Automation in Manufacturing
Dr. Shrikrishna N. Joshi
Department of Mechanical Engineering
Indian Institute of Technology, Guwahati

Week – 07
Mechanisms
Lecture – 02
Ball screw based linear motion drives

Hello everyone. I welcome you all to the lecture 2 of week 7. As we know that we are studying various mechanisms in this week, and we will be continuing the same discussion, we will be continuing some other aspects of the mechanisms in next week as well. The lecture 2 is focused upon the ball screw technology which is used in linear motion drives.

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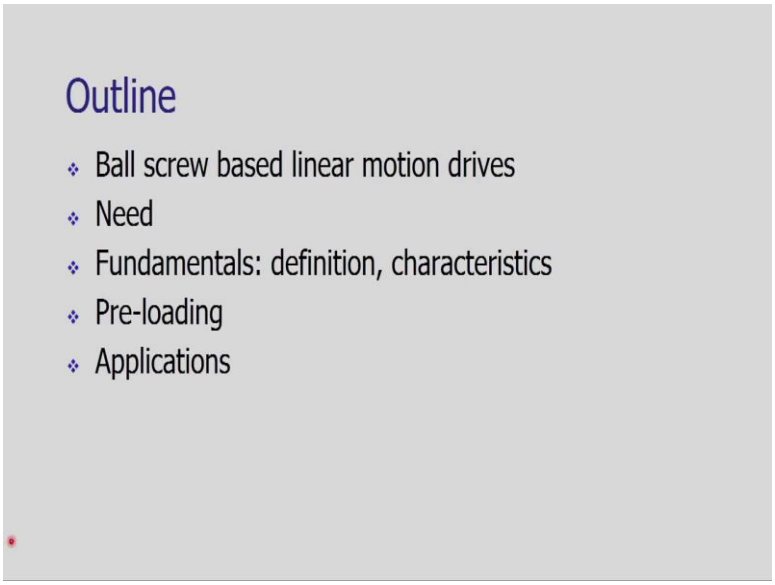

The outline of the lecture can be seen on our screen. At start of the lecture we will study the definition of ball screws and how the ball screws are helping to get the precision linear motion in the automation industry. We may also look at the need to go for the ball screw base technology, why it is important to go for ball screw base technology. A discussion will be carried out on the characteristics of the ball screws.

After that we will study the pre loading necessity in the ball screws, why it is necessary to have the pre loading in the ball screw mechanisms. At the end of the lecture we will have a detailed discussion on the applications of ball screw in the automation.

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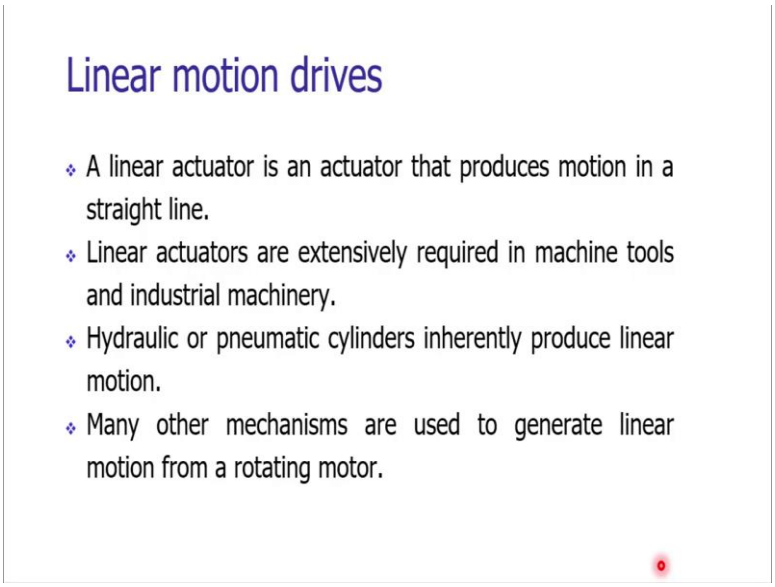

In automated equipment, we need various linear motions, we need linear relative moments with the variety of links of the machine. A linear actuator basically is an actuator which is producing the motion in a straight line. When we are getting a straight line motion from an equipment, that equipment is called as the linear actuator. We require the linear actuators in machine tools as well as the variety of industrial machinery that may be required for the conveyance that is a transportation, for painting for packaging, for variety of auxiliary operations required in the automated manufacturing.

The hydraulic cylinders and the pneumatic cylinders are producing the linear motion. However, there are many other mechanisms which are producing or generating the linear motion from the rotating mechanical energy which is coming from the electric motors.

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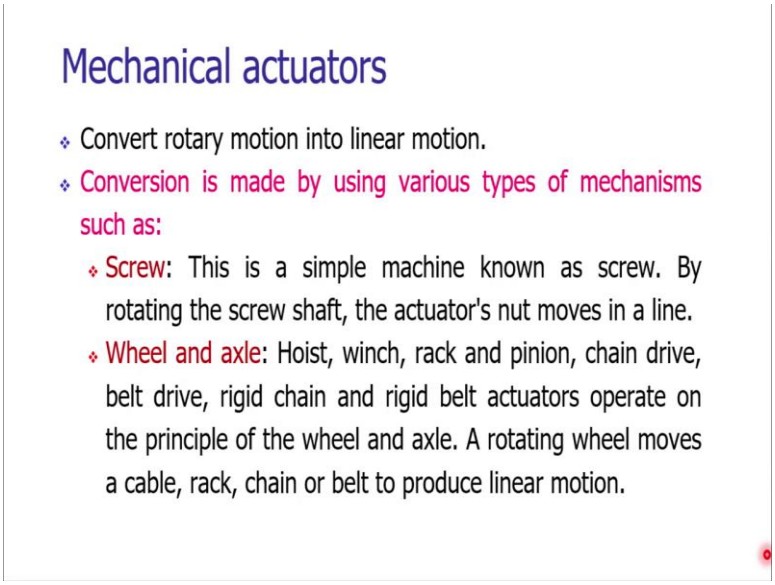

The mechanical actuators are converting the rotary motion into the linear motion, and there are many ways to convert the rotary motion into the linear motion. Very basic mechanism is the screw mechanism. If we are having a screw and nut arrangement, if you rotate the screw there would be translatory motion of the nut along the axial direction of the screw.

We may also have wheel and axle based arrangements. Variety of applications are there. There are many variants of wheel and axle mechanism; these are hoist, winch, rack and pinion, chain drive, belt drive, rigid chain and belt actuators. In wheel and axle arrangement we are rotating the wheel, and that rotation of the wheel may be a manual rotation of the wheel, and that manual rotation would be utilized to have the linear motion of its links, that link may be a cable or a rack or a chain or a belt.

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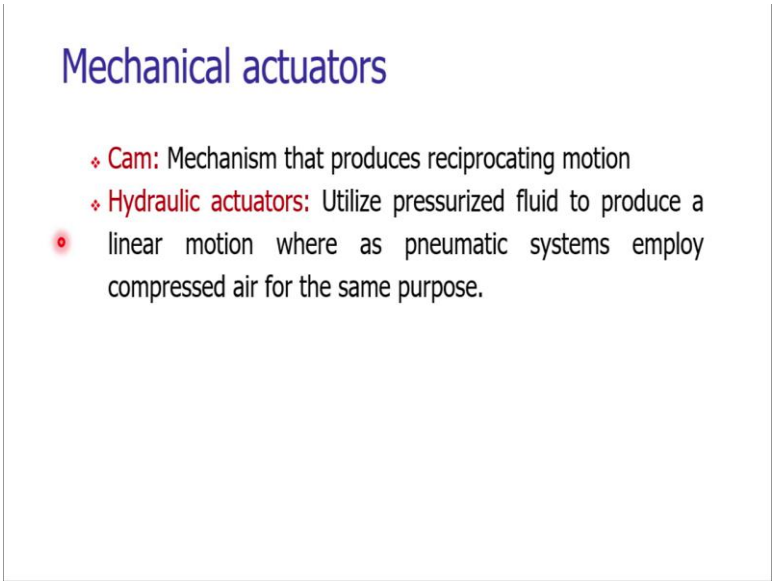

We may also have the cam mechanism. Basically, the cam is used to produce oscillatory motion or the reciprocating motion by converting the electrical, by converting the rotary motion which is coming from the motors, electric motors.

Hydraulic actuator is also considered as the mechanical actuator in which we are using the pressurized fluid to produce the linear motion. In pneumatics, we are using compressed air for the same purpose that is to generate the linear motion. We will learn the fundamentals of cam and their applications in the next lecture. We will have comprehensive discussion on hydraulics and hydraulic base actuators in the coming weeks.

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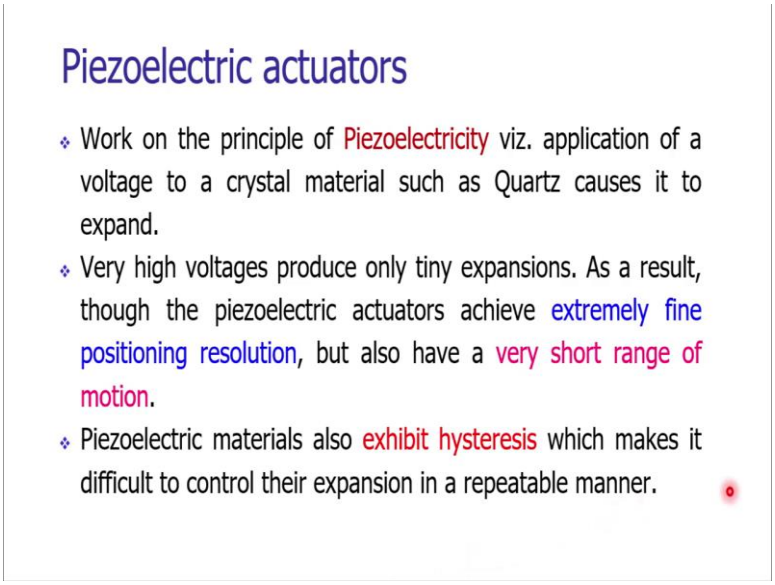

In automation, we may also need to have precise small quantity of linear motion. For that purpose, piezoelectric based actuators are used. These actuators, they work or they utilize the principle of piezoelectricity. We have already seen the definition of piezoelectricity in our previous lectures. It is the application of voltage to a certain type of material, quartz, quartz material or the crystal material.

When we apply the electrical potential to these kind of materials, they will expand, there is a change in the volume of these materials. But to get that precise expansion or precise motion by using this piezoelectric actuators, we need to employ or we need to utilize very high voltages.

The piezoelectric actuators are capable of providing extremely fine positioning resolution. That is why these actuators are utilized in the watches. We already seen the concept of the quartz based watches in the week 1.

But the severe limitation or the fundamental limitation of the piezoelectric actuators is the range of motion. These are providing very small range, very tiny range of operation maybe in millimetres. That is why, they are not that popular when we try, when we when we need to have the long travel of the mechanical elements. One more limitation of the piezoelectric actuator is that they exhibit hysteresis. They do have the inherent error problem which is making it difficult to control their expansion in a repeatable manner.

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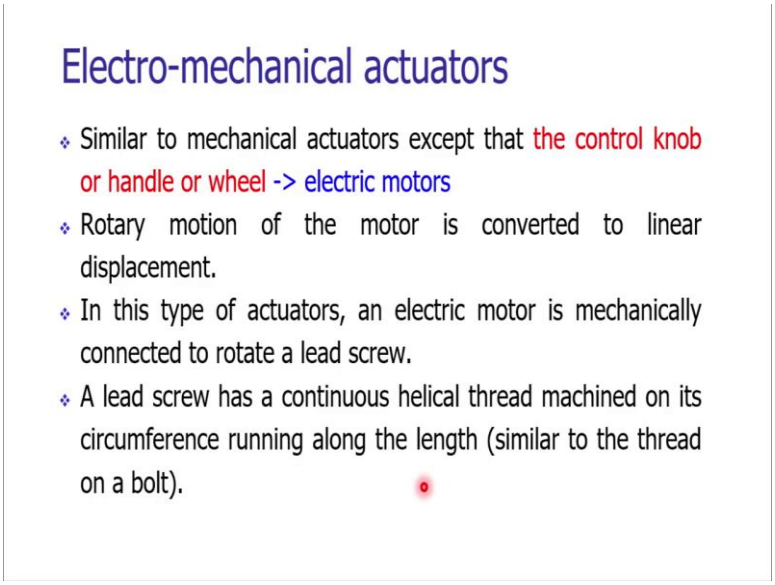

In automation, we use many electromechanical actuators. The electromechanical actuators are very similar to mechanical actuators. Only thing is that, we are replacing the control knob or handle or wheel by the electric motors. In mechanical actuators, the wheel will be rotated by hand. Here we are replacing the hand based rotation of the wheel by using the electric motors by using the electrical energy.

To convert that rotary motion of the electric motor shaft, we need to have the connection of the electric motor with the lead screw. In electromechanical actuators arrangement, we are connecting mechanically, the electric motor with the lead screw. Electric motor is driving the lead screw and the lead screw is rotating and the nut on the lead screw is translating.

The translatory motion of the nut can be utilized for our application, say the translation of the work table or the stage. The lead screw has a continuous helical thread, which is machined on its circumference and it is running along the length, which is very similar to a thread on a bolt. Either we may have a sliding contact of the nut with the screw or we may have the rolling contact.

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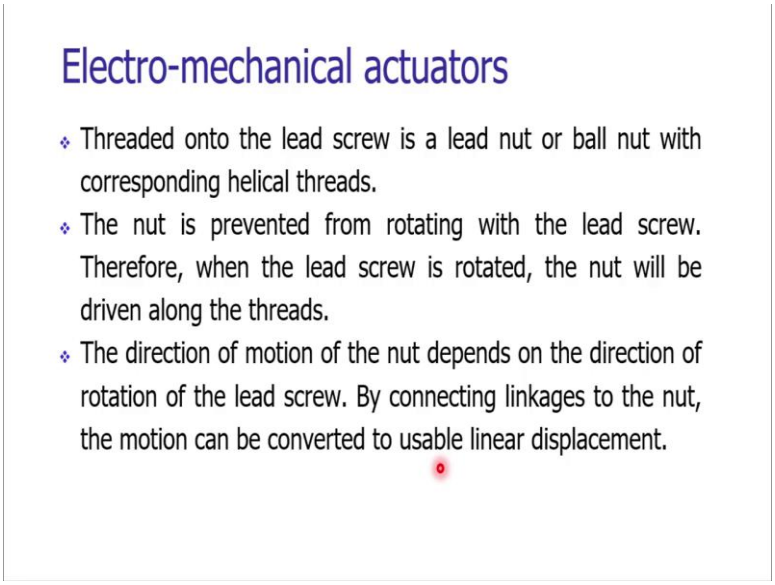

A nut or a ball nut is threaded onto the lead screw it is connected to the lead screw. The threaded nut or the ball nut is also having internal helical groove which is complimentary to the lead screw helical groove. The nut is basically prevented from rotating with the lead screw. We are restricting the rotary motion of the nut. Due to the restriction of the rotary motion of the nut, the nut will move along the axis it will translate along the axis along.

The longitudinal direction the rotation of the lead screw is basically controlling the direction of motion of the nut and that the motion of the nut further can be utilized by connecting it with certain other linkages to get the usable linear displacement. If we connect the nut to the other elements of the automated equipment, we can utilize the translatory motion of the nut for our required application.

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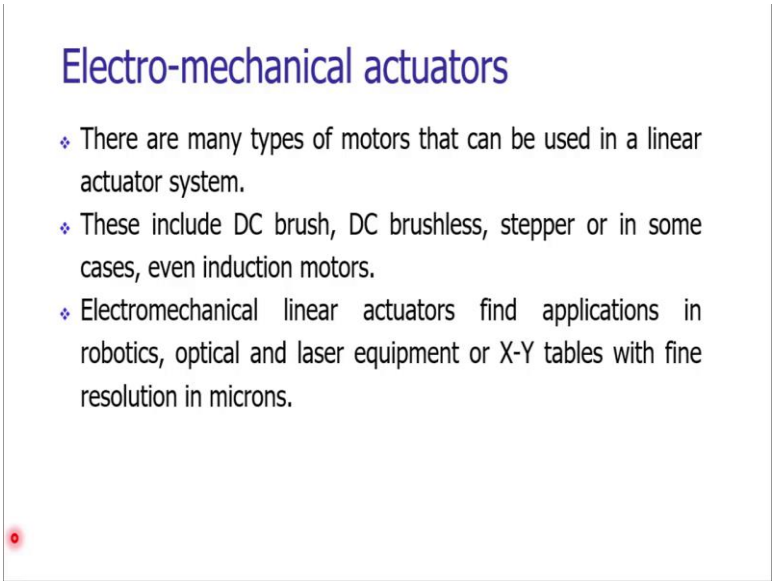

In electromechanical actuators, there are many types of electric motors used and these are the DC motors, AC motors, stepper motors, and the servo motors. The electromechanical actuators find enormous applications in robotics, optics, and in laser equipment. Basically, the electromechanical actuators are the key element in automation industry.

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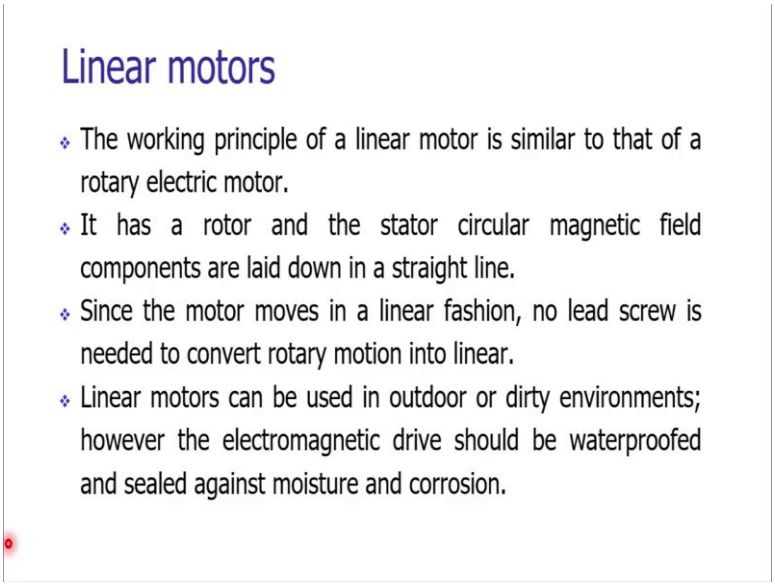

Well, to generate the linear motion we can also utilize the linear configuration of the electric motors as well. We have seen in electrical motors that the electrical energy is

converted into rotating magnetic field and that rotating magnetic field is driving the shaft of the rotor, if we are having a configuration that is providing us the linear motion of the magnetic field. Instead of having a circular magnetic field, can we lay down the magnetic field in a straight line and due to the movement of the magnetic field in a straight line can we have the relative motion of the mechanical elements which are associated to that.

The same concept is utilized in linear motors where we are using a straight movement of the magnetic field which is generating the linear motion. These are widely used in the industry. Linear motors are prone to the problems associated with the dirt, humidity and moisture. The linear motors are very useful in the industry, but they are underperforming, they may malfunction, when they are exposed to the moisture, or the corrosion and dirt in the environment. We need to have the waterproofing of this equipment; we need to have the proper sealing or the linear motors to protect them from the dirt, dust, moisture, and the corrosion.

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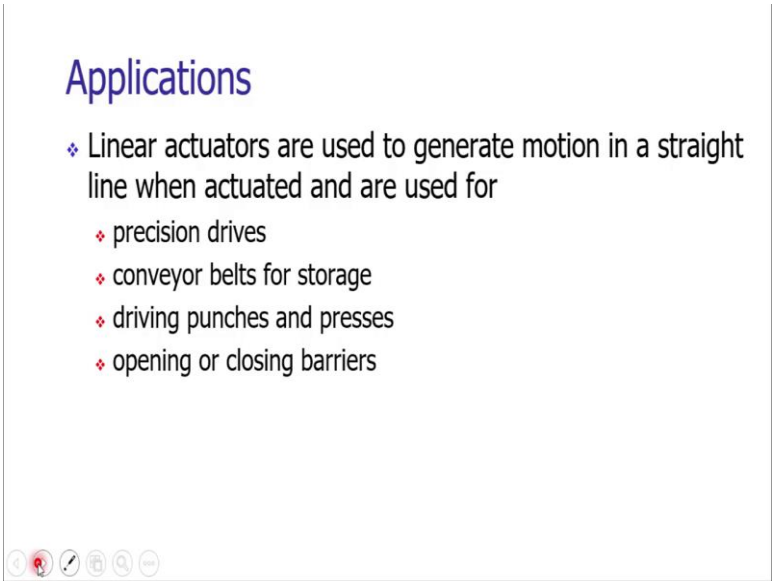

Overall, we can say the linear actuators are having many applications in getting the precision drives to operate the conveyor belts which may be utilized for the storage application or the conveyance application.

We can utilize the linear actuators for driving the punches and press in mechanical deformation applications. The linear actuators are utilized for opening and closing the barriers in the safety applications as well.

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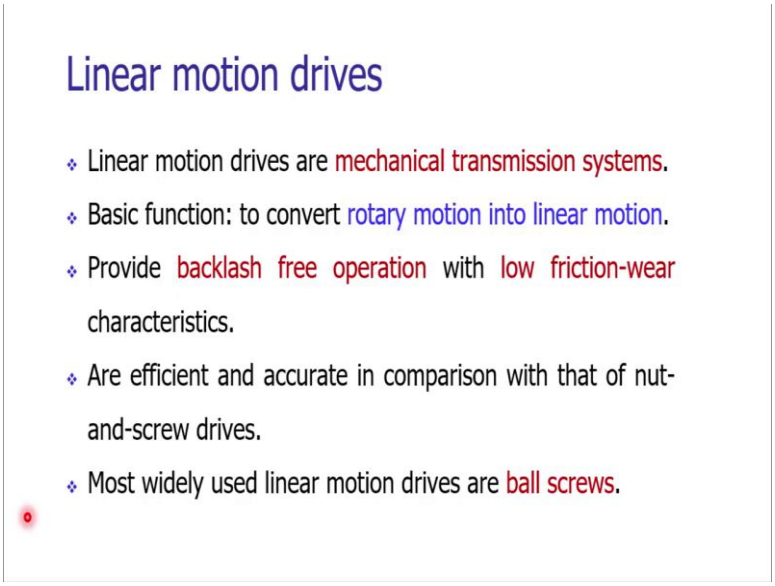

Well, in the context of automation in manufacturing, we are focusing on the precision linear motion drive which will be having very less backlash and which is providing very low friction and the wear characteristic. We have seen many linear actuators or many linear drives, but the most prominent linear drive is the ball screw based linear drive. It is widely used. Let us study the various aspects of the linear drive which is on the ball screws.

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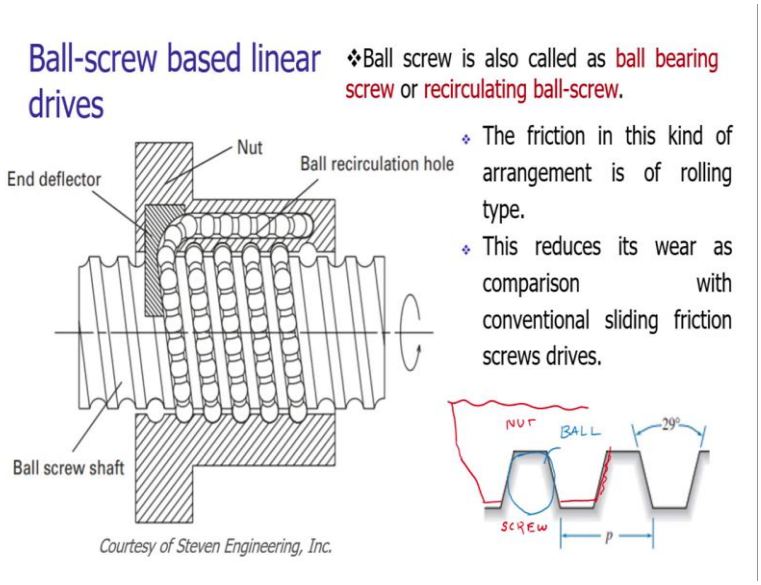

The ball screw based linear drives are also called as ball bearing screw or recirculating ball screw. We know that in a typical screw and nut arrangement, we are having sliding friction. Due to the sliding friction, the efficiency of the typical screw and nut arrangement is low. If we replace that sliding friction with the rolling type of friction, then we can enhance its efficiency. For this purpose, we are using the ball bearing screw concept to get the higher mechanical efficiency.

How it is possible? For that purpose, we need to reduce the friction between the mechanical elements involved in the screw and nut arrangement. In the typical screw and nut arrangement, we are using the acme kind of thread; the angle of the thread is 29°. This is the screw, and we may have a nut here, and we are having a nut which is having the complimentary profile and there will be sliding friction along the surface. Instead of having the sliding friction, can we convert this sliding contact into the rolling contact? Instead of having a thread, let us use another mechanical element a spherical ball.

This spherical ball will rotate and it will provide the rolling friction. The ball will roll inside the groove generated by the screw and the nut. The same concept has been utilized in development of this precision drive. On our screen we can notice, there is a screw and this screw has helical thread the shape of the helical thread is semi-circular. The helical thread is from one end of the screw to the other end. It is extending, it is travelling from one end to another end.

There is a nut, the nut is also having internal groove, internal helical groove, the shape of the internal helical groove is also semi-circular. The nut is engaged with the screw and inside the gap produced due to the shape of the nut and the screw; we are having number of spherical balls which are made up of the steel.

This ground polished fine finished balls are utilized to transfer the rotary motion of the screw to the nut. And as we know that, if we restrict the rotary motion of the nut, the nut will start travelling along the axial direction or along the longitudinal direction. But the problem in circulation of these balls is that, if we do not restrict them they may come out of the nut. We have to re-circulate them; we have to reuse them for the transmission of power transmission of motion. For that purpose variety of arrangements are there.

In this case, if we just look at here the shaft is rotating, that rotary motion will be given to the balls, the balls are rolling, and that rolling motion will be transmitted to the nut, the screw, the internal thread of the nut. That rotary motion will try to rotate the nut, but nut will not rotate due to the restriction which we are offering to it. Then, due to that restriction it will translate along the longitudinal direction.

But if we do not have any restriction for the movement of the balls, the balls may come out of this engagement. To prevent that we are utilizing or we are providing an arrangement which will be recirculating these balls which will be reusing these balls during the operation. For that purpose we need to have a variety of passages. The passage may be the internal passage or we may have the external passage.

In this case, we consider the shaft is rotating and as the shaft is rotating the balls are rolling inside the groove. They will roll and they will come at the end of the nut, they will come at the end of the engagement of the nut with the screw. If we do not restrict, they will come out of this assembly. Here we are using and end deflector an mechanical arrangement which will deflect the rolling balls through a channel and that that channel may be provided inside the nut or it may be outside the nut by using another tube.

This channel will be taking these rolling balls and they will be directing them to the engagement at the start point of the screw and nut arrangement. Here we can see, there is a passage will be there on the circumference and through this circumferential passage the balls will further put inside the gap of the screw and the nut. In this way, the rolling balls

are transmitting the motion from the rotating screw to the translating nut, and they are again getting engaged in the operation.

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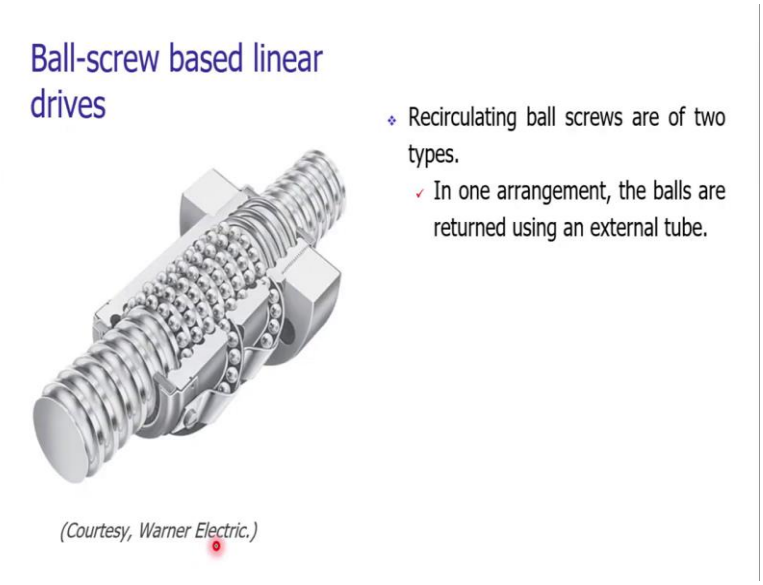

As mentioned, we can have the transmission of balls or returning of the balls from the end of its operation to the start of the operation either by using an internal passage or by using an external tube. On our screen you can see an arrangement. This is the screw, this is nut, and these are the external tubes.

As mentioned, when the balls will come after finishing of their jobs, they will try to get out of the engagement, but we need to have the deflection of the ball to take them, to guide them, to get engaged once again inside the screw arrangement. The outer tube is provided, it is a steel tube through which the roll balls are coming and they are getting engaged.

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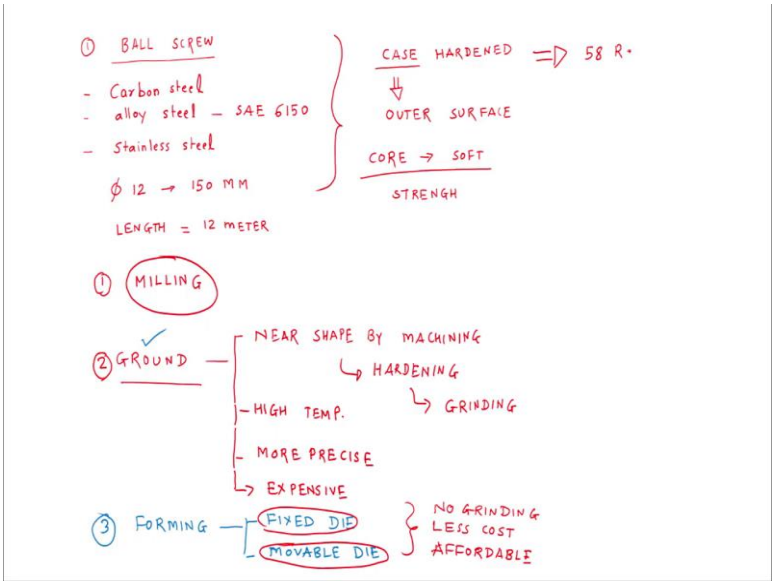

The ball screw and nut arrangement has basically two elements, first is the ball screw and the second one is the balls. Now, let us study the ball screw. As we have seen that we need to increase the mechanical efficiency, to increase the mechanical efficiency we are reducing the friction among the mechanical elements. The fundamental requirement of a ball screw is that it should provide minimum possible friction with the rolling elements that is the balls. For that purpose we should have a very fine finish of the ball screws and the geometrical accuracy of the ball screw must be very high.

The ball screws are used tremendously in automation industry. Their life should also high. There may be contact of many number of rolling balls with the ball screw. To minimize that wear and tear we need to have very hard surface, very good quality surface. For that purpose, we have to do some sort of heat treatment.

Basically the ball screws are made up of carbon steel or they are made up of alloy steel. Ball screw are also made up of stainless steel, basically the alloy steel of grade SAE 6150 is widely used. In industry, we may have ball screw which is having the diameter from 12 mm to 150 mm. The ball screws are case hardened. Case hardened means their surface is hardened; the hardness of the surface is enhanced by using the heat treatment process such as carburizing. We are increasing the temperature of the screw, we are hitting the screw, and we are keeping that screw in environment which is having high carbon content.

Due to increase in the temperature, there will be the deposition of carbon, there would be the reaction of the material of the carbon, will get lost on to the surface of the screw and as we know that carbon is increasing the hardness, we want to have the harder outer surface and softer inner surface. We want to have harder outer surface and softer inner surface, that softer inner surface or the core is providing good strength. The case hardening is at outer surface. However, the core is soft and this is providing the strength.

The ball screws are having a length up to 12 meters. How to manufacture the ball screws? The ball screws are typically manufactured by using 3 operations, first is the milling process. We may have the rotating and translatory motion of a bar, circular bar, and there is a relative motion of these rotary and translatory motion of the circular bar with the cutting tool and we can generate a helical thread by using milling operation.

The second is the ground or the grinding. In this operation, we are generating the near shape of the helical groove by using the milling operation itself. Near shape would be done by machining and then we are carrying out the hardening operation. After getting the near shape, we are carrying out the hardening operation, and then we are going for the grinding. The grinding will take the raw shape into the final finished shape.

Due to the hardening operation, the ground ball screws can withstand very high temperatures, they are more precise, they are more precise, but they are expensive. A simple milling operation is very economical, but the grinding based operation and hardening operation could be expensive due to involvement of many processes in making the final product.

The third operation is the forming operation. We can generate the ball screw by using two dies, first one is the fixed die and the second one is movable die. In forming we are having a fixed die which is having the shape of the screw thread, and there is a movable die we are rolling we are having a relative motion of the rod circular rod with the fixed die and a movable die. The rod is held in between the fixed die and a movable die.

As the movable die is moving the rod will be compressed, it will be deformed according to the shape of the groove that is made on these dies. This operation does not involve any grinding, therefore the cost is less and these are affordable basically. In general, we are expecting to have around hardness of 50 RC on the outer surface of the ball screw.

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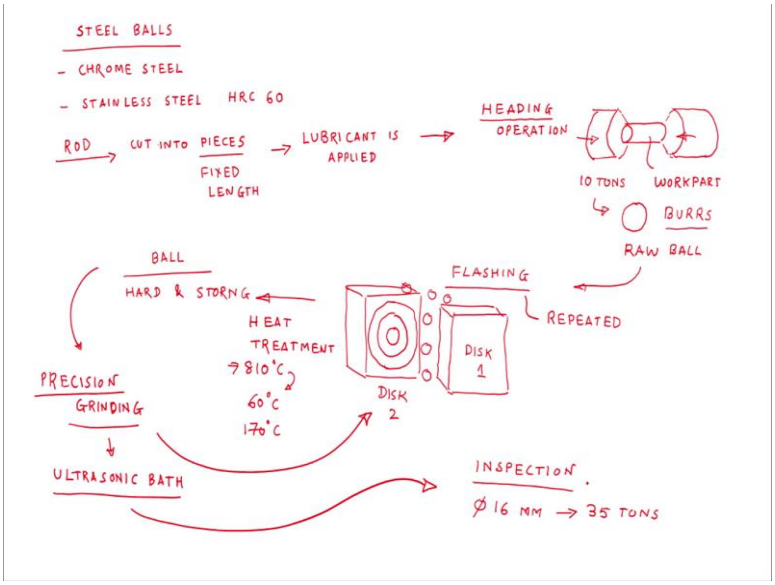

The second and most important element is steel balls. They are made up of chrome steel or stainless steel and it is expected to have the hardness value about 60.

How these steel balls are manufactured? The steel balls are manufactured from a circular rod, that rod is cut into pieces, the pieces are having fixed length, then a lubricant is applied and then we are carrying out the heading operation. As the name suggests, heading means we are applying the forces on the heads of the work parts.

If we consider a work part, the piece of the rod, and we are applying we are applying the force on two of its ends and we are forming it. A huge force is applied around 10 tonnes of the force is applied on the steel pieces, so that the small piece of the rod will be converted into a spherical ball. It is converted into a spherical ball, but it may have burrs, the surface will not be smooth, it will be uneven, it may have the burrs. This is called as the raw ball.

The raw balls are further processed by using operation that is called as flashing operation. In flashing operation, we are utilizing two disks and this disks are having circular groups. Both these disk do have the circular groups. We are fixing one of these two disks and we are having the relative motion of the other disk with respect to the disk 1. We are moving disk 1 of the disk with respect to the other one.

During the relative motion, we are taking the raw balls in between these two disks, so that the burrs or unwanted portion will get removed. The disks are the metal disk and they are hardened, they are having hard surface. During the process of relative motion between the disk 1 with the disk 2, with the balls we are just removing the burrs.

This flashing will be repeated unless and until we get the required surface finish on the raw balls. As we know that we need the balls which are having a good strength and they are hard. We want to have the hard and strong balls. For that purpose, we need to carry out the heat treatment. The balls are heated to 810° Celsius, then they are quenching, they are reducing the temperature up to 660° Celsius. Again, they are gradually heating up to 170° Celsius. Due to heating it up, cooling it down and further heating to 170°, the balls will become strong and their molecules will get aligned.

After the heat treatment we are going for the precision grinding. In precision grinding as well, we are using the same concept, we are having two sheets, one is the fixed sheet and the other one is a rotating sheet. And in between this fixed and rotating sheet we are taking the balls, so that whatever the irregularities are there on the surface whatever the asperities are there on the surface that can be removed. After the precision grinding we are going for the ultrasonic bath.

In the ultrasonic bath, the balls are given very high frequency vibrations, the balls are processed at very high frequency maybe around 20 kHz or 40 kHz. At such a high frequency, whatever the burrs or dust particles are there on the surface of the balls will be removed and we will have very clean and fine mirror finished of the rolling balls. After the ultrasonic bath of the roll balls, the inspection will be carried out, that is expected that a ball of 16 mm diameter should withstand about 35 tons of the load.

These balls are inspected by using optical equipments, and when there is a unusual reflection pattern from the surface of the ball that balls are removed from this lots. It is expected that, the ball should provide a defined reflection pattern if the asperities are there on the surface we may not get the required reflections from the surface of the ball. In this way the steel balls are manufactured. These are very critical elements in a ball screw based arrangement.

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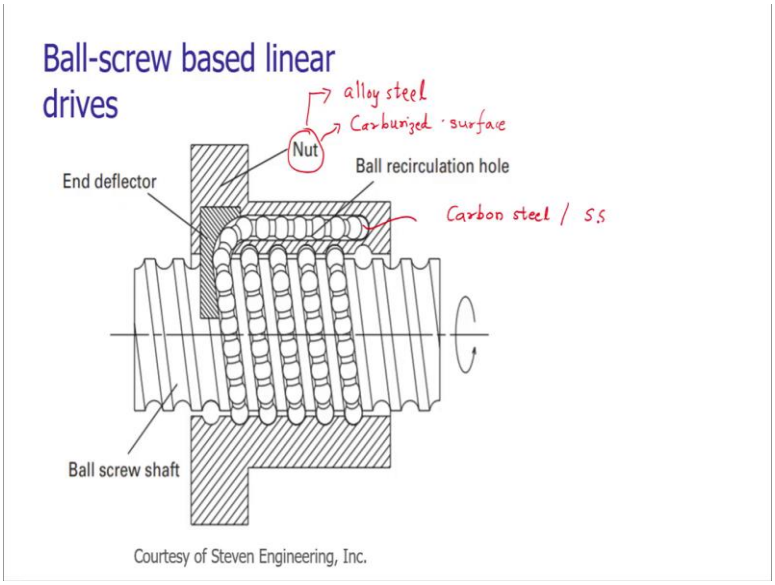

In addition to the screw and the balls, we are having the nut. The nuts are manufactured by using alloy steel and their surface is carburized. The ball circulation system if it is outside is made up of carbon steel or stainless steel.

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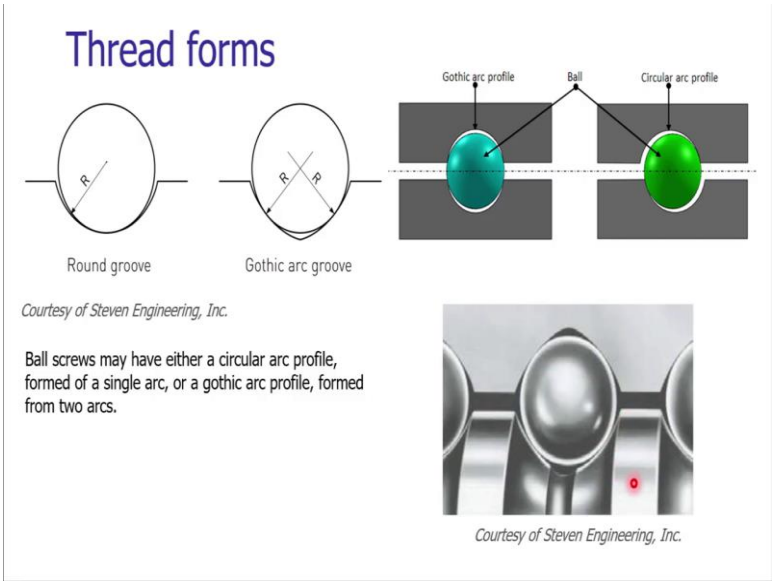

In general, a round groove is developed in this ball screws and in the nut arrangement, but there may be chances of having wear and tear of the screws or the balls. In that case, we may not get the proper contact of the balls with the screws. To have the sufficient contacts or the multiple number of contact points a gothic arc based groove is utilized.

Here we here you can see instead of having only one contact point, here we can have two number of contact points. For that purpose, we need to change the profile, so instead of having only one curve we can have two curves which are connected to each other, so that we can form a gothic. We can notice here, due to the gothic curve we can ensure the contact of the ball with the screw and the nut arrangement.

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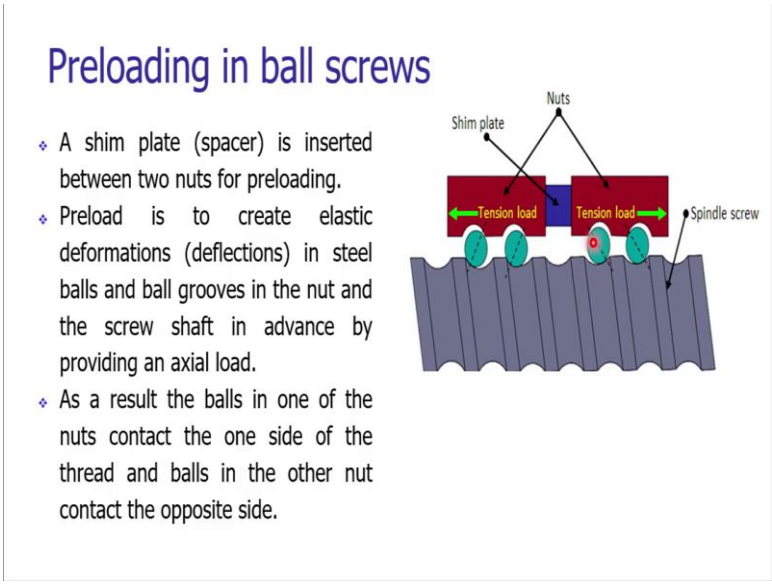

On our screen, we can see a ball which is in contact with the screw and the nut arrangement. Backlash is the problem in ball screws. Due to wear and tear, due to inaccuracies, due to prolonged utilization of the screw and nut arrangement, there may be a backlash, there may be disengagement of the balls with the screw and the nut arrangement.

For that purpose, we are pre-loading the ball screws, we are applying tension to the ball screws and we are ensuring that there is a continuous contact of the balls with the screws and the nut. For the purpose, a shim plate. it is nothing, but a spacer is inserted between two nuts. We are using two different nuts and we are putting a shim plate. This shim plate is applying the tension on the nuts, and that nuts are applying the tension on the balls. We can increase the length of the shim plate, as we increase the length of the shim plate we may apply the required tension on the balls. Due to this application of the tension on the balls there may be elastic deformation of the balls. And that will ensure the proper contact of the balls with the screw.

Here we can see due to the application of the tension load in opposite direction, these balls are having a contact on one side of its diameter and these balls are having the contact on the opposite side of the diameter.

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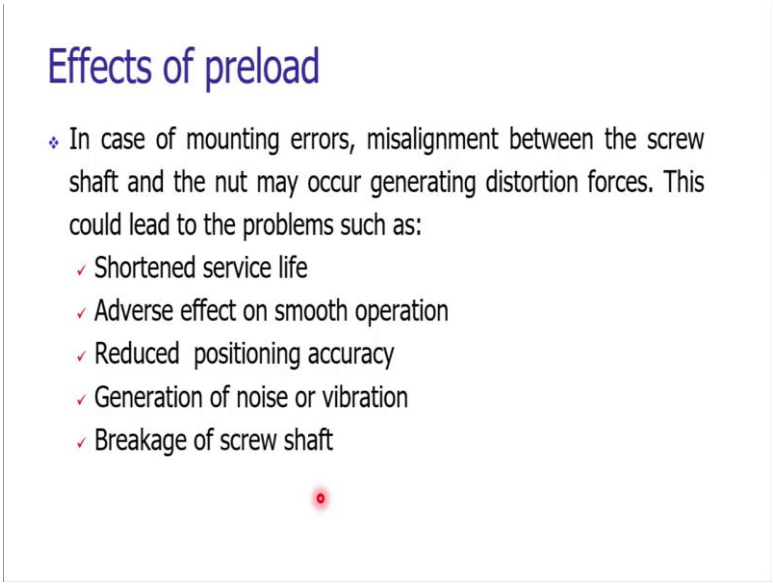

But there may be chances of having mounting errors, if the spacer is not properly mounted, and if the pressure applied, if the tension that that is applied on the nuts is not proper due to the misalignment there are chances of having distortion forces.

Due to this distortion forces the screw and nut arrangement may have shortened service life. It certainly affects the operation we may not get the smoother operation, the accuracy would be less there would be reduction in the positioning accuracy, there may be generation of the noise and vibration, and there may even be catastrophic failure of the screw and nut arrangement, then the screw shaft may get broken down.

That is very essential when we apply the preload, when we apply the shim plates, and when we apply the tension in the nuts, it should be in a proper condition with due care.

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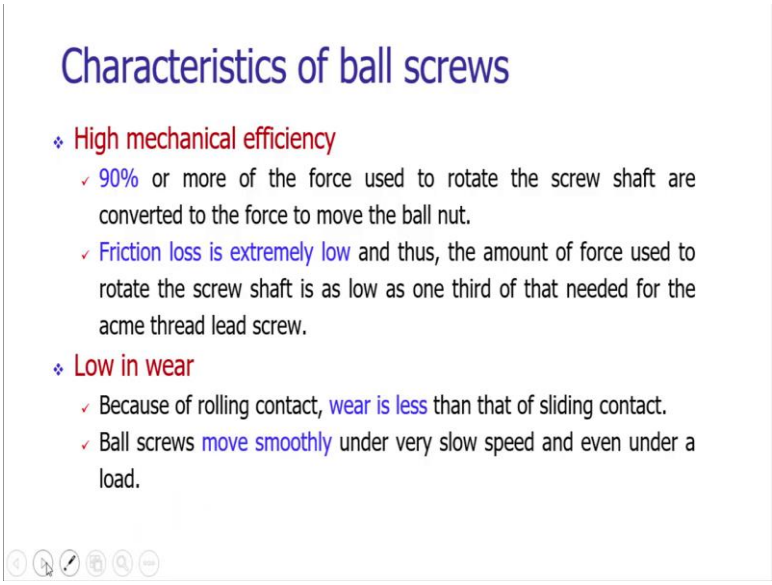

What are the various characteristics of the ball screws? The ball screws are providing us very high mechanical efficiency. 90% or more than 90 % is the mechanical efficiency, whatever the force which is used to rotate the shaft ninety percent of the force would be transmitted to the ball nut. The losses due to friction are very low. The small amount of force is used to rotate the screw shaft. As we are using the rolling friction, the wear and tear of the contact parts is less and there is a smooth operation.

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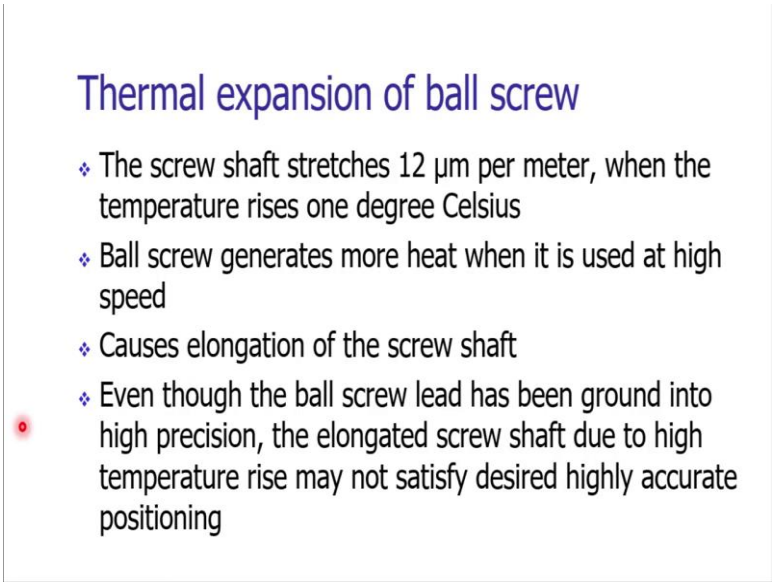

But when we are working at very high speed applications in ball screws, due to whatever the friction is there in between the balls and the screws, there will be generation of heat energy and that heat energy will certainly affect the operation. There would be thermal expansion of the ball screw.

We need to consider the coefficient of thermal expansion of the ball screw and we need to continuously monitor the temperature of the process. If a screw shaft stretches say about 12 micron per meter when the temperature rises to 1°Celsius. So, 12 microns per meter is the coefficient of thermal expansion of a typical ball screw.

Due to the thermal expansion the shaft is getting elongated, and even though we are taking due care during the manufacturing we are getting very high precise, high highly polished, highly ground screw shaft, due to increase in the temperature the screw shaft will lead to certain inaccuracies in the product.

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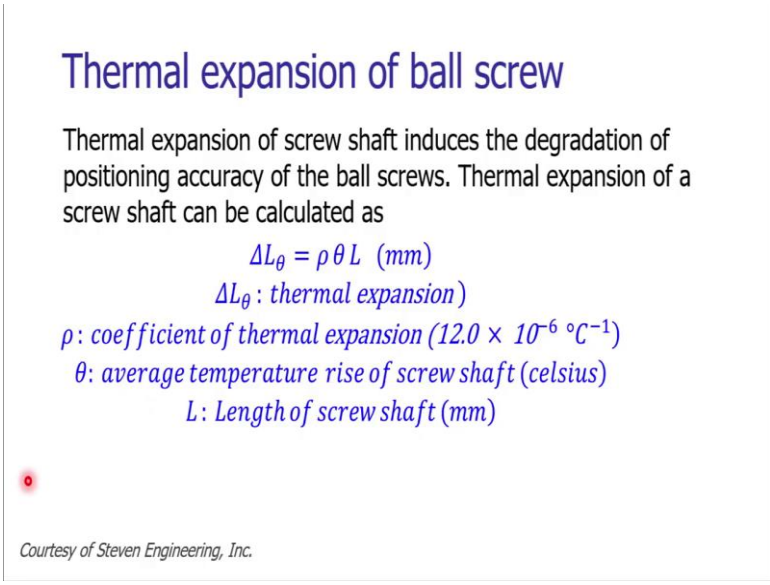

For that purpose, we need to compute the thermal expansion in the screw shaft. That can be computed by using the correlation which can be seen on your screen.

$$\Delta L_\theta = \rho\theta L\ (mm)$$

ρ is coefficient of thermal expansion, Θ is the average temperature rise of screw shaft, that is in Celsius and L is the length of the screw shaft. Length of the screw shaft is

known to us. Coefficient of thermal expansion is a basic property of the steel shaft that can be taken from the trade literature.

The temperature rise in the screw shaft can be monitored. To monitor it we can use either contact type of sensors or non-contact type of sensors to get the in situ information, in process information about the increase in the temperature rise. For that purpose, either we can use the thermal imaging cameras or we may can or we may have the RTDs that is the Resistance Temperature Detectors. But the RTDs may interfere the rolling operation. Thermal imaging cameras or non-contact of sensors are very much suitable to monitor the temperature of the ball screws.

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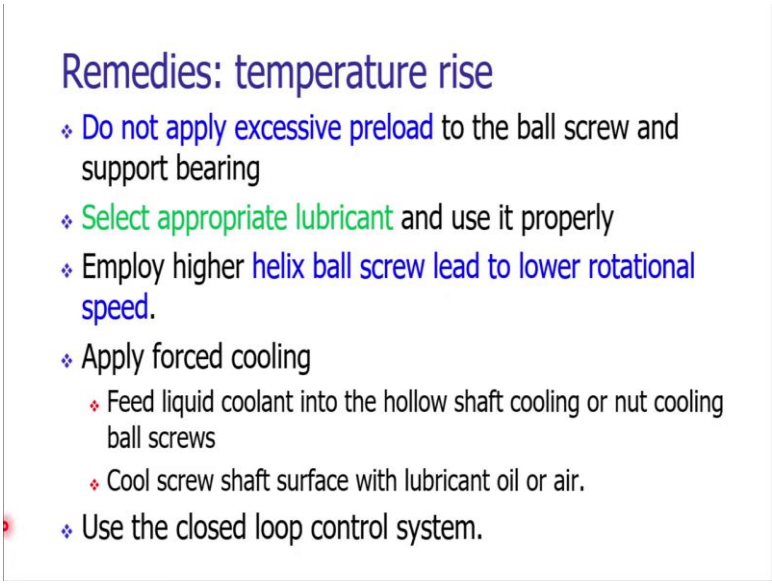

How can we mitigate the temperature rise? How can we solve the problem of the temperature rise? The temperature rise can be reduced by reducing the excessive pre pre-loading to the ball screws and support bearings. If we are applying more load more preload on the ball screws, more heat will get generated. There has to be a balanced or the optimum value of the preload that to be applied on the ball screws.

There has to be sufficient lubricant and we should apply the lubricant on the ball screw not on the balls. We may even have the forced cooling, we can have a forced application of the oil or air, either may on the exterior surface of the ball screw or it may be in the inner surface of the ball screw.

We can even control the temperature rise by using the closed loop control systems. As mentioned, the input from the sensors can be utilized to adjust the process parameters to adjust the speed of the rotation of the ball screw, to avoid the further inaccuracies in the product.

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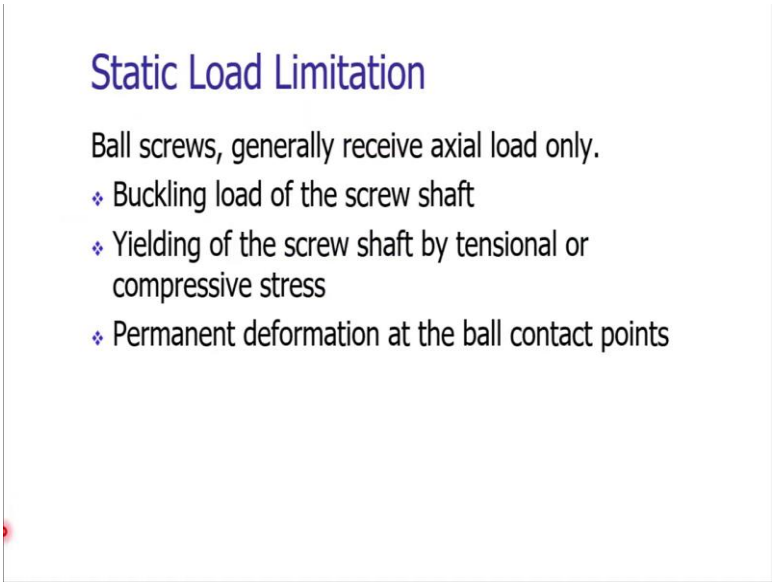

The ball screws are generally receiving the axial load only, and we need to consider during that is during the design of the ball screws the buckling load that is applied on the screw shaft. In addition to the buckling load, we have to even also see whether the screw shafts are safe in yielding due to the tensile and the compressive stresses. Yielding is due to the tension or the compression buckling of the screw shaft and the permanent deformation of the ball contact points.

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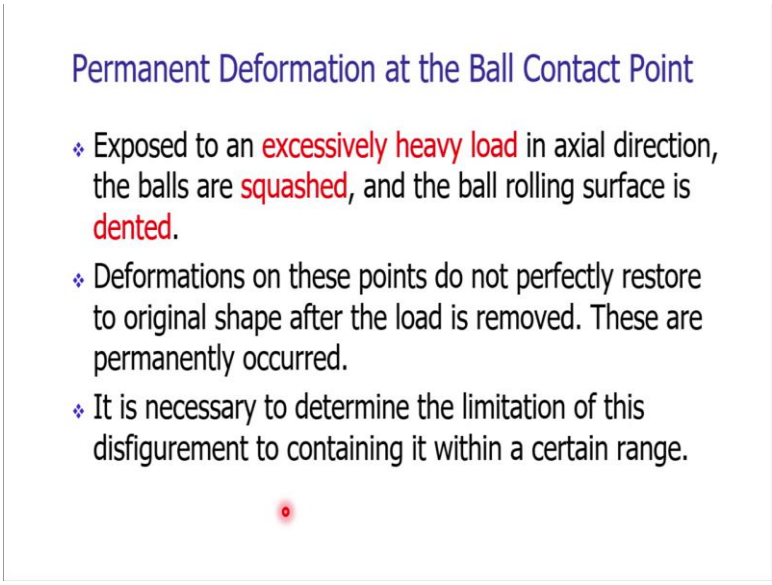

These 3 aspects need to be considered during the design of the ball screw shaft. Due to very high loads in axial direction, many a times the balls are squashed and the ball rolling surface is dented. Deformation on these points which do not perfectly restore its original shape after the load is removed these are permanently occurred.

These dents are nothing, but the deformation on these points which are not getting restore its original shape. We are having the permanent plastic deformation, when we are removing the load. These permanent deformations are the dents and these are not expected. Therefore, the level of permanent deformation of the dents or the level of permanent deformation of these points need to be considered during the processing, during the designing of the ball screw shafts.

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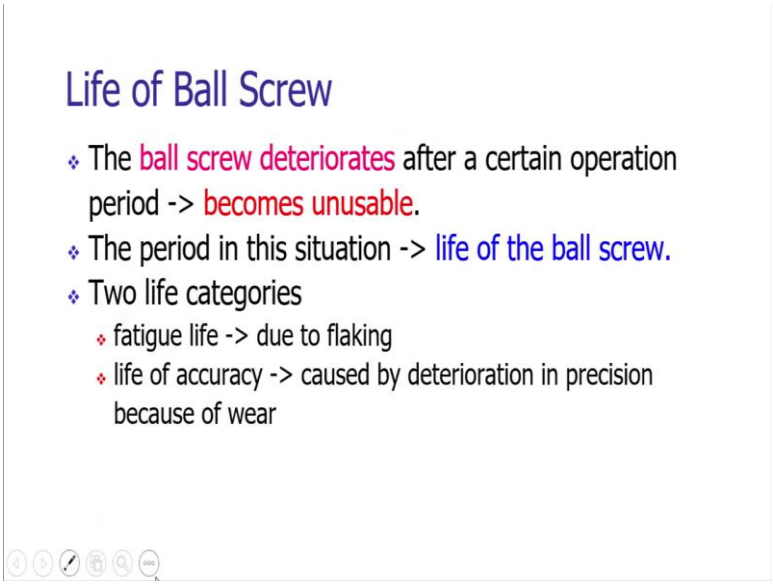

The life of ball screw is getting deteriorated after a certain operation and it is become unusable, it cannot be used for further operation. That period from start of its utilization to end of its utilization is nothing, but the life of the ball screw.

There are basically two life categories of the ball screw; the first is the fatigue life. The fatigue life is examined based upon the flicking. When there is a flicking occurs, we can see that the fatigue life has reached. And the life of accuracy. This life of accuracy aspect is dependent upon the deterioration in the precision because of the wear.

Due to flaking there may be the complete failure of the screw shaft, but we can judge the life of the screw shaft base based upon the accuracy it is producing. If there is a deterioration in the precision generated by the screw shaft, we can say that the life of the screw shaft is over. The physical condition is leading to the fatigue life and the performance condition is leading to the life of the accuracy.

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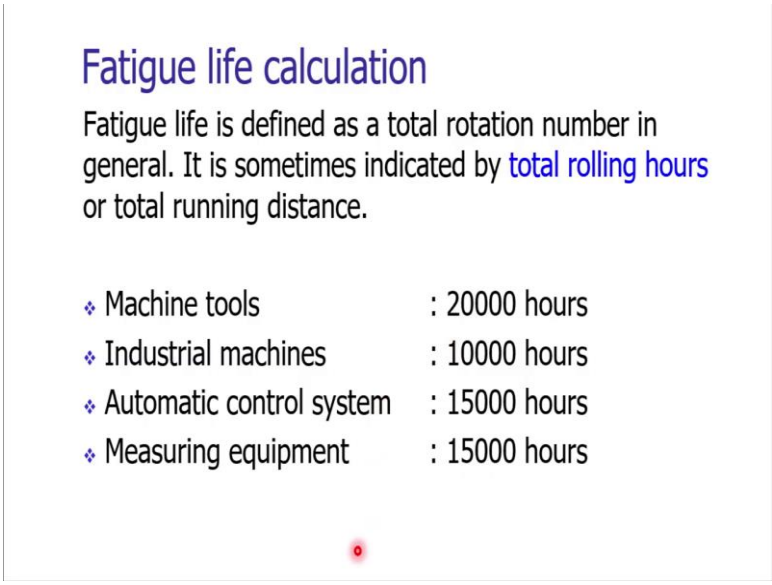

The fatigue life is basically considered or it is defined as the total rotation number in general, the total number of rotation that the shaft or the screw is providing to us. It is sometimes indicated by the rolling hours as well.

In general, some numbers are there on your screen. For machine tool, the fatigue life of the screw shaft is considered around 20000 hours. For measuring equipment, we are considering it is 15000 hours. For industrial machines, it is around 10000 hours which are heavily used heavy duty operation, where the fatigue life would be less due to its heavy utilization. Automatic control systems and the measuring equipment it is around 15000 hours, but for the general machining operations and CNC milling machine tools it is around 20000 hours.

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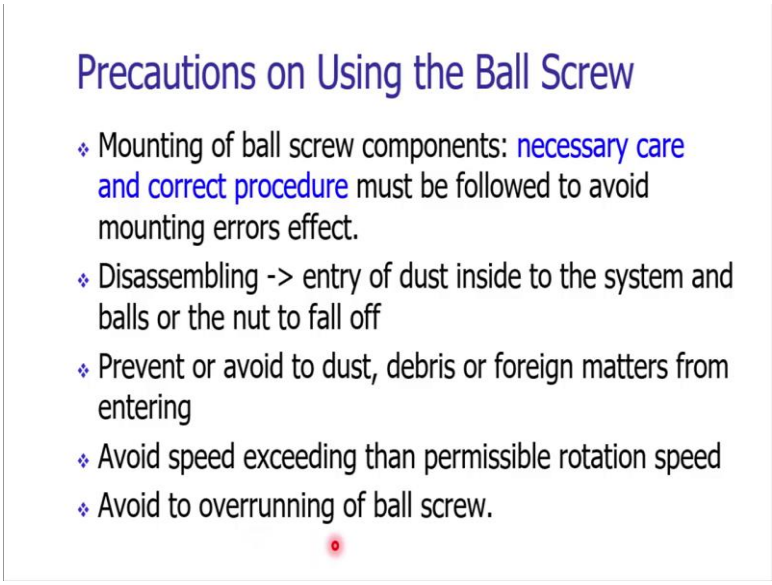

Now, let us see what are the precautions that we need to consider during the using of the ball screws. We need to avoid the mounting errors. As mentioned, during pre-loading the shim plates are used, two different nuts are used and there may be chances of having the mounting errors. There is a necessity to reduce the mounting errors by careful assembly of the operation.

During this assembly, we need to avoid the entry of dust inside the system because we need to have very less friction. If the dust particles are there that may increase the friction. In addition to the dust, we should avoid the debris or the foreign matters that to enter inside the screw and nut assembly. It is not expected to increase the speed more than the permissible limits. If it is there, it will certainly affect the life of the ball screw. We should not utilize the ball screw after its life. We should avoid the overrunning of the ball screws.

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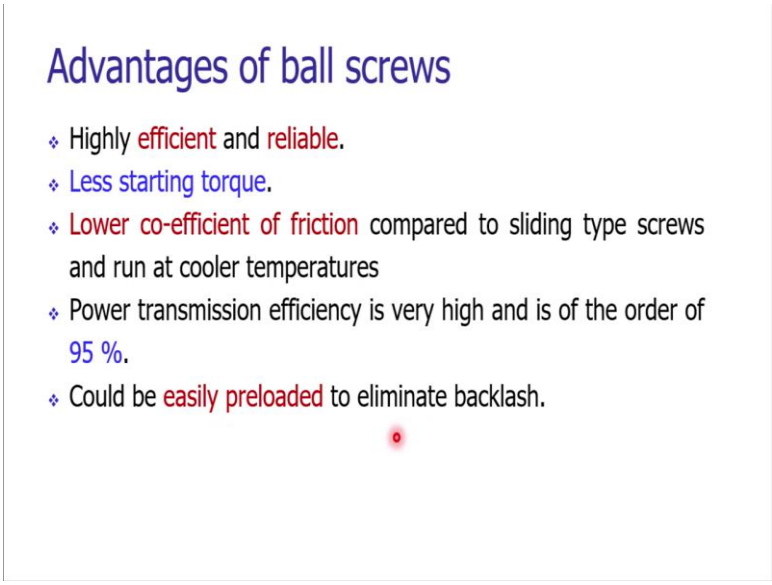

What are the various advantages of the ball screws? The ball screws are highly efficient and reliable. They require very less starting torque as the friction is less, coefficient of friction is less. We require less torque at the start. Since, the friction is less, the temperatures is less the heat energy produced is less, therefore we can achieve a very high power transmission efficiency about 95%. We can easily preload the ball screws. We can easily eliminate the backlash inside the assembly.

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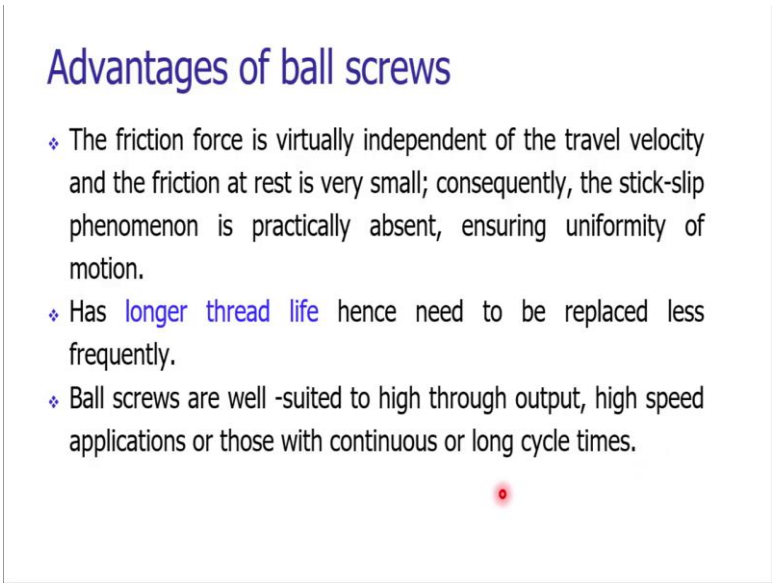

As there are no stick slip phenomena which is there in the sliding friction, there is no stick slip phenomena that is why we can ensure to have uniformity in the motion. We can have smoother motion when we are employing the ball screws for our operation, for our application.

Since, there is a rolling friction all the advantages associated with the rolling frictions are helping us to attract wider applications of the ball screws inside the automation industry. The thread life is longer. As the efficiency is very high where we are getting very high output we can go for the high speed applications as well and we can expect longer cycle times.

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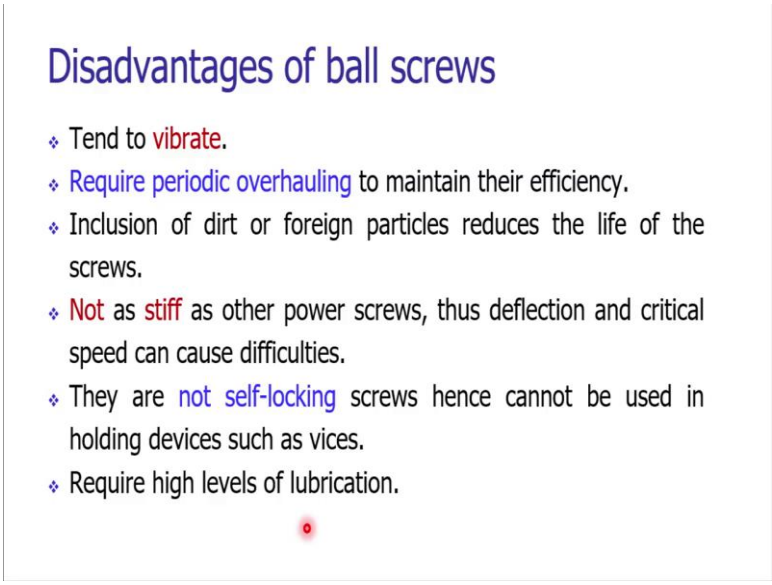

However, there are certain limitations to the ball screw. If there are mounting, if there are mounting errors that may lead to the vibration of the balls screw arrangement. We need periodic maintenance of the ball screws to maintain their efficiency. As the periodic maintenance is there, that may affect the lead time during the production hours. If there is inclusion of dirt or foreign particles that will certainly affect the life of the screw.

These ball screw based arrangements are not that stiff as the power screws which are used in the screw jack arrangement. There may be deflection, and that minor deflection at critical speed may lead to certain difficulties in the operation of the ball screws.

The ball screws are not self-locking, which is very good property of the sliding friction based screw and nut arrangement. Therefore, ball screws cannot be used for holding devices such as vices. In vice we are using the acme based thread, in UTM based machines when we apply when we want to apply the mechanical load using this screw and nut arrangement we are using square threads. These arrangements do have the self-locking property, but the ball screws do not have the self-locking properties. That is why they are not useful for holding purpose.

To have the rolling friction to have very high mechanical efficiency, the lubrication must be very efficient, the lubrication must be very proper in case of ball screws. We need to monitor continuously the surface, we need to continuously monitor the level of lubrication inside the ball screws. That is an additional work that is an additional assignment to the operator or to the engineer which is taking care of the ball screws.

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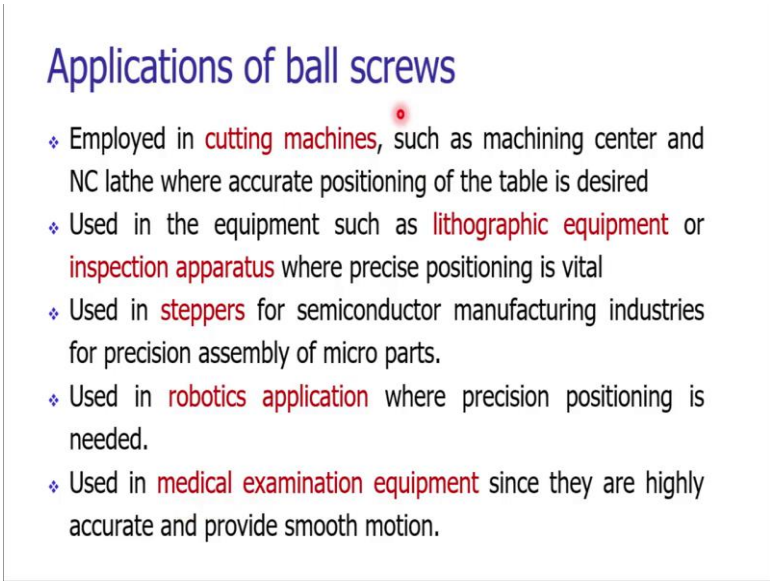

What are the various applications? Various applications can be seen on our screen. They are employed very heavily in CNC machine tools. They are also used in the lithographic based equipment; inspection apparatus for semiconductor manufacturing as well the ball screws are utilized.

The ball screws are also utilized in robotics application, where we need to have the precision positioning of the work parts or the elements of the robots. Medical

examination equipment, where we need to have very precise positional accuracy, there also the ball screws are utilized.

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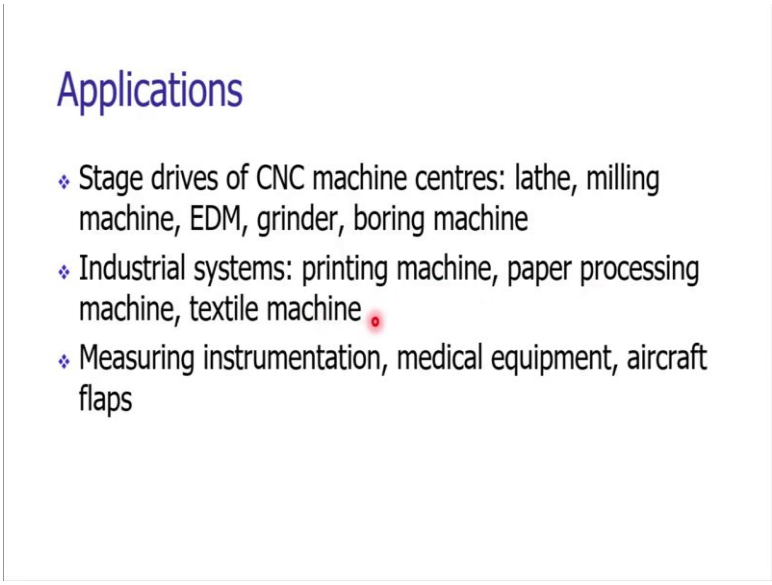

In addition to these, the ball screws are utilized for printing machine, paper processing machine, and the textile machine. Fine, we are at the end of lecture 2 now. Let me summarize. In this lecture, we studied a very important element in the mechanical systems of an automated machine or machinery, and that is the ball screw based linear motion drives.

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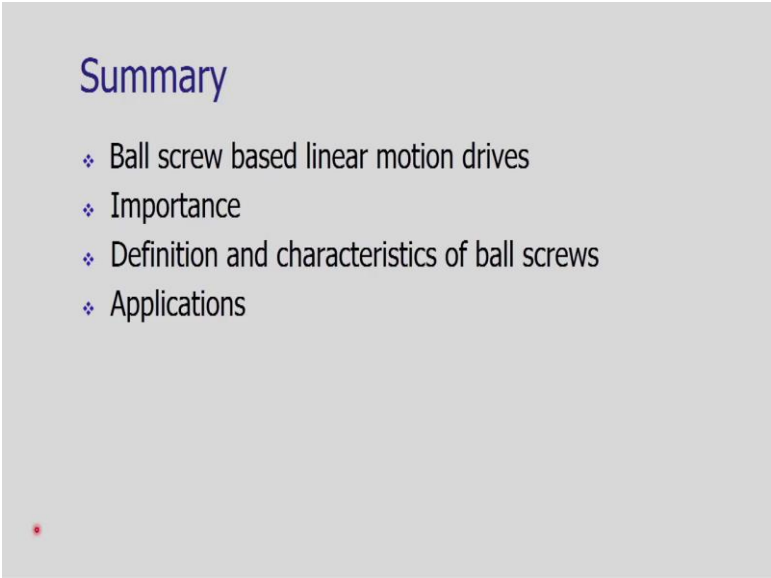

We studied the importance of the ball screw based linear motion drives. After that we studied its definition, basic characteristics, advantages, limitations, and all related fundamentals. At the end of the lecture, we have seen the applications of the ball screws in the automation. Before that we also studied the necessity to go for the pre-loading.

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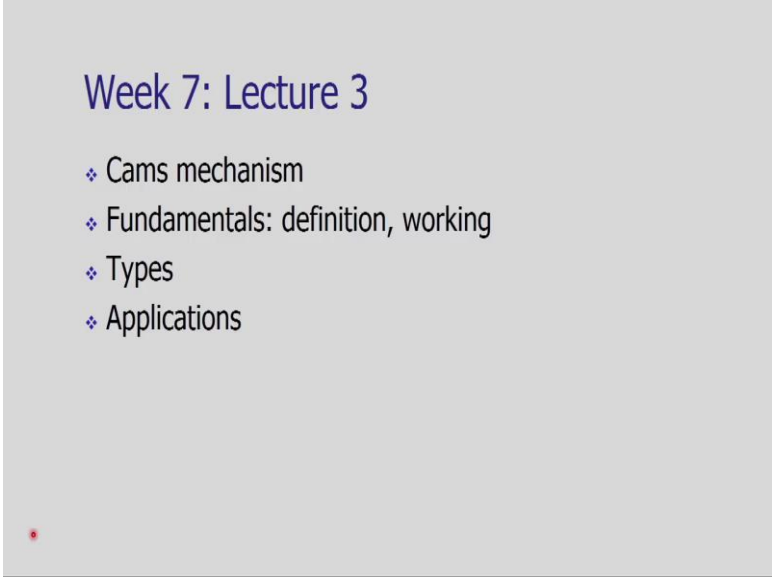

In the next lecture, we will be studying another important mechanism that is cams. Cams or cam mechanism is a very useful mechanism which is generating the complex motions which is very useful in replication of the motions. We will study its definition, working principle of cams, various types of cams being used in automation, and their applications.