Introduction to Mechanical Micro Machining
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Lecture – 59
Diamond turning (Contd.)

Good morning everybody and welcome again to our course on Mechanical Micro Machining. In the last class, we have seen some of the features of diamond turning machine and we have seen that we can cut a brittle material into a ductile mode.

If you can maintain your uncut chip thickness below a certain level; and by that way there are different materials and all materials have different different critical uncut chip thickness. So, you have to maintain that uncut chip thickness and so the material will be very very efficiently cut. Other than that we have seen that how to control the uncut chip thickness and the nose radius and how this two parameter of the cutting tool play important role in a material removal mechanism. And let us continue further on the diamond turning machining.

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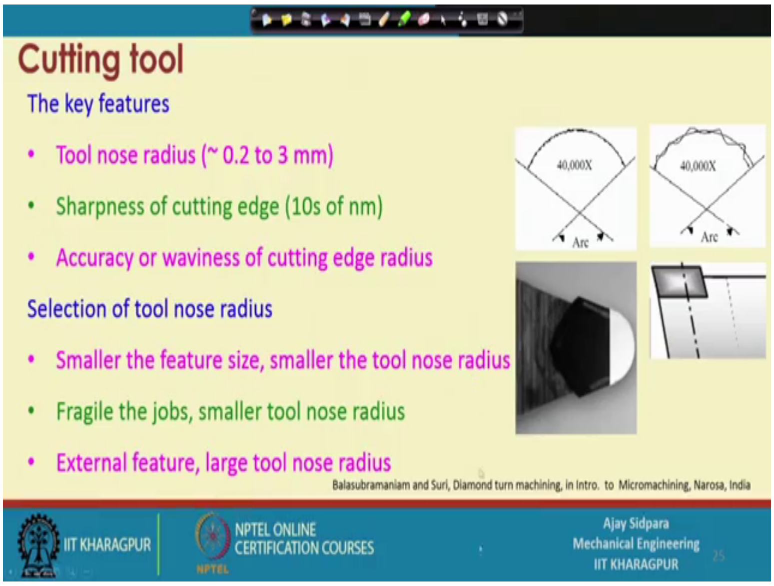

So, this is the slide which we have seen in the last class and here we have seen some of the thumb rule by which you can select the nose radius of a different value.

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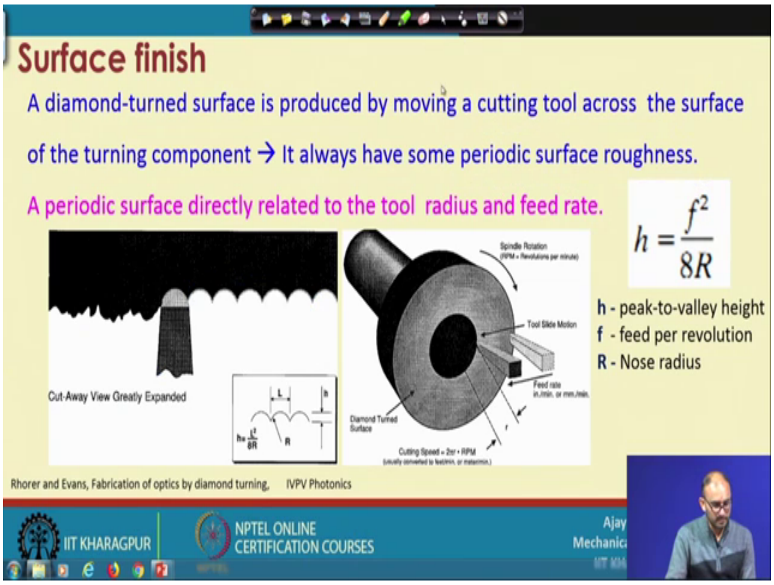

Now coming to the surface finish; now surface finish we can also do this thing by a conventional calculation, that is mostly we use this calculation for measurement or the finding out the peak-to-valley height in a normal turning operation. So, this is what we are doing and same thing is applicable for the diamond turning machining also, but here only difference is the our uncut chip there that whatever depth of cut we are putting inside, it is very very small. And we are maintaining the cutting edge that nose radius very very sharp.

So, these are the two parameter which play important; that is the feed rate per revolution and the nose radius and you can find out this h that is the peak-to-valley height by this particular formula; that is f square by the 8 R. So, this is the way we do that calculation you have to do cutting because we have seen in the diamond turning mostly we are doing a facing operation only not the turning operation. There are some application where we need some type of features on the surface of the cylinder only, but most of the features are on the face of the cylinder not onto the surface of the cylinder right. So, diamond turned machine surface is produced by moving the cutting tool across the surface of the turning component, it always they have some periodic surface roughness.

Now, we can; we know that surface roughness whatever we are getting here it is a sub Nano sub at the Nanometer level, but even at Nanometer level you can note avoid these particular things right because ultimately it is a physical contact. So, whatever you are getting here at this particular thing this may be the 10s of Nanometer 10s of Nanometer, but still you will get this thing because if you see under high magnification microscope you cannot avoid this. So, there are some application where these are also a problematic. So, once you complete the diamond turning operation then what you have to do? You have to go with the that slope look for your finishing processes. Because those processes are very very tandem and removing of this particular peaks is very very easy on this particular processes.

So, once diamond turning processing is over and you still find that this particular whatever this periodic surface roughness marks are available and this marks are actually creating problem in the acceptance of this component. Then what you have to do? You have to apply one post finishing operation by means of lapping process or there are different gentle polishing processes available, which will remove this particular mark without actually deforming the figure accuracy of the component right because many times what happen that, surface is something like this and whatever features are created on the surface those features are here right. So, you do not want to deform the figure accuracy, you just want to remove the roughness only. So, there are processes available which can do this thing without any problem.

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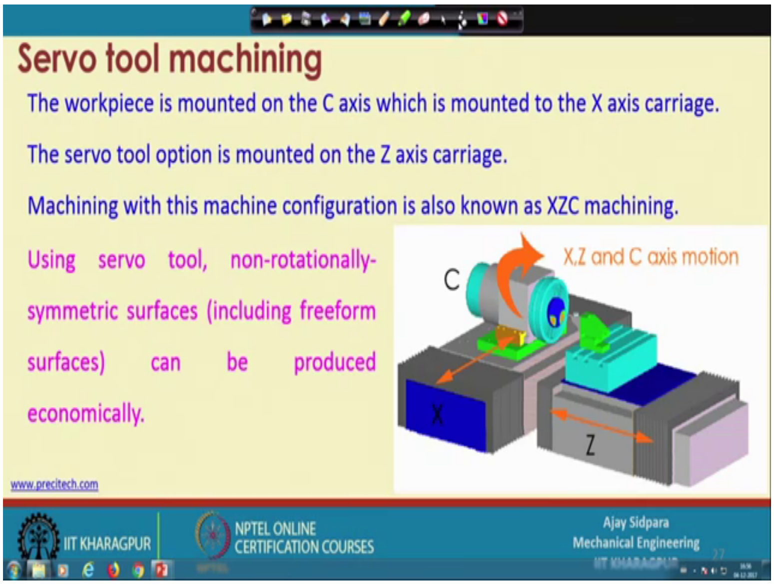

Now, coming to servo machining; servo tool machining. This is very very important feature of this machining or diamond turning operation or diamond turning machine, which will which will make sure that you can do lot of different different type of machining other than a conventional testing operation and turning operation. So, what is this per servo tool mechanism or servo tool machining so, here this is what it is showing right.

So, here the workpiece is mounted on the C axis. So, this is our workpiece and this is the whole C axis actually move in the X direction and our Z movement is here and the servo tool option is mounted on to the Z axis carriage. So, this is now; what is the servo tool option. So, how fast you can move this thing in towards the workpiece and how fast you can retreat this thing. So, that will actually tells you, that will tell you about that how to get a different different features here on do the workpiece surface. So, we will see in that thing in next two or three slides.

So, machining with this configuration is also known as a X Z and C, because we are using three axis here X axis is here, X Z axis is here and C axis at this location. So, using server tool known rotationally symmetric surfaces including freeform surface can be produce economically. So, here what happen that; if you just normally move this X Y X Z and C axis then what you will get? Actually you can get the facing operation only. Suppose, you want to do facing operation here, then you can do facing operation if your workpiece is long, then you can turn this around and then you do a turning operation, but right now we are our all focused is on the facing operation only.

So, if you do not operate this servo tool then what is happening that, you are actually doing cutting with a in this particular configuration is facing only. Then different materials available, different diameters available, you can do that operation, but this thing is little bit different.

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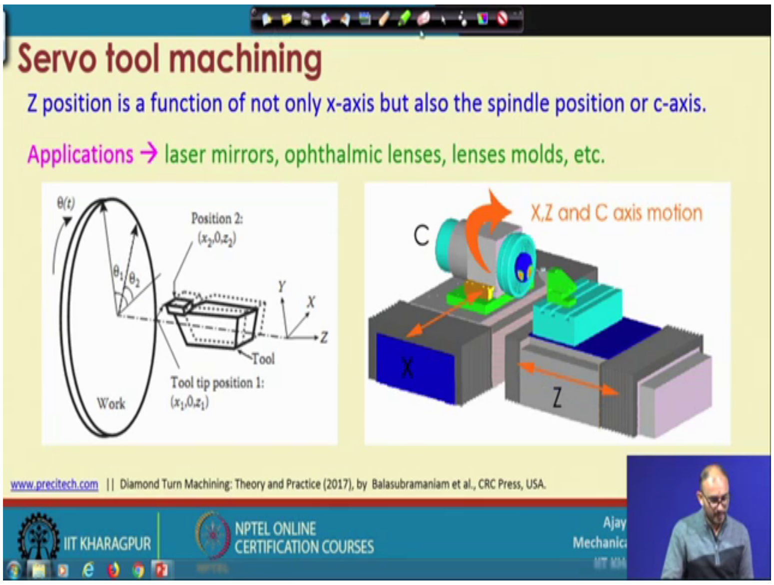

So, how this thing is different? Now what is happening here that mostly in all the facing operation what is happening that, this rotation it is independent to the movement of the Z axis right. So, we never calculate that how much is the rotation with respect to the movement of the Z axis right. Our tool is always program with respect to x and z axis only; not with respect to the theta right. So, Z position is a function of not only x, but also the spindle speed spindle position or the c axis.

So, now here what it is showing that, if your workpiece is rotating with a theta 1 and theta 2, how much is their placement or how much is their displacement of your tool; that is starting from x 1 z 1 to the x 2 z 2. So, now, it is very very synchronized motion. Now whatever is this rotation your tool always knows that how varies the location of your particular point. Suppose, you are looking with this particular point, so your tool will know always that varies this position. So, if you want to do machining at this location only and if you want to rotate your workpiece with a high rpm suppose you are rotating it at 10 rpm only. Let us start with the low rpm.

So, when this particular point comes to this location, at that time only your tool will go inside and do cutting and then again quickly it will retract from this surface right. So, that is the at a low rpm. Now consider you increase to the 100 rpm right. When you do that 100 rpm your point will quickly reach to that location because it is rotating at high rpm. So, response of this particular servo material should be also very very fast. So, at that time there are two different methodology, by which you can do one it at a very very low rpm and one is it at a high rpm. So, our the what is the meaning or what is the objective of this thing that your position of your workpiece in a rotational direction is always known to the tool. So, that is why it is called as servo tool mechanism right.

So, what is the application the laser mirrors, ophthalmic lenses, lens mold now we have seen one of the videos there the molds were created at a different different locations right. So, there are different molds were created here; at this location and this location. So, at that time what was happening that, whenever you are reaching to this (Refer Time: 08:03) your tool will do machining here. Then there is off time here. So, tool will retracted and again this location will come to this location and then again tool will interact at this location. And then it will move in the x direction also sort of once this circle is over then it will look into this circle, then this circle like that right.

So, these are the different different lenses which are not actually the facing operation you cannot create these type of things by facing, we will see some of the examples right. So, again similar to that by the same figure is there, but now here that is the thing that whenever it is rotating here, now you can see these are the two dimples available. So, your machining will be done at these two location only. Now how do you know that the when this location is coming to this part, then both the things whatever you are moving is Z and then your rpm this both things are actually couple or integrated. So, that is the only way you can actually find that when your particular location is coming into that particular Z position and then your tool will actually go quickly in that do machining and then quickly come back after that right.

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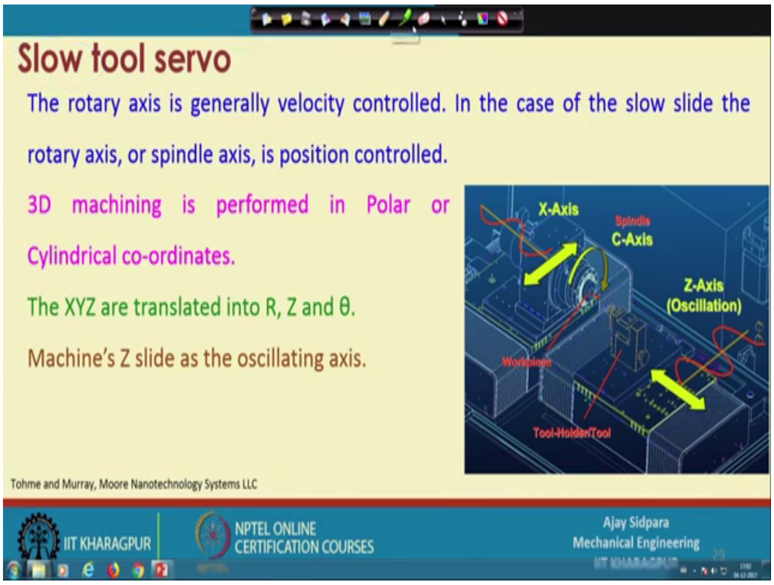

The first thing is the slow tool server right. So, rotary axis is generally velocity control that is what we do that whenever you rotate you generally look around the rpm only, we do not look around other than that what is the position. But in this particular slow slide rotary axis is our spindle is actually position control right. So, these two words are very important to understand velocity control in the position control.

Velocity control; that means, you are looking about rpm only right position control that means, in within the rpm that what is the theta how much theta you have rotated right. So, this particular linear distance is very very important to under; that means, whatever this, the arc is there how much is the so, that is called the position control. That is useful in both the case; slow tool server as well as the fast tool server, but let us start with this slow tool server. So, you should know that what is the position of your particular location on the workpiece and that is why it is called the position controlled right.

So, this is what is happening in the; workpiece. So, this is your work, this is your cutting tool, this is your workpiece and now whenever your workpiece is rotating this particular thing will actually move sinusoidal way. So, this is called the X Z axis oscillation. So, by oscillating this particular thing, now at which amplitude in which frequency you are oscillating, that will actually big controlled by the two things one is the slow tool server was slow to means, that your amplitude is more, but your frequency is less so; that means, it you can go more into the depth, but you can actually cannot do something very

very at high frequency there right because the whole things are different in the two different systems. So, let us see that right.

So, 3D machining is performed in a Polar or the cylindrical co-ordinates. Now what is happening that earlier we are not worried about the; what was that position of theta, but now theta is very important in this case. So, to make sure that your tool is knowing that theta, then it should actually work into the cylindrical or the Polar coordinate. So, what is happening there? X Y Z actually, it is translated into R theta in the Z axis. So, that is the only way by which you can get the things done by for this particular process. So, machines Z slide as the oscillating axis.

So, this is the way you it will oscillate in the Z axis. So, here what is happening that whole thing will oscillate. So, this Z slide. So, whatever is this Z slide, so, this whole thing is the z slide. So, this size is very very big and it has also some weight. So, if you want to move at a very way faster that is not possible that because you cannot move a very very high inertia component to a such a higher frequency, but you can give a more amount of depth that is called the Z movement that is what is showing here.

Now, let me show you that video first then what things are there right.

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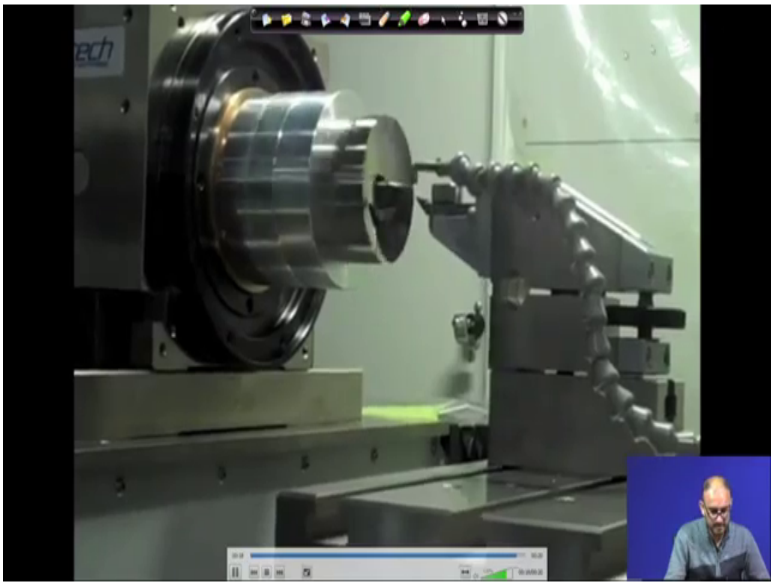

So, now, what is showing here? Now see this is the component where you want to do machining here and this is the cutting tool. Now you can see the whole table is moving and depending on that movement, depending on this rotation at one particular instant only your tool is coming into contact, rest of the time it is coming back right. So, you can see that at one location only it is coming in contact. So, by that way you can actually do machining at a one particular location not all over the cylindrical surface.

So, this is the one example; and this is the tilted parabola, but this is also one example

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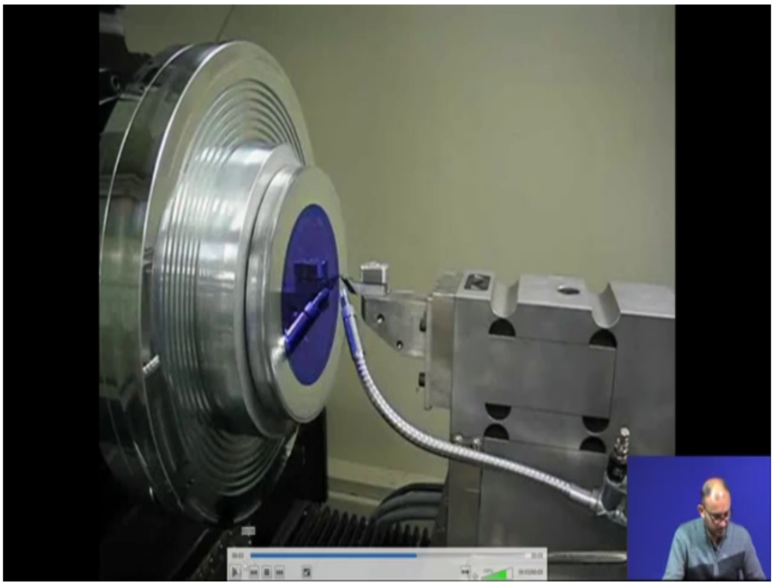

Now, you can see; then how you can do machining on a tilted. So, now, here the objective is that; that instead of a flared surface you want to create one tilted surface. So, now, tilted surface is something like this. So, this is the oval this is the surface and this is what you want to create. So, your cutting tool is here at this location now this is your cutting tool; now when this location comes into this position that I am cutting tool will move up to these only and when this particular look or point comes into this, then your cutting tool actually moves up to this location right.

So, your stroke is very very large here in this particular case if you see here. Now you can see your stroke is very very large it is in terms of millimeter right. So, when you want to do that thing then what happen that you; you are completely moving the Z slide. So, at that time you can get a very large amount of stroke. So, this stroke is very very important for doing different type of operations right. So, this is what is called the slow tool server.

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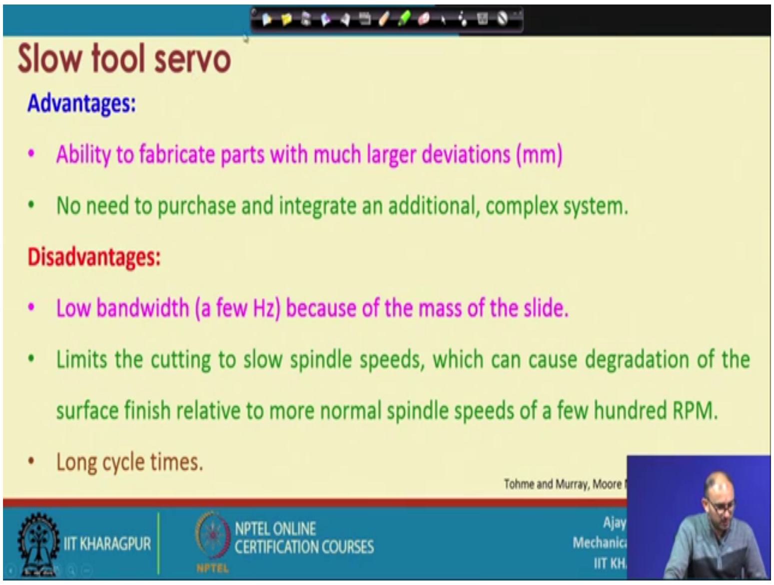

But what are the problems here that there are some advantages also, some disadvantages also first thing is ability to fabricate the parts with much large a much larger deviation. Now we have seen in that example that, suppose you have a Z offset; that means, at one location you need a depth of a starting at a Z 0 and other location you want to go with a 1 millimeter or 2 millimeter inside. So, at that time your deviation is very very large. So, at that time you can do with this particular slow tool servo. So that is the advantage large deviation part can be machine very quickly machine very efficiently not quickly.

No need to purchase or integrate an additional or the complex system. Because if you want to do this thing then in a conventional machine what you have to do? You have to provide some type of oscillating mechanism by which you can control the part and other than that you have to integrate those things, because integration of a external or additional system with the machine is very difficult, but once it is inbuilt in the machine, then it is very easy to program also and the move the cutting tool according to your part program.

But there are some disadvantages, first thing is the lower bandwidth because of the mass of the slide because you cannot go with a very very high frequency. The movement of those component whatever we have seen earlier, those things are not that much easy right. So, first thing in the low of bandwidth; whatever we have seen that we have seen that our component was this one and then we are moving this cover cutting tool from here to here. So, at that time suppose you are rotating at a very very high speed, then you can you cannot actually frequently move this thing here and there that is the big problem. So, you cannot operate at a very very high frequency that is the problem because all mass is very very difficult to move because of its weight.

Now, that limits the cutting to slow spindle speed because we have seen the cutting speed was very very small at this location. So, what is the problem because of that which can be degradation of the surface finish relative to more normal spindle speeds of a few hundreds of RPM. So, to do those things actually you have to rotate with a 10s of RPM only, then only you can actually point capture those point or you can track that particular point.

Because we have to also maintain at which frequency it is rotating or it is moving in a sinusoidal motion oscillation; oscillating motion and depending on that you have to select the spindle speed. So, RPM is very very low and because of the RPM, you were actually sacrificing the surface finish, but that can be actually reduced little bit by making sure that your tool is very very sharp for a different operation. And we know that if you go with a particular this type of lowest low RPM then; obviously, actually you will you require a very long cycle time to complete the operation.

So, these are the few disadvantages of the slow tool, but still slow tool servo is very very useful for a different different this type of machining operation. So, that is the advantage of using slow tool servo.

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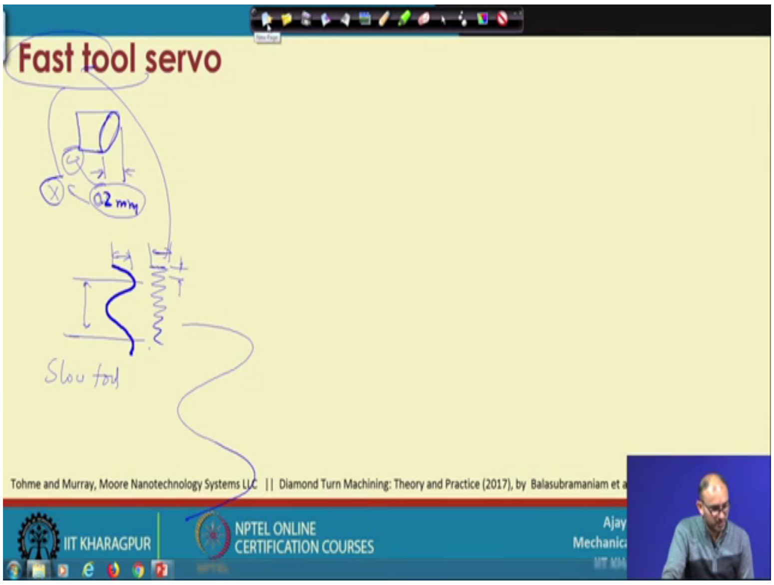

So, now what to do? For a higher speed that we need a fast tool servo; so now, only difference thing is that now your tool is moving at a much faster rate in a to and fro motion, but now there are problems because once it is a we call it a faster rate. Now same example; so this is your workpiece and this is the thing. Now earlier case this was the consider it was a 5 millimeter. Let us say 2 millimeter right. So, at that time we were using it. But with a 2 millimeter and this particular combination actually this is not fitting well right. Because when you are telling fast tool that means, it is moving like a this way. And when you tool consider is a slow tool servo then what is happening that, it was moving like a something like this right.

So, within this thing it may actually complete only more one or two only, but what is important? This amplitude is very important here and other thing is that what is the bandwidth. So, those two these two things actually make the system different. So, fast tool what is there? You have a small amplitude, but you have a large frequency. So, if you control this thing in a 0.2, then this particular thing is now correct right. So, this deviation is only 0.2, then now you can do you have to move with a 200 micron only. So, if you move on to keep on to move that 200 micron, then it is very easy you can quickly do machining of a different different type of component at a high fast tool servo right.

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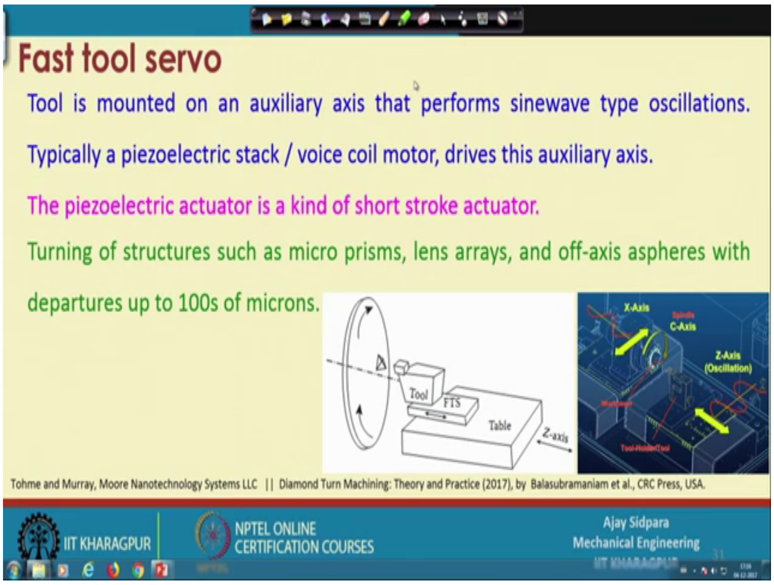

So, tool is mounted on auxiliary axis, that perform the sinewave type oscillation. Now earlier case what we were doing? That our whole slide was moving, you are not requiring type of auxiliary axis, but here this auxiliary axis is very important here because we want to move to a very very small movement, then you have to mount something on the slide and then slide that is called oscillation on the auxiliary axis you are putting the tool. And what you are using for movement typically is a piezoelectric or the voice coil motor is used for movement of the auxiliary axis. So, this is what it is showing. In earlier case what was that; this this was the slow tool servo right. So, this is the your Z axis was the slow tool servo.

Now, this whole thing was moving here and here, but now your stroke length is reduced, but your frequency is increased. So, setup remains same, but what is we are doing that we are adding this additional component here that is called the auxiliary axis and this auxiliary axis is actually independently working by means of by a piezoelectric motor or the voice coil motor. So, by that way you can actually do a machining of a very very small component here, because now the size on the depth is also very small then only you can do cutting bigger size you cannot cut here.

So, let us see that example also.

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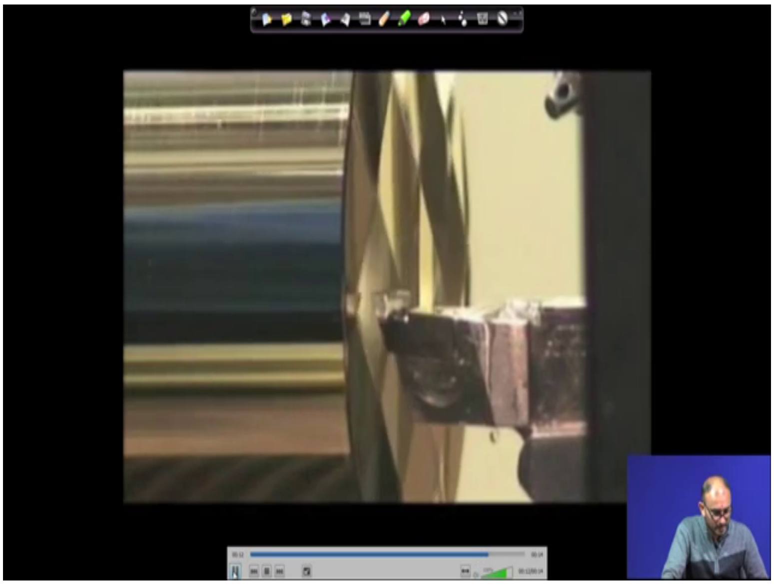

Now, you can see that how fast this particular tool is actually oscillating for getting a different type of features here. And you can see the RPM is also comparatively high in the compared to the servo slow tool servo. This is the speed at which it is moving. Now you can see it is top, now by manually this person is actually rotating a spin spindle and then you can see that with a small rotation, your tool actually responding with respect to the rotation of the workpiece. Now you can see that just by rotating this is the one particular segment of the mirror. So, this is actually the mirror, now you can see there are small small segments available. So, these are the small small segments on to the surface right, you can see that these are the square kind of thing. So, machining is actually done at that location only rest of the location is free. So, there is a boundary between all the features right. So, this is the way you can actually do machining or of a different features by mean using fast tool servo.

So, piezoactuator is a kind of a short stroke actuator. So, why do you need short stroke actuator? Because now see that these features are very very small now you want to create this type of lenses here many location. So, now, our objective is to remove this much amount of material very very selectively. So, you consider there are 100 features on a one at one particular periphery of the workpiece surface. Then 100 times it should go inside and come outside right. So, at that time you need a fast tool servo which will actually perform this particular operation very quickly and that is the reason you have to go with the fast tool servo right.

So, turning of structures such as micro prism, lens arrays and off axis asphere mirror with a departure of 100s of micron earlier case what we are looking? We are actually looking at a few of some millimeter, but now that particular stroke is reduced. Because by reducing the stroke you can increase the frequency and if you want to go with a very large curvature then you actually you can go with the a slow tool servo, but this is not the things here which we want to do with the fast tool servo. So, by using this both the things what you can do? You can take out both the example means whatever advantages are there you can take out both the thing. So, what people I right now doing that there are some more advancement things are going on here that these they are putting this particular fast tool servo here, but these thing is also equipped; slow tool servo is also there, slow tool servo is also there.

So, now, how these thing works? The suppose when you want to create a very last deviation. Now suppose this is the surface, that what we have seen earlier case. So, this is the deviation what we want to create at that time you do not operate this thing fast tool servo let it be there only, but we do not operate and then work with the slow tool servo only and do all the cutting. So, whatever this size is that 2 millimeter or something whatever is there you cut down with this part, but and once this part is over. And other than that what you do that when you want to operate this particular fast tool server then you do not operate this slow tool server. So, what we are doing here that, we are actually combining this both the thing that is the called course movement plus fine [fine] right. So, both the things we are actually integrating in the single system.

So, now you can know you can see that you can get advantage you both the thing, you can actually do machining of a very very large step here; that means, whatever is the inside cavity is there and you can do cutting with a fine features also when you want to do and you can combine both the things also right. So, now, suppose you have one example here, suppose this is the surface and now you have a small small features on the this surface right.

So, you can actually synchronize both the thing that this particular tool is located here and then it is going inside and at the time that is this motion is by the slow tool server and for machining of this particular small feature this is called the fast tool servo. So, by these two different ways actually you can do, you can get the advantages of fast tool servo and the slow tool. But this becomes more and more complex because for programming is not that much easy.

When you are adding each and every one by one axis then programming also becomes very very difficult because just writing a program with the three axis is not very big thing, but as soon as you put the fourth axis, fifth axis and a sixth axis then controlling all the things and you should have machine and the software interface everything should be capable to handle this type of program and that is the problem sometimes person who is operating this particular machine may encounter.

So, that is the reason that working with a both the things will create a one type of tandem thing, but every time it is not enough for making the thing, because you have to see the programming efficiency and the expertise of the person who is handling this machine.

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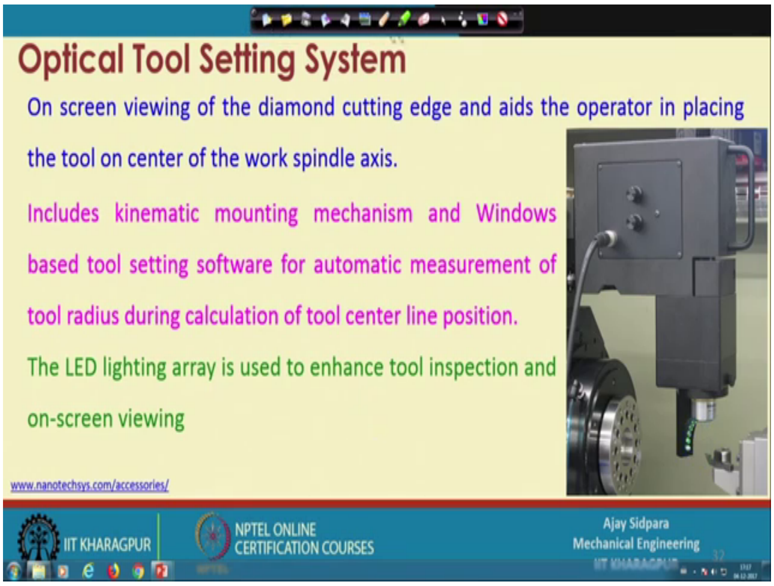

So, now let us see some of the small small things that optical tool setting system that these are the some of the systems available, where you can do tool setting because now this microscope will give you the complete idea about the what is the geometry of the cutting tool and whatever things you want to maintain with respect to the workpiece. So, that is the thing.

So, it in on screen viewing of the diamond cutting edge and aids the operator in passing the tool on the center of the workpiece work spindle system. So, that is very important because we know that we are looking at a micron scale here. So, by naked eye you cannot actually fix this thing; right. So, you need some optical or some type of high magnification microscope so that you can do this thing much better way.

It includes the kinematic mounting mechanism and windows based tool setting software for automated measurement of tool radius during calculation of the tools center line its position. Because even if it is integrated if you want to do manually, then it is again a time consuming a not correct. So, it is actually the integrated with the windows system software. So, just by giving the command of movement in XYZ direction, it will actually actuate your cutting tool at that location and that pressure that movement should be also in some micron level so that you can actually find the exact location of the cutting tool with the workpiece system.

And light arrays available because this light is very important, because whenever you are working with a negative rack angle when you want to do machining of some type of brittle material; highly brittle material at that time you have to see that where you are looking at that so when light is just not passing through the surface, we have flared surface and your light is passing here then it is not a issue, but when your surface is something like this at the time, you can it finding out this location is you difficult if you do not put the light. So, this particular light will make sure that light is actually passing through the all the location and your tool is completely exposed and you can do all the measurement before machining and after machining.

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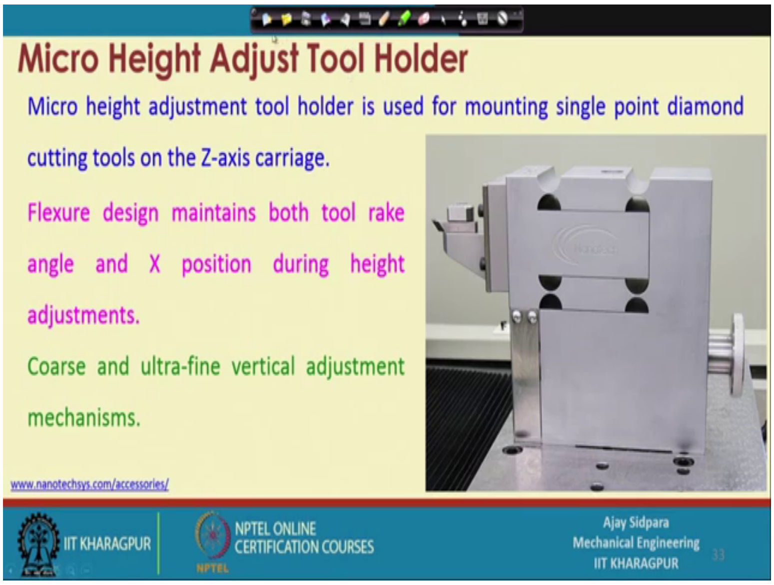

Another is that micro height adjustment of the tool holder. So, this is also one of the thing, because now this thing will make sure that you are actually maintaining the height. Earlier case it was used for maintaining of the other feature, but this one is very very important in this case that you have to maintain the height also. Now our workpiece is located here and we want to maintain the; at we want to go to this location. So, course moment you can give and then fine movement you can give by this particular tool height adjust. So, it has both the thing that micro at the and the micro level also you can do adjustment so that you are actually reaching to the same location right.

The Micro height adjustment tool holder is used for mounting single point diamond cutting tool on the Z carriage. So, flexure design maintains both the tool rake angle in the X position during the height adjustments. So, this is called the flexural mechanism whatever this thing is there right. So, this whole thing actually maintained because whenever you are moving here and there; and if it is too much rigid, what is happening that you are actually sometimes sacrificing the location of this both the thing the rake angle and the exposition during the height adjustment right. Because whatever you are doing? You are actually maintaining the Z motion here this is called the now suppose this is your workpiece this particular movement is called the Z, wherever you are moving in the no this is called X axis whenever moving on the surface of the component, but when you are going in depth wise that is called the Z motion.

So, we have to when you are moving up and down we are doing maintaining the height at the time you are maintaining the X position in that part. So, at that time you have to also make sure that what is the X position on the workpiece and what is where your rake angle tool rake. So, at that time you have to maintain both the things. So, because this is whatever it is showing when you are looking from the top, this is the surface and when you are looking from the side this is the surface. So, in both the way you have to see that you are actually fixing to the same location of this flexure mechanism actually very important, and that will not create any problem in the fine tuning. And coarse and ultrafine vertical adjustment mechanism can be possible by this particular system.

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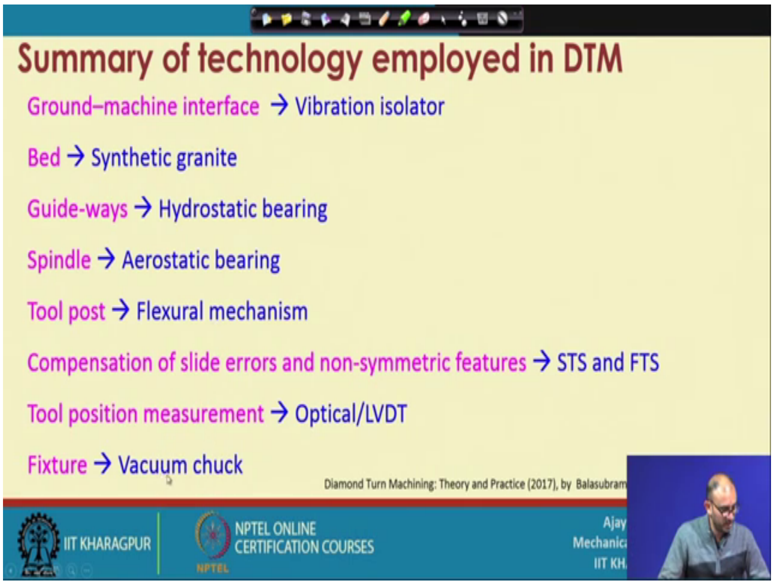

So, now let us go to the summary of this technology, that now let us summarize the what things we have to we are employing into the DTM machine and most of the thing you can see that these things are actually used for the micro machining center also right. So, ground base mostly it is vibration isolators is required. So, that you can you cannot get any vibration from the floor bed is the synthetic granite that the polymer granite what we have seen in the micro machining, guide ways are the hydrostatic bearings, because the hydrostatic guides were important to move the large amount very heavy load that is mostly the Z axis. Spindle is aerostatic spindle because we have to rotate with a very very high precision. Tool post is a flexural mechanism just now we have seen it compensation of the slide error and non symmetric object that is why we use slow tool servo mechanism and the fast tool servo mechanism.

Tool positioning measurement that is optical earlier whatever we have seen that was the optical and this LVDT also we can use then here variable differential transformers. So, by that way you can actually do measurement by it small small amount of distance. Fixture is the vacuum check, because here what we are doing the we are machining of a optical materials only. So, even a small amount of fixing load, that is the load by which you are gripping the component by means of chuck that will also create problems. So, mechanical chucks are actually not recommended for holding any component here and vacuum chucks are mostly using the diamond turning.

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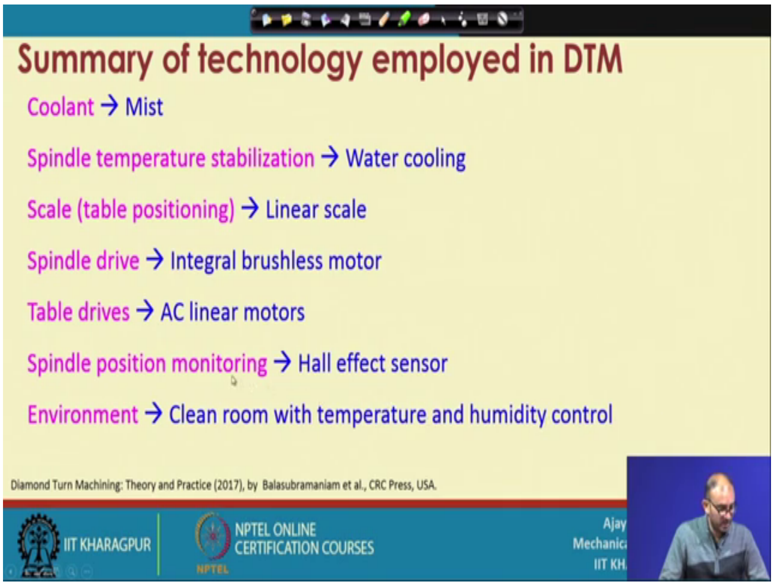

Coolant is mostly mist, because flood coolant will create lot of problem there spindle temperature stabilizes and water cooling is used for the spindle scale is mostly linear scale because we have seen the linear scales are more reliable, when you want to do measurement on a translation direction. So, whether it will all the it will take care of all the backlog (Refer Time: 31:31) and everything. Spindle drive it is integral brushless motor is used and the stable drive AC linear motors are available for movement of the tables. And the spindle positioning motion for how what are the RPM because now we know that here the spindle RPM is not as high has the micro cutting, because in that case we need 50 100s of 1000s of the RPM; that means, 50,000s sometimes even right now spindles available with the 3,00,000s, 4,00,000s RPM that much speed is not required here because here we operate generally 3,000, 2,000 RPM only. So, the Hall Effect sensor is enough to capture that particular spindle speed position.

Environment we need a clean room because our material is optical material which is creating a lot of problem with the temperature and we are using all this very very sophisticated linear scale and the air spindle and all the things. So, it is better to go with a air clean room requirement, where temperature humidity and dust controls are very very important. And let me, finish this lecture here and we will continue with the some new topics in the next class.

Thank you very much.