Introduction to Mechanical Micro Machining
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Lecture – 38
Components of machine tool (Contd.)

Good morning everybody and welcome again to our course on mechanical micro machining. In the last class, we have started discussion about air bearing and we have seen that there are lot of advantages of air bearing compared to roller bearing and the hydrostatic bearings, and we have found some of the, good advantage of using air bearing for micro machining application for movement of X Y and Z axis. So, let us continue this topic further and let us know that how these things are for utilise in terms of different-different advantages.

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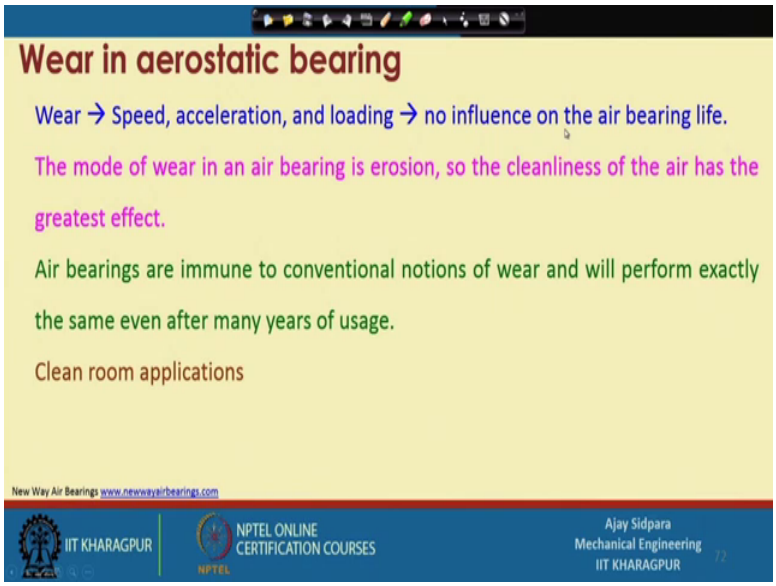

So, in the last class, we were in the, wear of the aerostatic bearing and we have seen that we are not getting any physical contact between the two surfaces and as a result, we can go with a speed acceleration loading as a no problem for the bearing life and then coming to the stiffness of air bearing. So, how the stiffness means?

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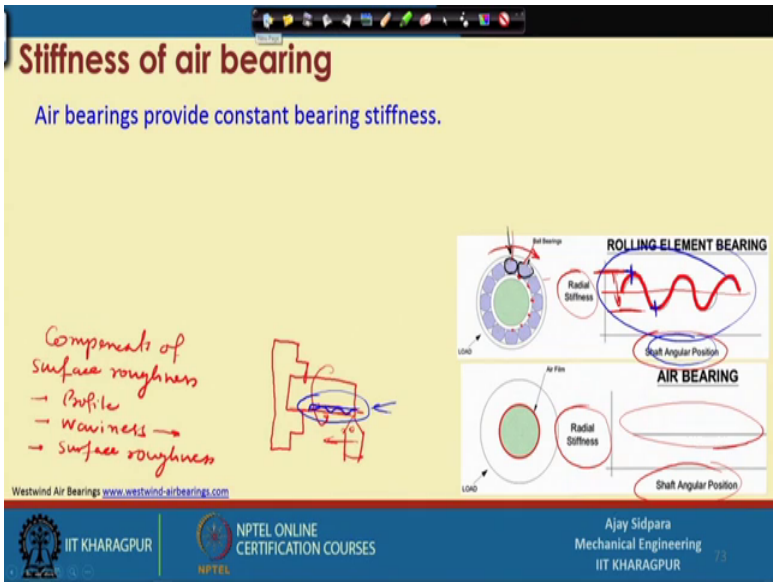

Stiffness means, when you apply a load, how much is the deflection of that is? Smaller the deflection, higher is the stiffness that we have seen in one of the videos in the last class. So, air bearing provides a constant bearing stiffness, why it is like that, because if you see this roller bearing. Now, roller bearings have different-different type of rolling elements if you see this thing. So, these are the rollers. What is going to happen then, when it is on the loading, correct?

So, at the time contacts are here only. So, these are the contact points. So, these are the contact points with, with shaft. So, this is the shaft and this is a bearing. So, when it rotates, at the time this contact points creates a very-very large variation in the stiffness. So, this is the variation in the stiffness and what is our objective? We should get a uniform stiffness along the angular, what are be the angular position of the; let it be 5 degree, 10 degree are up to the 360 degree, one full rotation.

There should not be any type of variation in the radial stiffness, but that is not the case, in case of ball bearing, but what is happening in the roller bearing. So, in the roller air bearing. So, air bearing what is the advantage that we are getting a uniform film of the air, all around the shaft and because of that reason that we are getting a continuous or a uniform radial stiffness along the, against the shaft angular position. So, what is advantage here that, when you do machining operation and you are getting a radial stiffness, different-different may suppose, this is the high stiffness and this is the low

stiffness. This is the total variation. So, that is a problem in the machining; now, considered that you are doing one machining operation and let us consider.

So, this is our turning operation, you are taking this example frequently. So, let us continue with the same example and this is your tool and your tool is moving in this direction and this is rotation direction. Now, what is going to happen, because of this, because we have seen in, few class before. There are different component of the surface roughness, components of surface roughness right. So, those are the profile, then waviness and surface roughness and we have seen that waviness is created, because of the some vibration in possibility of the machine tool.

So, this particular, what are you talking about radial stiffness? If the various; there is a various in the radial stiffness, what is going to happen that now, considered that it is right. Now, it is at this location that the stiffness is high. So, at that time, when you are cutting something here, suppose, you want to do a straight cutting up to this, like this. So, this is your depth occur and then you are give feed in this particular direction from right to left direction.

So, when you are starting. Now, what is going to happen that at that time your stiffness is high. So, let us consider that which particular path, you are going to get. So, you are starting with this particular path. So, as the spindle in, that, RPM increase, that is changing the angular position. Now, your stiffness is getting change, depending on that.

So, this is the highest location and this is you consider the lowest location. So, at that time, because of this variation, in the radial stiffness, what is going to happen that, you may get a some type of variation in the geometry also. So, this is the same profile, whatever you are getting in terms of the radial stiffness, same profile you may get in terms of the dimension. So, that is the problem here, but if you are getting a constant, radial stiffness, what is going to happen that you will got the, you will get the same thing here also. So, that is very-very useful, particular when we are talking about micro machining or micro turning operation, where you want to cut a straight channel or the doing a straight turning operation, right.

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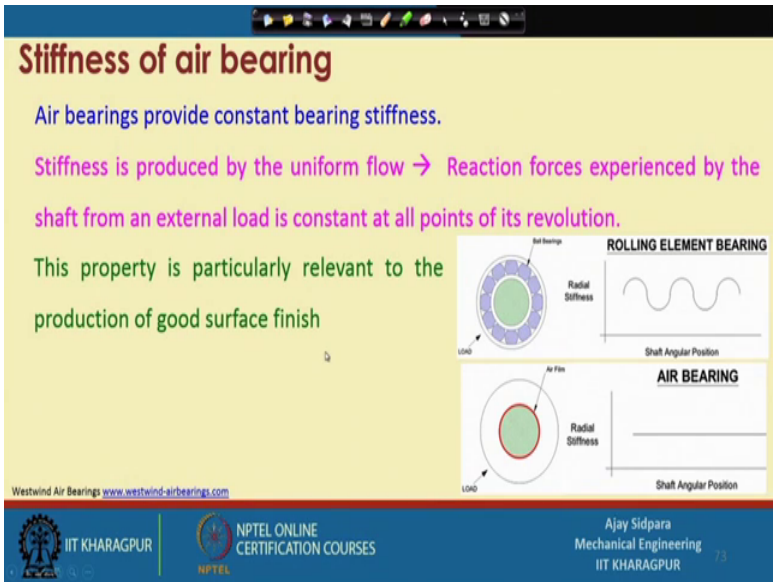

The stiffness is produced by the uniform flow in the air bearing and reaction forces experience by the shaft from the external load is constant at all point of it is revolution. So, that is what is going to happen in this particular case, because you are not getting a, you are not getting a point contact, which is distributed by several different type of ball bearings, but here you are getting a uniform airfield and that is the reason, you are getting a uniforms radial stiffness, this property is particularly relevant to the production of good surface finish, that is what we have discuss here that a, we are.

We want to avoid the change in the profile and change in the waviness. Roughness is mostly unavoidable, because it, whatever if the small scale, you definitely get the surface, roughness at a some type of rough peaks and valleys, but that can be accepted, if with is the within the tolerance limit, but we want to avoid the waviness and the profile errors. So, that is what is advantage here that, we have seen that, if this is variation in the radial stiffness, then the same thing will be reflected into the component, which you are going to machine tool life with the air bearing.

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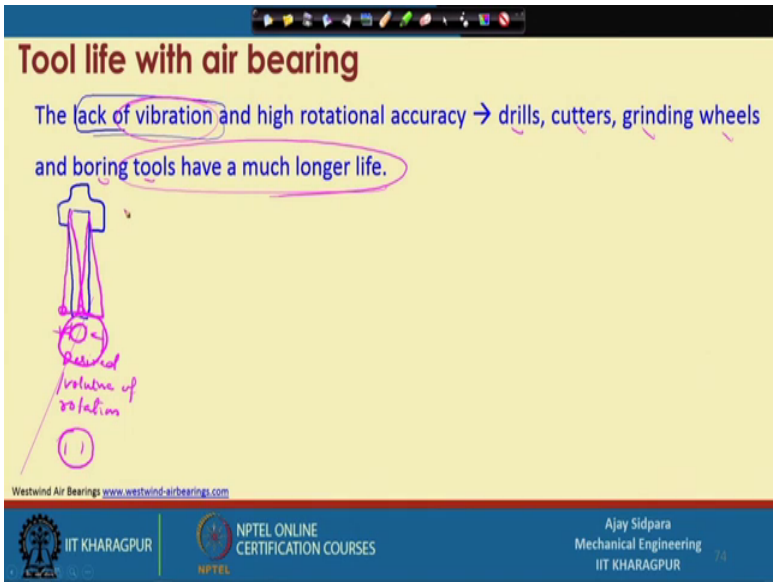

So, how it will affect the tool bearing? So, lack of vibrations in high rotational accuracy drill, cutter, grinding wheel, boring tools, have a much longer life. Now, what is advantage of this thing that, we know that if there is a vibration, because of vibration what is; so, happening that suppose, your tool is, this is your initial condition of the tools. And this is consider your tool holder. It is holding the tool. Now, if there is a vibration, mostly vibration is there, this direction.

So, now, consider you are getting a small vibration, this particular (Refer Time: 07:01) and same before this side also. So, your, this is your desired, desired volume of rotation right. So, this is the area that may area or volume, whatever we are looking from this, then you will look seeing this only, but if you see from the top then, we will get one circular path right. So, this is the area, where we want to actually focus; that means, when you are drilling a hole, we are sure that whatever is the diameter of this, this is the diameter of the hole, which we are going to drill.

But when you are getting vibration here, what is going to happen? Your actual diameter is now this much, because this is what is going to happen and that is also sometimes not feasible, because what is going to happen at then, when you are going down and down with such a vibration, your tool will be broken. It will not sustain such a one sided force, because now, what is going to happen? Because of this, vibration or the, some type of what you can, the run out that you are, one of the edge will do all the work, but

remaining edge will not participate in the machining, because by that time it will come on to the other side.

So, that is the reason that you are getting a non uniform distribution of force is and at the time, your tool will be broken and that is, common for all the cases; that means, that is applicable for all the tools, wherever you are getting, a vibration or the different type of other, problems. So, here because of that, you have very long life, long life; that means, in terms of wear and in terms of breakage, because we have understood that when you do micromachining with a micro cutting tool, your breakage is more frequent and you are not able to study the cutting tool life in terms of wear.

So, that is the problem. So, in this particular case, if you are using air bearing then you are sure that there is no vibration, because of the mechanical contacts and you can further study the wear characteristics of the different type of cutters right.

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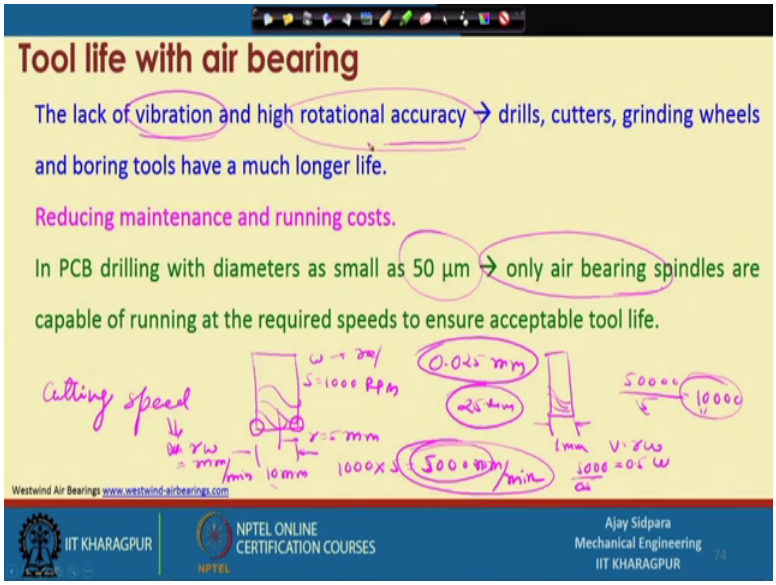

So, reducing maintenance and the running costs, because now, what is going to happen that if you have vibration or rotational accuracy problems, then there are problem that after sometime, what you have to do? You have to calibrate it, because if you are understood the, there is vibration, then you have to find out some problems that they, how to, what are the parameters, which are creating problem and then you have to spend some time and money for that and this is a maintain, because every time after a one day

or after one week, you have to schedule one maintainer so that, you can avoid this vibration and the rotational accuracy problems.

But if you are using this particular thing, there is a chance that you can, prolong this particular thing, that if you are doing maintenance after one week, if you are using air bearing, it may be after one month or one year also and similar way, you can, reduce the cost during the maintenance and the some type of the, costs related issues right. So, if you consider the PCB drilling that, whatever we are doing the drilling and PCB, because you want to create some type of, in circuits on the (Refer Time: 10:14) at the time, we start with 100 microns of diameter of hole also. So, sometimes it is as small as 50 micron.

So, if you are looking at this particular 50 micron diameter, only air bearing spindles are capable to run at a require speed, because what is happening here that when you are rotating at this particular thing, what is important is the surface speed or cutting speed right. So, now, consider this is the one diameter, one, one of the tool, this is diameter, you considered 10 millimetre right and rotating at a speed is a 1000 RPM correct.

So, now, consider this is the, this is the edges right, whatever edges we are thinking about this thing. So, this diameter radius is the, r is 5 m m and you consider, this is the omega correct. So, we know that v equal to r into omega right. So, this is in revolution per minute RPM and this is in millimetre. So, whatever you are getting, your getting mm per minutes. So, this is your cutting speed right. So, if you calculate this particular cutting speed what we are talking here right now, that you consider this is 1000 RPM, 1000 multiplied by 5.

So, you are end up with a 5000 mm per minute right. This is 5 radius, is 5 and omega your rotational speed is 1000. So, you are getting 5000, millimetre per minute. Now, consider another tool correct. Now, consider, let us not going to, too much in micron detail. Let us consider 1 millimetre only, correct and against we are getting the, same thing again.

So, now let us see that if you are, if you want to maintain this 5000 millimetre per minute. Now, consider, we have formula again v equal to r omega then we want to maintain. This is a 5000 and equal to now, our radius is reduced to 0.5. Now, our diameter is 1 millimetre. So, what should be the omega. Now, you consider these things.

So, it is a 50000 divided by 5, because it is a, this will come here 0.5 and then 10 will goes, it is a 50000 divided 5. So, now, it is a 10000 correct.

So, now you can see here, that if you are changing your diameter or reducing your diameter to maintain a one particular cutting speed, what you have to do? You have to increase the RPM. So, that is what is going to happen then? Now, considering instead of a 1 millimetre, you are working with a 50 micron. So, here that is, this a diameter. So, you are talking about 25 micron is the radius. 25 micron is radius means 0. 0 25 mm if you multiply this thing and then you calculate this, it will be in terms of lakh.

So, if you are working with this thing, then what is going to happen that, only air bearing, because when you are rotating in terms of 2 lakh RPM or 3 lakhs RPM, at the time, what you have to consider, there should be vibration, because even a small sub micron vibration is enough to break this tool and similar to that, it should be free from run out; that means, run out should be within a prescribe limit or whatever is the allowable limit.

So, in this particular case you, this is the only air bearing, which will helpful in the final decision taking. The machining or the doing a PCB drilling or any other type of machining operation, where you need a high speed, high speed with the air bearing.

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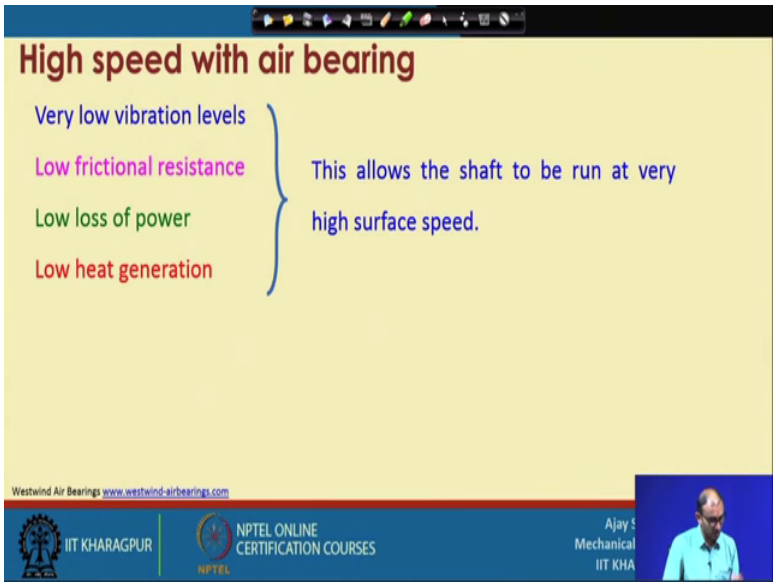

That is obvious that, it has a very low vibration level. So, when vibration level is low, you can actually go beyond a certain limit of speed low frictional resistance. So, because once the friction is not there, air is no possibility of heat generation and heat generation is one of the limitation, which is, because of the producing heat and there is a friction also and if there is a some type of thermal deformation of the component. So, that is not present here, that is good thing.

Low loss of power, because now, when you are rotating, when there is a friction and we are, have to apply more and more power to work on this particular things, but that is not the issue here and a very low heat generation. So, these are the some of the advantages and, because of that you can actually allow the sub to be run at a very-very high surface speed, high surface speed; that means what? We are just now, taken one example about the cutting speed. So, that is the surface speed.

So, these are the advantages of that and now, thermal growth of the air bearing, because if you consider a rolling barrier, rolling type, element ball bearing type. Element when you rotate, beyond a certain limit, at that time there is a, chance of getting thermal growth of the bearing. So, because of the thermal growth, what happened? The some of the allowances will be change and your, particular location, which where you are targeting. That will be shifted to some other location that we have seen in one of the videos; in the thermal compensation of that ocular system of the machine tool.

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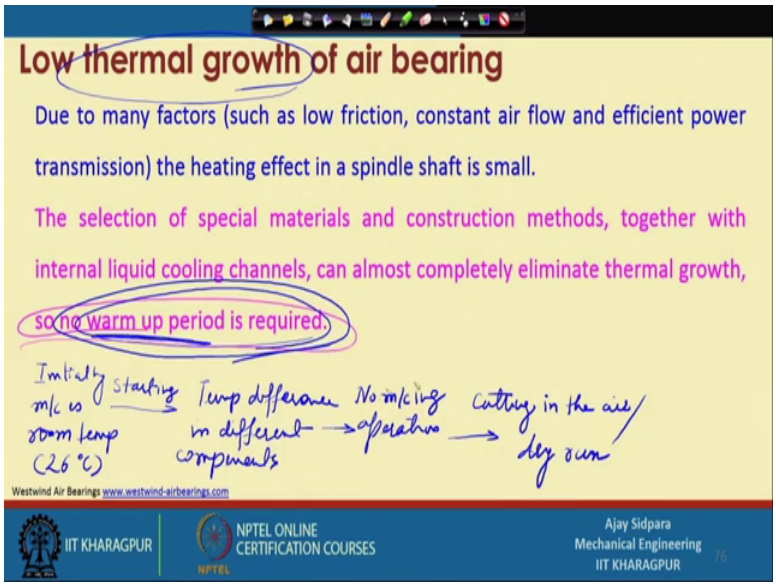

So, what is happening here that due to too many factors such as low friction constant airflow and efficient power transmission, heating effect in this spindle shaft is almost small right. We are not getting friction; so no question of, heat generation, because of the friction constant airflow. So, there is no variation in the air flow. There is a air also, create some type of a small amount of, affecter, that is coding effect, but that is also not present and efficient power transmission, because there is no physical contact.

So, there is mostly no question of generating heat around a air bearing and selection of a special materials and construction methods together with internal liquid cooling channel. So, even if you think that a small amount of thermal change will create some problem then you, what you can do that you provide, some type of liquid cooling channels then you can completely eliminate thermal growth and there is no warm up period is required. So, what is this warm up period, that when you start a spindle or when you start a machine.

Now, initially what is going to happen here at the initial stage or initial; that means, initially machine is room temperature, when you are not starting the machine right, then you are starting the machine. When you start the machine; now, you know that there are different components, which are made of a different-different materials, when you have surrounding temperature. Now, consider you have temperature is 26 degree centigrade right.

Now, when you start the machine of different, there are a lot of different moving element. Rolling elements are there, and then you are getting a temperature difference in a different-different component temperature difference, different component. So, what is going to happen, because of that, that you will gets some of the allow; that means, some of the loosening of the, loosening of the connection in the sense that you are not actually getting the target value at one particular location.

So, because of that there is a growth of the different components in a different, because materials are different, the thermal coefficient of expenses are different. So, you will get a different growth in there. So, what you have to do that, you have to give one warm up period. So, you start the machine, do not operate any operation; so here, no machining operation. Operation starts the machine, do not do any operation and then what you do

that, you do a dry cutting, so; that means, air cutting. Cutting in the, in the air or considered as a dry run.

Why this is important; because we want to make sure that all the components, whatever the components are there in the machine tool, they reach to there, whatever the maximum thermal growth right. So, because if you start the machine and put the component and then you do, operation on that, what is going to happened that, if they are all, are not reaching to the same level of deformation there, there actually starting the deformation thermal growth and they will reach to a maximum thermal growth after sometime.

So, you have to avoid machining during that particular warm up period. So, you have to provide some warm up period. So, that there is a pool expansion or the pool thermal growth of all the component and there should not be any further problem during machining. So, whatever is that defect your getting that, whatever is the change in the original position of the original position to the, required position that will remain constant, because you have already given warm up period.

If you do not give warm up period then you are particular required dimension and the original dimension will keep continuously changing till it will reach to this location. So, that is, what is very big advantage here, that it has low thermal growth. So, you do not need to give a warm up period, as soon as you start the machine within a few minutes, you can start or doing operation also. Now, let us discuss summary of this particular aerostatic spindle. What are the advantages?

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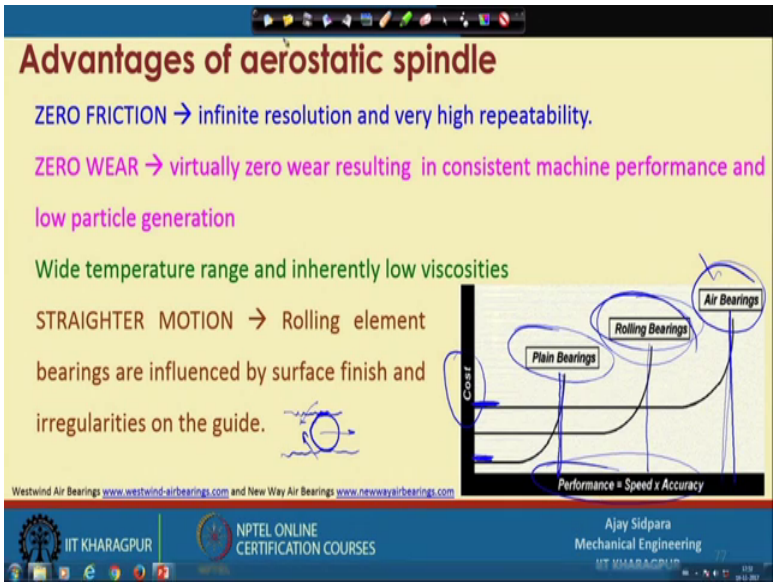

So, it is the zero friction infinite resolution a very high repeatability is possible here with a condition that you are adding a one particular encoder also that, if encoder resolution is not good then there is no way you can, you are getting the complete, advantage of the spindle speed, zero wear, it is very big advantage virtually is zero wear, resulting in the consistent machine performance and low particle generation, because whenever there is a physical contact, you always getting a wear of the any of the surface, which is small, which is very show up, compare to other surface and those particle will further accelerate, the wear of the surfaces and then you are getting a inconsistent machine performance, but there is we know that virtual is zero, we are present here.

So, you are not getting a variation in the machine performers and that is the advantage. Why temperature range and inherently low viscosity. So, that is, because air has a very low viscosity, even if you considered the hydrostatic bearing, there is a viscosity is depending on which type of oil or which type of liquid you are using, but here that is not the issue. So, temperature is a very-very wide range. Straighter motion, rolling element bearings are influence by the surface finishing irregularities on the guide, because we know that, if the surface is very-very rough at the time. Rolling element is also in physical contact. Now, considered this is the ball and these are the two surface is between which, it is moving.

So, this is outer race, this is inner race and it is moving in this. So, you need a certain amount roughness there, where what is going to happen that, this will starts sliding in stuff instead of rotating, but if it is a very-very rough, what is going to happen? This particular contact will, we are these surface and there is contact will start eroding, because of this vibration wear and then it will create a problem, but a small irregularities on the surface will not make much difference here, because your air is the one of the thing, which is actually suspending the two surfaces, not the physical surface or physical context. So, that is advantage.

Now, if you see this particular graph now, on the Y axis, it is a cost on the side, it is a performers; obviously, cost of the air bearing is very-very high compare to now, you can see, it is starting from here compare to the air bearing and roller bearing is in between these two.

But if you see performers advantage speed and accuracy, then it has a limit for the plane bearing very quickly, you can reach there, but if you go with the roller bearing then you can extend this performers little bit and it has a very-very high performance in terms of air bearing, but it is, it does not mean that you always go with the air bearing, because there are specific advantage, why we still use plain bearing for a different-different application and do not use always air bearing. So, there are range something is in between, these two that is also depend on the cost in the performance issue, right.

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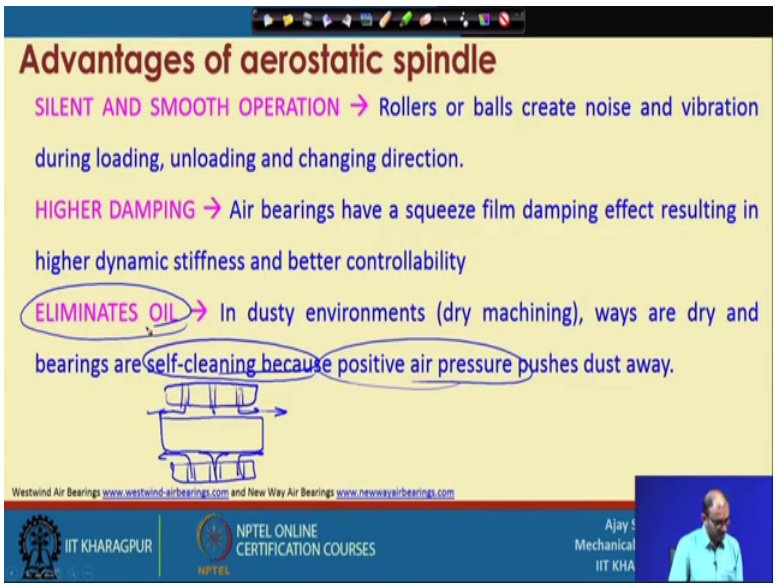

So, let us continue silent smooth operation. So, rollers or balls create noise and vibration during loading, unloading and changing directions. So, that is one of the advantages here, that noise is also sometimes not good for the, operation also, because if you are adding some type of sensor, echo sensor, which are based on the, some type of signals, which are created by the noise then it will create a some type of disturbance, because of this part, when you are getting a smooth motion that is sometimes will good for the operator, also that is not working in a noise environment and unloading vibrations during the spring and changing direction.

You, every time you will get some type of noise and vibration, if you are using a roller and ball type of bearings, higher damping, the air bearing save the squeeze film damping effect, resulting in the higher dynamic stiffness and the better controllability; that means, we have seen that, if there is a variation in this, forces, because of the variation, this air bearing will automatically, it just itself.

And there is no problem in the stiffness eliminate oils, because we are not using over range or anything in dust environment or dry machining, because when you do not use oil at that time, there are very; many times very fine particles are actually spreading all over the, machine surface as well as the, around the machine part ways are dry and bearings are self cleaning, because of the positive air pressure, which pushes dust away.

If you remember that earlier animation that we are, where we have seen that this is the shaft correct and these are the actually bushing, through which we are passing the air correct. So, this air was coming like this and then it is moving to the atmosphere right. So, what is advantage, if by chance if there are some dusts available, because this is a positive air pressure. Suppose, they are actually expelling everything away, it is not sucking inside correct.

If it is going inside, then there is the problem that then whatever the dust particles are there that will become a part of the, system or part of the full closed loop circuit, but here what we are doing that, we are expelling everything I would. So, it is a self cleaning even if there are small particles are available, those particles will be quickly out into the atmosphere and you are not getting any type of problem, because of the small particles and you are not using any oil also.

So, when you are using this type of clean room requirement application, at the time you are not using any type of liquid. So, it is very good choice for this type of applications, higher speed that we have seen, that you can go with higher speed and higher acceleration.

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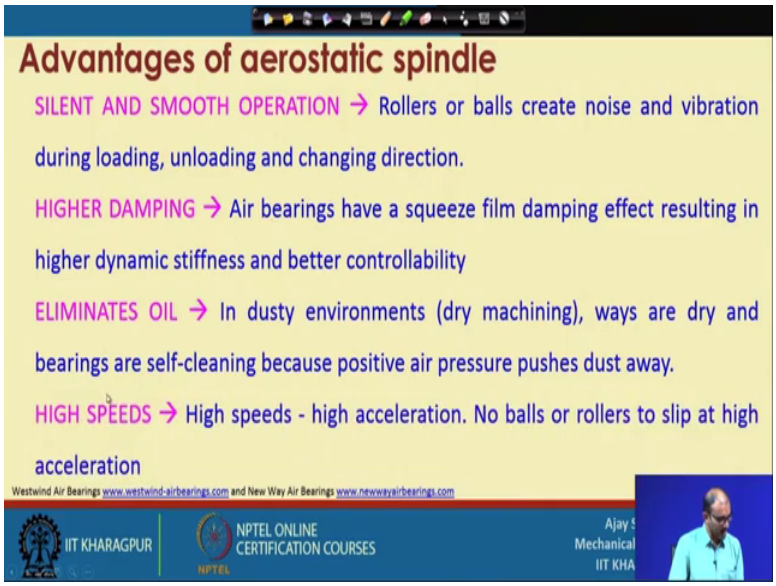

Because you are not getting any type of slip or acceleration in the, surfaces.

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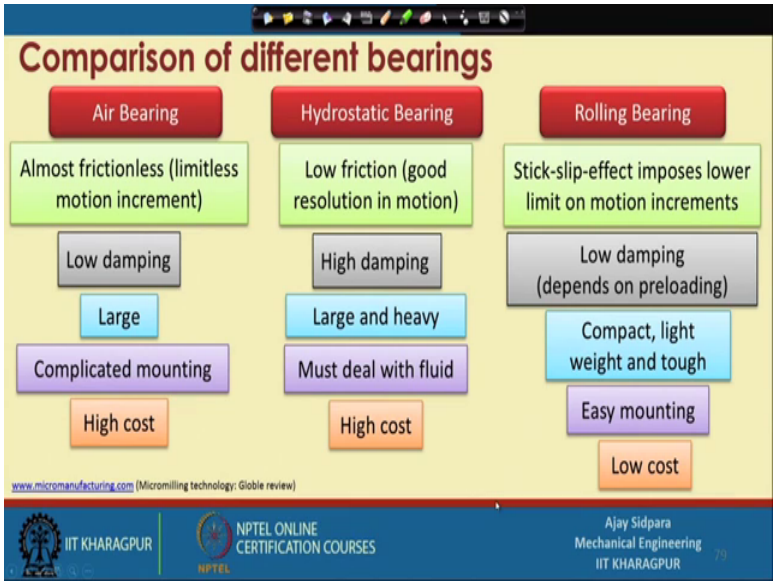

Now, let us see the, what are that comparison between the all three air bearing is, there hydrostatic bearing, we have seen and we have also seen the roller bearing. So, here we

have seen that it is almost frictionless and limitless motion increments are possible, because whatever the finest, increment is possible by the encoder, you can give that motion, that is possible here, it is a low friction, because still we are using liquid, the liquid viscosity play important role here and here it is a stick slip, because here it is a mechanical contact between the two surfaces and that is creating problem in the getting the frictionless surfaces.

Damping (Refer Time: 26:10) here it is a low damping. Here, it is a high damping. So, this hydrostatic bearings are more good in the high scale; that means, the large scale machining that we have seen that, if you put more load on the top of it, this is not a big issue for the hydrostatic and it is depends on the preloading that we have seen in that video that, if it is a forcely fit into that (Refer Time: 26:31) then you are not getting too much variation, because of the part. So, it depends on the preloading.

Now, system it is a large system, because, why it is large; because you are not using only bearing, but you have to provide some type of air supply also.

Air pump is required, air compression is required, then regulatory systems are required. So, it is very big system, it is not just a standalone and compact thing, similar thing for this also, but it is also heavy here, because you have to control the circulation of the oil here. Here what we are doing that, we are just providing the air, but we are not collecting air that back, but here, we are doing both the thing. We have to provide the air and then again, you would recirculate all the things inside the surface.

So, it is also heavy, because you have to provide some type of power, power, power part. So, that you can actually circulate the hydrostatic liquid or any type of oil in a, different way here. It is compact lightweight and tough, because here these are independent, because you can independently work only, condition get you have to regularly lubricate this thing. No any additional circuitry required for any type of thing in both the cases, you require some type of close loop circuit. So, that you can monitor and the regulate the air supply and the liquid supply.

But it is compact, you wants to install it, then only lubrication is the issue and depending on the lightweight and toughness, you can get the required results. So, you will comfortably and that is the reason then most of the conventional application. We still use the roller bearing, because we do not require such a high precision and that also comes

with a cost complicated mounting. Because now, we have to maintain a frictions of micron here and there also very judgementally, because that is otherwise, there is a large problem here, must deal with the fluid.

Because now, we have seen that fluid is creating lot of problem here, circulatory system should be monitor, then there should not be direct contact between the two surfaces. So, that is a big issue, very easy mounting here, because you have to press, fit it and then you have to maintain that it should not be any type of other problem, because of the loading or the any type of, straight loading or the fatigue loadings cost is very-very high here, because you are again spending lot of money in the monitoring and the control of the air supply surfaces should be very-very straight, because if there is a straightness problem then again, because, again there is a physical contact between the two surfaces.

When you are talking about the film thickness around 15 micron or 20 micron, your statement should be much smaller than at least 10 times, smaller than what you are talking here. So, cost is very-very high. Similar air cost is also very high, because here you are still using the same way, but you are using a liquid in place of a air here. It is a very-very low cost, because it is a manufacturing cost only.

Once you install the things, you do not need to provide additional support from any other parts. So, from this comparison you can see that, there are different type of bearings available all of them have advantages and disadvantages. It is up to us or the machine supplier or machine builder, which one is good for one particular application. Now, see if you are going with a conversion machining, you can still use the roller bearing, because at a few microns here and there will not make much difference there.

If we are going with high loading capacity, you can go with hydrostatic bearing, because load carrying capacity is very-very higher, if you are going with a very-very gentle machining or extremely small dimension, where 1 micron or 0.1 micron deviation will also make different, then you can go with a air bearing; so these are the different comparison.

And, let me stop this lecture here and we can continue this, topic further in the next class.

Thank you very much.