**Introduction to Mechanical Micro Machining**
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**Lecture – 57**
**Diamond turning (Contd.)**

Good morning everybody and let us continue our discussion on Diamond turning machining. Last class, we have started this topic and we have seen that this particular process as wide application area in a optics fabrication and the different type of lance fabrication and, we have seen there are different classification of the diamond turning operation like a X Y Z axis; that means, number of axis degree of freedom and then second one was the X Y and R theta type of thing.

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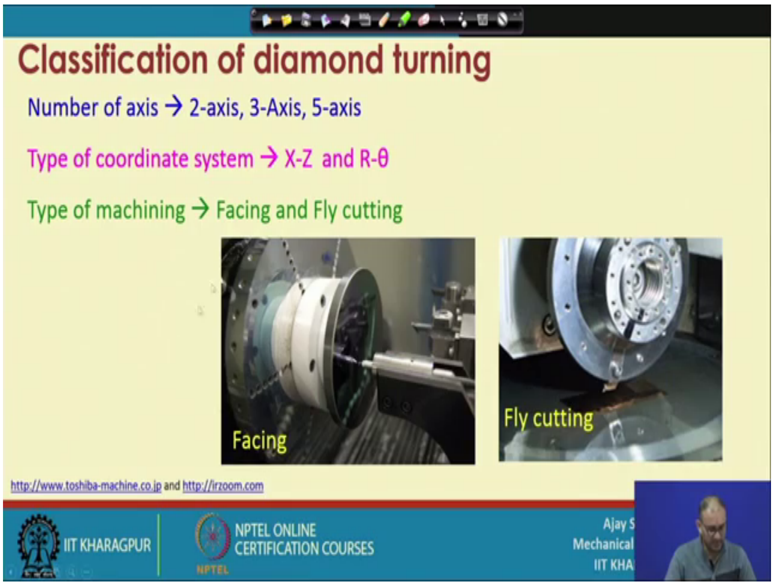


And third one is the facing and the flying operation.

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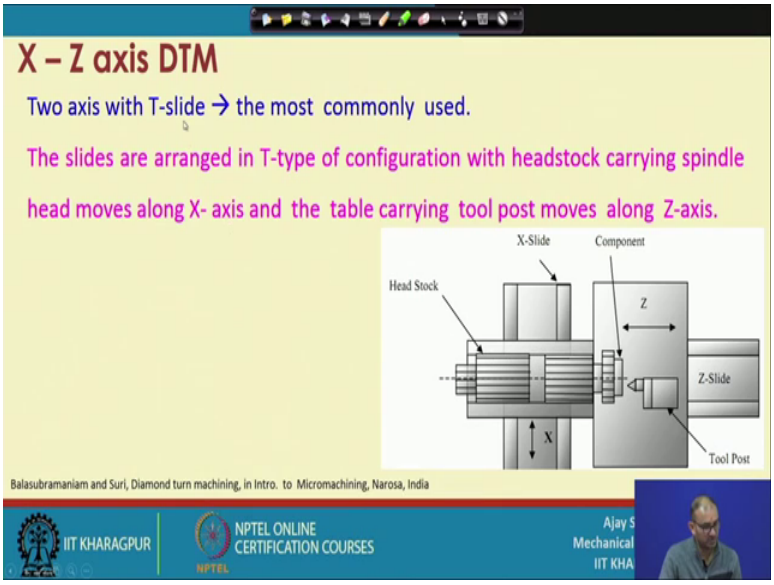


So, let us further continue by further own discussion of different axis, now this is called X and Z axis configuration. Now, how these things are different now you can see here the if you consider one normal turning operation, what happens that you give both the things to the now this is your cutting tool right. So, how what we do there for depth of cut we are giving a movement in the this direction.

So, that is; obviously, same as our conventional turning operation, where to what you want to do, but when you want to do facing operation for facing also what we do we give our X direction in these part right because, for both the axis X and Z axis is mostly we give this both the motion to the tool only not to the work piece, work piece just rotates only and depending on that rotation, we create a features on the either on the cylindric face surface or on the cylindrical surface, but here things are different.

Now, you can see here that in Z slide actually you are moving only Z axis in this case your; that means, your tool is moving only in Z axis and, for this tool whatever is this headstock a the whole headstock is moving in the X direction correct.

So, this is what is different than the conventional turning operation, why this is required because many times what happen we will see some of the application and, we have seen also that fabrication of those mold micro mold at that time you are machining was done here at this location at that time your tool was no stationary, but tool was considered as a milling tool. So, it was rotating at a high RPM, then you do machining here then you want to shift to this location instead of tool moving in this direction, your whole job was moving in this direction right. So, that was happening we will see that we do again.

So, at that time you can do cutting here. So, it is better to mount your all work piece or the head stoke on a X axis. So, that your whole work piece will move in a up-and-down motion, that is when we are looking from the top and your job, or your tool is moving in a Z direction only. Another than that that you can actually control the location that where you want to do machining of a different different shape on the work piece, that can be also controlled if this freedom is given to the work piece not to the tool right.

So, it is a two axis with a T slides, why it is called T slide because, now you can see here that this particular tool is moving in this direction and, your work piece is moving in this direction. So, that is why it takes a shape of a T. So, now, this is the T shape so, this is called T slide. And it is most commonly used because, now if you take this shape, then any conventional or routine type of features you can create on the face surface. So, that is the advantage right.

The slides are arranged in T type configuration with headstock carrying spindle head moves along the X axis and the table carrying tool post moves along the Z axis, that is what we have discussed that we are not giving both the motion to the tool, that is X and Z instead of that we are giving only Z motion to the tool and, X motion to the work piece, so that is called X and Z axis DTM.

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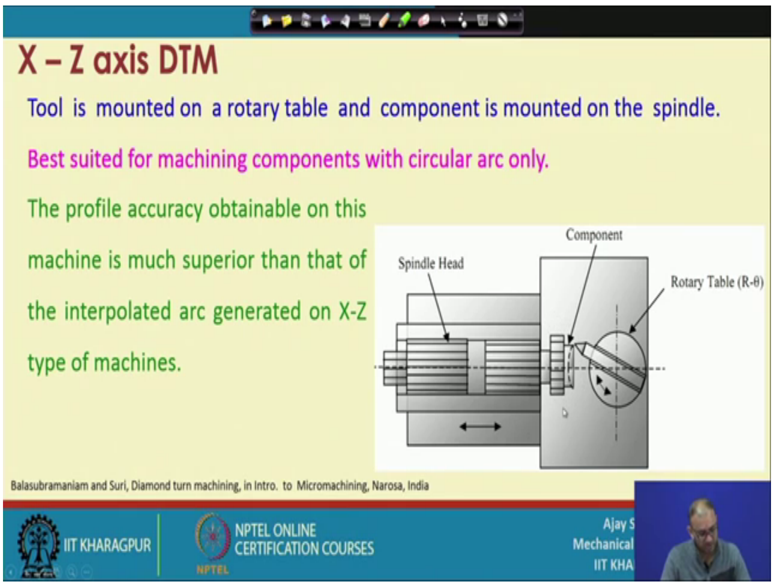

Now, tool is mounted on a rotary table, now this is no this is not X Z this is a R theta sorry there was a mistake little bit. So, this is a R theta this is R theta axis now, these things are different. Now, you can see it here now what is happening that this is a rotary table instead of moving in the X direction or the Z direction now, we are giving a movement in this direction. So, what is the advantage of this the suppose you want to create some features which has a some concave surfaces or convex surfaces, then you can get this thing done very easily.

Depending on the overhanging of this what is the radius of rotation of this particular cutting tool in terms of R and theta you can get those things feature. Now you can see this line for creating these particular features if your machine is in X and Z direction that is the part, suppose this is the X and Z then what you have to do suppose you want this object rights, then what you have to do the you to give a very small amount of X Z, X Z, X Z, then only you can create a this type of feature this thing is not visible by naked and, but when you magnify it you can get those these features visible in a microscope. So, that is the problem.

But if you follow this particular path what is happening your tool is actually sweeping the surface right, it is not actually put making this thing in a micro step or the NANO step. So, when your tool is sweeping in this direction it is very easy to create these features by X and Z R theta configuration. So, let me show you that video that how these things are feasible in R theta mode.

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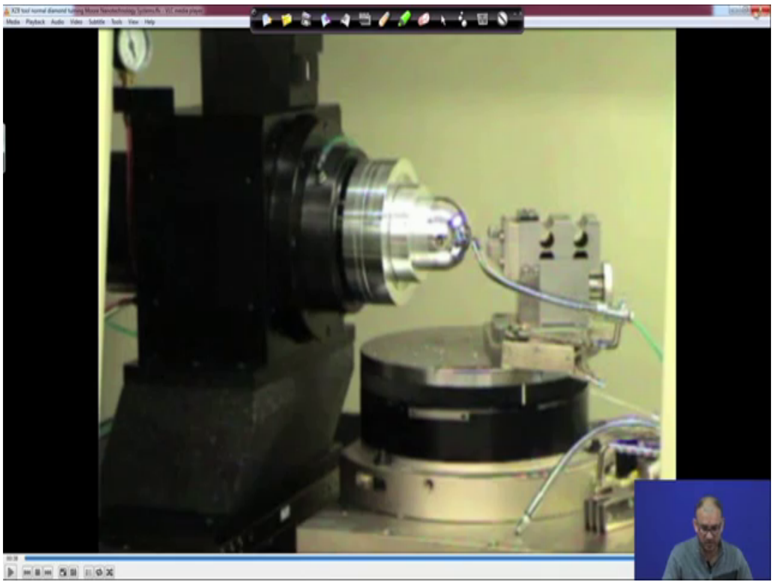

Right so, this is the R theta mode now you can say this is the same rotary table here and, your tool is located here, your work piece is here and your tool is actually moving around the surface. So, that you can actually create some type of spherical shape here s o, depending on the radius of rotation of this particular cutting tool, you can get the same surface on a work piece.

So, now you can see it is rotating. So, this is more convenient than giving the micro stepping on a X and Z axis correct. So, this is one of the applications. So, R theta axis, similar way what you can do you can actually create a concave surfaces also, now you can see that your tool is located at this location at this location and, then you sweep it then what it will do it will actually create some type of cavity instead of a formation of a spherical surface.

So, that is also one of the ways right. So, tool is mounted on the rotary table that is here and components mounted on the spindle, the best suited for machining component with a circular arc only. So, these are the concave convex surface is a spherical surface you need only circular arcs. So, depending on that arc you can create a features on a component.

So, profile accuracy obtainable on this machine is much superior than that of the interpolated are generated by the X Z type of machine. So, here that is the big advantage because ultimately suppose you want to avoid those particular forms generation, then what you have to do if you use X and Z axis most type of machine, then you to apply some type of polishing process on the top because, those marks are many times visible by naked eye also, if the stepping interpolation is where it is micro verse bigger size tens of micron, then it is visible.

So, you need some polishing process and then you can remove those things, but if you use R theta things, then what is the advantage that, you can go get rid of those particular things and you do not need any type of subsequent polishing board finishing process.

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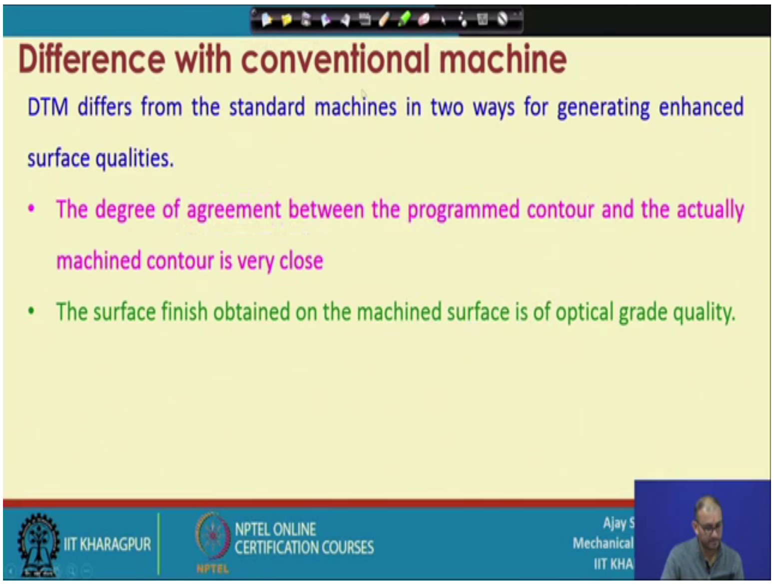


So, how in terms of machine how this thing is different right. So, DTM differs from the standard machines in two ways for generating enhanced surface qualities, one is the degree of agreement between the program contour and the actual machine contour is very very close.

Now, what does it mean that suppose you are actually machining a surface now, suppose you want to do a cutting of a this particular surface right. So, this is the surface and your cutting tool is at this location and, doing a facing operation you are rotating in this direction. So, when your tool is following this particular path that path following is done by a part program correct.

So, how much is the accuracy of that particular part program; that means, the word program you are giving and at which path your tool is moving. So, that particular agreement is very very high here. So, sometimes it is in a less than one nanometer sometimes is in terms of 1 nanometer also.

So, that is the advantage of using that whatever program you are getting the same way your tool will work, why it is working because we have very very highly sophisticated components on the diamond turning machine. So, that you that those things will make this possible; So, that is the one thing that whatever program you are giving your machine itself machine will work exactly on the program control, but your machine will not sacrifice the accuracy or the resolution of your part program.

And the surface finish obtained on the surface machine surface is the optical (Refer Time: 19:52) optical grade; that means, it is in terms of the lambda by 2 what is (Refer Time: 19:56) by 2 10 something like that what we can tell it. So, it is the nanometers surface roughness.

So, that is the advantage of using this thing and conventional turning operation of facing operation, getting those things even if you use a CNC machine, it getting those surfaces at a nanometer say or level, or younger storm level it is not possible because, the machine also needs some of the things which are not available on a conventional machine.

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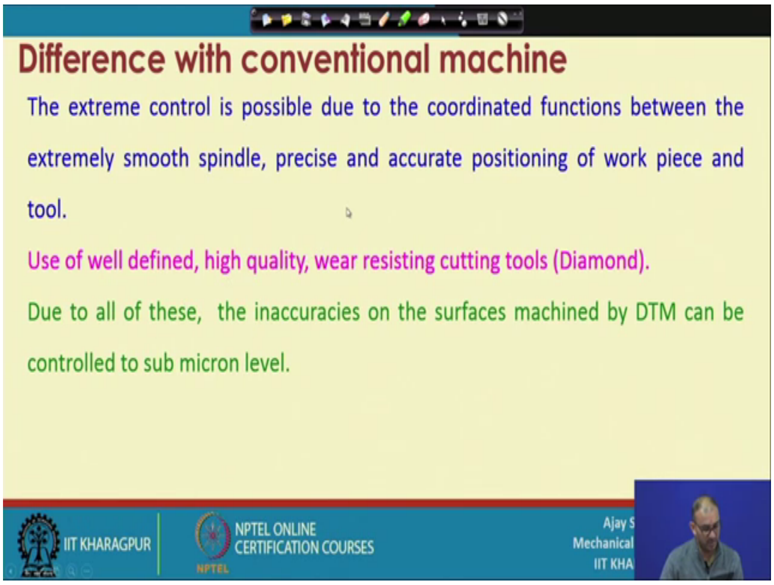

So, extreme control is possible due to coordinated functions between the extremely smooth spindle precise and accurate positioning of the work piece in the tool, because now suppose you want to follow one particular path. Now, this is the particular path you want to follow; now this is very very skewed surface, now you want to do machining of that part.

So, now first thing you require the very smooth motion of the spindle because, if you will get a some type of uneven or the some type of fluctuated movement of the spindle, or rotation of the spindle the these features generation is very very difficult and precise an accurate positioning of the work piece and tool.

Now, you can say these surface it is very difficult to you cannot because it is not a symmetric axisymmetric surface is not there. So, most of the times what happened that for creating these particular surface these surface, you can actually use some type of cutting tool and then you create scoop out this material and for this particular surface, you have to scoop out material from here right. So, accurate positioning of the work piece that where you are positioning your work piece with respect to tool, that will decide that how exactly you are or making this particular component alright.

So, it is a two different feature and both features are different this is a concave surface this is a convex surface. So, how to get those both the features on a machining on the work piece surface, that will be decided by the how many axis controls, you have and how precisely your work piece tool and the spindles are moving. So, use a well defined high quality and we are resistance cutting tool that is why we use a diamond because diamond is the hardest material. So, unless you use a ferrous material for work piece has a work piece material you can actually enhance this particular life.

So, mostly your diamond turn tool and this particular process is more suitable for the non ferrous material. So, because it is a very high we resist and high quality it can retained it is safe for a longer time compared to other cutting materials, due to all of this the inaccuracy on the surface machine by DTM can be controlled to a sub micron level.

So, that is the surface; that means, what are the figure level is the suppose, you want to create a concave surface you can create a concave with a sub micron level of figure accuracy roughness will be; obviously, in terms of the nanometer level or sub nano meter level.

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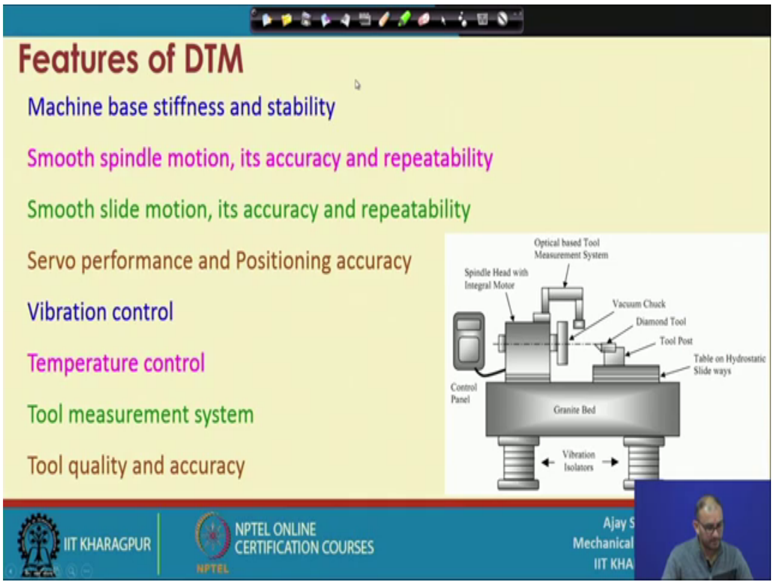


What are the features required on the diamond turning operation. So, first thing in the machine based stiffness in the stability because, if you use a granite bit and if you see this most of the features, this most of the features are actually aligning with the machine construction what we have discussed in the micro machining because, there also we need a very very high damping coefficient of material, then we need a very high stiffness on the structural loop everything is required here also, because here requirement is even more stringent because our depth of cut is in a ones of microns only.

And in that case you can actually give more depth in terms of tens of micron, but that is this particular process demands even more than what is required on the micromachining machine. So, here machine stability stiffness. So, most of the things are actually repeated compared to that is similar to what we have discussed in the micro machining machine component.

So, we are not going into more detail, but I am just listing out the what are the things available. So, stiffness is required so, what parts components you are making how they are connected with each other that is important, smooth spindle motion and the it is accuracy and repeatability. So, mostly we go with a aerostatic spindle here, most of the diamond turning machines aerostatic spindle that is why accuracy and repeatability is ah; obviously, achievable that we have discussed already in a aerostatic spindle lecture.

Smooth slide motion with a high creation repeated here what we hydrostatic is the slide way here and, we have seen the hydrostatic slide way can easily move without any more friction. So, friction directly depends on the what is the viscosity of the fluid what we are using. So, here it is the hydrostatic slide way so, it is similar to the aerostatic way, but you will not get any type of (Refer Time: 14:31) and the friction in the slide surface.

So, it can smoothly move with a record accuracy in the repeatability. Servo performance and position accuracy that we will see the far what is fast tool server and what is slow tool server and, how quickly and how exactly you are positioning your tool with respect to work piece.

So, that will decide that what are how these things will work in tandem because, if you say that any of this particular component is not working as per it is requirement then your all efficiency of the machine will be actually calculated based on the worst performance of that component not with the best one because your whole thing is actually restricted operation is restricted because of the some worse performance of one component.

So, that is the thing, but here we are using a different different type of motion with a fast tool server and slow tool server. So, that you can get a actual position accuracy vibration control you required because we know that we want to create a surface with a nanometer or sub nanometer accuracy, then you need a vibration isolation so, that no vibration will come through the floor from any of the machine or any other things to the machine.

So, vibration water is coming from the machine that will stay there, but you are using some type of very very more suitable material here is, the vibration dampening will happen within the component. So, it will also not propagate from one component to other component, temperature control is required because we know the, we were cutting optical material here and optical materials have sometimes very susceptible to the temperature.

And, other than that you are using also very very highly sophisticated instrument with a submicron of accuracy. So, if you do not control the temperature because of temperature variation, you will get a different micro expansion on nano expansion of the component and that will actually create a problem in the positioning and the accuracy.

Tool measurement system you require because, we know that we everything depends on how your tool is sharp and, what is the waviness and the different type of angles on the diamond cutting tool and how long you are maintaining that thing, because it is not that after one operation you are changing the diamond cutting tool also. So, diamond cutting tool can be used for a many different type of components so, you need a in process optical tool measurement system here what is shown here at this location.

So, this particular tool measurement system will give you a real time view of the cutting tool that, what is happening with the cutting tool when it is interacting with the surface. And once operation is over, then it will capture the 1 image of this cutting tool and, you have already captured 1 image before you do the machining. So, then it will compare that how is the difference between the reference image and the actual image. If the tool wire is very very high then you can replace the tool if it is not high, then you continue with the cutting tool.

So, this particular to optical based tool measurement system is also required here so, that you can monitor the status of the tool. Tool quality and accuracy if everything is correct, but you are not using a right cutting tool; that means, what is the waviness of the nose radius and, what is the cutting edge radius and how other things are there on the cutting diamond tool those things also play important role.

So, if you see here the tool temperature control vibrations and small motion of the different axis motion of the spindle steepness of the structure, these old things we have discussed in the machine tool components of a micro machining center right.

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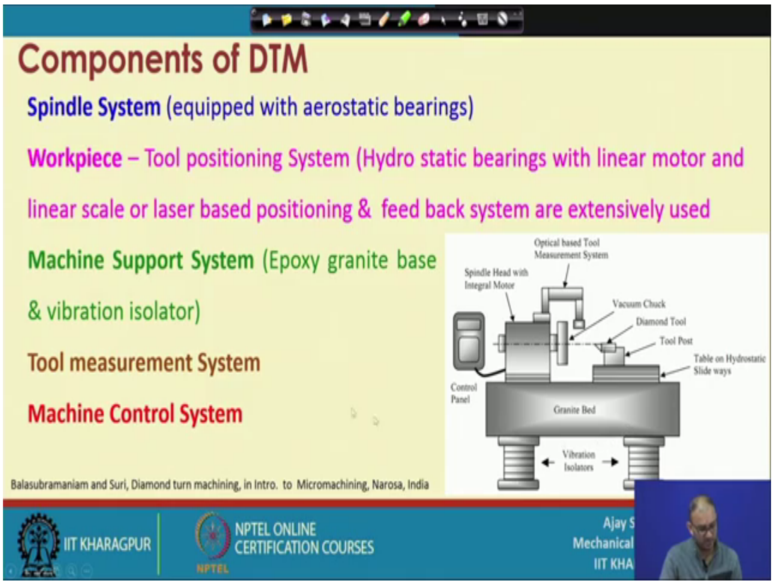


So, first thing is the spindle system what are the different components here. So, it is a aerostatic spindle we use here. So, that is the reason that you have a very very a high accuracy and the repeatability in rotation. Work piece positioning system mostly it is the hydrostatic bearing with a linear motor and the linear scale, or the laser based positioning and the feedback systems are extensively used.

So, here you for movement you can use the hydrostatic of the linear with a linear motor because, we have seen advantage of linear motor also because, it is also on the magnet base and you are you will exactly get the required accuracy, in terms of and sub nanometer level and linear scale is required here because, you want to actually measure the how much it is traveled on a surface; whether it is in X direction or the Z direction. So, linear scale with a submicron accuracy or resolution that will make sure that you are getting the required result.

Laser based positioning system because sometimes, if you use sometime non contact positional measuring system or feedback system then it is more advantage instead of a contact type of things. So, there depends on how much customization you require and how much more sophistication you require on the machine, depending on you have to spend more question other things also.

Machine support system, we have seen the epoxy granite base and vibration isolator same thing we have discussed in the micromachining machine component. Tool measurement system that is located here and the machine control unit. So, machine control unit will give you a synchronize motion between the spindle and the cutting tool. So, we will see there some of the features, you need a very very fine synchronization between the degree of rotation of the cutting work piece and the how much penetration of the work tool is done on the work piece surface.

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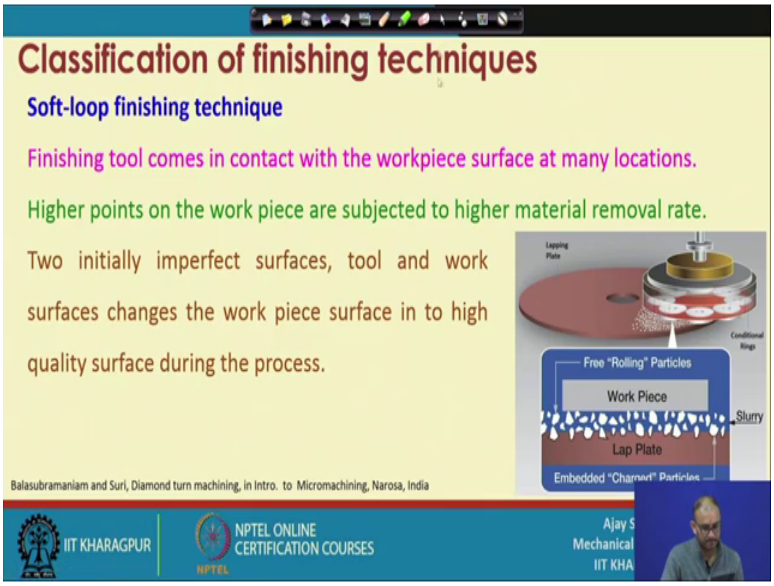


This is the same slide, now classification of the finishing process. Now, there are two ways you can classify the finishing process, why we are talking of finishing process here because diamond turning is also one of the finishing process. Where you can get the surface finish less than 1 nanometer so, that is why it is also considered as a shaping and finishing process while the normal polishing process whatever you are using lapping and some type of advanced finishing processes, they do not actually create shape they will actually do finishing only. So, we classify this thing in terms of two categories one is called soft loop finishing process.

So, what is this soft loop that mostly it is related to the lapping process; that means, abrasive particles are randomly dispersed on the surface work piece is locality and, this is the lap which will actually carry these particles and how this thing is there that difference in the cutting tool come in contact comes in contact with the surface at many locations.

Now, if you see our turning operation, or we are using a single point cutting tool; So, our location is only one point, but here what happens that we are using 100s and thousands of abrasive particles. So, when you plunge this work piece down what happens and when it is going down at that many abrasive particles will create a contact with the work piece. So, material removal will happen at a different different place with a different magnitude because, we know that sometimes when you are pressing the particles small particles will not indent more, but big particles we indent more. So, different location on the work piece you will get a different material removal. So, that is the one of the characteristic of the soft loop finishing technique.

Higher points on the work piece surface are subjected to higher material removal rate; that means, this is the big particle suppose. So, this particle will remove more material compared to small particle because, it is indentation depth is more. So, you will get a variable removal rate at a different different location.

So, how this thing that two initially imperfect surface is tool and work piece surface changes, the work piece surface 2 2 initially imperfect surfaces tool and work piece surface is changes, the work piece surface into the high quality surface during the polishing. So, now you can see there now suppose you have two surface. Now this is the one surface this is the work piece surface, now it is very very only one right and you have some particles here.

Now, let me create something like this. So, this is the very very uneven surface and this is the abrasive particles here right, these are the abrasive particles and at the bottom portion you have a lap. So, this is the lap. right Now you have both have relative motion now this is moving in this direction both direction this moving also in this both direction. So, as time passes what happens is these two are the imperfect server our objective is to create surface on the work piece. So, this is the work piece.

So, when time passes what happen because of this random motion here it will do removal of the material from here every location because, we know that whatever portion is at the smaller location at this location it will remove first right. Suppose this is the surface and you are continuously bombarding particles here, then this part will remove first this much amount.

So, after some times what happened that your surface become your work piece surface become like this. So, this is your work piece surface because, all the uneveness whatever was there here that is removed by the abrasive particles here. So, initially two surfaces are imperfect, then when time passes at that time those two things becomes a highly polished surface and you can get the required surface finish on the work piece surface. So, that is called the soft loop finishing right.

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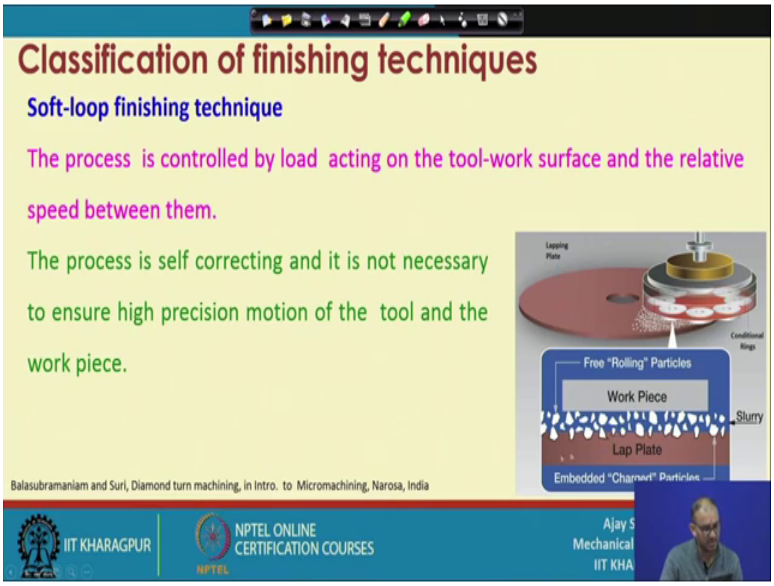


So, the process is controlled by load acting on the tool work piece surface and the relative speed between these two. Now, that is very important because now see everything depends on how much you are loading, it suppose this is the work piece, and this is the abrasive particles which are located here right and, this is the base material.

So, now first thing how much you are loading; loading, will decide that how much abrasive particles suppose this is the abrasive particles this is the work piece, if loading is more whatever happened this particle will enter more and if loading is less that that time it will end means (Refer Time: 24:24) less. So, this is called more loading more N. So, this is the N force normal force and this 1 is the less N right.

So, that will decide the indentation now decide the speed that how much speed is required. So, now speed is depend on the how much which way you are moving this component right.

So, first thing is the indent is suppose your work piece is indented here, this is the work piece and this is indented here, now indentation is not the only thing because now you have to remove this much amount of material right, this much once it is indented this much amount of material you have to remove. So, now you have relative motion in this direction on this, if it is moving in this direction in this direction, when it is moving at that time this much amount of material will be removed because, now your work piece will tool will move in this direction.

So, this much amount of material is removed so everything depends on two parameter one is the load acting on that how much is the normal force and at what speed you are moving so, relative speed between the abrasive particle and this part right. So, process is self-correcting it is not necessary to institute the high precision motion on the tool in the work piece.

Now, we know that abrasive particles are randomly co-oriented and randomly distributed. So, it is a self correcting. So, after sometimes you make sure that your work piece getting finished. So, you do not require very very highly precise motion because, you do not want to control the motion of each and every particles, that is what is happening in the normal diamond turning operation, where only single point is there. So, that you can you have to move that thing very precisely, but that is not the case here.

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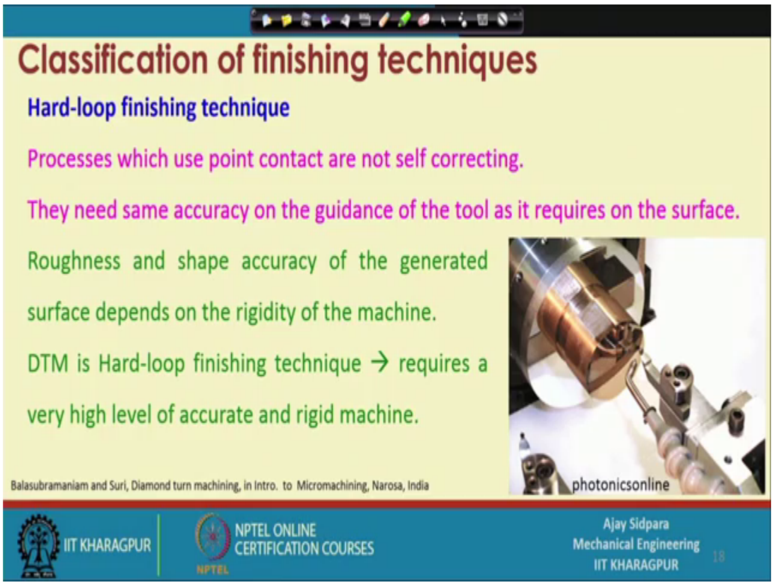


So, what is the hard loop polishing so, a diamond turning is a hard loop because we are using a single point cutting tool here. So, only one point work piece come into contact with the cutting tool right.

So, process which uses a single point are not self-correcting right. So, if you give more time nothing is going to happen because, you are getting material removal from the single location only not multiple location. So, they need the same accuracy on the guidance of the tool as it requires on the surface right.

So, whatever is the surface accuracy is required suppose you required a concave shape right. So, your tool should also move like a concave shape right. So, it has to move like this only every time then only it can create generate this particular surface in the polishing process what happened that there are multiple [vocalize-noise] cutting points are there.

So, you have to need one lap something similar to shape like this and then you be a motion. So, you can easily get the surface polished or surface machine right. The roughness and shape accuracy of the generated surface depends on the rigidity of the machine. Now, how much in the conformation between the motion of the cutting tool and what is the feature accuracy required on the work piece surface.

So, everything depends how much is the rigidity of the machine. Once you give a depth of cut of a point one micron, then can it continue with a point 1 micron, or at all the machine surface or not. So, that will decide by this part and diamond turn is a hard loop polishing process and that is the reason that it requires a very high level of accurate and the rigid machine.

So, these are the two different ways we can classify the machining operation of a diamond turning and the other way polishing processes. So, let me finish this lecture here, we will continue this topic in the next class.

Thank you very much.