Introduction to Mechanical Micro Machining
Prof. Ajay M Sidpara
Department of Mechanical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 56
Diamond turning

Good morning everybody and welcome again to our course on introduction to mechanical micro machining. So, today we are going to discuss about the diamond learning process. What we are discussing here that till now we have seen that, we have discussed about the micro machining processes and where we have seen that the size of the component is micro scale or sometimes it is a big scale, but we are doing some micro machining at a smaller scale on the surface of a big component. Today's topic is little bit different than the micro machining.

What we are doing here that our component size may be in the meter scale, but what we are doing we are removing material at a micro nano scale; that means, our depth of cut is fraction of micron or sometimes not exceeding more than 10 micron. So, this process is different than the conventional micromachining operation, but still it is considered as a micro machining operation or the process because it is still a turning process.

So, we will see some of the examples and how this process is different than the conventional turning process. So, let us continue our topic discussion on diamond turning.

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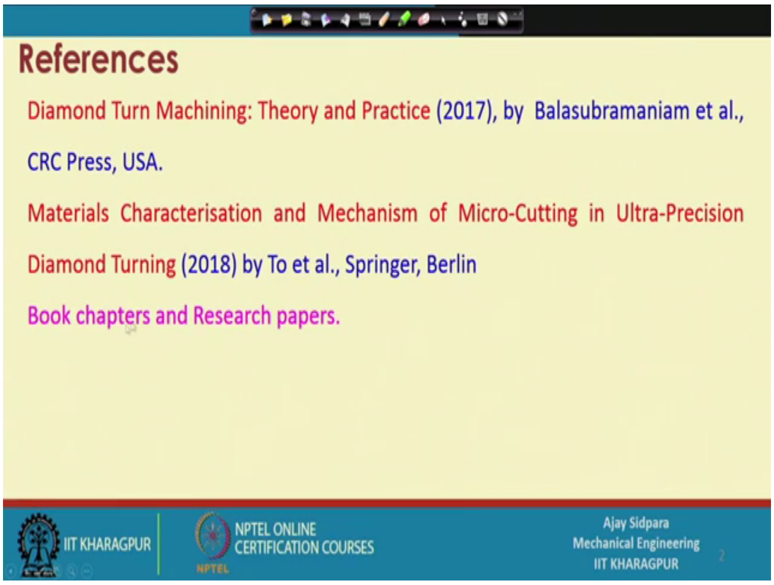

So, for this particular topic, you have you can have these two different books and recently published. So, you will get most of the latest technology trends and theory and all the practice is mechanism about the diamond turning processes.

And there are many book chapters available, many things I have covered from the book chapters and research papers are also available for more discussion about this particular process.

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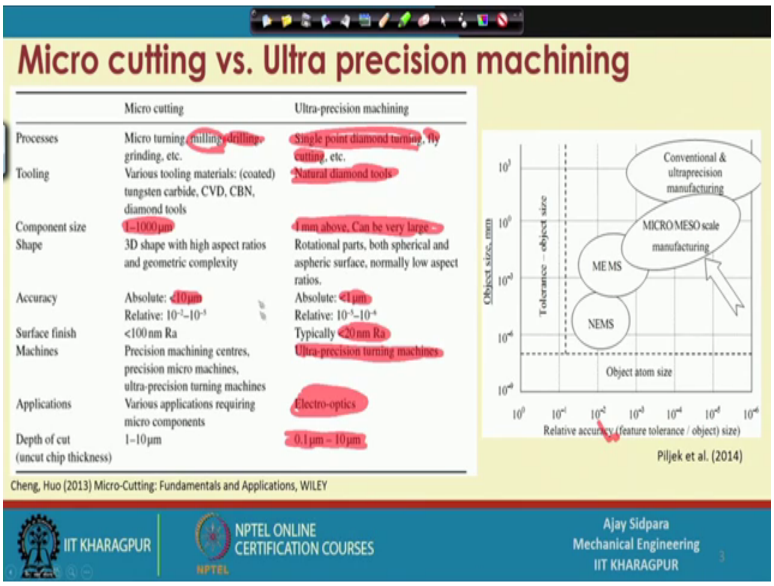

Now, we have discussed this thing long time before, when we continue when we discuss about the introduction section. Now this graph I am again putting here, because this will tell you that where this diamond turning or the ultra precision manufacturing is sitting in a and graph of an objective size versus related to accuracy.

Now, if you see whatever we have discussed till now micro machining micro machining is here at this location because now if you say that it has a relative accuracy that is very important and part size is here at this location it is in a tenth of millimeter to the few hundreds of micron. And if here if you see that, its relative accuracy means, it is a feature turning that what is the tolerance of your component divided by object size.

Now, this is what we have discussed. What we are going to discuss is this one that is ultra precision manufacturing, where we can you can see the part size may be in terms of the meters and what we are talking about the relative accuracy, it is much better than their other processes in this nano electromechanical system, micro electromechanical system or our micro machining operation.

So, here that is very important why it is very very low in the relative accuracy because low in the sense the high accuracy because smaller the value higher is the accuracy because our part size is very very big here in the meter scale and what tolerance we are making? It is in nanometer scale or the anchor storm scale. So, that is the reason that you will get a very very high relative accuracy in the conventional machining process and let us see the how these two processes are different.

So, this is these are the differences between this whatever we have discussed micro cutting by mechanical method and this is the ultra precision machining processes. Now you can see the process is what we have discussed till now, we have discussed milling operation there then we have discussed the drilling operation, grinding also little bit we have discussed by febrile for fabrication of micro cutting tools and here what processes they use mostly it is a diamond turning operation and fly cutting.

We will see this both the processes how these processes are useful. Tooling we have seen that we can use many different type of tool a and coatings also mostly it is a tungsten carbide, and then you do some type of coating to enhance the cutting tool life and reducing the surface finish, surface roughness and the wear of the bar formation of the components. Here what we are using we are using only natural diamond tools; because we want to make sure that our tool should retain its specification that means, the rake angle and other kind girls so, that you can actually get the define features onto the workpiece surface.

Component size this is very important here, because if you see this component size what we have discussed here that is here 1 to 100 1000s of micron and here it can be very very large also. We will see some of the example where the size of the component is at the meter scale. Shapes you can make any 3D shape, that is that is the advantage of micro cutting by mechanical methods here you can also do many things here rotational part spherical a spherical surfaces.

But mostly we get all these features in terms of turning operation. Absolute accuracy is less than 10 micron, but here it is very very high less than 1 micron and relative accuracy; obviously, it is highly this is related to this part. Surface finish you can very very easily get less than 20 nanometer, we also high you many times you will get less than 1 nanometer of surface finish on the different optical components. Machine we use here the ultra precision turning machines for fabrication of different different features.

But here there are we have seen that a bigger size machines are available micro machines are also available, depth of cut what we are doing the depth of cut is very very small here. You can see 0.1 micron depth of cut also you can give, depending on the precision and the resolution of your machine. An application is mostly the optical materials because we will see some many examples there, there most of the components optical in nature; that means, suppose you want to fabricate some lenses or mirrors, then you can go with a diamond turning operation.

So, these diamond turning or ultra precision machining has very large application area where you can get this thing done very quickly and compared to other processes, which are also available in the market. So, let us see further on this topic right. So, why we need diamond turning that is the first thing.

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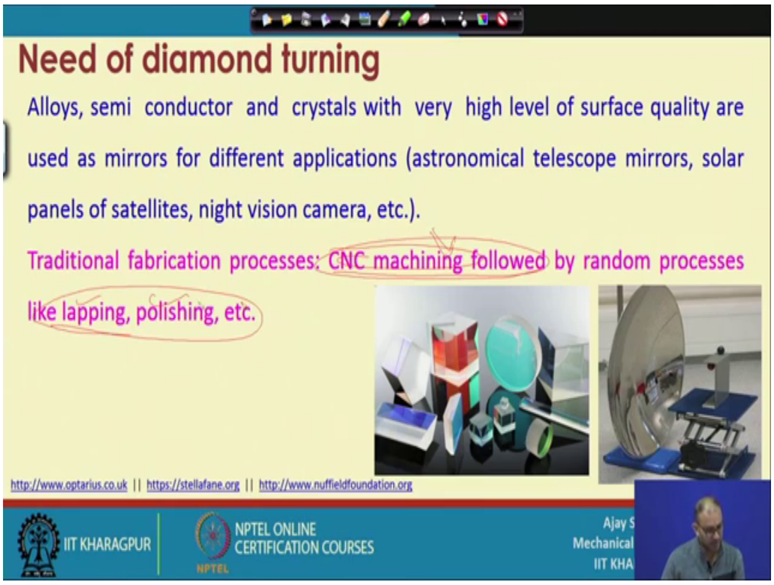

Because if you see the yellow is semiconductor crystals with very high level of surface quality are used as a mirror for different application, mirror and lenses astronomical telescope, mirror, solar panel, satellite, navigation night vision cameras even whatever mobile camera also have lot of lenses available.

So, all these lenses require very very high level of surface finish quality; that means, you need a form accuracy also very very high and the surface finish should be extremely high in the cases. So, at that time you need some process, which will give this type of a requirement on a optical component. So, if you see this different type of crystals available, these are mostly used to transfer or the transmit the light from one location to another location, some of the mirrors are there that will lights will be reflected and then you can get focused at different location and these are the some of the telescopic mirror.

So, that you can get the required photographs or some type of image is taken from the satellite right. So, traditional placing what fabrication process and these are the CNC machining process by the random process like the lapping and polishing. Because what we are doing here that, if you do not use diamond turning then you need a two step process.

So, first one what we are doing here that first you give a shape of that, suppose your shape is something like a concave type of this type of shape, then you have to make sure the shape you are reaching by CNC machining process mostly you can use them normal CNC machine.

And once your shape conformation is over then you have to look at the surface roughness, then for finishing of this component you do you have a many process available depending on the size shape and the properties of this material you can select lapping process or different polishing process so, that you can actually take care about surface finish or the surface roughness. So, it is a two step process, but here diamond turning what it is doing that, it will do both the things it will do shape correction also and it will do surface polishing also.

So, in a single step you will get advantage over both the processes right.

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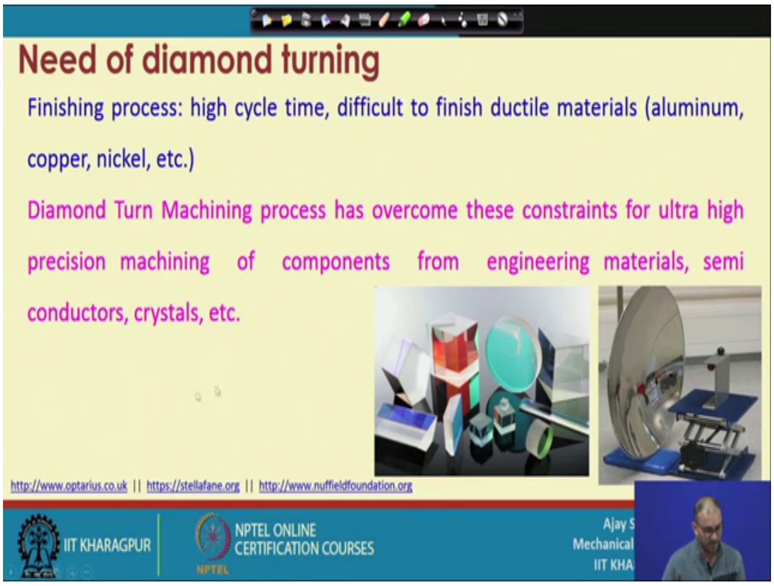

So, if you use that CNC machining and the policing part machining you can actually quickly do, because mostly it will not take much time depending on the size of the component and the shape of the component. But for policing what we are doing that we have to reach to a strong level all the sub nanometer level surface finish.

So, at that time you have to spend more time and you have to make sure that there is no further damage to the surface. Because our objective first is to remove the turning marks or the machining marks and then you reach to the required level of surface accuracy. So, that is the reason that it takes a lot of time here, the high cycle time is required because process is very very slow, because we do not want to damage the surface difficult to finish ductile material because when you finish ductile material, cheap formation is very very difficult because look of this ductile nature, it will actually do mostly the flowing things instead of a shear cutting.

So, copper, aluminum, nickel these materials are very difficult to police by this type of finishing processes. So, diamond turning machining process has overcome these constraints for ultra high precision machining of components from engineering material, semiconductor and crystals.

So, mostly if you see any non ferrous material and which has some connection with the optical applications or some type of where you are talking about the light transmission and everything at that time, mostly it is understood that mostly it will be processed through the diamond turning operation.

So, what are the applications of diamond tronic?

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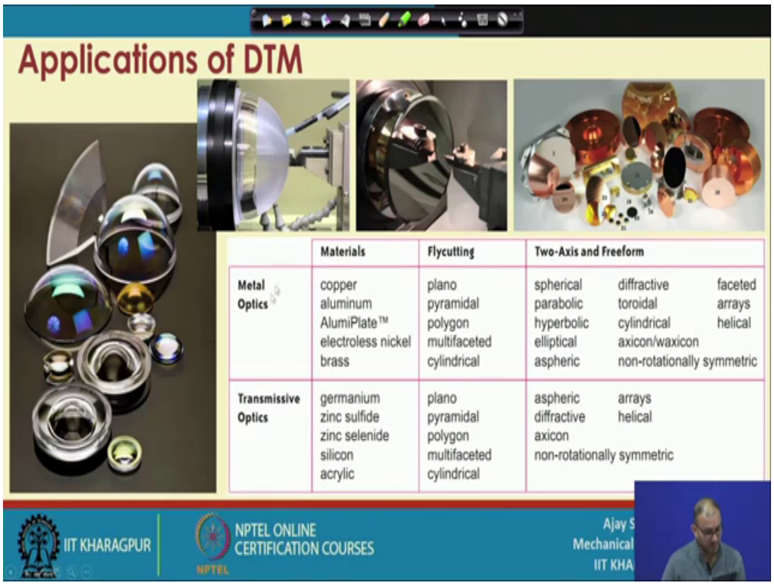

So, if you see oh most of the lenses, most of the lenses are fabricated by the DTM. So, this is one of the application where polymer is being machined on a diamond turning operation, and most of the metals non ferrous mostly because when you are using a diamond as a cutting tool, ferrous materials create problem for because of the carbon migration from the workpiece to the tool and because of that, you will get the different type of wear on the diamond cutting tool very quickly compared to the non ferrous materials.

So, copper, aluminum, brass and different type of a silicon is also one of the materials, and all these materials can be polished and you can see the surface spin is it is extremely high. You will quickly achieve less than one nanometer surface finish by setting optimum process parameter for their speed feed and depth of cut. Now these are the different different things and now if you see what are the different domains.

So, there are different type of optical material metallic optical materials available and the transmitter optic are also there. If you see material copper, aluminum, aluminum plate electroless, nickel, brass. So, these materials can be processed by diamond turning operation and this is the fly cutting. So, we will see that fly cutting what is fly cutting. So, these are the different different shapes you can actually fabricate by a diamond turning operation on this metallic surface.

And if you use it two excess of freeform. So, this is a turning operation and this is the fly cutting operation. So, here you can get the spherical, parabola, hyperbola, hyperbolic, elliptical appearing. So, objective of this thing was showing this slide is to you can see that different variety of the shapes you can fabricate buy a diamond turning operation. So, it is not purely a turning operation, but you have a freedom to move your z axis, x axis and c x is independently from each other and in synchronous also so, that you can get the required feature produce on a different surface.

Optics material mostly the germanium, silicon, acrylic, pmma is also one of the material. So, in this case also you can create a lot of different different cells by using two different set up by one is the by fly cutting and another is our conventional is a two axis machine that is x and z axis, and another is a free form where you need a additional c axis over the additional z axis so, that you can move to get different optic of freeform surfaces.

So, let me show you some of the videos here because that will give you more idea that how these things works.

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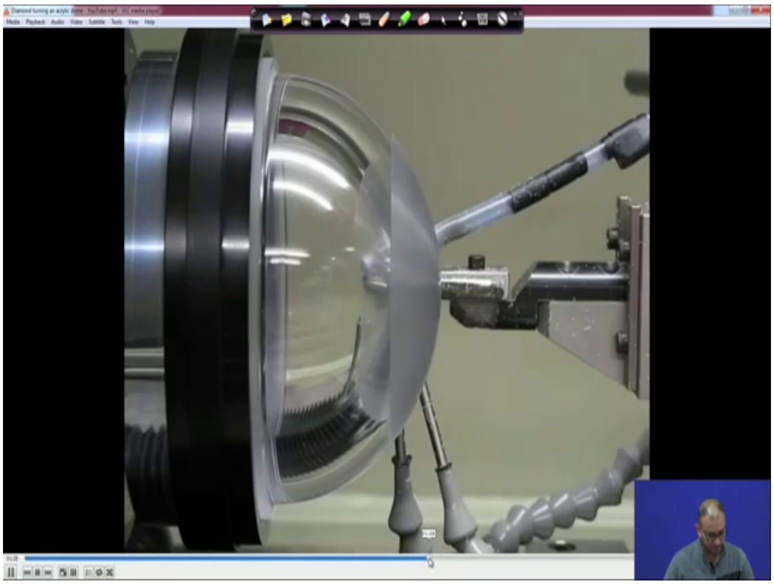

Now, this is the acrylic dome machining. So, this is right now is the shape. So, we have to cut this thing in such a way that you can get very very fine polish surface on the top, this is the tool post and cutting diamond cutting tool was on the other side, and this is the one type of mixed cooling or coolant or something, which will make sure that the component is not flooded by the cutting tool as well as it is removed cheap from the surface very quickly.

Now, you can see this is the surface which you can get by diamond turning. And you can see the reflection of different machine component here, this is the bellow on the carriage probably and you can see that how this thing is being machine.

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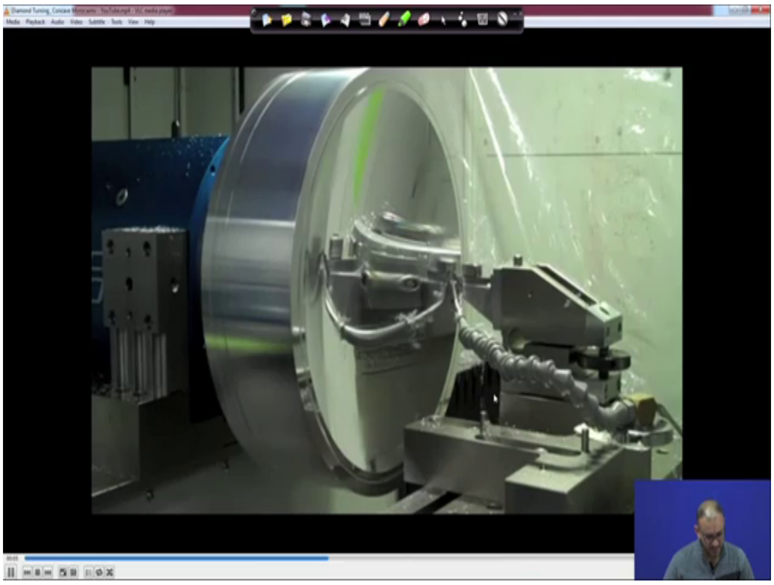

So, this is the one example, now if you see bigger size component now you can say this size is at a meter scale and these particular mirrors are mostly the aluminum mirror, where you want to get some type of a application on telescopic things. And this is the diamond single pole diamond cutting tool and this is the removal of this part.

And this is for a concave mirror similar to earlier application here also size is very very large and you can see these are the chips whatever is coming. So, you can see that it is almost a fine features. So, you machining requirement is very very less in this case and this is called the off axis mirror.

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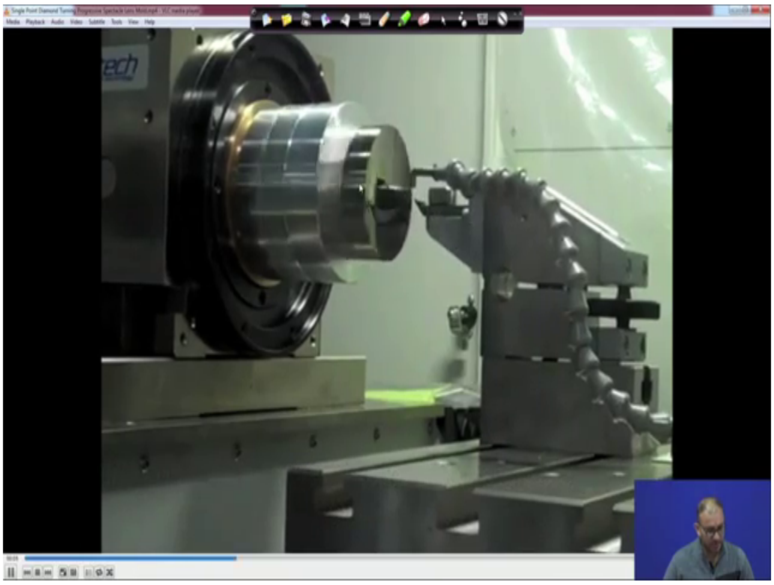

Now, you can see that you have a, synchronize between the rotational motion with respect to the movement in the z axis. So, these are called the servo mechanisms, fast hold servo and the slow tool servo we will discuss this thing in detail.

And suppose you want to make something different. So, here what it is doing that here this is fixed and your these axis is working z axis is working in a synchronous manner.

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So, it is the tool is now rotating, and you are making a different type of lenses on the surface. So, this is the lens mold.

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So, and after that you can actually.

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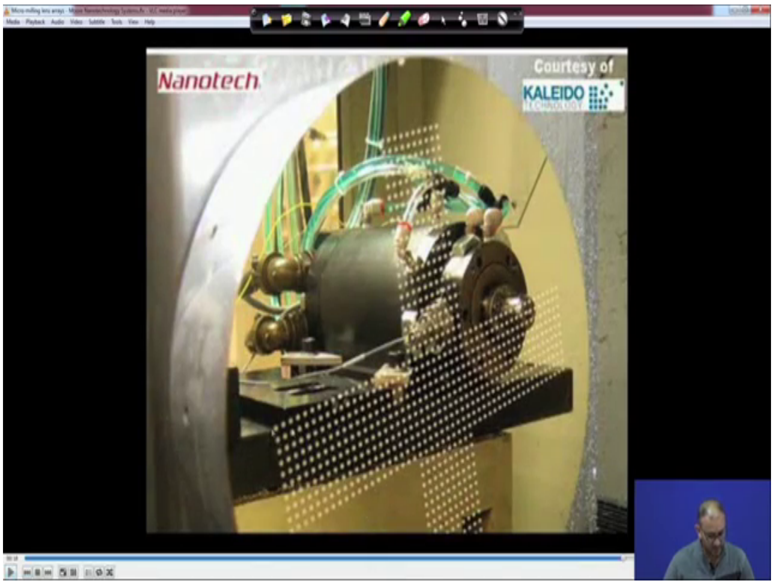

Create 100s of mold here on a very very optical grade surface and then you do some type of polymer molding and you can get the required mold in a mass production

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So, this is called rafter cutting raster fly cutting. So, what is happening in the fly cutting? So, here what we are doing that our cutting tool is located on the spindle side and oh it is a single point cutting your workpiece is located at the bottom and then you rotate the workpiece here in its own axis and then you rotate your cutting tool in this direction.

So, that it do the machining operation. It is not visible here because it is rotating at a very very high rpm.

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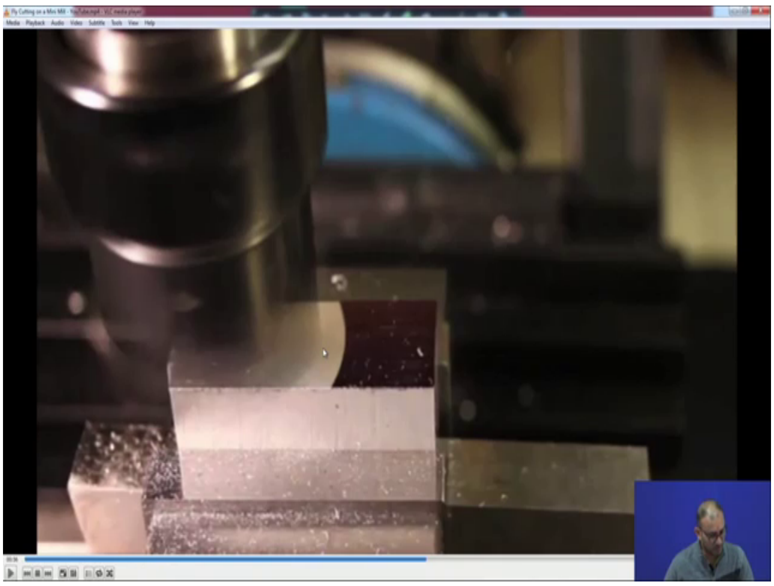

Now, let me show you this is the bigger conventional example, now you can say this is the work piece and this is the cutting tool. So, it is a single point cutting tool, but it attached with the spindle axis of the machine and then it rotates when it rotates it has only single cutting edge, which will remove the material. So, to get this thing down you have to rotate this thing is a high rpm in a very low feed rate. So, you will not get any type of mark on the top surface.

Now, you can see that it is rotating and now you can give feed at it on to the workpiece. So, now, it is remove the material. So, what is the advantage of this thing that, here what happened that you can actually do material removal on a very large surface, depending on what is the working area of this particular fly cutting tool. If it is a larger; that means, you can get them even the tens of centimeter of workpiece they cut in a single pass, no need to do a multiple pass for machining of those components and another thing that this is the curvature.

Now, if you see that you put this particular cutting tool on a horizontal axis, then whatever is this curvature you can create a concave surface on a any circular component or the non circular compound. So, that is another advantage because if you want to create a concave surface by a three axis milling machine, then you have to give a very very small amount x, y and z axis simultaneously and that will create lot of problem at the literature.

Because now, it will this micro movement of in x, y and z direction, that will create some problem at the different type of for tool marks. So, you have to remove those tool marks at the later stage, but here what happened that, we are actually using the circular motion that mean whatever is the radius of this particular cutter, the same radius of concave surface you can create on a surface on the any workpiece or optical material without any problem.

So, this is the conversion machine, but same thing is happening on a diamond cutting tool also. Remaining this fast food service slow to server we will see when it comes.

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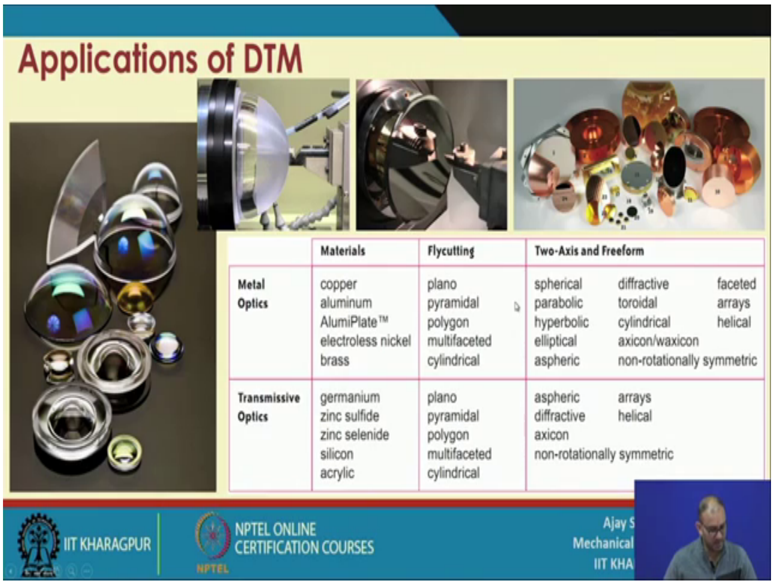

So, these are the different applications of a diamond turning operation of diamond turning machining. So, we can see that it applications there applications are very large in terms of processing of metal components, polymer components and there are many different type of shapes also you can produce by this process.

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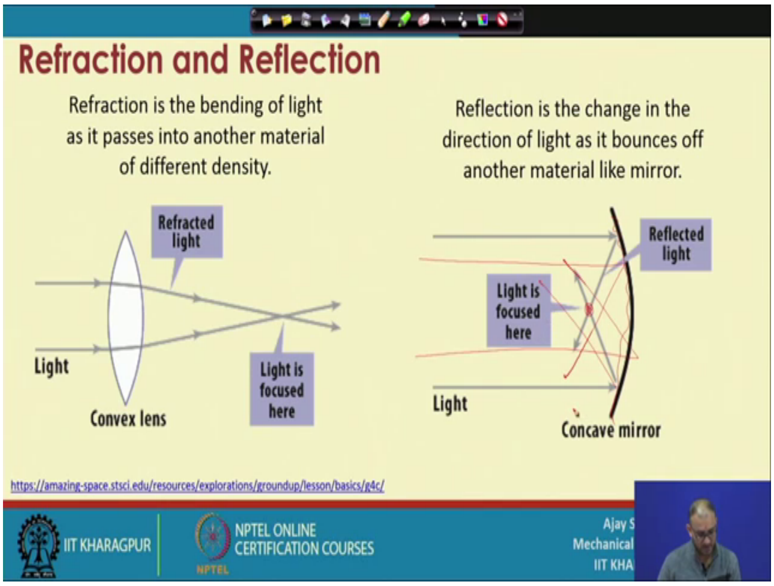

Now, what is the reflection because we can get two different type of things, one is you can fabricate lens also and you can fabricate mirrors also. Now, if you say what is the application of lens that this is there one lens here and live and light is passing through it, then it will focused at one location. So, that is called refracted of the light. When light is passing through the object, then it will actually bend and after bending it will actually coincide at one location depending on how many rays are coming from the left direction.

So, you need a focus point here. So, refraction is the bending of light as it passes into the another material of a different density. So, now, the air density is different workpiece this material refractive index is different and then you are getting the light focus. Now what is important here in this location. So, your important thing is then how this thing works.

So, our objective is to get this focused point right. Now, what happened that if there are roughness is here, there suppose this is not completely polished with a high degree of surface finish and other thing that its shape is not this type of suppose it is there is some variation in the shape, suppose shape is something like this it is not exactly concave or convex on the other side then what happened that this particular ray will go here, this ray will go here, there is another ray which is coming from here it will go here and similarly this way and this will like this way.

So, you will not get a focus point; that means, all rays whichever light whatever is coming from left direction to the right direction, they will not actually converge to one location, but they will not cross at a one location. So, that is the big problem here. So, if you do not get the shape accuracy and the surface accuracy very very fine, then you will get this focus point at a different different location.

So, light is not converging to the one single point and because of that you will lose intensity you will lose the surface accuracy also here; that means, whatever things you want to transfer from here to here you instead of a circular point, you will get a oval point or you will get some other shape. So, at that time you are losing many features of the light. So, that is the why you require very very high surface finish in the shape accuracy on a lens.

Another thing is the mirror. Because here what we are doing in lens we are transmitting light from through the surface, but here what we are doing we are reflecting the light. So, here whatever the light is coming parallely in this direction and depending on the concaveness of this particular mirror, you will get focus pointed at different different location right.

So, what is the reflection? Reflection is the change in the direction of light as it bounces of under material like mirror. So, mirror also you need a very very high finish. So, similar to what we have discussed here now if there is a roughness here, and the shape is not exactly concave; that means, there is no figure accuracy then this ray will come here this ray will go here at this location another ray which is coming here it will go here this ray will go here.

So, you will not get this particular focus point, and that focus point is may important because sometimes you want to concentrate your all energy to one location, to get things done there are different material science applications available in different type of microscopic imaging available applications, where you want to focus the light at a one location only. Smaller is the focal point more is the important things you can discover from that material player research applications.

So, these are the two different applicants; most of the times we go with the lenses and mirror by processing through the diamond turning operation. Now what are the different classifications of diamond turning?

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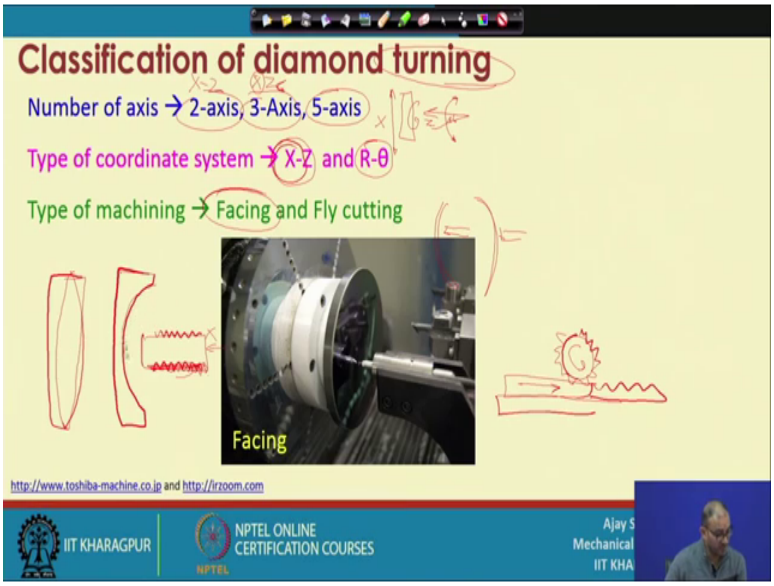

So, there are two one is the number of x is 2 x is, 3 x is, in the 5 axis. So, here this 2 axis; that means, we are talking about the normal turning operation, whenever we are talking about turning operation this is the x and z axis x and z axis only.

So, here 3 axis; that means, one of these axis will move independently. So, mostly it is xz and c axis because we want to control the movement around the z axis and if you want to add one more axis, then you what you can do that you can give the tilting of the x axis also. So, this is your cutting tool, then you give a tilting of this particular cutting tool in this direction theta with respect to there this is the z, this is your workpiece, then workpiece can also move in this direction that is called the x direction and rotation is; obviously, there.

So, in that way you can actually give more freedom or the more flexibility to the movement of the workpiece or approach to the cutting tool. Another is the in terms of coordinate system, if you consider the X and Z then it is a normal turning operation where we generally give a programming to the X and Z; that means, in X direction you give a depth of cut and then in Z direction you give a; Z direction you give depth depth of curve and we actually then X direction you can give a movement that is when you do facing operation. R theta means here what we are doing we are not actually working with a cartridge in coordinate, but we are actually working with a polar coordinate.

So, suppose you want to create some type of concave surface or convex surface, this step and your cutting tool is here at this location then what you can do? You can actually do machining a by means of R and theta system. Then type of machining is a facing operation and the flying operation. So, this is what we are doing a facing operation if you see diamond turning, diamond turning most of the lenses what we want to create we want to create features on a flat surface only.

Now, if you see we have seen there are lot of application, suppose this is the component where we want to create some type of surface. So, what we do suppose you want some lenses, then what we do we cut we do cutting along something like this correct. And suppose you want concave surface then in the one surface we do something like this correct.

So, most of the applications are actually focused to the facing operation, turning operation is what is that suppose this is your workpiece and you want to turn this surface; that means, our objective is to get features on this surface, node to this surface. So, at that time we do, but those applicants are very limited because suppose sometimes what happen that you want to create some features here, and you want to suppose you are creating some features here that is the one of the application where you can do some type of mass molding of a polymer material or polymer sheet.

Suppose here you have some type of features created sample something like this and all the surfaces, and then what you do that you create take this particular wheel here. So, this is that wheel, and these are the features what we have created on the surface and there is a polymer sheet which is coming in this. So, you rotate this particular part and then do you move this polymer sheet through it.

So, what we are getting that we are getting or this feature transfer on to the polymer sheet and then there are different application for different application of a polymer material with a textured surface. So, this is one of the application, there are another two-three applications are also there where you want to create some type of lenses with a circular patterns, you create those patterns on the cylinder and then you actually do a molding of their polymer material or some other materials by that way you can do much machining on a as a turning operation.

But most of the application 90 percent or more than 90 percent applications are related to the facing only. So, you can get different different features on the facing surface and that is why X and Z and R theta comes into picture.

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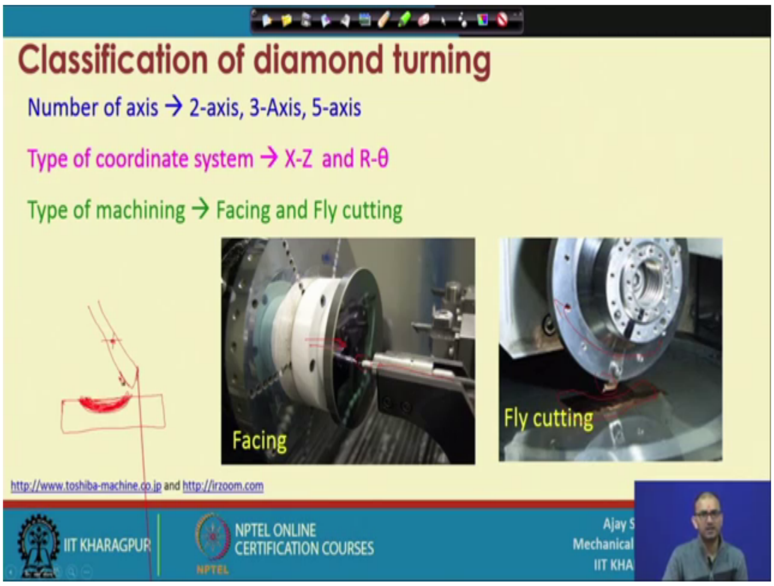

And this is their fly cutting. So, now, how is that these things are different? Now, you can say the cutting tool is located here on a tool pose, but here cutting tool is located on a spindle size or workpiece is on the headstock.

But our workpiece is now located on a tool port; that means, on the base surface. So, when this particular thing rotates at that time it will (Refer Time: 27:38) power the material from the surface. So, this is our surface and this is our cutting tool. So, this is our cutting role it is rotating from this particular axis. So, when it is moving at that time it will remove this much amount of material all right.

So, if you want to create a concave surface then you continue this thing down and down and you finally, you get a concave surface out of it. And if you want to create some other features then also you can get this thing done very quickly. So, let me finish this lecture here because now many things we have to discuss further on a diamond turning operation, we will continue this topic further in the next class.

Thank you very much.