Automation in Manufacturing
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Week – 06
Electrical drives
Lecture - 03
Stepper motor and servo motor

In this week, we are studying various electrical drives. Let us look at the outline of this lecture.

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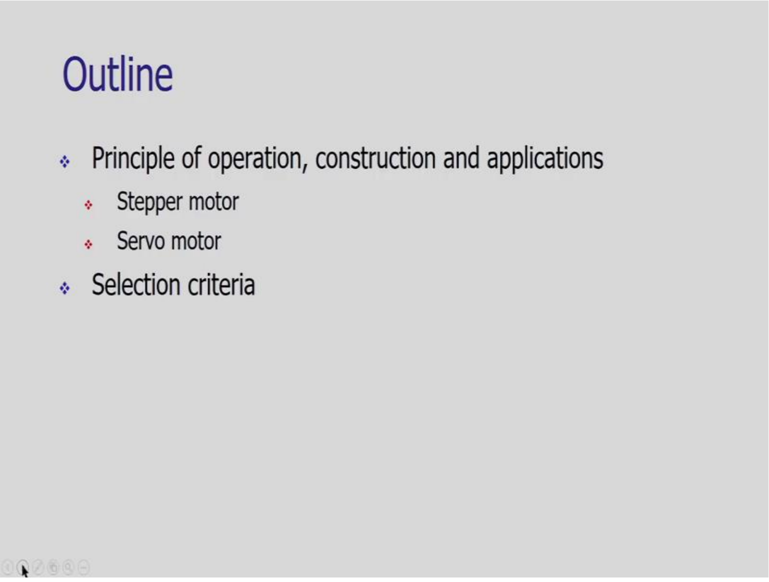

In this lecture, we will be studying the two important electrical drives. These are stepper motor and servo motor. We will be studying the principle of operation, construction and application of stepper motor and servo motor. At the end, we will have a discussion on the selection criteria, how to select electrical drives for the required purpose in building up an automated system.

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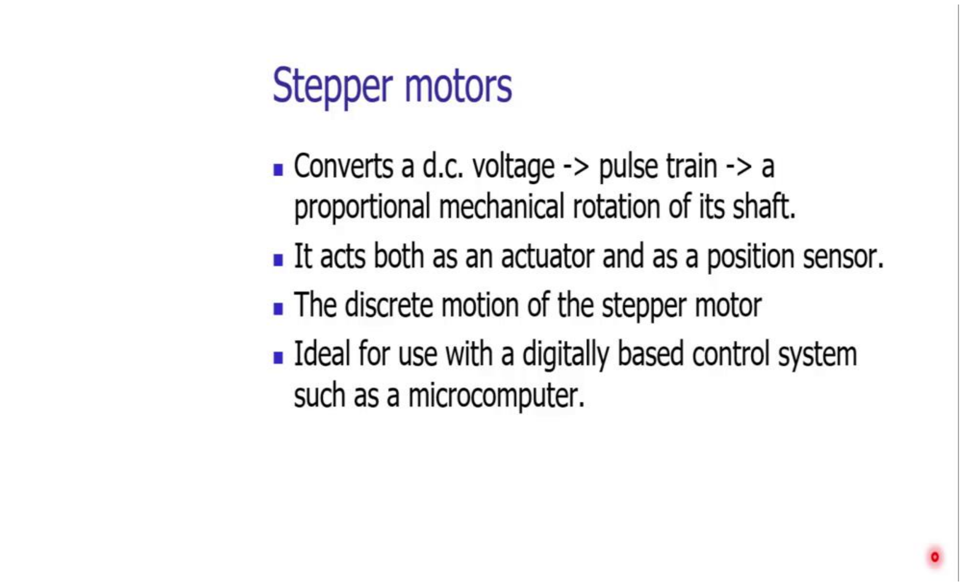

In this lecture, we will be studying two important motors, these are stepper motors and servo motors. Stepper motors are widely used in open loop control systems. The stepper motors are simply converting the DC voltage that is applied into a train of pulses into a series of pulses. This pulse train is proportional to the mechanical rotation of the shaft.

The motor converts the DC voltage into pulse train and that pulse train is making the rotation of the shaft. This peculiarity of conversion from DC voltage to the pulse train is very much useful to consider the stepper motor as an actuator, as the energy provider, as the energy facilitator as well as the position sensor. The stepper motor has integrated position sensing facility.

The stepper motor is working based upon the discrete motion. It is not on the continuous input which is we are getting. It is working based upon the discrete motion and creating the rotation of the shaft in a discrete way. Therefore, the stepper motors are very much useful when micro computers are used to control the system to operate the system because the microcomputers are working digitally and require pulses to process. Therefore, the pulse train facility or the utilisation of pulse train based working of the stepper motor is very well suited for the microcomputers.

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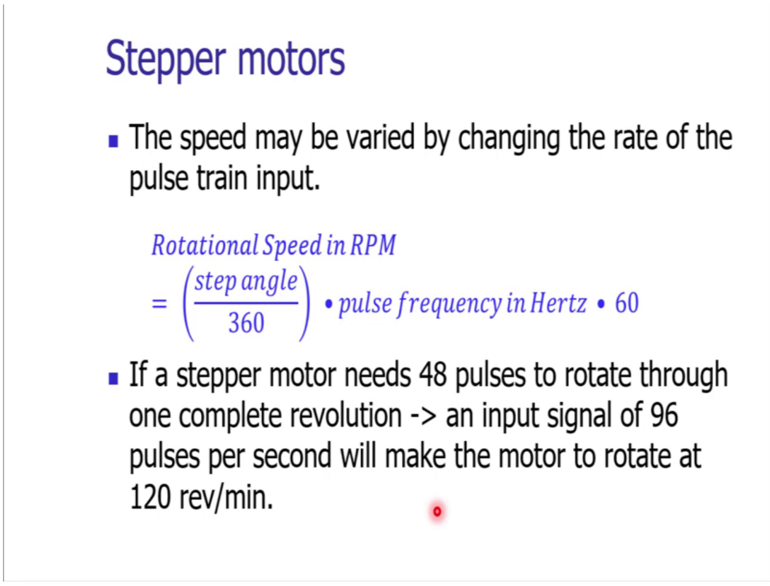

The variation of the speed of a stepper motor is dependent upon the rate of pulse train input. As the rate of input and the rate of the pulse train input are changed, the speed is varying. We can see the correlation between the rotational speed of the stepper motor in RPM as a function of the step angle, pulse frequency in Hertz.

The rotational speed of the stepper motor can be expressed as

$$Rotational\ speed\ in\ RPM = \left(\frac{step\ angle}{360}\right) \times pulse\ frequency\ in\ Hertz \times 60$$

What is the meaning of the step angle? As the stepper motors are working by taking the input in discrete format they are taking the input in pulses. For single pulse of application of energy how much is the rotation of the rotor is nothing but the step angle.

How much would the rotor rotate in angular direction in angles? This is the step angle divided by 360 pulse frequency in Hertz. How many pulses are being applied per second? Let us see a simple example. Consider a stepper motor it requires 48 pulses to rotate through a complete revolution. To have a complete revolution of the shaft we need to apply around 48 pulses.

When 48 pulses are applied, the shaft will complete the revolution of about 360 degrees. For one pulse it would be around 7.5 degrees. That is the step angle of 7.5 degree. If we apply an input signal of about 96 pulses per second, this 96 pulses per second is the pulse frequency. Let us multiply the 96 with 7.5 divided by 360 into 60. That will come around 120 revolutions per minute. The stepper motor will have the RPM of 120 revolutions per minute.

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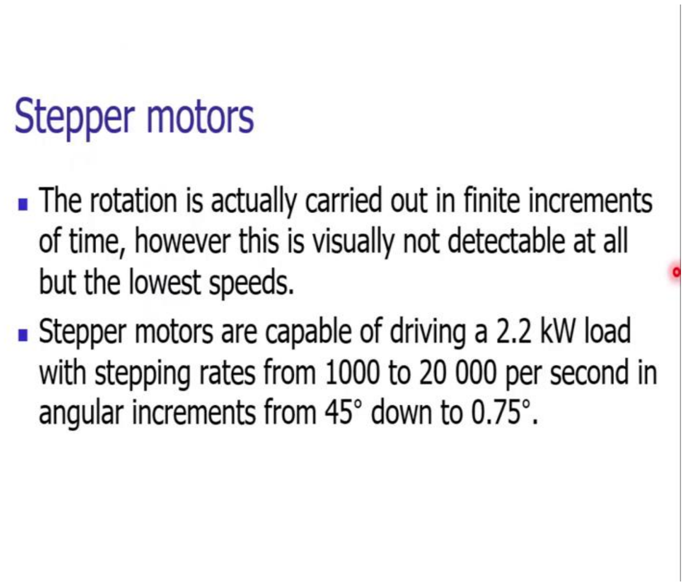

In stepper motors the rotation is basically carried out in finite increments and these finite increments are of time, but it is very difficult to notice these increments. Visually it is not detectable when the shaft is rotating at high speed, but if the speed of the shaft is reduced, then there is a discrete rotation, a discrete increment or discrete variation in the position of the shaft. The shaft is moving in increments along the angular direction.

The stepper motors are capable of driving around 2.2 kilo Watt of the load. They can handle very huge load. In general, stepping rates varying from around 1,000 to 20,000 per second and angular increments from about 45 degrees to down 0.75 degrees can be obtained.

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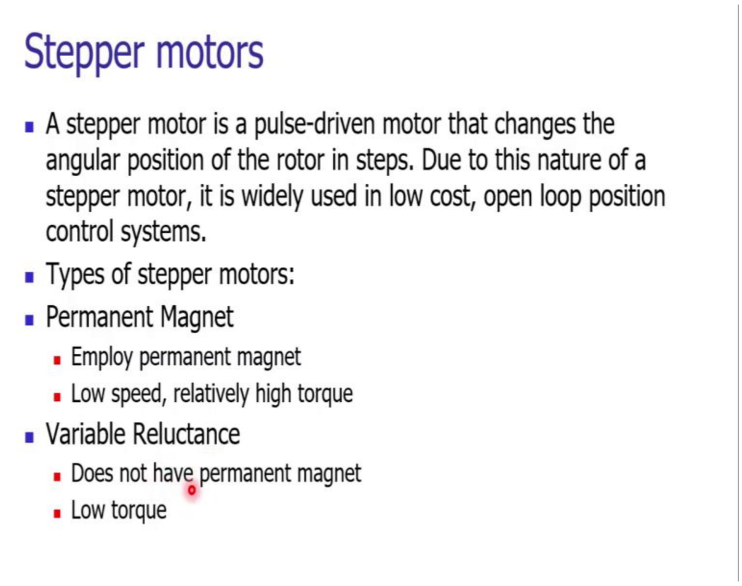

As the stepper motor is pulse driven motor it is widely used in automation industry. Its prominent advantage is that it can be considered as the position sensor as well. Based upon the number of pulses sent to the motor, the amount of rotation can be found out. Stepper motors are having low cost and they are widely used in open loop pollution control systems. Basically 2 types of stepper motors are being used permanent magnet motor and variable reluctance motor.

In permanent magnet stepper motor, permanent magnet is employed. They are useful for low speed applications, but they are capable of providing very high torque. As far as the variable reluctance stepper motor is concerned these motors do not have any permanent magnet arrangement, but they are providing low torque in comparison with permanent magnet stepper motors.

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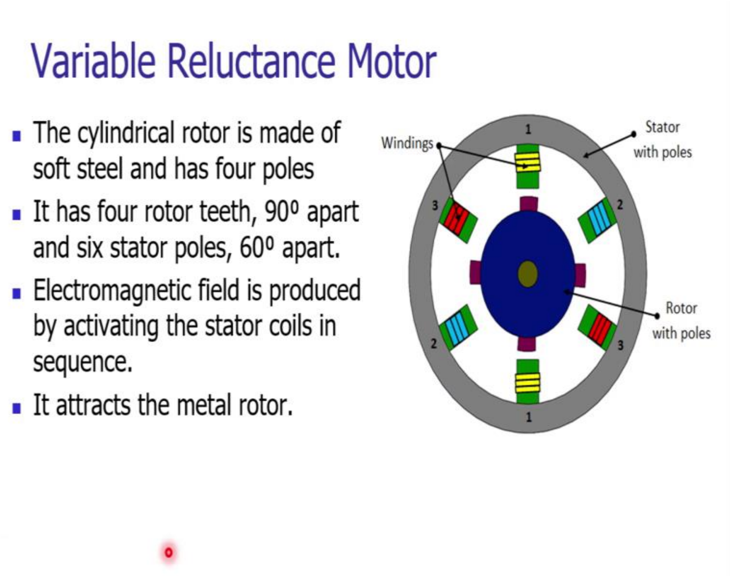

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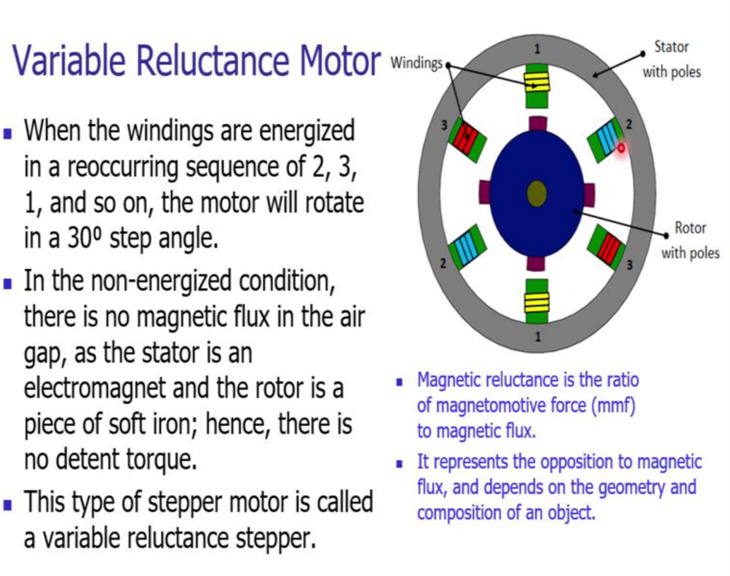

The variable reluctance motor is working on the principle of magnetic reluctance. Magnetic reluctance is very similar to the electrical resistance in electrical circuitry. The magnetic reluctance is referred in magnetic circuitry. It is a ratio of the magneto motive force that is mmf to the magnetic flux. The reluctance basically is representing the opposition of magnetic flux and it primarily depends upon the geometry and composition of the object.

A typical variable reluctance motor has a stator with number of poles. There are around 6 poles and they can be considered as 3 pairs of poles. There is a rotor in all electrical motors, there is a rotor stator gathering in the construction; the rotor also has poles.

There are 4 poles in the rotor. The stator poles are having electrical windings and when they are energised in a sequence of 2, 3, 1 and so on the motor will rotate in a step of 30 degrees step angle. In the non-energised condition there is no magnetic flux in the air gap as the stator is electromagnet. When there is no energy and no electricity is applied, there will not be any magnetic power magnetic flux. The rotor is simply a conductor. At no load condition and no electricity application there will not be any magnetic flux in the air. This type of motor is called as the variable reluctance motor.

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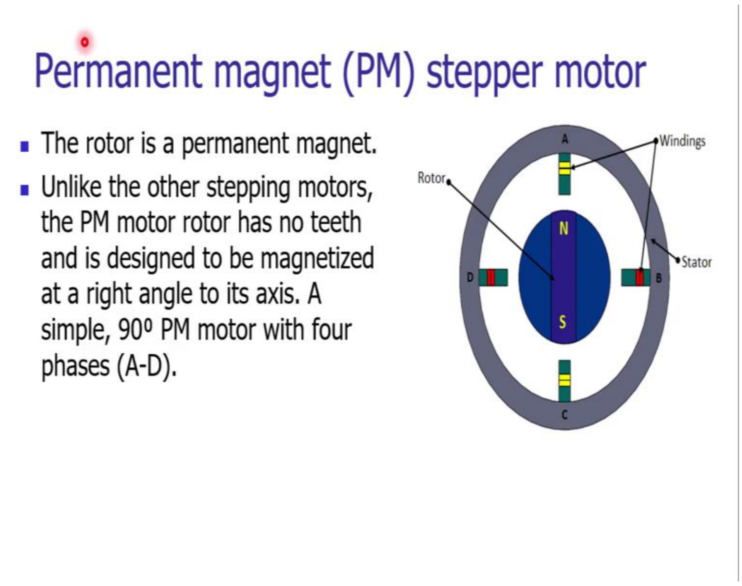

In permanent magnet stepper motor, the rotor does not have any poles mounted on it instead it is having a permanent magnet, but the stator is having a number of poles. Arrangement of permanent magnet stepper motor can be seen. on There are 4 poles or 2 pairs and a permanent magnet rotor.

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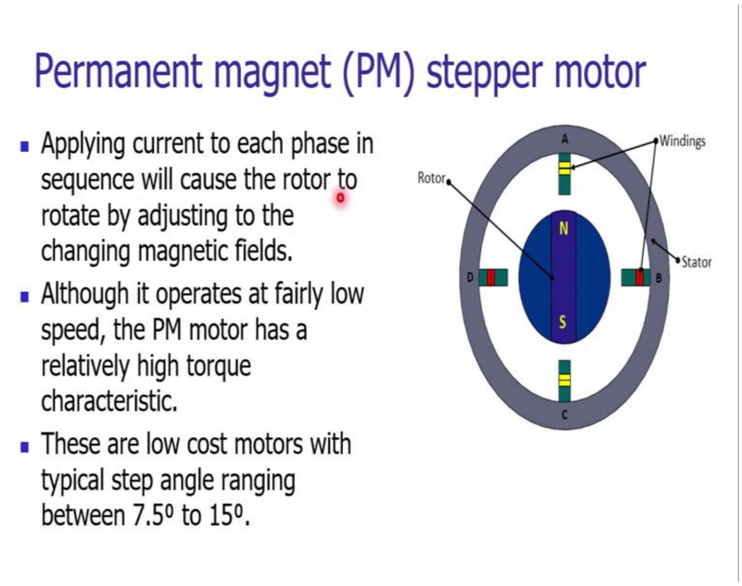

When current is applied to each phase in the sequence that will cause the rotor to rotate by adjusting to the changing magnetic fields. As the windings of the stator poles are energized in sequence according to the pulse input given by the microprocessor, the magnetic field will be generated which will rotate the permanent magnet. As the polarity of the windings is getting changed, the permanent magnet will try to orient according to its nature. If it is getting the opposite pole it will get attracted to that particular pole and in this way the required rotation of the shaft can be obtained.

The permanent magnet motor are fairly having low speed, but they produce relatively high torque. The permanent magnet motors are quite economical, they are less expensive and they provide a step angle of about 7.5 degrees to 15 degrees.

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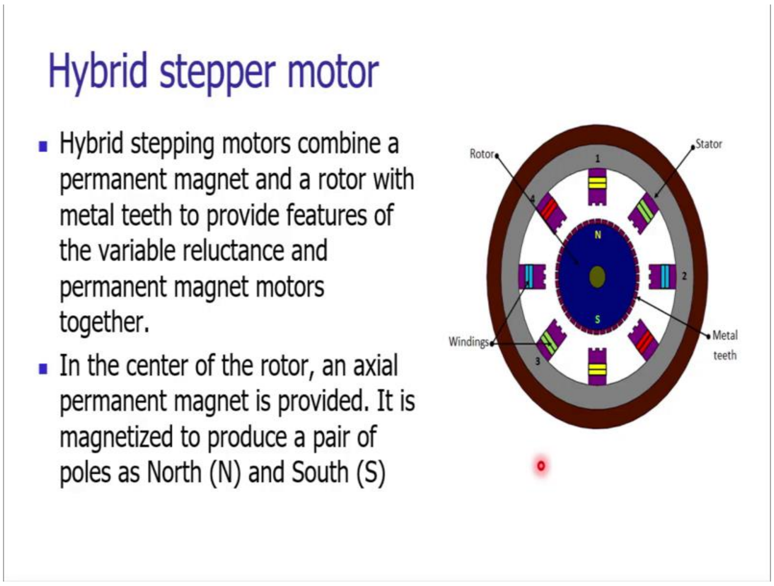

There are certain limitations to the permanent magnet stepper motor and variable reluctance stepper motor. These 2 types of motors do have certain good advantages. These advantages are combined together and a hybrid stepper motor is developed. The hybrid stepper motor has the features of the variable reluctance stepper motor and the permanent magnet stepper motor. In the construction of the hybrid stepper motor, the rotor is a permanent magnet and there are teeth on the periphery of the rotor.

The stator as usual has number of poles which are energised by the electric current. These poles are having the windings, but there is a peculiarity, the stator poles also do have the teeth. The number of teeth or number of poles are provided to have the finer adjustment in the increment of the rotor.To have very fine increment and a very small stepping angle in order to have a better resolution, the number of the poles are increased on the rotor as well as the stator.

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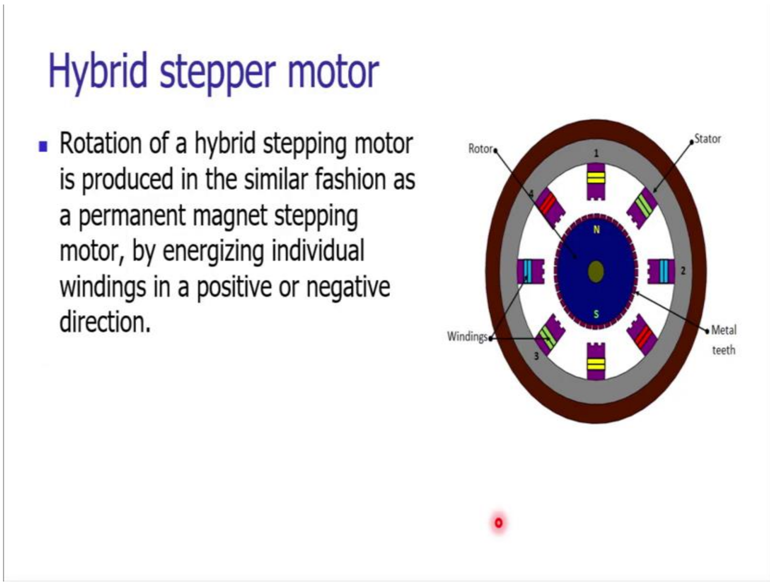

The working principle is very similar to the permanent magnet stepping motor. The individual windings are energized in a sequential manner and as the windings are getting energised and the north and south poles are getting developed, the rotor will rotate to get aligned to the opposite magnetic poles. The permanent magnet rotates due to the sequential energising of the poles.

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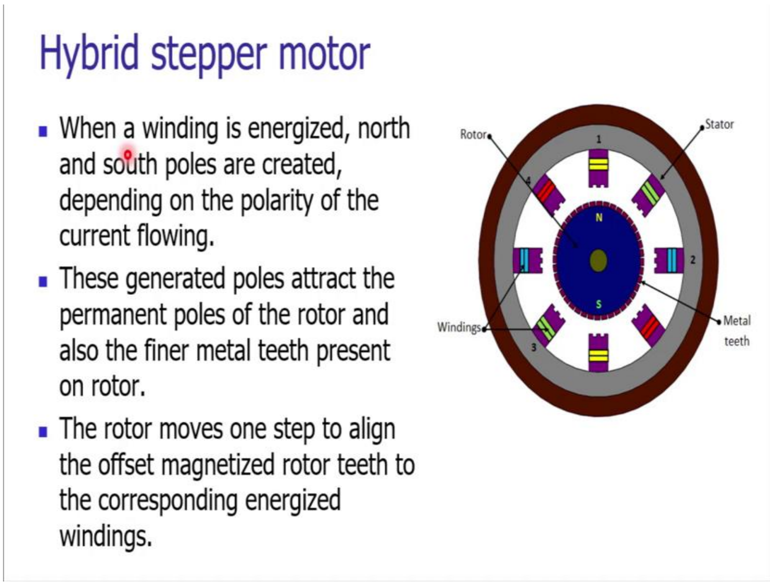

When a winding is energised the north and south poles are created depending upon the polarity of the current and these generated poles attract the north and south poles of the rotor. The teeth on the north pole would behave like a north pole and the teeth on the south pole are behaving like the south pole. When the stators are energised, there would be major step increment in the rotation, but the finer adjustments can be done by having the number of teeth on the rotor. As the poles are getting attracted to the opposite poles on the stator the teeth on the rotor also are getting attracted to the the opposite poles that is created on the stator.

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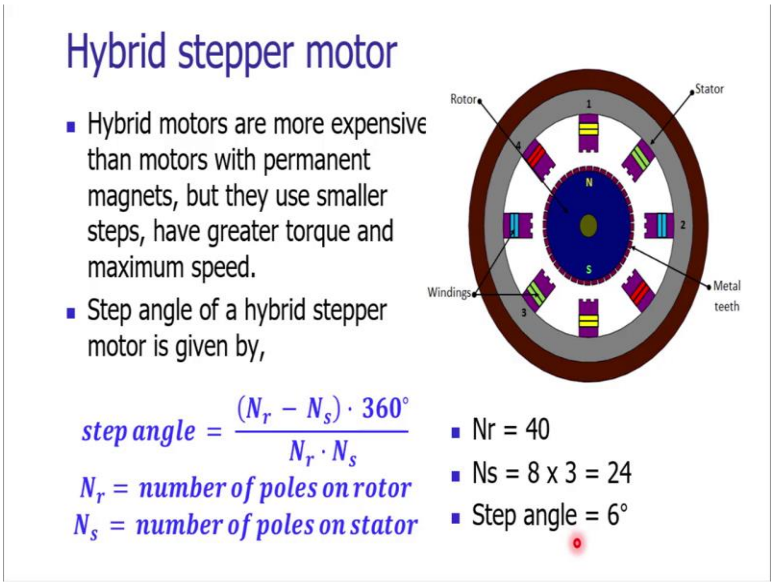

The construction of the hybrid stepper motor is complex as it has a permanent magnet, parallel slots, teeth over, peripheral surface machining of the teeth which is a very complex taskand a very precision task. In addition to that number of poles are needed and these poles also do have the teeth. As the construction is complex the hybrid stepper motors are expensive. These motors also require the electronic circuitry and microprocessor to control its operation. But, these motors are providing us very small steps which is the important advantage. They are providing greater torque and maximum speed.

The step angle in hybrid stepper motor can be easily computed by using this correlation. It is the ratio of 2 factors.

$$step\,angle = \frac{\left(N_r - N_s\right)\cdot 360}{N_r \cdot N_s}$$

N_r = number of poles on rotor

N_s = number of poles on stator

Let us take typical example. On the screen, we can see the number of stator poles are 8 and there are 3 teeth provided on each pole. Number of stator poles are computed as 8 that is the number of stator poles into number of teeth. The individual tooth is also considered as a pole.

Number of stator poles = 8 * 3 = 24. In a similar way, the teeth which are there on the rotor are also considered as the poles which are small poles or the micro poles. The number of poles on the rotor are 40. If we put these values in the correlation the step angle is about 6 degrees.

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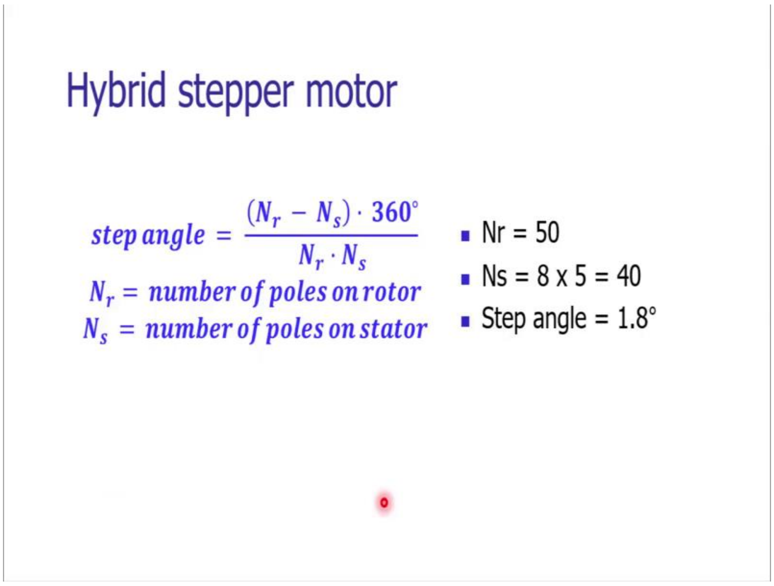

Let us take another example in which we are taking the number of poles on the rotor are 50 and we are increasing the number of poles or number of teeth on the stator poles. By having 2 more teeth on the stator pole, we are getting number of teeth on stator as 40. We are increasing the number of poles on rotor as well as increasing number of teeth on the rotor as 50. If we take Nr as 50 and Ns as 40. We got a very good step angle that is 1.8 degrees.

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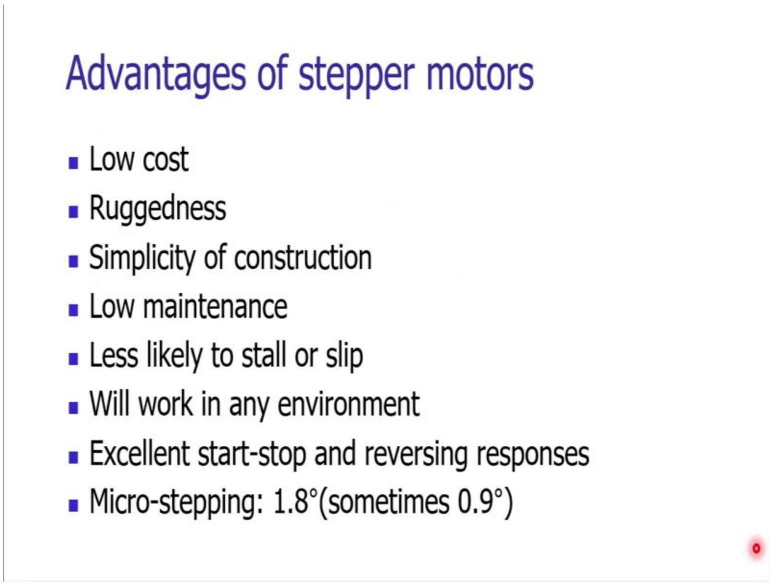

The prominent advantage of stepper motor is the micro-stepping. As The stepper motors or the hybrid stepper motor are able to provide around 1.8 degrees step angle to us. The stepper motors are having the low cost and are rugged in the construction. Some of the stepper motors are having simple construction. There is low maintenance because there are no brushed contacts, there is no arcing or there is no wearing of the rotor or the stator.

The microprocessor is controlling the energization of the stator coils. There are less chances of having the slip or stalling of the motor. Stepper motors are able to work in any environment and they do have excellent start, stop and reversing responses. A very good reversing characteristic can be obtained using the stepper motor. The direction of rotation of the shaft can be reversed with ease.

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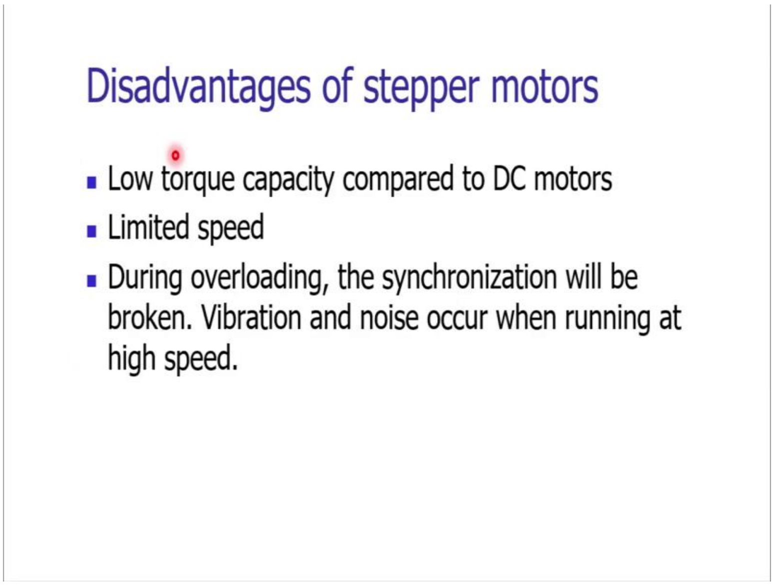

There are certain limitations to the stepper motor and these are the torque capacity of the stepper motor is less in comparison with the traditional motor that is a DC motor. Low torque is obtained when the power capacity is less and they provide limited speed. When there is a overloading the synchronisation will be broken. When the loads are too high on the motor, there may be chances of having breaking down into the synchronisation of the rotor with the stator and when the speed is increased further, that may lead to vibration or the noise during the operation.

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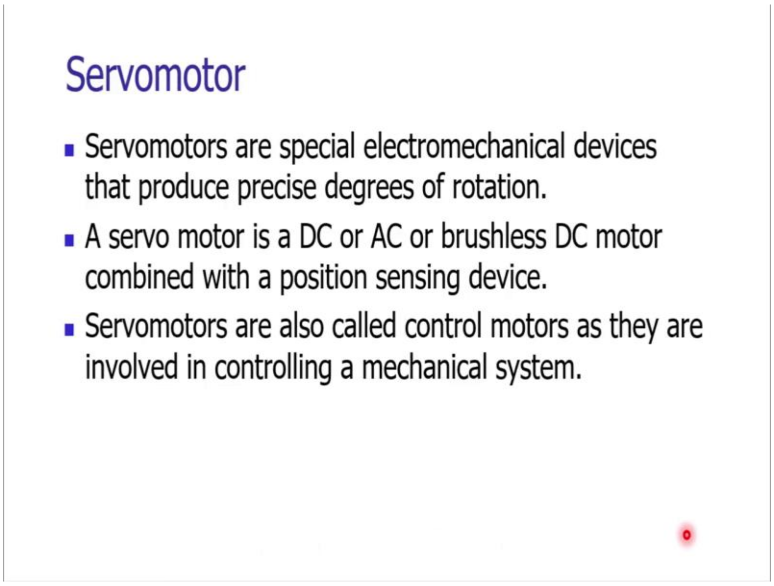

The next type of motor which is very widely used in the automation where we require to have the monitoring of the performance of the motor itself. Till now we have seen that the electricity is applied to the motor, the motor is generating the mechanical power, but the rotation of the shaft is not getting monitored.

Whether the required output is obtained or not will not be sensed or will not be taken into account, but in closed loop control system, we need to monitor and get the information whether the required output is as per the standard which is required in the development of automated products or automated system.

The servo motors are providing these kind of facilities and they are special electromechanical device. The special electromechanical device is called because they do have integrated monitoring system. Basically the servo motors are DC or AC or they are the brushless DC motor. These DC, AC or brushless DC motors are combined with a position sensing device and that position sensing device with appropriate signal conditioning device will give the input to the microprocessor and the microprocessor is accordingly varying the input to the DC motor to get the required output. These motors are also called as the control motors because they are controlling the mechanical system.

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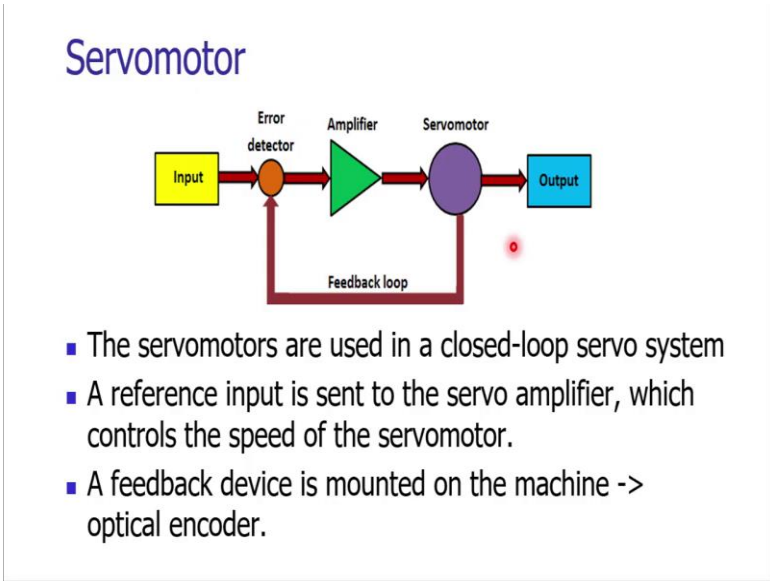

We can see the schematic of the arrangement which is used in servo motor. The servo motor is providing the output. The performance of the servo motor is continuously being monitored and the performance is given to the microprocessor or the electronic circuitry.

The electronic circuitry is getting the input, the energy source and that would be amplified and given to the servo motor. The input would be changed according to the error which is there in the comparison with the desired value and the obtained value of the servo motor. The desired value is the number of the revolutions per minute and the obtained value from the servo motor is the actual or the real value which is obtained at the rotor shaft.

What kind of positioning sensing devices are used and these are the optical encoders. Optical encoders are having the photo transistors. They are using the light and a perforated disc; as the light is passing through the perforations it is sensing the number of pulses and counting the number of pulses and based on that number of pulses, the angular velocity of the perforated disc can be easily obtained. If the perforated disc and a set of photo transistors are mounted, then the continuous monitoring of the motor can be obtained and this arrangement is provided on the servo motors.

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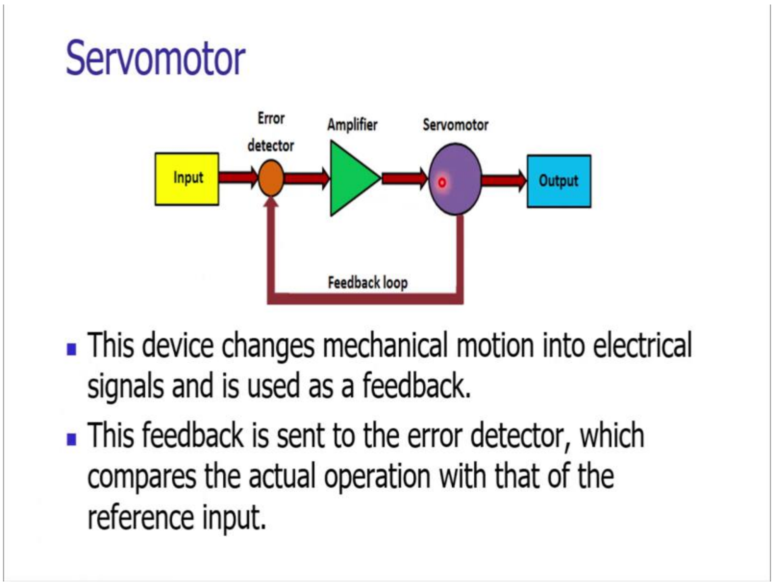

The device is as usual providing the mechanical motion and there is an error detector which is just comparing the actual operation values with that of the reference input or the standard values.

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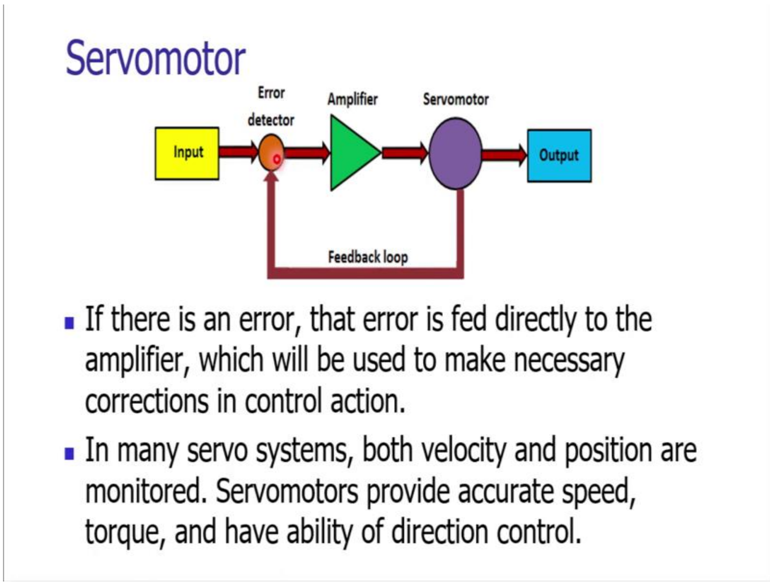

If there is an error, that error would be corrected in consultation with the microprocessor. In servo motors, the velocity and position are monitored. As the velocity and position are monitored, we are online in situ modifying the velocity and position and the servo motors are providing accurate speed, torque and the ability to control the process directly.

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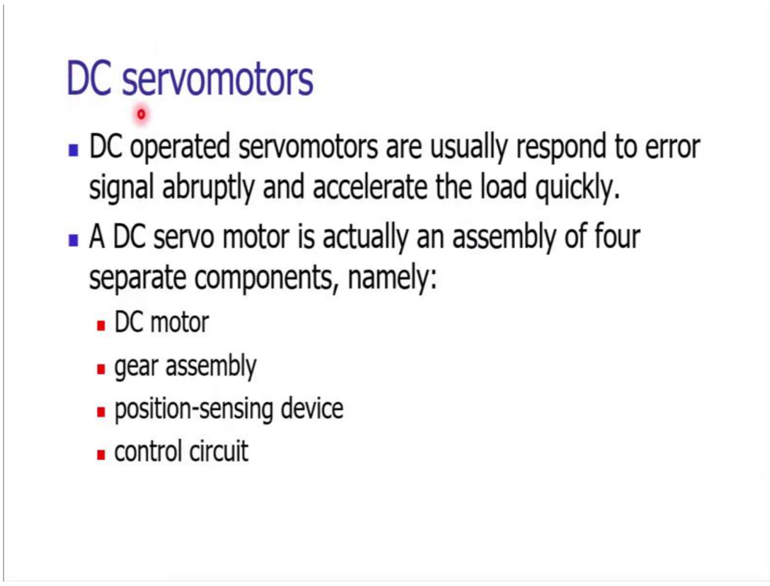

The first variant in servo motor is the DC servo motor. In DC servo motors, a simple DC motor and a position sensing device are used. The DC operated servo motors respond very fast to the signal and they are able to accelerate the load quite quickly. A typical DC servo motor has 4 components and these are DC motor, a gear assembly, position sensing device and the control circuitry .

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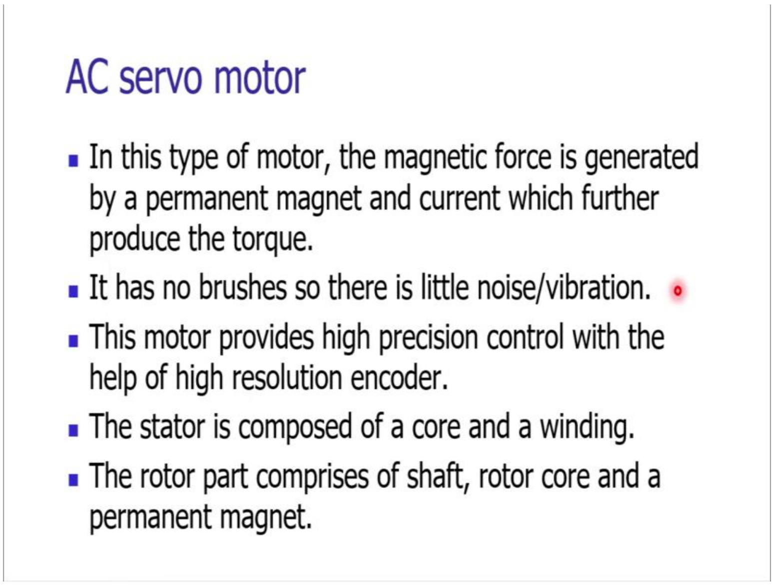

The next variant is alternating current servo motor and in this case we are adding the position sensing device to an AC motor that makes the AC motor as the AC servo motor. In this typical arrangement the magnetic force is generated by the permanent magnet and the current arrangement which is producing the required torque. There are no brushes in the AC motor, the noise would be very less. AC motor has better precision control and they do have high resolution.

The AC motor may provide better precision control when high resolution encoders are incorporated. It has the stator which is composed of the core and the winding and the rotor is shaft rotor core and a permanent magnet.

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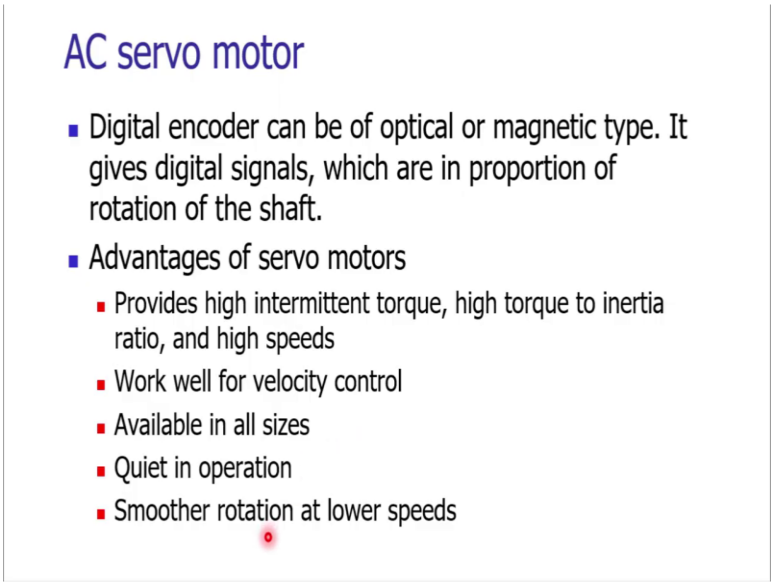

What kind of encoders can be used. Either an optical encoder can be used or magnetic type of encoder. These encoders are providing the digital signals which are in proportion to the rotation of the shaft. The various advantages of the servo motors are as follows. The servo motors are providing high intermittent torque, very high torque to inertia ratio.

Very good amount of torque can be obtained in comparison with the inertia of the motor itself. The servo motors are able to provide very high speeds and its velocity can be easily controlled. The servo motors are available in all sizes. We can have a variety of sizes according to our requirement. They are quiet in operation, the noise would be less, the vibrations are less and they are smoother in rotation at lower speeds as well.

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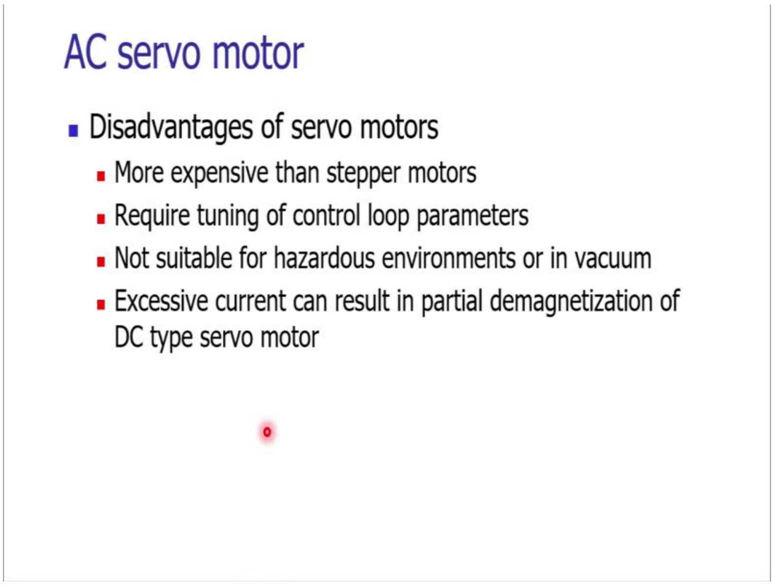

However, they do have certain limitations as well; they are more expensive. Naturally the construction comprises of the encoder device, microprocessor circuitry, the cost associated with the servo motors is quite high in comparison with the stepper motors. It requires tuning of the control loop parameters. You have to calibrate the servo motor quite often and since the sensing circuitries are incorporated since sensors are embedded the servo motors are not suitable to work in hazardous conditions or in vacuum.

When the temperatures are very high and the environmental conditions are harsh the servo motors are not suitable for such harsh conditions. In case of the excessive current, there may be partial demagnetization of the DC type of servo motor. If excess current is applied that may lead to the demagnetization of the DC type servo motor that is one of the limitation.

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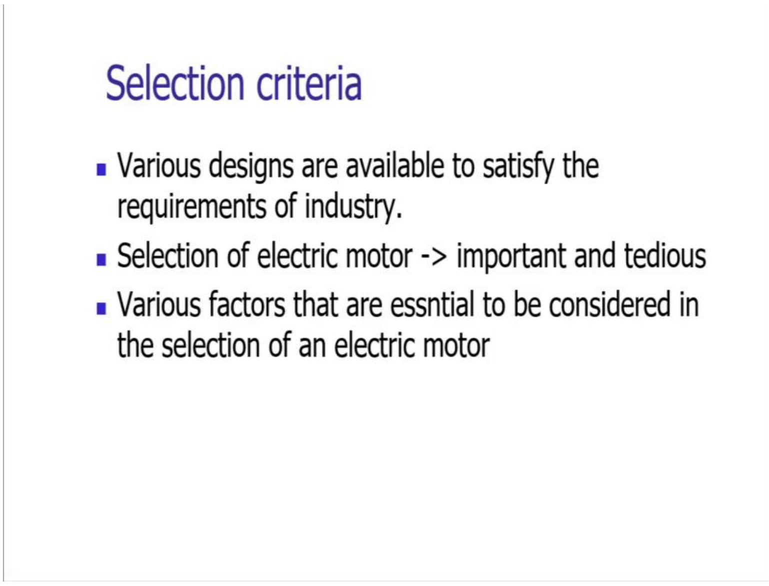

The selection of an electric motor is very important as far as the efficient utilisation of the electrical resources that is electrical motor. Though it is important, it is a very tedious task. There are various factors associated with the selection of the electric motors. Some of the essential factors that need to be considered during the selection of the electric motor will be discussed.

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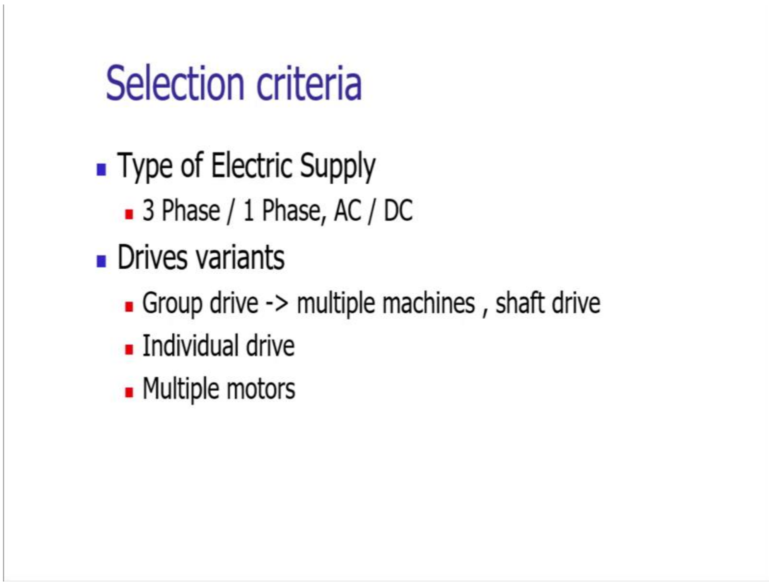

The first factor is the type of electric supply whether a 3 phase supply or a single phase electric power supply is utilized or the alternating current supply or the direct voltage supply is applied. Based upon the type of electric supply the appropriate electric motor is chosen. Next is drive variants whether the proposed electric motor is being used to operate or to serve multiple machines by using a single shaft. The electric motor is providing the input to electric shaft and that electric shaft is operating multiple machines through cams.

Such kind of drive is called as the group drive. Whether a motor is required for such drive than the consideration or the requirements may be different than the individual drive. In the individual drive a separate individual machine would be entitled for an individual process or individual operation. In certain cases, multiple motors are required to carry out the operations. Based upon the type of drive, the appropriate electric motor can be chosen.

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Next is electrical characteristics. Whether we need to control the speed, what would be the starting torque, what would be the stalling conditions if you are working in a low speed domain there may be chances of the stalling conditions. If we are working at a very high speed and then we have to just reduce the speed or stop the operation what would be braking characteristics. The electrical parameters associated with the speed control, torque control, stalling and braking need to be considered when we select a proper electric motor. The electrical motor is an electromechanical device.

It is converting the electrical energy into mechanical energy and the construction is very much important. What kind of bearings are desired whether it is a ball or roller bearings which are supporting the shaft inside the motor. The shaft is supporting the rotor or the bush bearings are used. If the bush bearings are there then the friction would be more, the wearing of the shaft would be more and there may be chances of having the vibration and noise.

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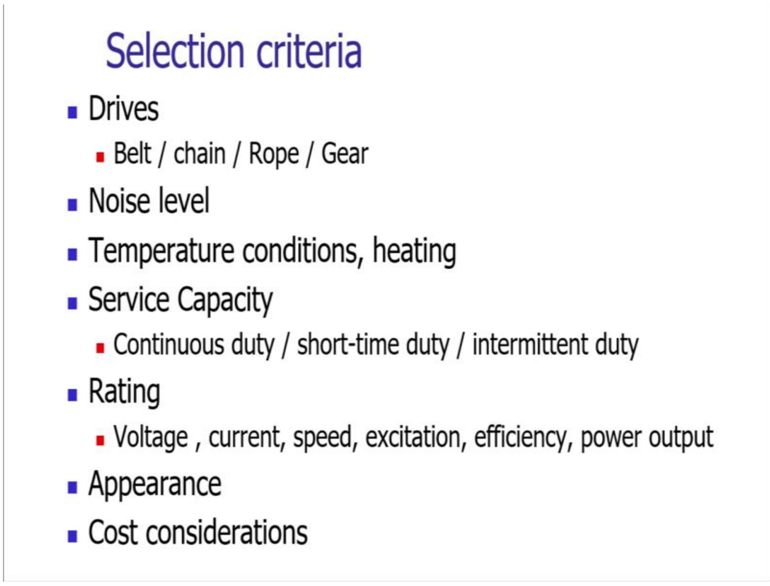

Then the drives or the loading condition where the mechanical energy is applied. Are we applying the mechanical energy in a belt drive or a chain drive or a rope drive or we are operating a gear based drive, what would be the loading conditions to this electric motor these factors are also to be considered during the selection. What noise level we are expecting if we want to have a very quiet operation and we have to go for the AC drives or brushless DC motors. If the noise levels can be adjusted or accommodated, the brushed DC motor can be used because they are economical and the expenditure can be reduced.

The brushed DC motors are having the heating problem. Can we utilise these brushed DC motors in harsh conditions where the temperatures are already very high. The surrounding temperature conditions are also affecting on the selection of the electric motor. The service capacity we need to take into account for what duty for what type of duty the electric motor is being applied. Whether the electric motor is being continuously utilised for the operation or they are used for short time duty or it may be a intermittent type of operation as well.

Many manufacturers are available those who are computing the rating based upon the utilisation of the electrical energy, voltage current, the speed characteristics, the characteristics related to the excitation, the torque stalling, efficiency of the drive and the power which is coming out based on the ratings are decided. During the selection even we can give focus on the rating and based on the rating the appropriate electric motor can be chosen for our desired purpose

Appearance is very important nowadays; aesthetics how the motor construction look like whether it is suitable. The appearance would be very much essential when such drives are used to make the robots or the gadgets or the toys are made. The cost consideration is the most important; the electric motor should be cost effective, less expensive and they should be able to satisfy all requirements of the designer or the end user.

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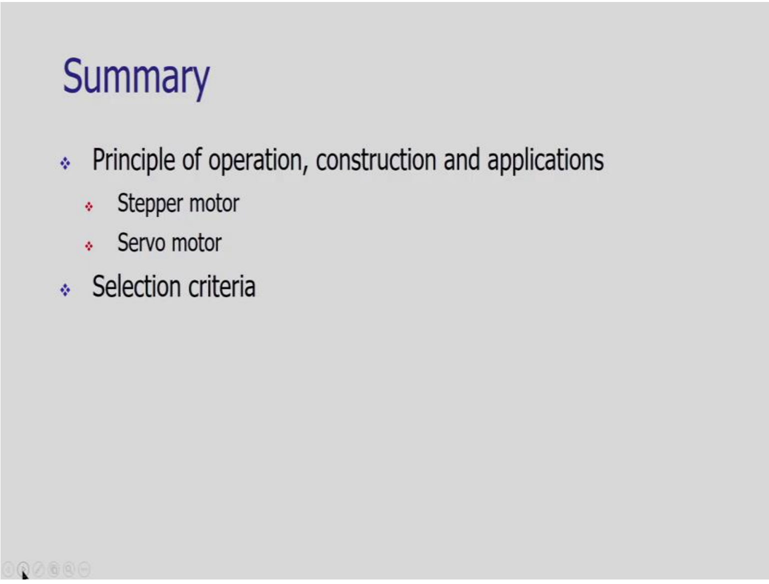

In this lecture, we have seen 2 important electrical drives. These were stepper motor and servo motor. We learnt the principle of operation of these electric drives, their constructional details and applications in the automation industry. At the end of the lecture so we have carried out a discussion on the selection criteria, how to select an electrical motor for the required purpose.

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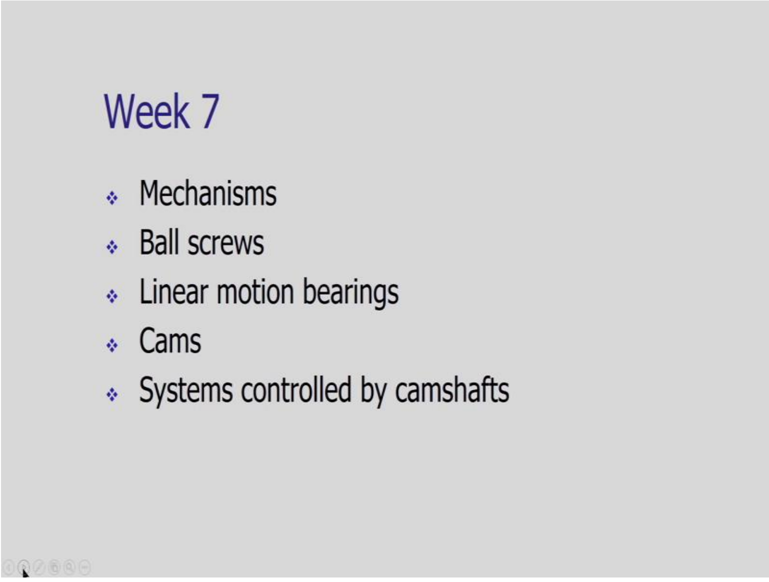

In the week 7, we will be studying the various mechanical systems or mechanisms which are required in the development of an automated system. In the lecture 1 of week 7, we will be studying the introduction to mechanisms, a detailed discussion on the constructional details of the ball screws, their advantages will be carried out. We will see about the linear motion bearings, various types of cams. Cams is a very useful mechanism and it is widely used in the automation industry. There are certain systems which are controlled by the camshafts. Some of the systems we will study in this lecture.

Overall in week 6, we have seen the requirements of various drives in automated system and then we carried out the discussion on various electrical drives. We saw the DC motor, AC motor servo motor and stepper motor 4 prominent types of motors which are used in automation industry. At the end we studied the selection criteria based on that how to select an electrical motor for the automation purpose.