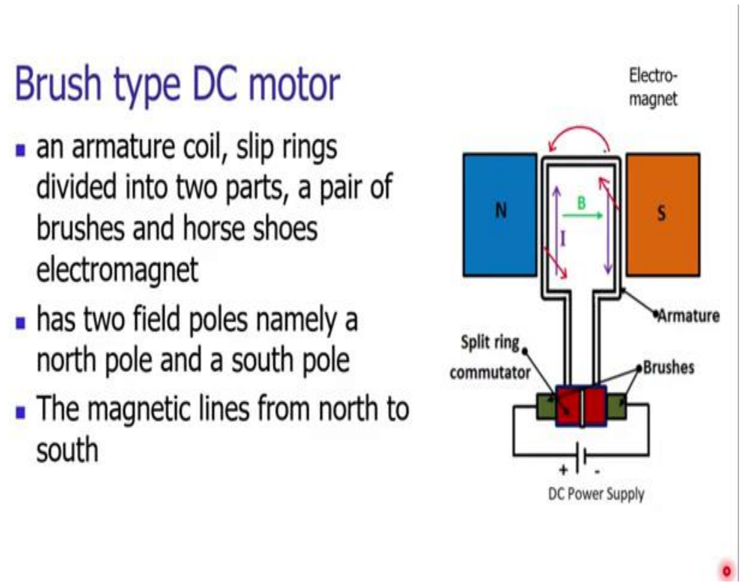

The first and basic type of DC motor is brush type DC motor. The construction of DC motor is very simple. It has an armature coil. We can see the schematic of the DC motor. There is an armature coil. The DC power supply is applied across these armature coils. There is a pair of brushes, and that brushes are in contact with the split ring commutator.

The DC power supply is applied to the armature coil through brushes and split ring commutator. The DC motor has the important element that is an electromagnet. It has two poles that is a north pole and a south pole. The magnet is externally energized. And when the electrical energy is applied to this magnet, there is a generation of magnetic lines from north to south poles.

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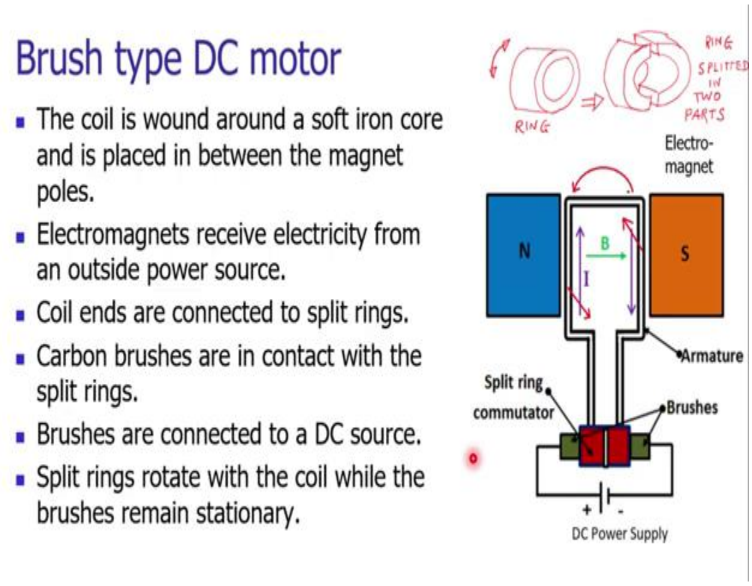

The armature is nothing but a coil which is wound around a soft iron core, and it is placed in between the magnetic poles. Now, let us see why this arrangement of split ring is provided. Split ring is an arrangement in which we are splitting a typical ring into two parts. And these two parts are connected to the end of the armature coil. The armature coil or the armature is supported at both the ends in bearings, and it is free to rotate in that bearing. When the DC power source is applied, there will be generation of electricity, and that electricity will be passed through the armature coil.

As it is passing through the armature coil, it generates a torque; it generates a force in the downward direction. And due to that there is rotation of the armature coil. When this portion of the split ring goes in the downward direction and it will be attracted toward the south pole, and the remaining portion will be moved in upward direction and it will be coming near to the north pole. As this portion is getting aligned with the south pole, there is a occurrence of change in polarity. This portion which is there in contact with the positive polarity will be connected to the negative polarity when there is a rotation about 180 degrees.

In this element, there is a change in direction of the current. This portion will come over here. And since the polarity is changed for this portion this portion is called as the half portion. When this portion due to the formation of magnetic field will be pushed in downward direction, it will come near to the south pole, but now the situation is that due to this split ring arrangement there is a change in polarity. And that change in polarity will push this element in the anticlockwise direction. As it is pushing in anticlockwise direction, this portion again will get closer to the north pole.

And as it is getting closer to the north pole, once again there is a change in polarity. It will restore its positive polarity and will move in a downward direction, it will be pushed further in anticlockwise direction and will come near to the north pole, and again there is a restoration of its positive polarity. And due to this positive polarity, the current will start flowing in its original direction. Due to this continuous changing magnetic field inside the armature coil, the rotation of the coil and torque over the coil is obtained. .

In this way the direct power supply, the direct voltage, direct potential difference which is applied on the armature coil is producing the rotational momentum of the coil. When a load is attached to the end of the armature coil, the rotational energy can be easily transferred which is generated for the intended application.

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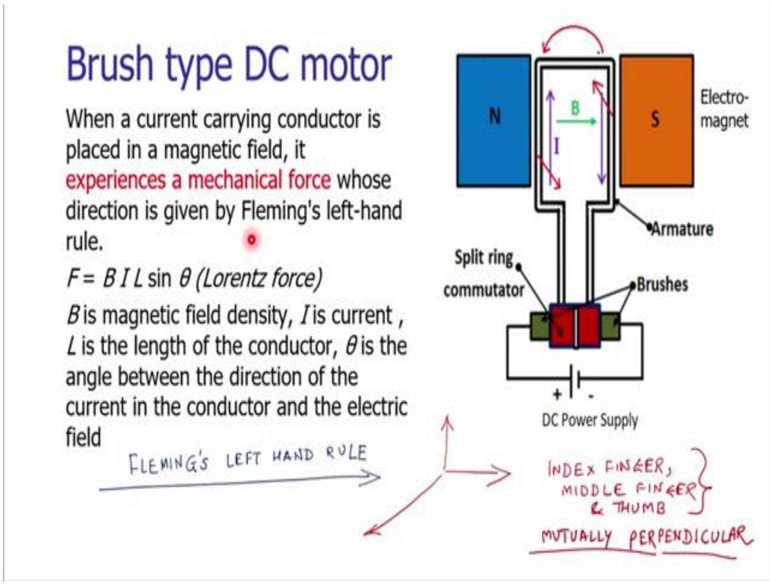

When a current carrying conductor is placed in a magnetic field, it experiences a mechanical force, whose direction is given by the Fleming left-hand rule. To understand the Fleming’s left-hand rule, we need to hold the index finger, middle finger and thumb of the left-hand in mutually perpendicular way.

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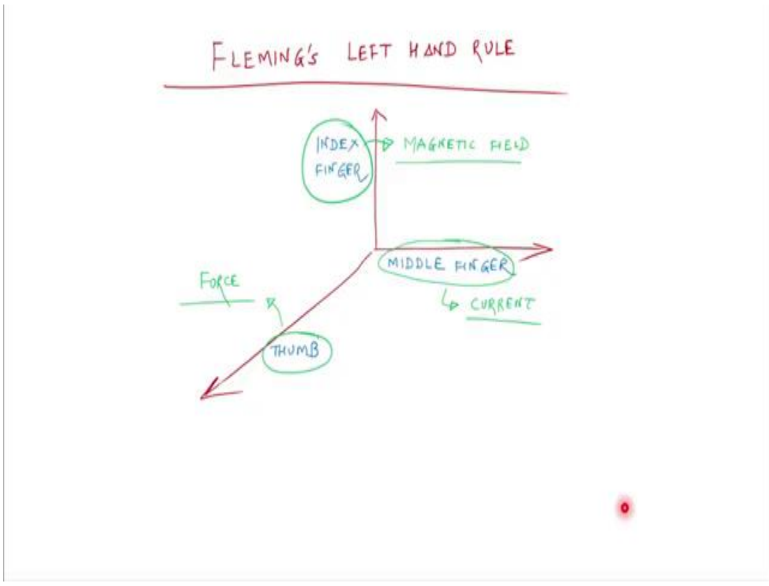

When we are having this arrangement, according to this rule, if the index finger is representing the magnetic field and the current is along the direction of the middle finger, then the force will be in the direction of the thumb. By applying the Fleming's left-hand rule, we can easily find out the moment of the force or the direction of the force along which the conductor is moving.

Now, if we apply the Fleming's left-hand rule over here, the index finger is representing the magnetic field, the middle finger is representing the current which is flowing across the magnetic field. Due to the interaction of the electrical field and the magnetic field, a force will be applied on the current carrying coil, and the direction of the force along the thumb direction, and the thumb direction would be in the downward direction.

If we hold our left-hand with index finger along the B direction, middle finger for the current direction, the thumb will go down of the left-hand and that is representing the acting of the force on the current carrying coil. In this way, the left-hand is helping us to find out the direction of the force which is acting on the current carrying coil.

The magnitude of the force is given by the Lorentz equation. It is called as the Lorentz force. The magnitude of the force is the product of the magnetic field density, the magnitude of the current, and the length of the conductor. Thus, BI L would be further in product with the sin of the theta angle. Theta is angle between the direction of the current in the conductor, and the electrical field which is changing continuously. With this, the force which is acting on the current carrying coil and its direction can be easily computed.

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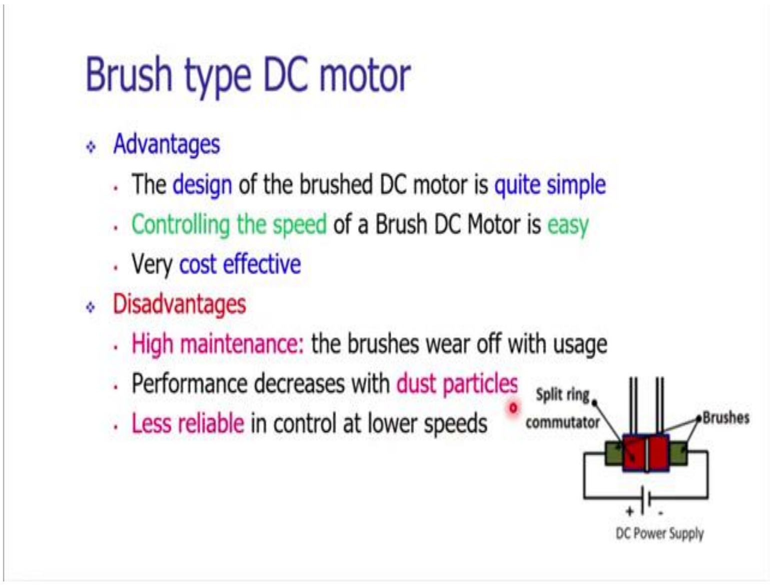

Now, let us study what are the various advantages that brush type DC motors are offering to us. The design and the construction of the brush type DC motor is quite simple. We need an electromagnet the current carrying coil that is armature. In actual, in the real DC motors, there are number of windings, then number of coils are there on the armature. The speed of the brush type DC motor can be easily controlled. Since the construction and the design is simple, these type of motors are very cost effective, they are economical and can be easily afforded.

However, there are certain limitations, and are fundamentally related to its maintenance. There is a split ring commutator which is in contact with the brushes. Through the contact of the brushes with the split ring, the electricity is applied to the armature coil. When the brushes are moving in relation with the split ring commutator, there is arching and friction. And due to this friction and arching, the brushes are getting worn out, they are wearing off with the continuous usage. And that may lead to the problem of sound, noise and the malfunctioning of the DC motor. Sometimes, there will be breakdown of the DC motor as well.

If this DC motor is used in harsh conditions where we are having the dust particles, that dust particles may lodge on the commutator split ring commutator, and that will lead to inefficient contact of the commutator with the brushes. Certainly there would be negative impact of this, and the performance of the DC motor will reduce. The DC motors are not good. They are not that reliable at lower speeds. They are the moderate or the medium speed application. But when the precise low speed application is required, then the performance of DC motor is not that good.

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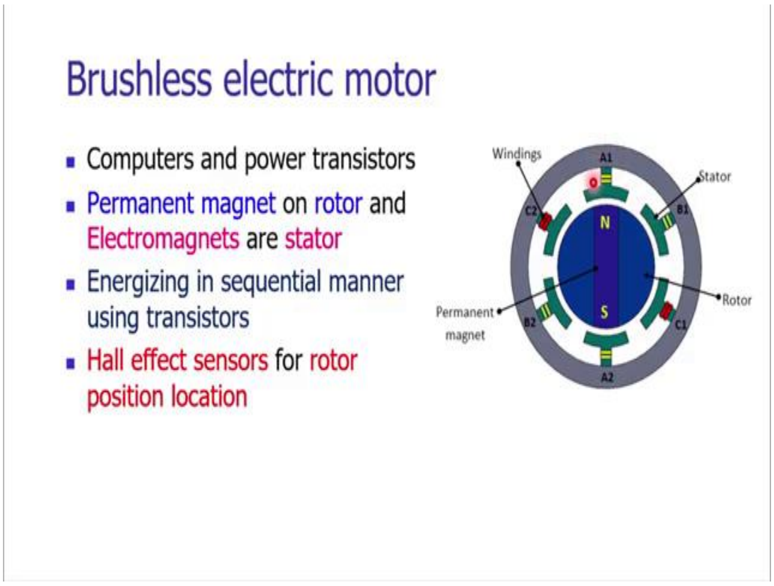

The next variant of DC motor is brushless DC motor. The brush DC motor, there is wearing off the brushes which is affecting the performance of the DC motor. To eliminate this drawback, an arrangement has been developed. In brushed DC motor, there is an armature coil, and DC power is supplied to the armature coil. As we need to pass on the electricity to the coil, some contact points are needed, and these contact points are creating the problem.

In brushless DC motor, the configuration is changed. Instead of having an current carrying coil as the rotor, a permanent magnet is used as the rotor. The motor is having a shaft. And on the shaft, a permanent magnet is attached. This shaft with the permanent magnet is kept inside the container. And on the periphery of this circular container, there are sets of electromagnets.

There are three pairs of electromagnets on the periphery of this circular rotor. These electromagnets are energized by using the electricity. And this energization will be carried out by using power transistors and computers. Since, the current is not sent to the rotor, there is no need of any brushes here. The stators are the stationary. As they are not moving, there is no need of the brushes for the stators as well. But these are the windings which are there on the stator coils. And these windings are energized in a sequential manner.

The pair A 1, A 2 will be energized in a such a way that the A 1 would be the south pole as the current is creating A1 as south pole, the magnet will get attracted towards the south pole A 1, and it will get oriented in the direction shown here. Then the B 1 will be energized and the current which is passing through A 1 will be reduced, it will be removed. As B 1 is getting energized, there is a generation of a south pole at B 1, the north pole will get attracted to the B 1. As it is getting attracted, it will try to align itself along the B 1, B 2, there is a rotation of the shaft. There is a rotary motion that will occur.

Next, the C 1, C 2 will get energized, then A 2 B 1 will get energized by changing the polarity. In this way by application of the current and change in the polarity, the rotor can be easily rotated, the location or the position of the rotor precisely can be monitored by using Hall Effect sensors. These are non-contact type of the position sensor. The information about the position location of the rotor will help the computers or microprocessors to energize the required stator windings. According to the signals given by the microprocessor, the power transistors will actuate the windings which are there on the stator poles. The sequential actuation of magnetic field will lead to the required rotation of the rotor in the brushless electric motor.

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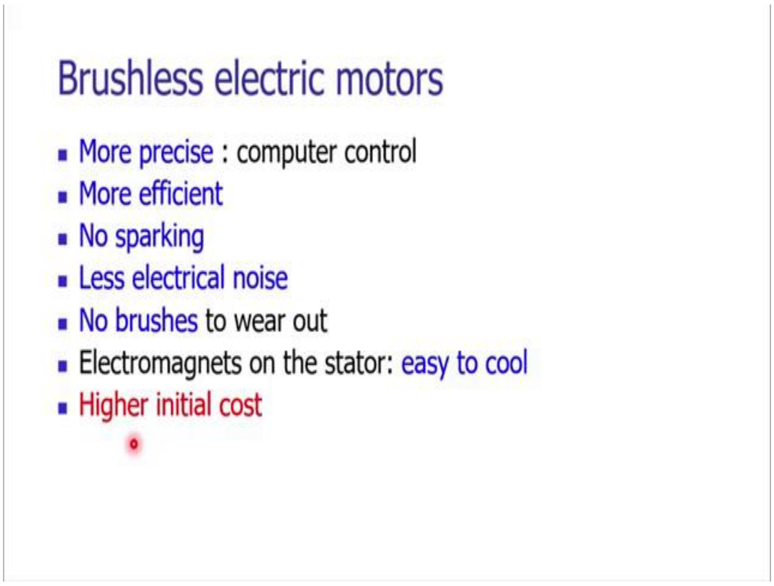

The brushless electric motor is offering us more precision. It is all due to the incorporation of microprocessor technology to get the required actuation done. They are more efficient; there is no sparking. As there is no sparking, the noise is also less. These drives are very quiet, and the maintenance issues are also very low. But the problem is the electromagnets on the stator coil.

Since the electricity is passed on the electromagnets, there would be heating of the stator coils. But as they are located on the periphery of the casing, they can be easily cooled. We can easily apply the convection heat transfer to enhance the heat transfer on the surface. The design of brushless electric motor is complex in comparison with the brushed DC motor that is why the cost of brushless DC motors is high.

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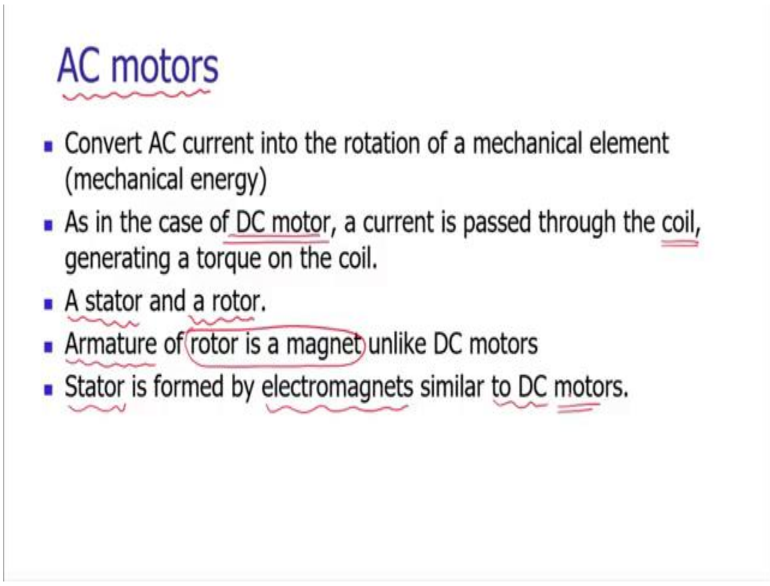

The next important electric motor is alternating current motor. The alternating current motor is AC motor, it converts the alternating current into the rotation of mechanical element. Instead of using the direct current or direct voltage, alternating current is used with certain frequency, and that alternating potential which is applied would be converted into the mechanical element.

In case of DC motor, a current is passed through a coil, and that current carrying conductor is placed in magnetic fields. Due to the interaction of the electricity which is passing through the coil and the magnetic field, a torque is generated on the coil and that is used to generate the required rotary motion.

In AC motor as well we are using a stator and rotor, but in AC motors rotor is used as a magnet. In DC motor, there was a current carrying coil, but instead of a current carrying coil a permanent magnet is used as a rotor in the AC motors. The stator body is formed by electromagnets, which is very similar to the DC motors. The difference between the AC motor and the DC motor as far as the construction is concerned. The AC motor has rotor as a permanent magnet, the DC motor is having a current carrying coil with set of brushes in the brushed DC motor.

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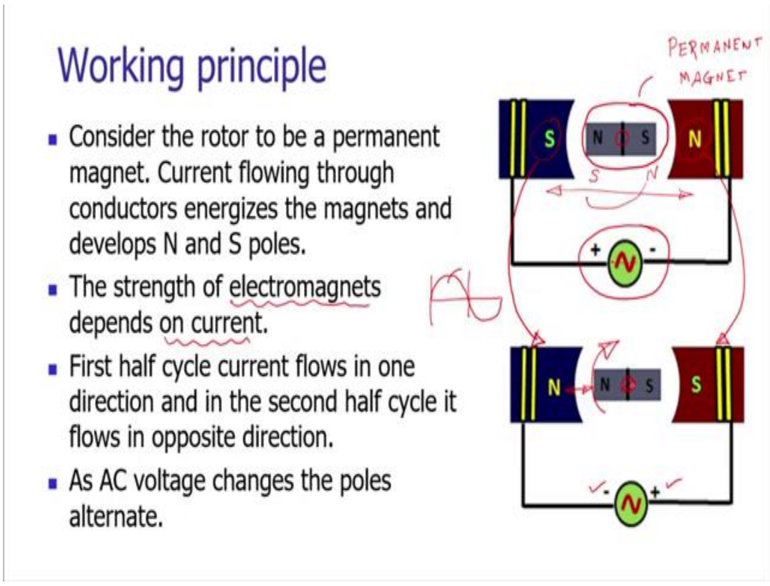

To understand the working principle of AC motor, let us consider the rotor to be a permanent magnet. The rotor is considered a permanent magnet. This is the permanent magnet rotor. The rotor is supported in bearings. And this assembly of the rotor is placed inside an electromagnet.

The electromagnet will be energized by using the AC power supply. The current which is flowing through the stator magnets that is electromagnets are generating rotating magnetic field, and that rotating magnetic field is compelling the rotor to rotate about its axis. The strength of the electromagnet depends upon the magnitude of the current.

For first half cycle, we are applying sinusoidal way of electric current. For first half cycle, let us consider the electromagnet is generating a south pole here, and the north pole over here. In this situation the north pole of the rotor magnet will get attracted towards the south pole, and it will get oriented in the fashion shown.

If we consider that this NS was SN pole in its previous position. When this half wave that is a positive towards this positive towards this south pole is energized and negative polarity is given to the north pole. Then what happens? This south pole which was there in previous case will get repelled, and this north pole will get attracted towards its opposite pole.

In this way, the rotor rotates by 180 degrees that is for first half wave of the alternating current. Now, for the next half, the polarity is changed. For the next half the south pole has become the north pole, and the north pole has become the south pole. Its polarity is reversed by reversing the direction of flow of the current. Due to the reverse in the polarity, due to reverse in the direction of flow of the current, there would be repulsion of the north pole of the rotor magnet with the north pole of the electromagnet, and there would be repulsion of south pole of the rotor magnet with south pole of the electromagnet.

Due to this, there would be again repulsion and the rotor will rotate about its own axis. In this way, by changing the direction of flow of electric current which is quite natural in alternating current, the rotation of the rotor magnet can be obtained about its own axis. In this way, the alternating current electrical energy will be converted into the mechanical energy.

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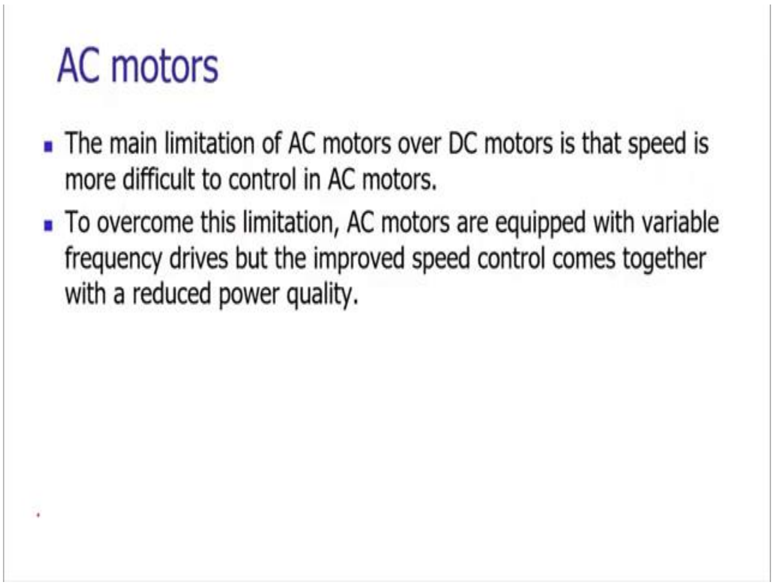

The fundamental limitation of AC motor over the DC motor is that the control of speed is more difficult in AC motors. The sinusoidal form of electrical energy is applied. And when a variable speed control is needed, it is difficult. To overcome this limitation, the AC motors can have the variable frequency drives, the variable frequency drives means an arrangement which will provide the variation in the frequency that is to be applied in the AC motor.

In general with the constant frequency, the ST AC motors are working. But for our intended application, the variation in the speeds may be required, the variation in the velocity of the spindle. For that purpose, an arrangement is needed which will provide the variable frequency of the AC current that is to be applied.

By using this variable frequency drives, there is improvement in the speed control, but the power quality would be reduced. In the transition from the low level to the high level through the variable frequency drive, the power magnitude may be reduced. We may not have the intended power that to be applied at the load.

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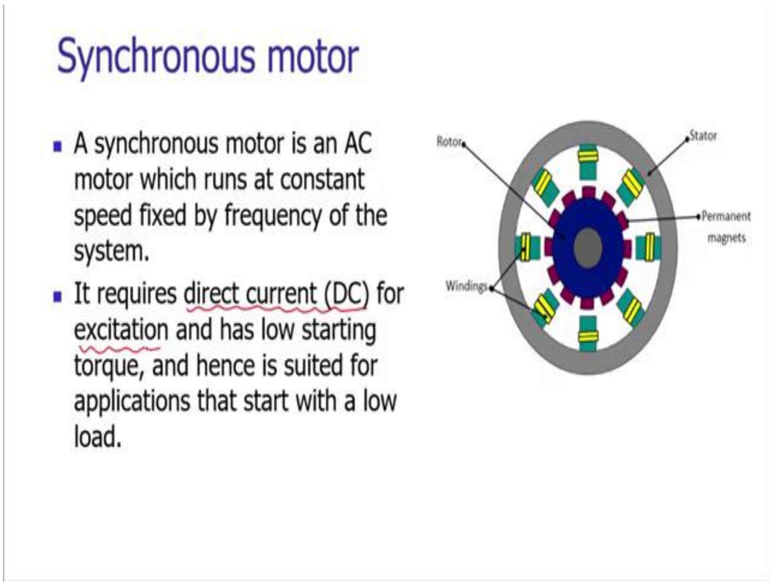

Now, let us look at the first variant of alternating current motor. This is synchronous motor. The synchronous motor is running at a constant speed, which is fixed by the frequency of the system. The synchronous motor requires the direct current for the excitation.

The rotor of the synchronous motor has certain inertia that is why it has the low starting torque. At start of the synchronous motor, it is difficult to generate the sufficient torque which will rotate the rotor. For that purpose, an external excitation, a separate excitation, separate energy is to be applied at the rotor to get start the rotating operation. Afterwards, the rotating magnetic field of the AC motor is rotating the rotor.

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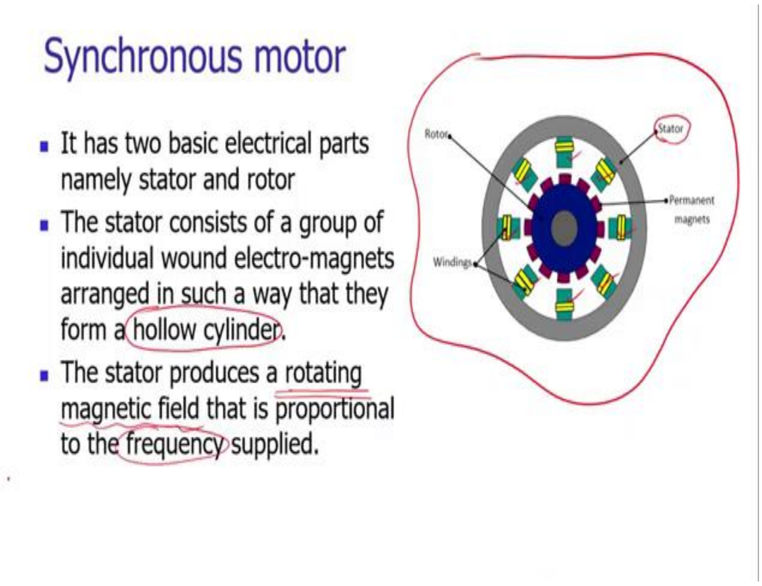

Synchronous motor is a variant of alternating current motor. It has basically two parts that is a stator and the rotor. The construction of the synchronous motor is shown. The stator of the motor comprises of a group of individual wound electromagnets. There are many electromagnets which are having the coils. They are arranged in such a way that they form a cylinder.

A multiple number of electromagnets are arranged such that they are forming a cylinder. These electromagnets are connected with the alternating current power supply as these electromagnets are getting energized a rotating magnetic field will be generated. And the magnitude and the direction of the rotating magnetic field is dependent upon the alternating current and the frequency of the AC power supply.

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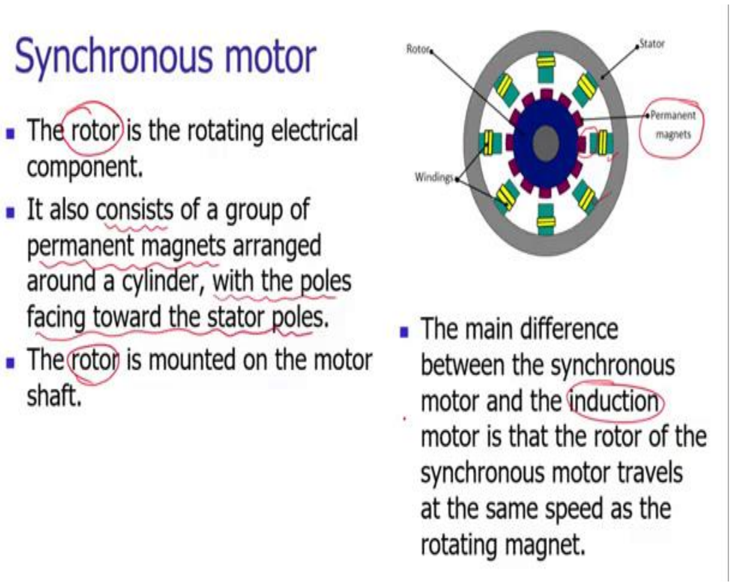

The rotor part, it also consists of the group of permanent magnets. Till now we have seen the rotor is a very simple in construction, it is a simple permanent magnet. But in synchronous motor, the rotor is comprising of many permanent magnets. These permanent magnets are arranged on its periphery, on its outer surface. They are arranged in such a way that their poles are facing toward the stator poles. Their poles are facing the poles of the stator coils. The rotor is mounted on the motor shaft. And the motor shaft is housed in bearings

When the fundamental difference of the synchronous motor and there is another important variation of AC motor that is the induction motor. In synchronous motor, the rotor of the synchronous motor is travelling at the same speed of the rotating magnet. This is an important application, this is an important advantage or the prominent advantage of the synchronous motor is that the rotor speed is similar to the stator speed. Whatever the stator is providing rotation in the magnetic field, the rotor will follow the same, but that is not the situation in the induction type alternating current motor.

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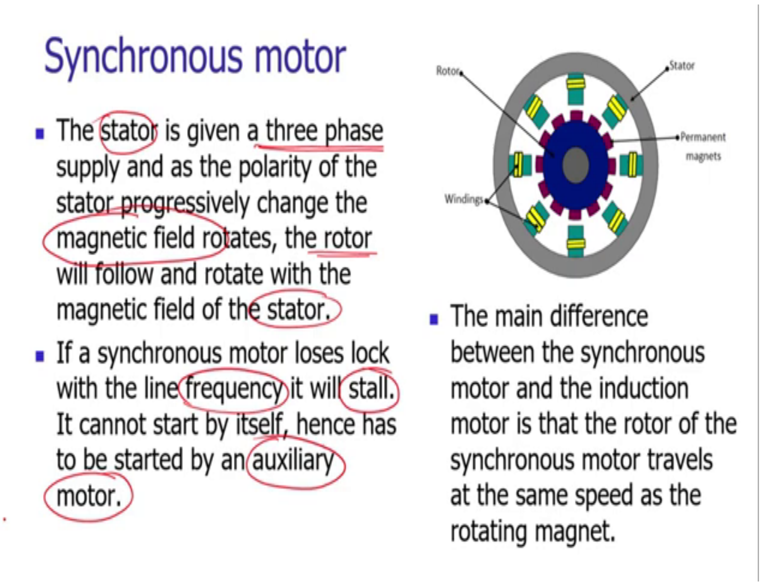

In synchronous motor, the stator is provided with three-phase power supply. And that change in the polarity is rotating the magnetic field. As the magnetic field is getting rotated, the rotor will follow that magnetic field. And in this way, the synchronous rotation of the rotor is obtained with the stator windings. Sometimes, the rotor will lose the lock with the line frequency. It may also happen that the rotor will lose the track, will lose the synchronization with the stator winding rotation. It is losing the synchronization with the rotating magnetic field provided by the stator winding.

In this case, the motor will get stalled, it will get halted. It cannot start by itself it does not have that facility. To start the motor in this particular situation, an auxiliary motor is required, that auxiliary motor is a DC motor. We have to attach or we have to help the rotor to start its rotation.

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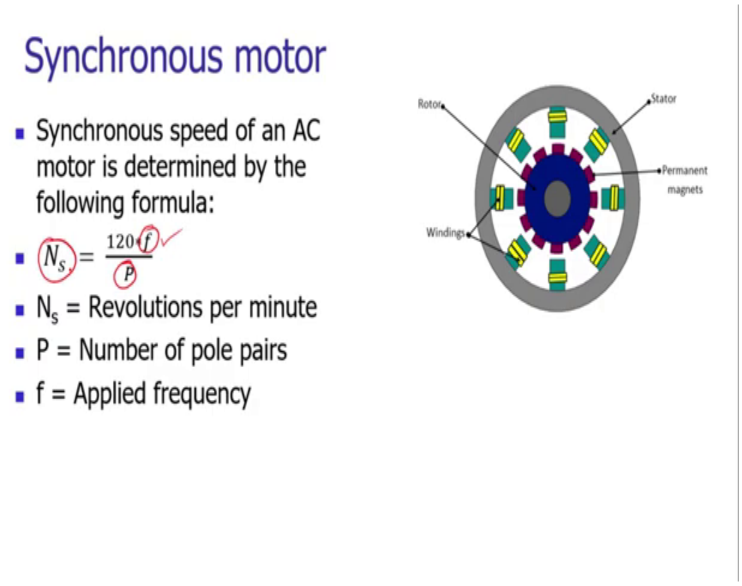

Now, how to compute the synchronous speed of an AC motor? Here is a simple correlation. The synchronous speed in revolutions per minute is function of the applied frequency and the number of pole pairs. The synchronous speed is directly proportional to the applied frequency as the frequency is increasing, so naturally, we are getting more revolutions per minute. However, the synchronous speed is inversely proportional to the number of pole pair. As number of pole pairs are increasing, the lower speed or less speed is obtained.

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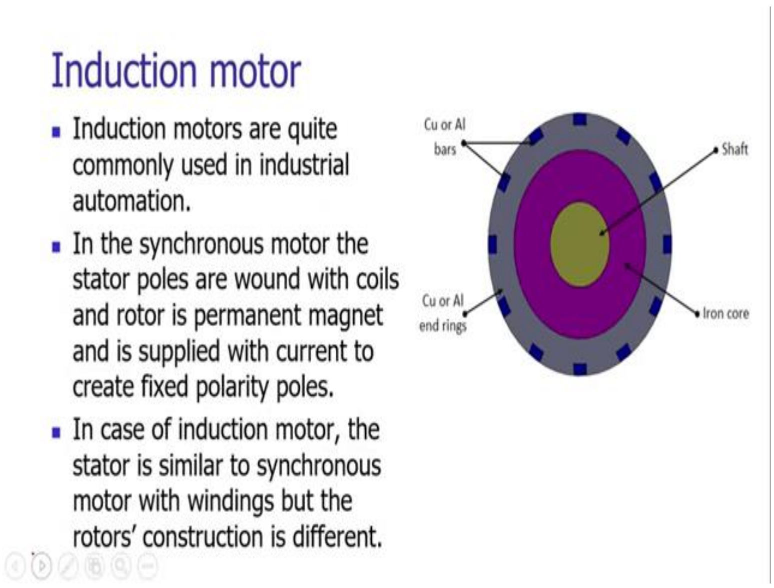

The next variation is the induction motor. They are commonly used in industrial automation. In synchronous motor the stator poles are wound with coils, and the rotor is permanent magnet. And the alternating current is applied to the fixed polarity poles of the stator. But in the case of the induction motor, the stator is similar to the synchronous motor construction, but the rotors construction is different. There is a difference in the construction of the rotor, but the stator construction is very similar to the synchronous AC motor.

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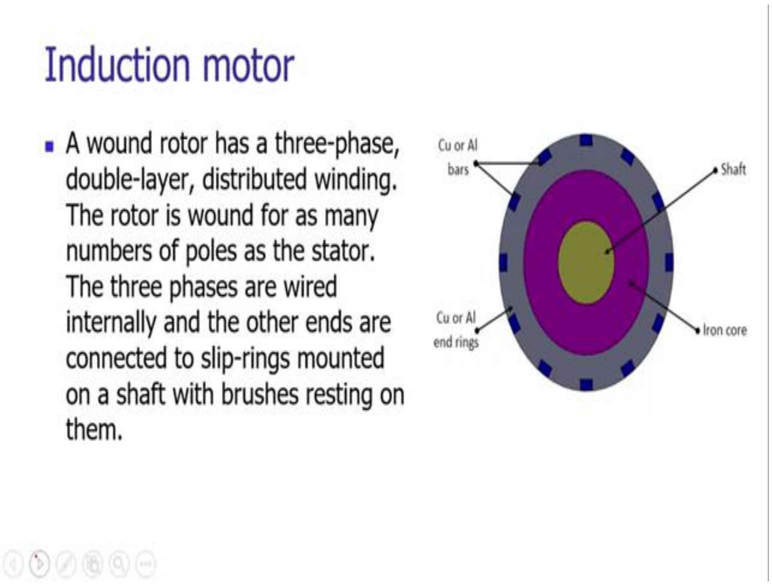

Let us look at what exactly the construction is the rotor is wound with a three-phase double-layer, distributed winding. There is a three-phase electricity supply the layers of the windings are double and they are distributed. The rotor is wound for as many as number of poles as the stator. The winding of the rotor is dependent upon the number of poles of the stator.

The wiring or the wire connections of the three-phases has been done internally, they are internally connected while the other ends are connected to slip-rings. The induction motor has the slip-rings which are mounted on the shaft they do have the brushes resting on them. The induction winding has the contact type of arrangement. In this case, there is a shaft with brushes. And these brushes are connected to the slip-rings which are mounted on the rotor.

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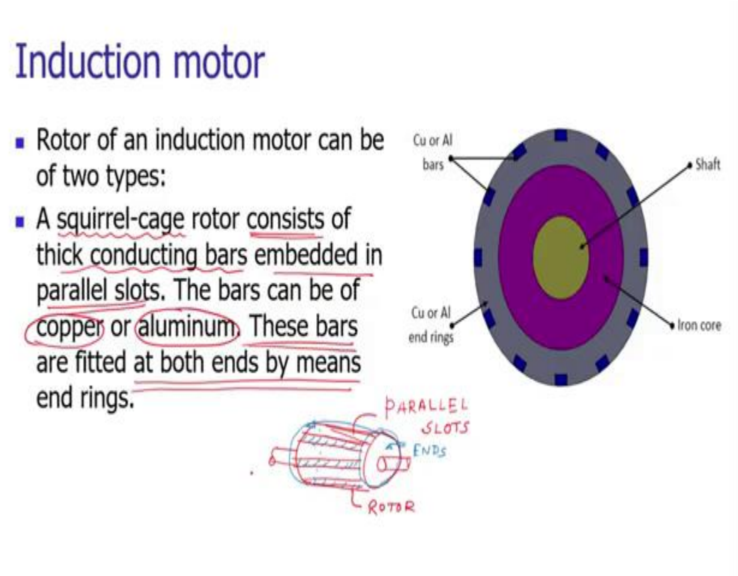

There are basically two types of the rotor arrangement. The very well-known arrangement of the rotor is the squirrel-cage arrangement. It consists of a thick conducting bars which are embedded in the parallel slots. The rotor body has parallel slots. And the thick conducting bars are embedded in that parallel slots. The bars can be of copper or aluminium which are very good conductors of the electricity. At the end of the bars, they are fitted by means of the end rings. The typical construction can be seen. There is a cylindrical block and the cylindrical block has the parallel slots.

Inside these parallel slots, the thick conducting bars of aluminium or copper are embedded. These thick conducting bars are connected at their ends. They are connected at both their ends. These two are the end plates. And these bars which are embedded in the slots are connected at their ends.

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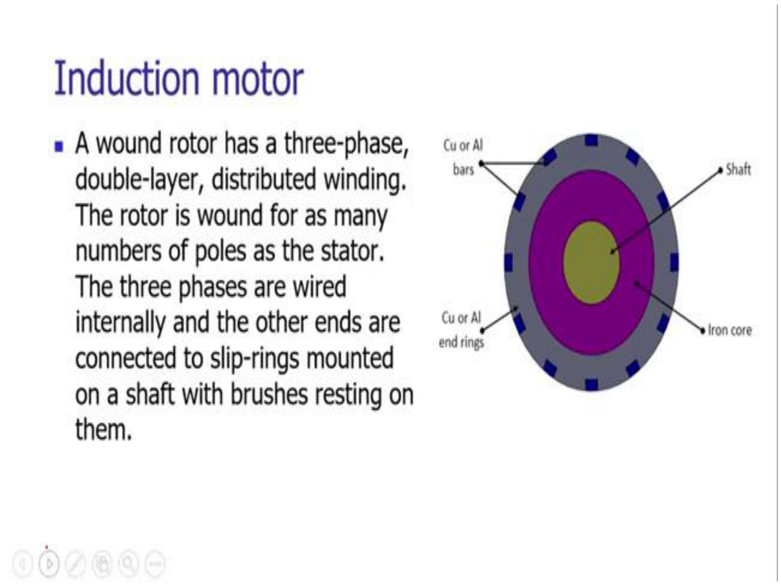

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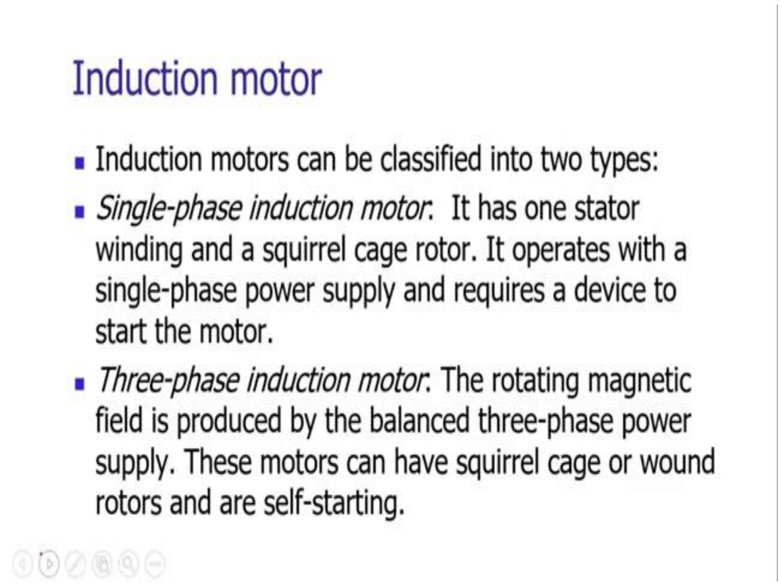

The induction motors can be classified into two types; single-phase induction motor which is having only one stator winding, and a squirrel-cage rotor. It basically operates with a single-phase power supply, a single-phase motor that is commonly used in our household applications as well.

Now, it requires a device that to start a motor as well. A single-phase power supply for energizing the stator windings, and accordingly production of the rotation of the shaft of the motor, but it requires a device to start the motor itself due to the inertia. The next is the three-phase induction motor. The rotating magnetic field is produced by balanced three-phase power supply. The three-phase power supply is incorporated. It is having this squirrel-cage, and a wound rotors. And these are the self-starting.

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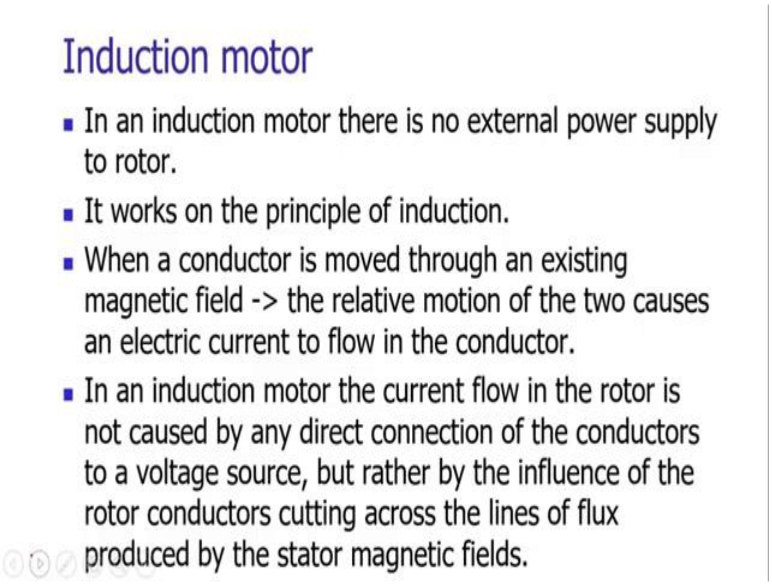

The induction motors are basically operated based upon the principle of induction. We have seen the principle of induction or the inductance as a very useful electrical property in our sensors lecture inductance based proximity switches. When a conductor is moved through an existing magnetic field, there would be a relative motion of the two. If we are taking a conductor in an magnetic field, there would be relative motion of the conductor with respect to the magnetic field, so that causes an electric current to flow in the conductor itself.

The current flow in the rotor is not caused by any direct connection of the conductors to a voltage supply. A flow of electric current is obtained in the rotor, but it is not due to the direct application of potential on the rotor. It is due to the induced potential that is coming from the magnetic field. The magnetic field of the energizing electromagnet is inducing electric current in the rotor and that induced current in the rotor is giving the mechanical energy.

The current which is flowing through the rotor conductor will cut across the lines of flux produced by the stator magnetic fields, and the interaction of current which is flowing through the rotor, and the stator magnetic fields will generate the mechanical power.

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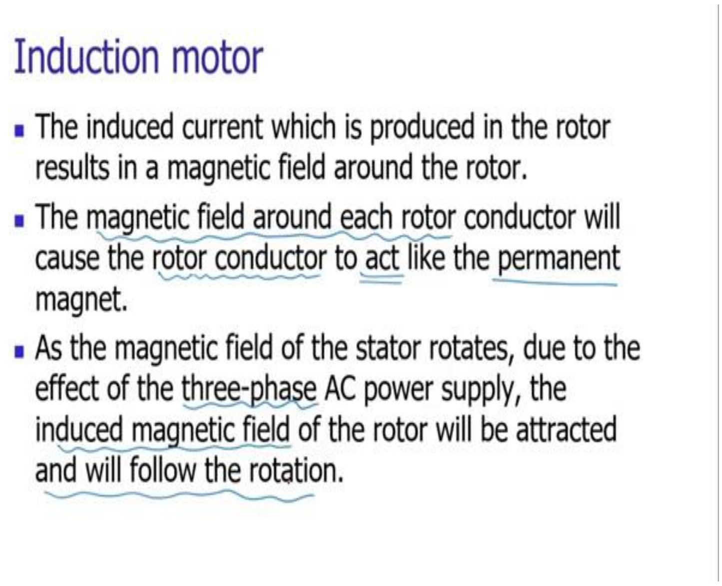

The induced current which is produced in the rotor is resulting in a magnetic field around the rotor. The stator windings are generating magnetic field to be converted or that magnetic field is inducing electric current in the rotor. And due to the electric current, the rotor will have its own magnetic field. This magnetic field which is generating around the rotor is making the rotor conductor to act like a permanent magnet. The rotors are simple metals; they are conductors. When these rotor materials are carrying the electricity, they are generating the magnetic field, and they will be acting like the permanent magnet.

In the three-phase motor supply, the magnetic field of the stator is rotating, it is moving due to the effect of the three-phase AC power supply. That rotation in the three-phase power supply is inducing magnetic field in the rotor which will be attracted and will follow the rotation. The change in magnetic field due to the three-phase power supply is inducing magnetic field in the rotor, and that will be leading to the rotation of the shaft itself.

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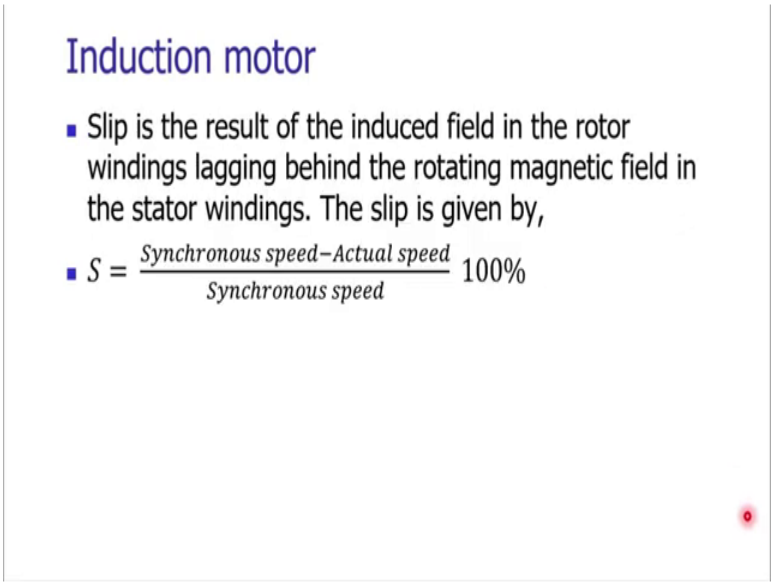

Slip is a characteristic of induction motor. Slip is resulting due to the lack of rotation of the rotor with rotating magnetic field of the stator winding. It is expected that the rotor should follow the rotational speed of the magnetic field given by the stator winding. But due to the inertia of the rotor, due to many environmental related factors, due to the inaccuracies in the motor, the rotor will have a lag it will have certain deficit in the rotational speed, so that is called as the slip in the induction motor.

It is the result of the induced field of the rotor windings which is lagging behind the rotating magnetic field. The slip can be computed as the ratio between difference of the synchronous speed that is a desired speed and actual speed to the synchronous speed or the desired speed. It generally is given in terms of the percentage.

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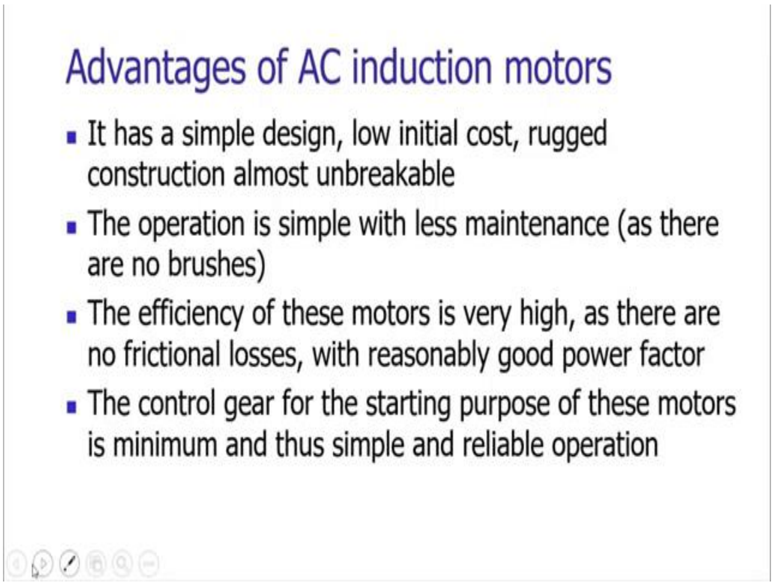

The AC induction motors are offering very good advantages. Fundamental advantage is that the construction is very simple that is why the cost of the AC induction motors is very low. They are rugged in the construction. They are robust; and are almost unbreakable. The operation is very simple and has less maintenance, because there are no brushes, there is no friction, there is no contact or arching.

The efficiency of these motors is very high. As there is no loss of electrical energy, there is no loss of energy in overcoming the friction certainly the efficiency would be on higher side. And they provide very good power factor and good performance. The requirement of control gear for the starting purpose of these motors is minimum, and thus they are offering the simple and reliable operation. The control gears requirement is less that is why the AC, induction motors are quite good in operation.

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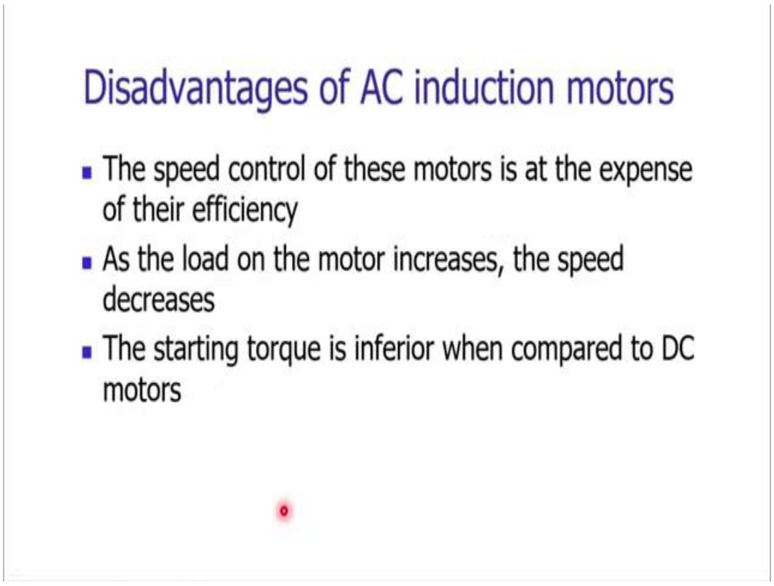

The AC induction motors also has certain limitations. The speed of these motors can be controlled, but this would be at the expense of the efficiency. It is very similar to the synchronous motor. The speed can be controlled, but that will impact on the negative side of the efficiency. If the load on the motor is increased, the speed will reduce that is the limitation of the AC induction motor. The starting torque which is provided by the AC induction motor is less as compared to the DC motor.

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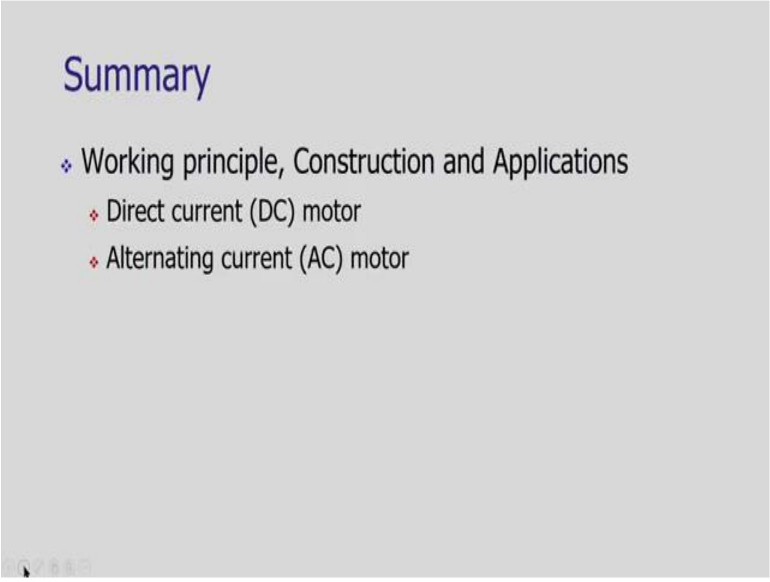

In this lecture, we have seen the working principle, construction and applications of two important types of electrical drives that is the DC motor - direct current motor, and the alternating current motor. We have seen their applications which are useful in the automation industry.

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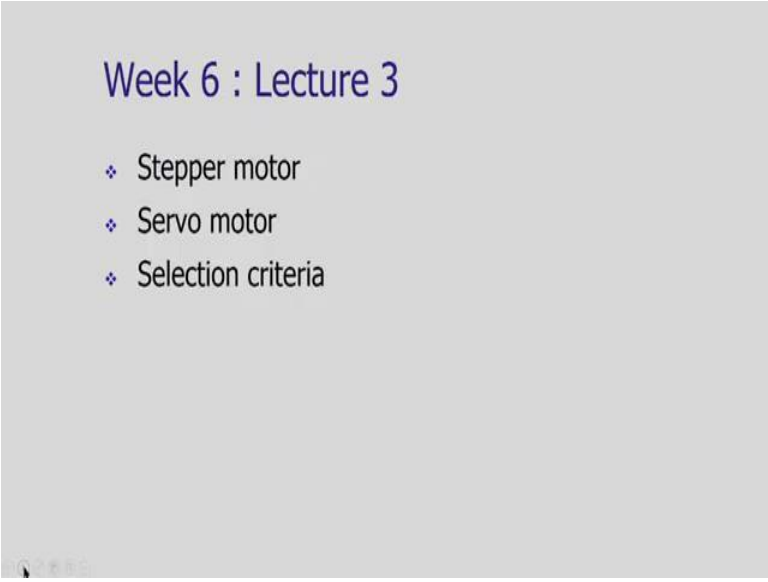

In the next lecture that is a lecture3 of week6, we will be studying two more important electrical drives; these are stepper motor and servo motor. For these two drives, we will be studying the principle of operation their constructional details, and their applications. At the end of lecture 3, we will be carrying out a small discussion on the selection criteria, how to select these electrical drives for our intended purpose.