Introduction to Mechanical Micro Machining
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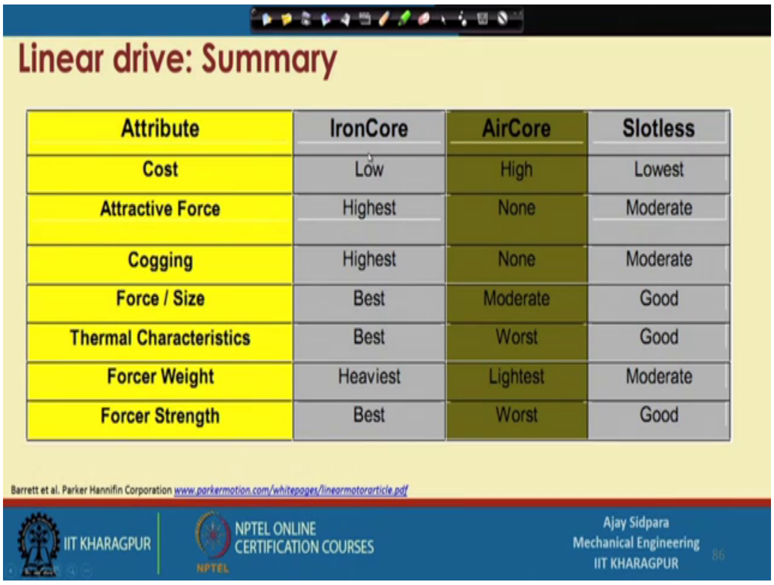
Lecture - 40
Components of machine tool (Contd.)

Good morning everybody and let us continue our discussion on the linear drive. In the last class, we have seen there are different kinds of linear drives and we have seen what are the advantages and disadvantages of those linear drives.



So, let us continue this topic further. So, in the last class, we have seen that there are three different kinds of linear drive. So, the one is the iron core, another is the air core or the iron less and third one in the slot less. So, if you consider this attribute like a cost attractive force is cogging force per size thermal characteristics, forcer weight and forcer strength, then there are different - different way, you can get the idea that which one is better.

In this case, if you consider coast only; then slot less is the lowest cost and air core as the highest force. Attractive force say; that means, attraction between the magnet and the forcer, then it is highest in this particular case and this is the moderate. So, if you see all the this thing that you will get actually something in between of - for this slot less as compared to this iron force and the iron core and the air core force per unit. It is now; see it is good in this particular case.

So, if you are, whatever first you have to decide that which one is your primary objective or the primary attribute. So, depending on that you have to select one motor; obviously, you have to compromise some of the parameters, because nothing; none of this motor is giving all the advantages which is required for a particular application. So, some compromise must be made for selection of these motors.

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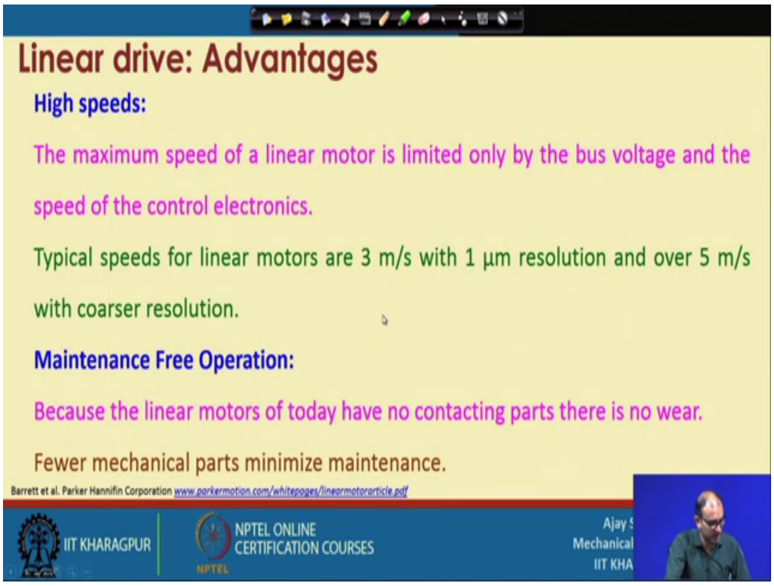

Now, let us discuss all the advantages and disadvantages of this linear drive. So, first one is the high speed, because speed is limited by the wear and friction in that conventional types here; because we know that here we are not getting any contact between the two surface so, this speed is limited by the bus voltage and the speed of the electronic control electronic. How frequently you are changing those polls between the north and south, depending on that you can get the speed here.

So, typical speed of the linear motor is 3 metre per second with a 1 micron resolution and over 5 millimetre metre per second for the coarser resolution; because we have seen in the earlier that everything depends on the resolution. If you are more, high resolution - what is happening that moment very - very fast is a problem, because again you have to get the signal processing, also such a high rate.

So, if your speed is 3 metre per second, you can get a within a 1 micron resolution; you get, but if you increase the your speed then what is happening, that similar way you have to actually increase the electronics for the resolution or the encoder also. So, that is very difficult. So, by increasing the speed, then what you have to do that, you have to actually used coarser resolution, then you have to actually compromise waste thing. Instead of a one micron, you can go with a 5 micron or 10 micron, then you can go with the very - very high speed.

So, that is the one of the way you can compromise with respect to resolution, if the primary criteria is the speed. So, it is a maintenance free mostly because it does not have so many mechanical components and another thing, that there is no contact in parts. So, whatever is the moving parts, those moving parts are separated with each other. So, it does not have any wear. So, that is the way it has some advantages in terms of maintains.

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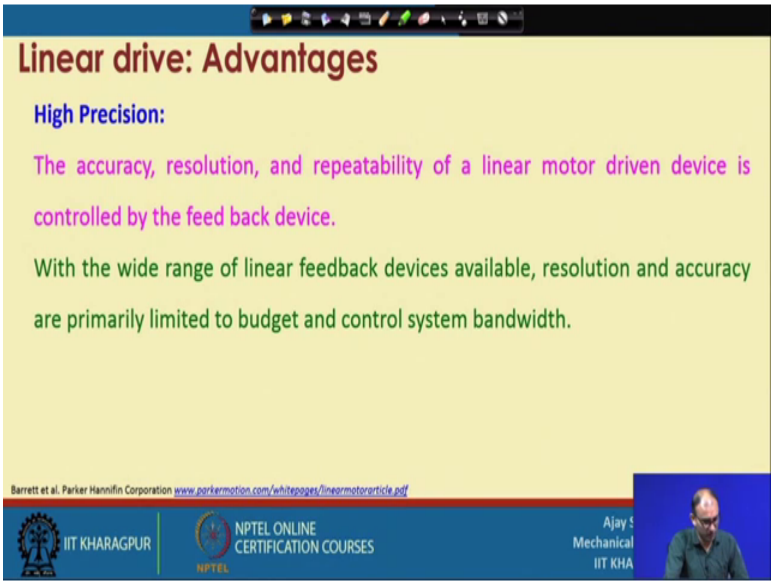

Higher precision is there. So, here everything depends on the feedback devices, the accuracy resolution and repeatability of a linear motor driven device is controlled by the feedback devices. So, what is the width? A wide range of linear feedback device available, resolution accuracy are primary limited by the budget and the control system bandwidth because we know that, we are getting a feedback resolution of linear encoder with a 0.1 micron also so, but the cost is also very - very high.

So, everything is, depends on the what is the budget of your system and what is the control system bandwidth of frequency, frequently you are getting how many data are; you are passing from a one second or the one unit time.

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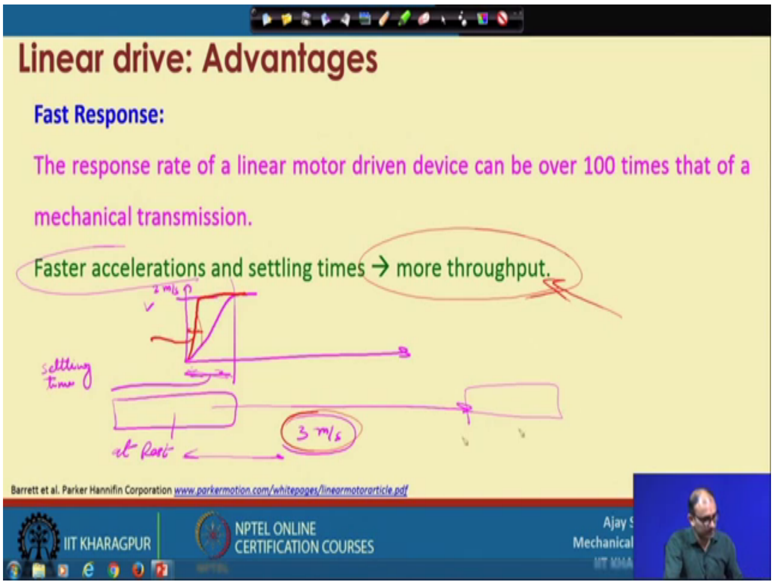

Response is very - very fast here, because it is give response rate with a hundred times more than that of the mechanical transmission. So, that is the advantage here. So, because of that, what is happening? You will get faster accelerations and settling time and no more throughput. So; that means, that suppose you are starting one motion, suppose you want to move one component from here to here, with a speed of a; consider that 3 meter per second. Correct! So, initially it is at the rest. Correct? So, from resting position to reach this particular location, you have to spend some time here. Correct?

If you see this particular graph, this is the velocity, then it will start and then, it will reach to this particular part. So, you consider this is the 3 meter per second, and then you have to spend some time here. So, this is called the settling time. Correct? So, if you spend this much settling time, then you have, whatever is the taken fraction of second is also some time, is important when you are working with a very - very high precision in hundreds and thousands of component. So, whatever is this time, you can reduce this time because now, you are getting faster acceleration.

So right now, supposed it is taking this much time and if you used this motor and it may take very small time. So, it is reaching this part. So, this is the time you have to spend in settling time. So, that is settling time. So, if you are, if it is responding very fast, then your settling time will be very - very less. Quickly you are reaching to your backward velocity and then, you can start performing your operation. If you are performing very -

very fast, that means your throughput is very - very high. Throughput means the production rate; how fast you can process over component. So, that is called throughput. Correct?

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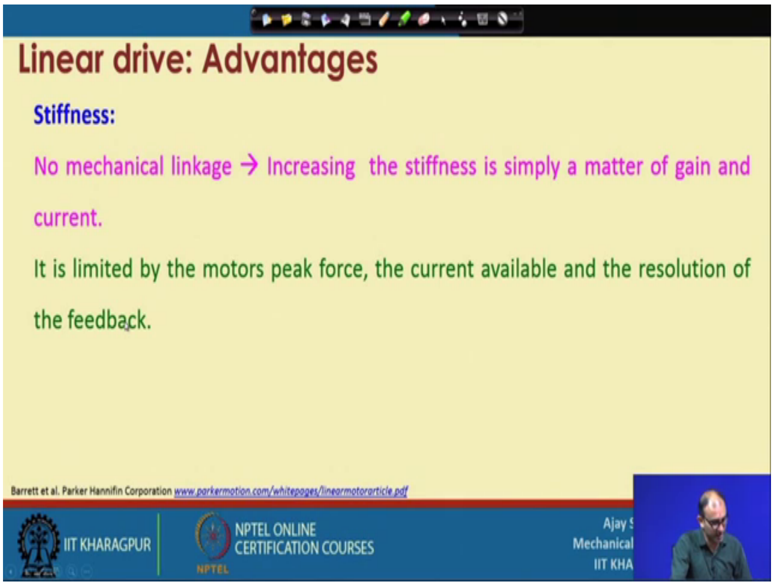

Stiffness - because no mechanical linkages are there. So, it is a matter of the gain and the current. So, how much is the current your supplying and depending on that, you can get the stiffness of the motor and it is limited by the motor peak force and the current available and the resolution of the feedback, because if you want to make it more and more stiff, then what is going to happen? That you have to sacrifice with the resolution, because then your weight will be very - very high, inertia forces will create a problem at the later stage.

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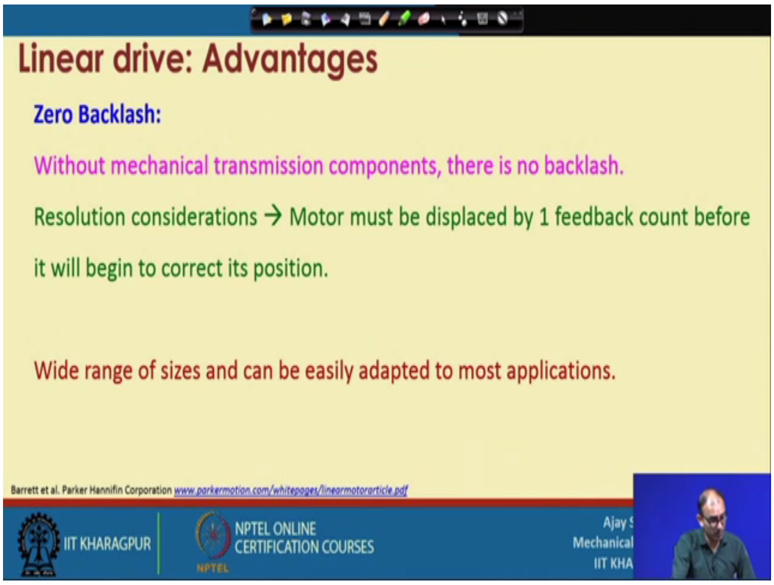

Zero Backlash is there, because without mechanical transmission component, we do not have any backlash. Here that we have seen in the air bearing also, and the hydrostatic bearing also. Resolution consideration, because motor must be displayed displace by one feedback count, before it will begin to correct its position, because that we have seen that if your feedback device is a one micron, then your motor must be displaced by one micron in that particular direction and we know that there is a wide range in size are available.

So, you depending on your application, you can find out that how much is the distance you want to do - 10 millimetre, 1 millimetre, 100 millimetre; depending on that you have different - different size as well as weight. Also if you want to keep a 500 gram weight or 1 k g weight, depending on you have to select a motor. So, there are wide range is available. So, selection is not a problem with this particular motor type. Only thing is the cost is important, how much precision you required, based on that you to select a linear drive.

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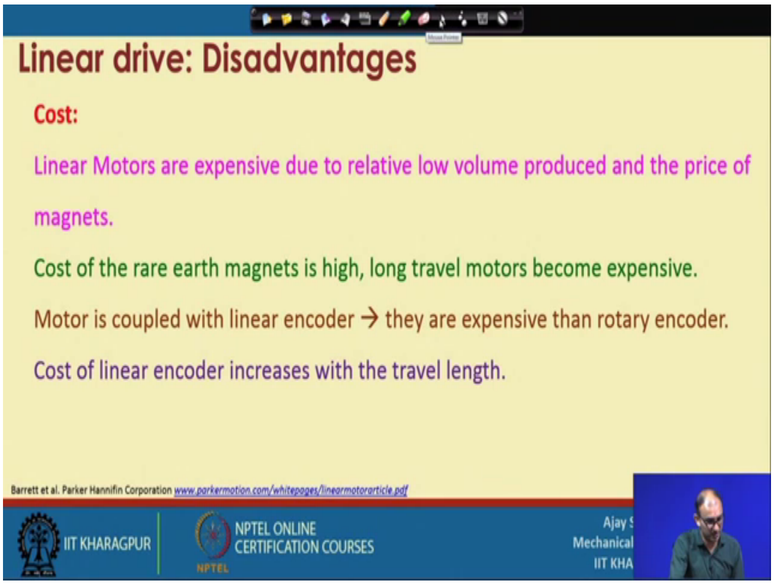

But since, there are systems with a very - very complex circuitry, there are some disadvantages also associated with the linear drive. So, first thing is the cost. Now, this motors are very - very costly and relative volume produce and the price of the magnet, because what we are doing here, that we are using a rare earth magnet and these magnet also, you have to make a very - very flat, because you have to also make those simplest as the longer travel motor, because more expensive; because we have seen that we are putting more magnets to get the longer travel. Correct?

So, that is the reason that, if you are increasing the travel length, then your cost will be increased; required to put more number of magnet with a very highly precise dimension, because there are also tolerances in the magnet,, if your magnets are not as per the design and then, you will not get the complete assembly done within the tolerance limit. Another thing, with that it is coupled with the linear encoder. So, linear encoders are costlier than the rotary encoder, because what is thing here, that I will, let me discuss those thing - that location because rotary encoders are just a this only.

So, whatever is the travel length you are getting, that is in the size of the rotary encoder will not change, but if the length is very - very large, then you have to make the linear encoder also very large. So, and this is the way that your encoders are very expensive compared to the rotary encoder. Again, the cost of the linear encoder increases with the travel length.

So, if you increase the travel length, two things happened. One is the cost of the magnet increases; another is the cost of the linear encoder increases. So, cost is big issue for expectance of this linear drive fall different - different applications.

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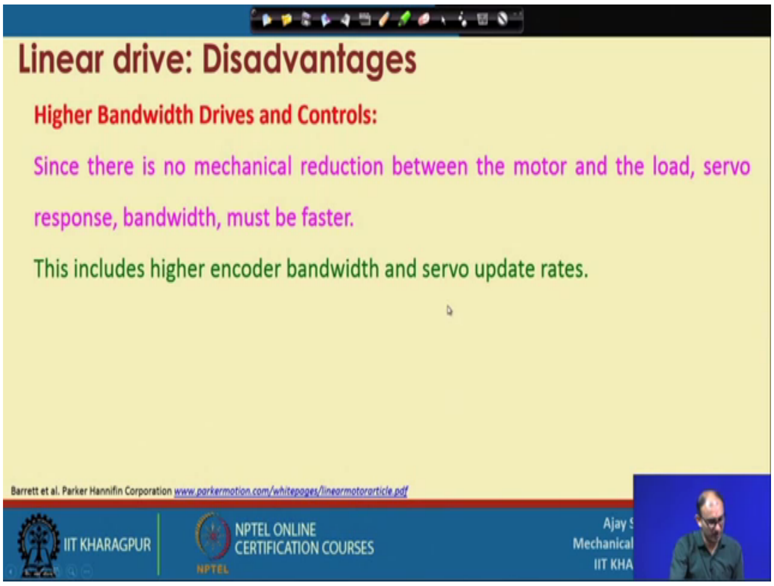

Higher bandwidth drives and controls are required, because we know that we are moving very - very fast way, because for moving 3 metre per second, you have to switch over this current very - very frequently and that is making very - very problematic situation, when you are working with a fast fashion. So, these are the no - mechanical reduction between the motor and the load server response, bandwidth must be faster. Right? So, how fast you are responding to the signal, the way you are changing the switching - the power supply, then you; how much time it required to move this thing.

So, everything should be very fast and when you make this thing very fast, then heating is also one of the issue. So, this includes the higher encoder bandwidth and servo update rates. So, you have to frequently update the next position, whenever it is reaching the part because if you are moving from one location on the location with 3 metre per second and you are stopping that things instantly at that location, then that servo rates should be updated; that location has been reached to that part. So now, you have to stop that part. So, inertia is also playing important role, how fast you can stop at one location.

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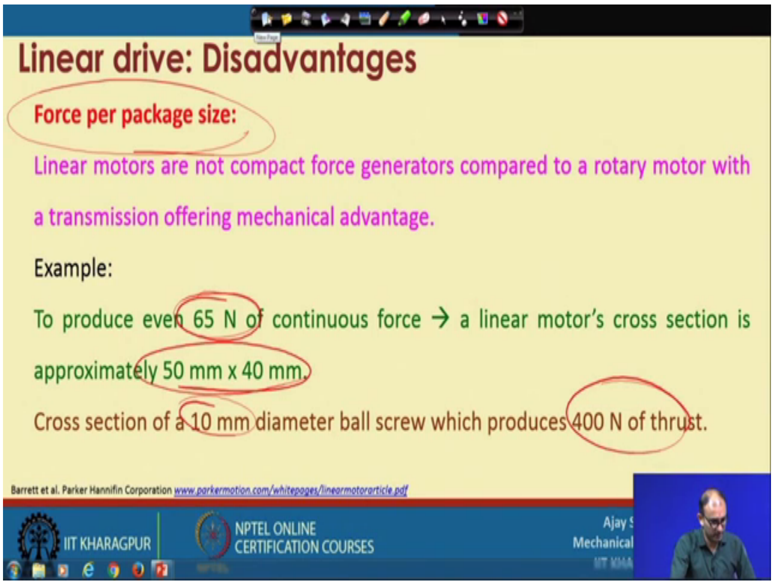

Force per unit package; that means, what is the size of the component, how much is the force you are getting. So, in this case, this is a downside of this particular motor. So, that linear motor are not compact force generator, because if you want to generate a very - very high force with a small volume. So, that is not the right choice for that compared to the rotary motor, with the transmission offering the mechanical advantage. So, if you take this advantage that suppose, if you want to create a 65 newton of a continuous force; So, if you take this force and how much if the cross section of the motor is required? So, you have a 50 by 40 is the cross section what is required.

But if you say, that 10 millimetre diameter of a ball screw, at that time it can generate 400 Newton of thrust. So, if you see this particular thing, then one way we are talking about the force which is very - very high in case of a ball screw and the dimension, if you consider that how much is the dimension of the system, then it is a 50 by 40, but here, within a 10 millimetre diameter, you can get very – very high, but this is not the criteria to select the or use the linear drive; is the precision and the friction and wear less component, but this is one of the example, that if you are primary target is the force, then it is better to go with the other systems.

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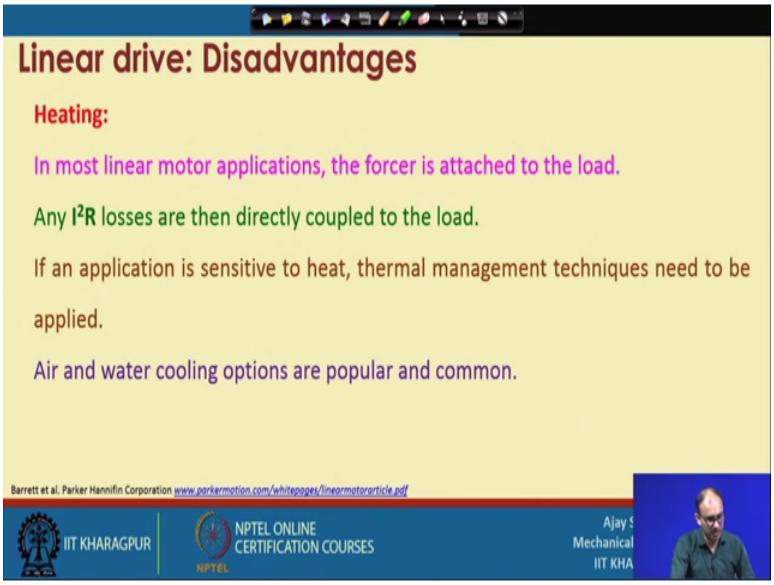

Heating is issue, because heating is because of the current supply, a most linear motor application forcer is attached to the load. So, any I square R losses are then directly coupled to the load. So, that is the problem here, but many times what happened that we apply some of the thermal management techniques; so, that is mostly the air cooling or water cooling we apply, so in that case, we can actually reduce the sitting problem very - very lower level and the other thing, that we know that we hitting is because of the electrical supply only, not because of the mechanical friction and wear.

So, that is one of the ways that we can make this thing, this particular decision is very - very low; So, that you can actually neglect this thing, for the other application.

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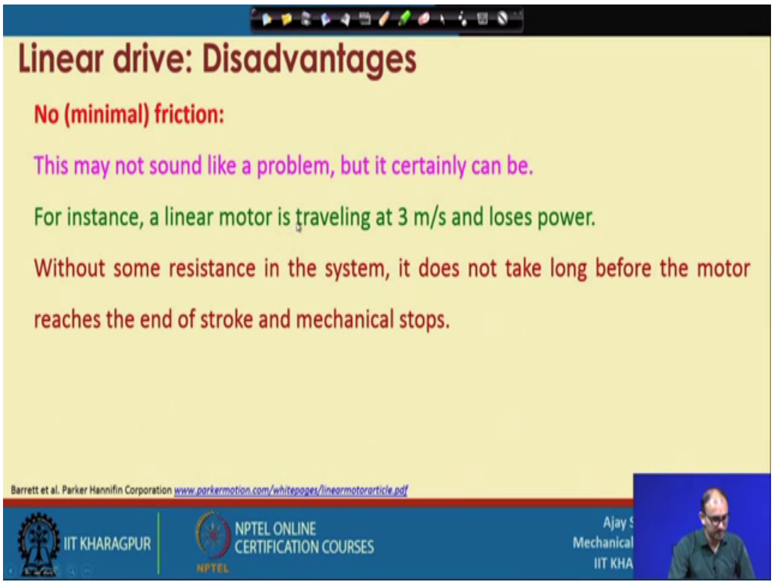

No minimal friction, because this is what we required, but sometime what happen the this is also creating a problem, because you have to have little bit of friction. So, let us see that this is may not sound like a problem, but it has a problem. Now, consider a situation, the linear motor is travelling with 3 meter per second and it losses power.

Now, what is happening here, because if you do not have a minimal friction, then what is going to happen, that this particular whatever motor is moving, it will directly go to the end position without wasting too much time; that means, it will not take so much of time to reach to the end position.

So, it will strike to that location and then, there may be some mechanical damage or some other problem. So, this is actually our requirement, but sometimes, when you are not a - you do not have a proper power backup or some other electrical sub – connection, then what is going to happen, that where in a sudden power failure or something happens, at that time controlling of this particular system is a problem.

So, you have to have some type of stopper. Also, that even if there is a power supply, you have a power back up. So, you can smoothly reach to the one location or you put some stopper. So that, it will not directly strike to the end position or the limit switches. So, those are the disadvantages of the linear drive.

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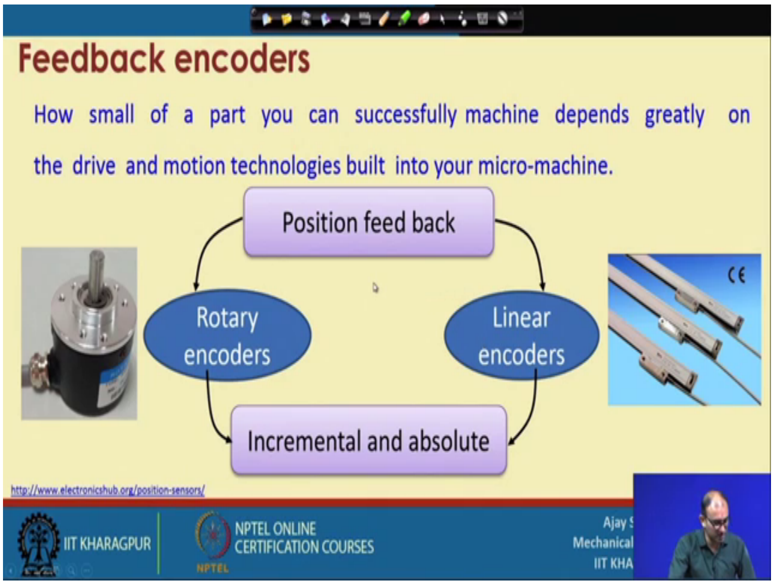

So now, coming to the feedback encoders; So till now, whatever we were discussing, every time we have seen that feedback controller or a feedback encoders are playing important role. Whatever is the resolution of the feedback controller, you will get the step size of that much only; not because of the system which we are using that we have seen, that if you have a linear that linear drive with a 0.1 micron of resolution, but your feedback drive has one micron resolution, then your system will work with a one micron only.

So, let us discuss about the feedback controllers. What are the feedback encoders available? So, how small a part you can successfully machine depends greatly on the drive and the motion technology built onto your machine. Micro machine, right? So, there are position feedback. So, position feed means, they we have two position. One is the linear position, one is the rotary position. Correct? So, in that way we have two encoders - one is called rotary encoders, which will measure the rotary position or the rotational direction of that. Other than rotary direction, you can also get the linear position. By the rotary encoder, we will see that thing. Another thing is the linear encoder.

So, for position feedback, we look about because looking with spindle RPM, then you have to put a rotary encoder into the spindle and if you are talking about the X, Y and Z linear motion, then either you use a rotary encoder or you can use the linear encoder. So, these are the two things and other than two, there are two different types. Also, if you are talking rotary encoders, it has two types - incremental encoder and absolute encoder and similarly for the same way for the linear encoder also. So, total we have four different type of encoders - one is the incremental rotary encoder, absolute rotary encoder, incremental linear encoder and the absolute linear encoder. So, let us see those things that how these are playing important role.

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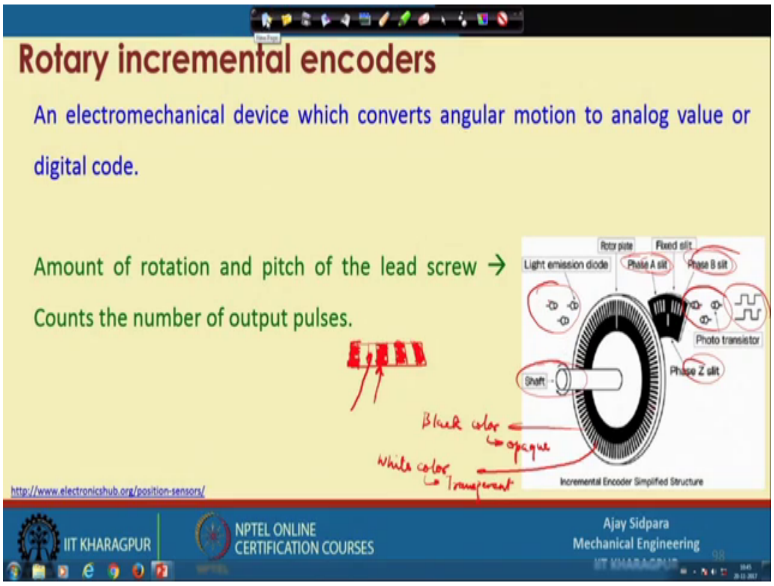

So, first thing is the incremental rotary encoder. So, this is a diagram of that part. So, what is this thing? That it is an electromechanical device which convert angular motion to a analog value or the digital code. So right now, we are talking about this particular incremental. So, how this thing is making sense? So, it has - this is a motor shaft. Correct? On the motor shaft, we have at edge one rotor plate. So, what is this rotor plate?

If you see this rotor plate, this rotor plate says some marking here. So this, whatever is the black colour black colour, these are opaque and whatever this white colour is, there is spacing in this. White colour are the transparent. Correct? And now, what is happening here? So, this is what we are talking about - this outer periphery. Correct? So, we have a light emilton - emission diode. So, light will pass through this thing. It has a 3 lights volts and similar to that, we have a slit A, slit B and the slit Z. Correct?

So, when light is passing through this thing, now, consider this situation that we have, a these are base part in these, are the consider the opaque in the transparent design.

Correct? So, light is passing through this part. So, when it is rotating, if this particular transparent parts come, the light will pass through it and on the other side, there is a phototransistor available. So, whatever is this, this things are aligned with each other.

So, this one, light is aligned with one; one phototransistor, another is similar to like that. So, whenever there is a transparent part, light will passed through it and it will get a signal whenever light will try to this opaque region. Black portion light will not pass through it, yours phototransistor will not get any signal. So, this is the how. So, if you rotate at a very - very faster rate, faster way you will get this particular signals. Right? So, that is for the slit A and slit B. Why we are using slit A and slit B? Let us see this diagram as, so, this is the signal.

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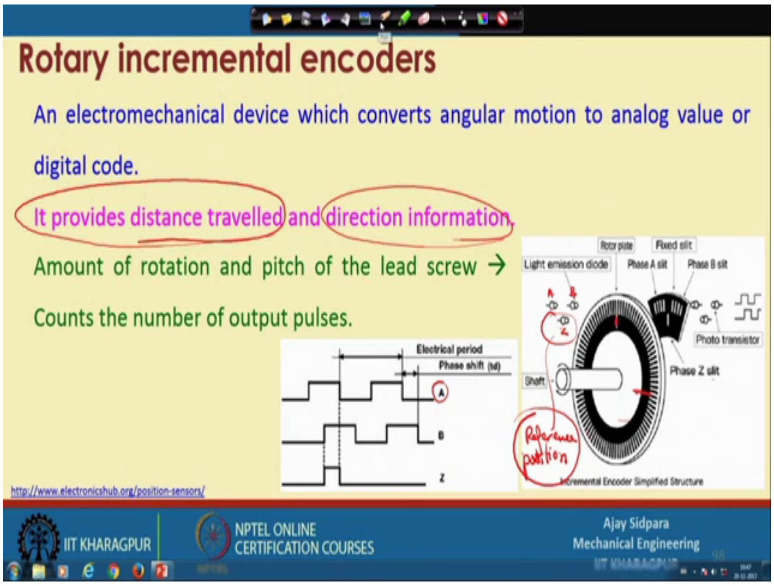

Now, this is what we are talking. Right? So, this is the signal of the A. So, whatever you are thinking also, let us write here A, B and Z. So, this is A; when it is passing through it you will get one signal opaque. So, this one particular pulse belong to the one time. The light is passing through and your phototransistor is getting a signal out of it. Correct? And similar way, you are getting A, B. So, this is A - B signal and this is called the Z signal. So, what is this Z signal? Because now, if you see this, A and B are actually lying on this particular black and white spoke kind of thing, but here, if you see the Z is here.

So, Z is actually the reference position. Correct? So, reference position is only one. Here, consider; so, now, that is because that if you are rotating this particular encoder and suddenly there is a power failure or something and then, your position is somewhere here. Correct? So, at that time, this particular incremental encoder will not be able to find where is the position. So, it will rotate it and again, when this particular Z will reach to this location, then at it will get the signal, that this is the reference position and then, it will start counting the position.

So, that is about that, for what it will do that? It will actually do a travel distance and the direction information. Now, considered that how do you know that it is rotating in clockwise direction or anti clockwise direction. Correct?

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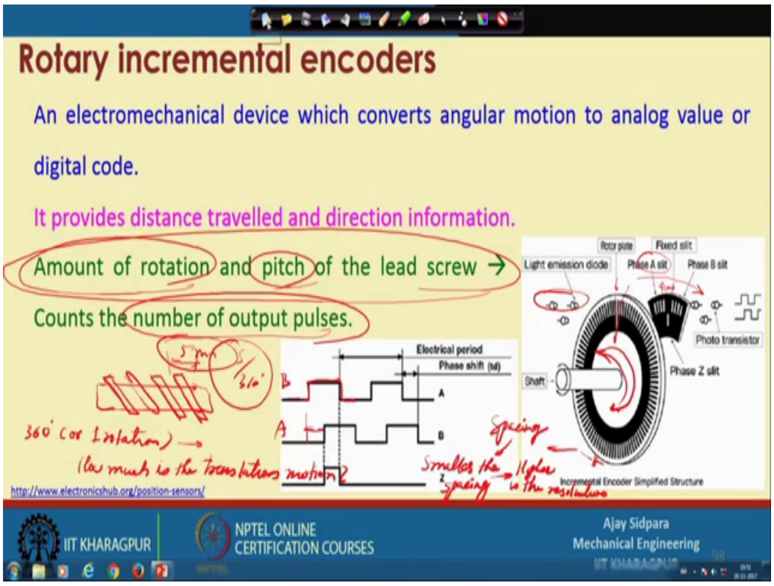

So, let us see that thing. Now, that is done by the slit A and B. Now, you can see that this A and B are actually side by side; not the one after another; that means, not back to back, but it is side by side. So now, consider that it is rotating in the clockwise direction. Right? So, if it is rotating clockwise direction, when it is rotating, your A slit will get signal first because it is located first. So, this is the signal strength of the A.

So, it is starting with this particular length. So, how much is this particular length between the signal A and B? That is the distance between this particular A and B. Correct? So, this is the A signal and after certain time, you will get the B signal. Correct? So, our sequences from A to B. So, it is rotating in the clockwise direction. If you rotate in anti - clockwise direction, what is going to happen? That you will get this signal B and this signal is A because now, B will get the first signal and then, it will get the A signal.

So, not only the rotation, but you also will get the information is, about the direction that it is rotating in clockwise direction or anti - clockwise direction, that is about the rotational motion. Now, how do you convert this rotational motion in terms of a linear motion? Correct? Because this rotary encoders are also use for measurement of linear motion, because now, consider this is the shaft and shaft has a lead screw. Correct?.

So, lead screw has a pitch. Correct? So now, first we have to find out the what is the amount of rotation. If it is a 360, because we know the what is the pitch,, that if you rotate one shaft with the 360 degree or one rotation, how much is the translation motion? Correct? So, that is pitch. So, if you are rotating one full rotation, we know the what is the pitch of the lead screw. Suppose, it is a 5 millimetre, 5 mm of the pitch of the lead screw, then what is going to happen? That full that one rotation you may move the 5 millimetre in the translation motion.

But if you move just a one degree or two degree, then what you have to do? You have to divide 5 by 360 degree. So that, you will get a one; again, motion in that particular direction. So, whatever is the motion you are getting, you have to actually back calculate with a calculation of the rotation in the pitch screw and whatever count you are getting, that count, we have to find that red count, the number of output pulses. So, whatever is the pulse, one pulse equal to the distance between these two things; that how much is the spacing between the a black colour and white colour. Smaller the spacing, higher is the resolution. Correct?

So, this is the spacing. So, how you can depend the smaller the spacing, higher is the resolution. Right? So, that depends on a what is the spacing, which means one micron, then you will get the signal within a one micron. If it is a 0.1 micron, you will get the signal with the 0.1 micron. So, that is how we can make it.

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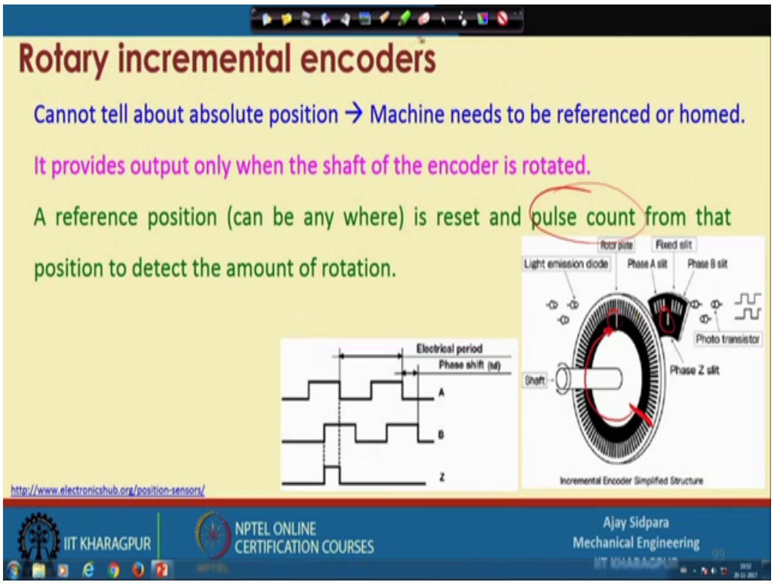

Let the problem, what is problem with this thing - that it cannot tell about the absolute position that we have seen in the earlier class. In the earlier slide, that suppose it reaching here, some location suppose, it is here, then what is happening here? That it has to move to this Z location. Here, this first to get there, what is the position because unless it will reached to the reference position, it will not tell you the what is the part. So, what is the location of this? What is that thing the machine needs to be referenced or the homed?

So, this Z is called the home position or the reference position. So, that is one problem here, with this particular incremental kind of thing. Right? So, it provides output only when the shaft of the encoder is rotated, it is obviously correct, because if your shaft is not rotating, you will not get the output. So, a reference position can be anywhere is reset. So, this suppose it is here and pulse count from that position is detected the amount of rotation. So, this particular thing will be reset; that means, it this particular location to go to that location and then, it will get the signals.

So, pulse count will start getting position, once it take this particular Z part. Right? Second one is now absolute; So, the earlier case for the rotary kind of thing.

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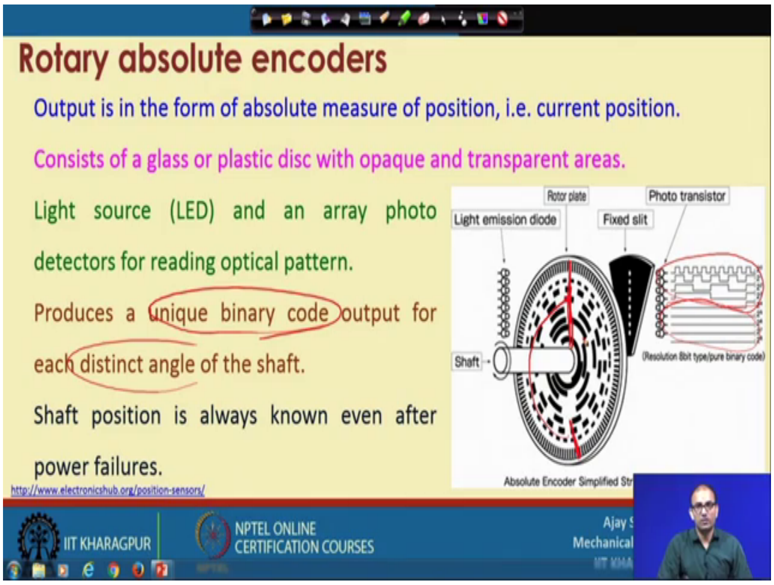

So, what is advantage? Earlier disadvantage was it was not able to find the exact position; that means - instantaneous position. But now, this one is called absolute. So, output is in the form of this; facility is able to get this thing done. So, how is the depend? Then, the earlier case that earlier case it was the lot of different - different type of slits and it was getting a signals, but here now, what is happening here? You have a series of LEDs and on the other side; you have a phototransistor on the part. So now, here what is happening that, it is creating one type of code.

Here, in earlier case, we are getting one signal here, but here, it is getting code on that. That code is actually unique for each and every instant of the rotation. So, when you are a rotating this parts. So, this black colour and this white colour part, everywhere it generate one signal and whatever is the final output of this, all the signals you will get a binary code and that binary code belongs to the one particular location of the signal. Correct? So, it consists of a glass or plastic base with opaque and transparent area.

So, these are the opaque and transparent area. In earlier case, this was available. This outer periphery, whatever is this line are available, but this is working on a different principle. So, light source and the area of photo detector reading optical pattern. So here, you will - you are getting an optical pattern. Earlier case, we are getting one, two or depending on one or two; that is called A slit and B slit. Z slit you are getting some wave form here. Here also, you are getting wave from, but these are the unique for a one particular instance, but in the earlier case, you are getting the same thing. So, that was the difference.

It produces the unique binary code output for each distinct angle of the shaft. So, what is the advantages - shaft position is always known, even after power failure. Right? Because now, once it is rotating, what is happening here - that if this is the one particular situation that with this is a particular location through which it is passing the light. So, if that is the case, then what is happening that, wherever you are not getting in the signal. So, those particular things are actually zero and you are getting signal from few location only.

So, for each and every location you are getting a unique system; that means there is a distinct angle or unique binary code. If binary code is unique, then you will never miss that position. So, as soon as light is switch on again after failure, then you are shaft or that encoder will tell you the where your position exactly here is.

But that was not the position earlier case, because in that case, if that Z was here, then you to move to that location and then, it will start the counting of the linear motion or the rotary motion. So, there was a length if you are talking about incremental encoder, but this is instantaneous motion detector, that it is called absolute encoder. So, let me finish this class here. We will continue discussion about rotary encoder and the linear encoder as well as code - some other purpose in the next class.

Thank you very much.