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

Lecture - 62
Sensors and metrology for micro machining (Contd.)

Good morning everybody and welcome again to our course on Introduction to Mechanical Micro Machining. So, today is our last class of this course; so, let us understand that what things we have studied in the previous class. We started a topic on acoustic emission in the force measurement system.

So, acoustic emission sensor we discussed about that how it is useful for measurement of sense sensing different type of signals; based on the micromachining operation.

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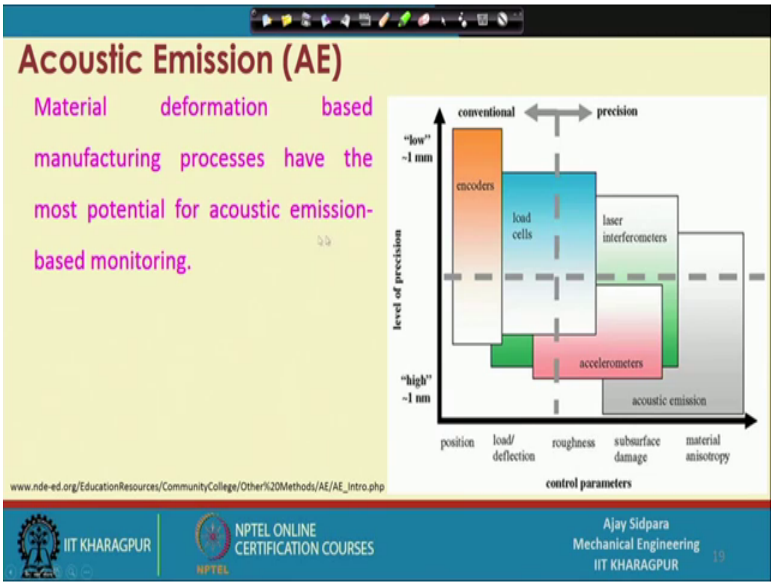

Now, you can see that these are the different type of systems available which will do measurement of a different quantity. And now you can see that in this particular x axis is what we are looking at here. So, this is called the position; that means, when you want to do measurement of a position what we use? We use encoder that we have seen long time before in the optical encoder; that means, the render encoder, rotary encoders and absolute encoder and incremental encoder. If you want to do measurement of a load and deflection, load cells are available which is mostly based on the strain gauge type of things.

Roughness and everything we use the laser interferometer and accelerometer also used for that. Subsurface damage and material anisotropic; that means what we are doing here? We are goings way down and down into the small and small component.

So, here if you want to do measurement at a very micro scale or the submicron scale then what we are can we have to do with a acoustic emission. This is the level of precision when you are talking about the millimeter to a certain level; we know that up to a submicron level we can use encounter for measurement or the position of the different part. But when you are talking about the nanometer level now you can see that most of the time acoustic emission sensors are very very useful in things, there are lot of area which are overlap with each other.

So, those areas can be very highly useful, now you can see here. So, this particular area if you take that other than acoustic emission sensor in load cell; this all three are actually useful for that; so, you have to select one of the systems which is more reliable and which is suitable for your application. But if you see this particular area this area is mostly dominated by the acoustic emission part.

So, that is why acoustic emission has very very strong demand or more reliable system which is used for measurement something at the microscale right. So, material deformation based the manufacturing processes have the most potential for acoustic emission base monitoring system.

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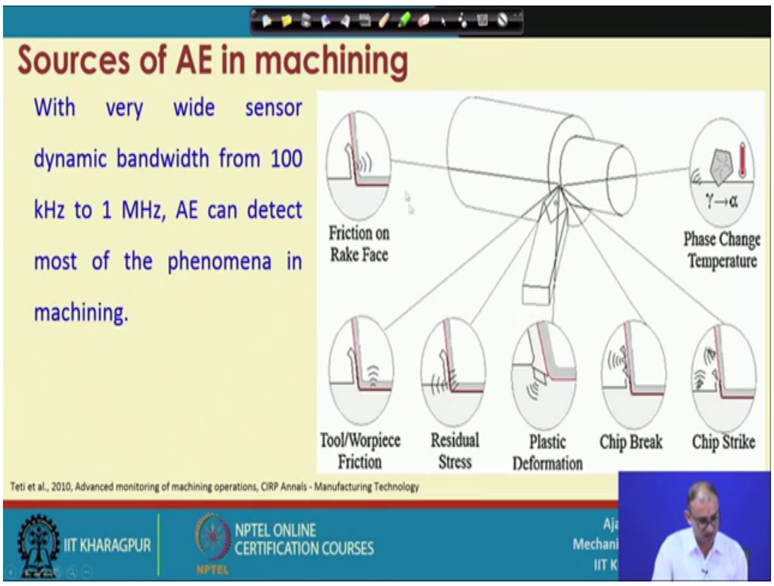

So, what are the different sources at in the machining? Now if you see when you do a turning operation many things will happen in the machining also. One is the friction on the rake face because when chip will flow over rack face, you will get one friction. Tool and work piece that is on the flank surface part, residual stress is also generated, plastic deformation takes place, chip breaking also happens then chip striking that when you are machining at a very very high speed and the brittle material; you will get discontinuous chip and this chip will sometimes again strike to the tool.

If there are phase change available when you do machining at a very very high temperature you will get phase change. So, these are the different sources by which you can get the acoustic emission waves and that you have to capture by this particular sensor. And you can see that it has a high bandwidth starting a not standing, but this is a very general available 100 kilo hertz to the 1 megahertz. So, it covers almost all the phenomena in the machining operation.

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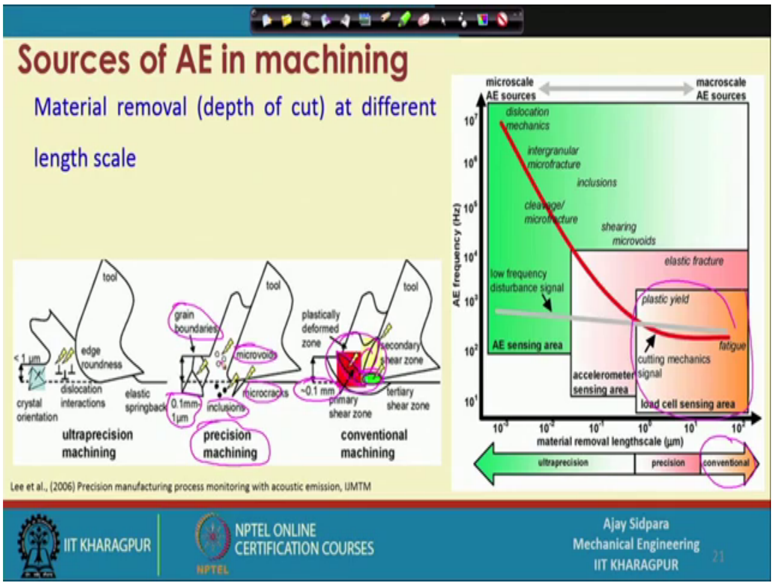

So, if you cover if you plot in terms of depth of cut now you can see here now this is the unconventional machining where you consider material removal length scale you consider as a depth of cut right. So, if you see conventional machining process when you talk about the depth of cut around 0.1 millimeter 100 micron or something we note that there are difference of one is the primary zone, this is the secondary zone this is the third tertiary zone shear zone.

So, in this way you can get the deformation and mostly you are end you look at to the very bigger scale. So, this is what we are looking at this particular part; so, this is the measurement area at this particular conversion machining. When you talk about the precision machining what we do that? Now our depth of cut is very small talking about 0.1 millimeter to 1 micron. So, here what happened and now what we are do we have already understood this particular now we have to look of the defect inside the material. So, there are inclusion, microcracks, microvoids; so these are the things of grain boundaries those things play important role in the machining operation right.

Because we know that we have to maintain the uncut chip thickness to the cutting edge radius ratio also; otherwise you are end up with the rubbing and the flowing of the material only, you will not get the actual cutting of the operation right. So, now, if you see this thing it comes under the accelerometer area also, but if you go with ultra precision where the depth of cut is less than 1 micron now you have to further go inside it. And then within the grain what you are looking at this part then you are looking at dislocation interaction edge, elastic spring back, crystal orientation that even in different orientation material behave differently; if material is anisotropic right. So, in this particular case what we are looking at ultra precision; now you can see that area covered by the acoustic emission.

So, this is the area covered and now you can see all the disturbances which happens at a very small scale dislocation mechanics, the micro fracture, inclusion, then the cleavage ir micro fracture. So, if you see in terms of micro mechanics point of view acoustic emission actually very very important tool to measure all this behavior at a micro scale right. So, that is the reason that acoustic emission is very important tool for understanding the machining at micro scale right.

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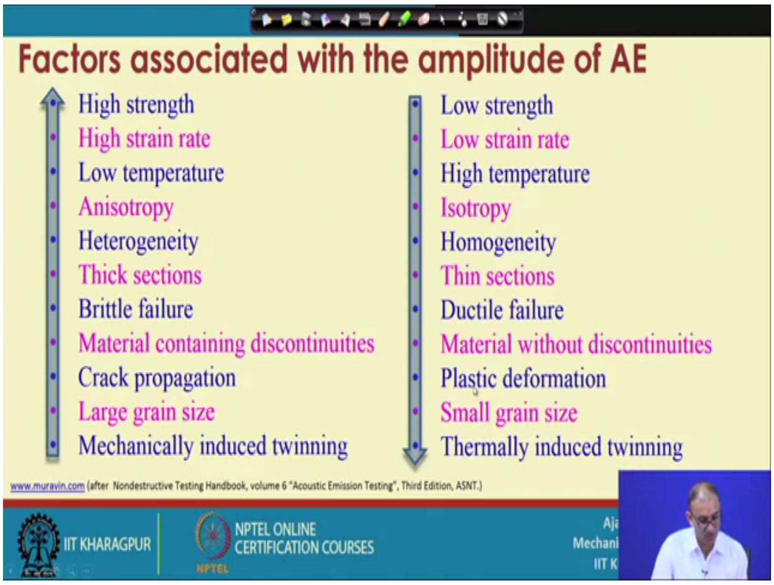

So, if you see the what are the factors which will increase the amplitude of the acoustic emission? If you see the high strength material then you will get a high amplitude high strain rate that is when your speed is very very high; you will get a high amplitude; low temperature if you increase the temperature material becomes soft, so, your signal strength will be low.

Anisotropic material give you high amplitude; heterogeneous mean there are different faces available, thick section; that means, your depth of cut suppose it is more then you will get more, brittle failure will increase the amplitude. Material continue a containing discontinuity then you are also getting lot of disturbance in the amplitude and mostly you will get a high amplitude. Crack propagation will increase the amplitude large grain size because if the grains size is large we know that we have to cut through the grain because one grain you cannot pull out completely.

So, your forces requirement will be very very high and you are getting a high amplitude and mechanically induced twinning. So, when you actually you induce twinning by mechanical method then again your material become more strong and then you are grinding with the more signal of the amplitude.

So, by these are the parameters which will increase the amplitude of the acoustic emission signal. And these are the signals which these are the parameters which will reduce the amplitude of the signal. So, you can say this is exactly opposite to this thing high strength, the low strength and high strength strain rate then low strain rate. So, by that way you can get the rest of depending on the which type of material and which type of condition you are creating for machining; you can understand that by qualitatively that what type of signal you will probably get out of the acoustic emission sensor.

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And there are different methods available by measurement of the cutting tool and the workpiece; you can see these are the different. These are contact type this is the by means of some eye magnification camera, this is laser base and this is by the touch probe. So, let me show you some of the videos by which you can more understand that what things are there. So, this is the first thing by which you can do a touch probe machine measurement.

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Right; so, it is touching and then it is getting a signal and you will get a signal of the tool.

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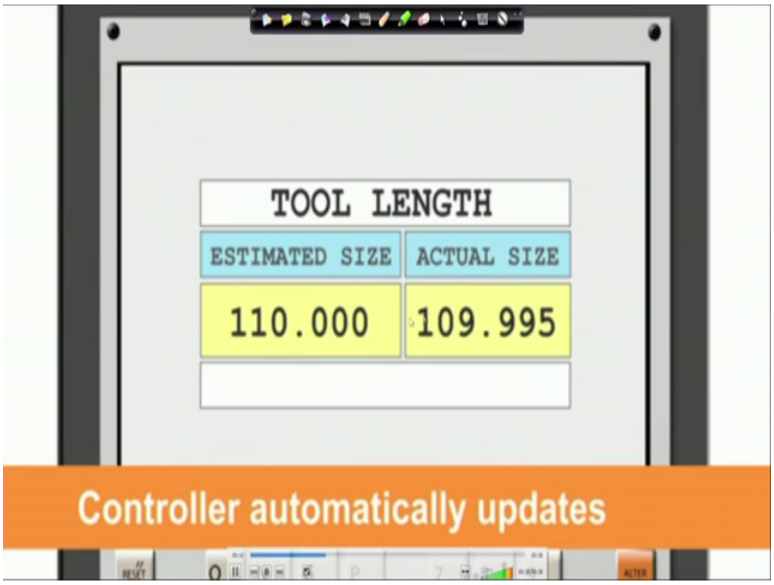

And that initially it was like this is the actual one. So, you can actually do correction in the tool length.

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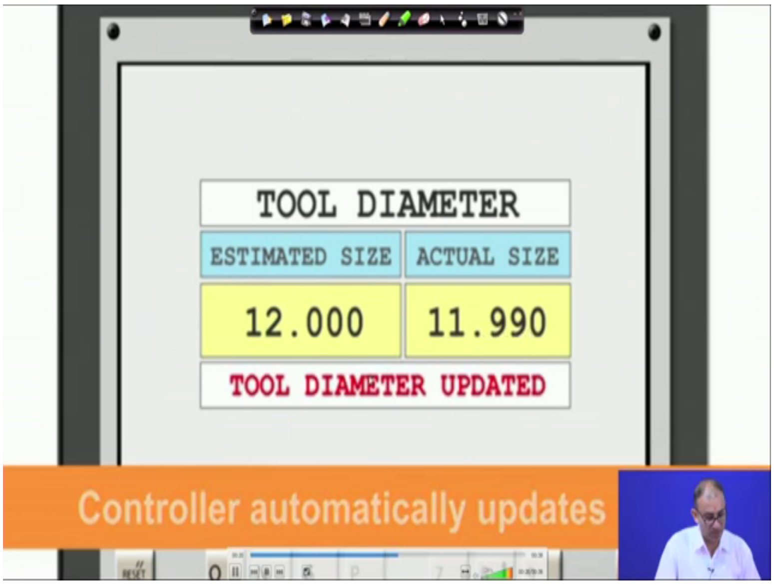

And by this way you can do correction in the diameter and this is the diameter correction; you can see even it is in micron level still you can get those things done and then you can do a detection of the tool wear by measure.

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You can see this is the tool wear which was happened after machining.

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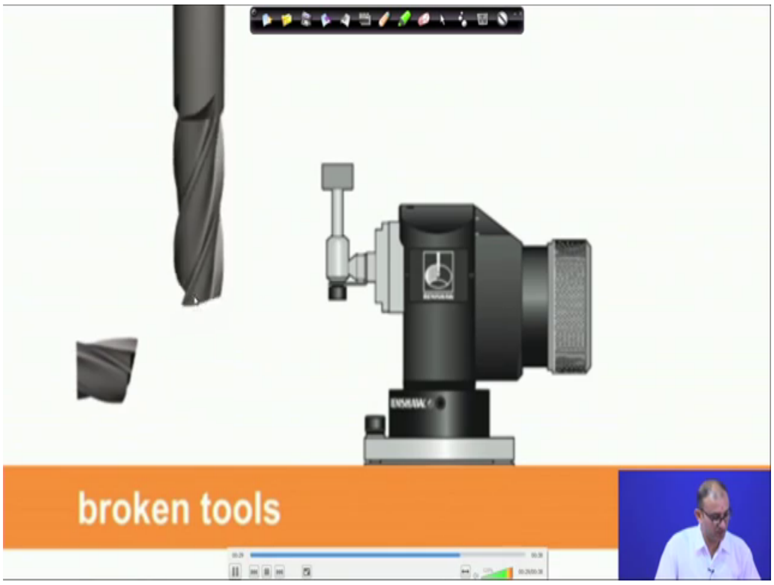

Or it is a tool broken all the things you can get you can get all the information from this contact type things. And for the laser measurement this is the noncontact. Here what you are doing? That, you are measuring the different type of tool which mostly it is a micro tool.

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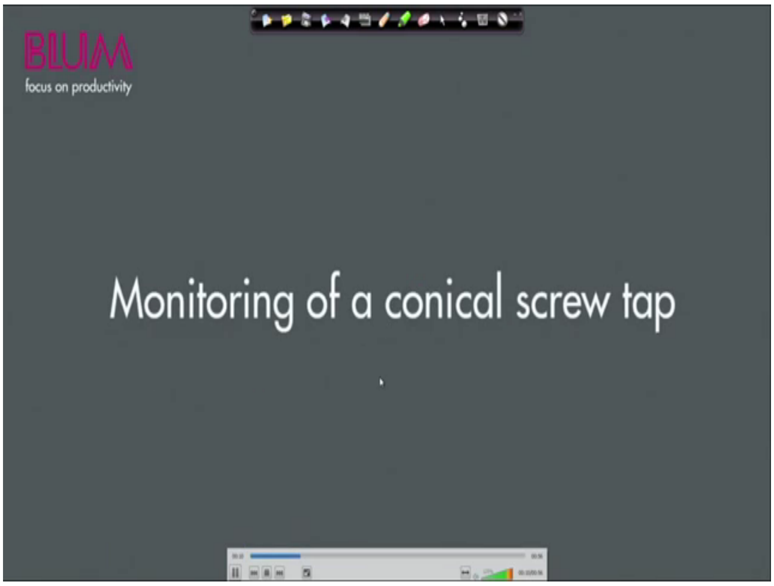

Right now here conical screw tap we are using.

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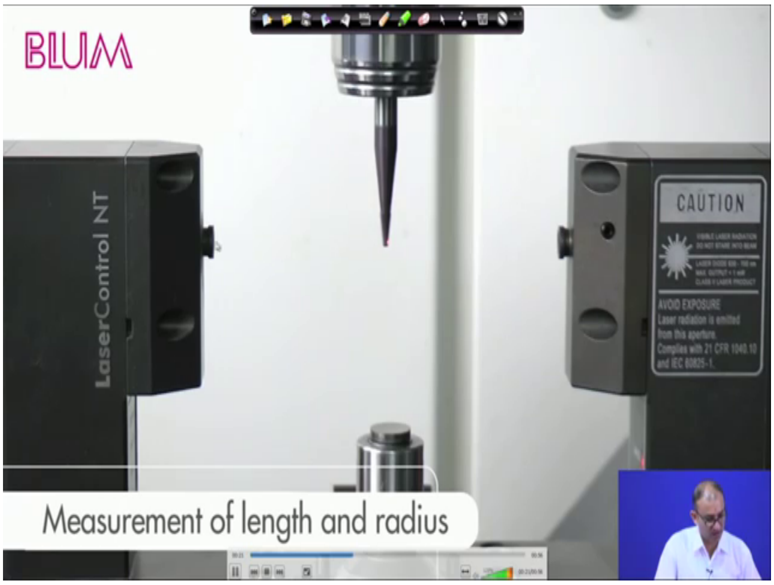

But you can use micro tool also. So, laser is coming from one location another it is a receiver. So, when it is coming here touching this location you can get the laser signal here and then you find out the length and the radius measurement then you can also if it is going up and up continuously then you can do measurement of a tip profile also.

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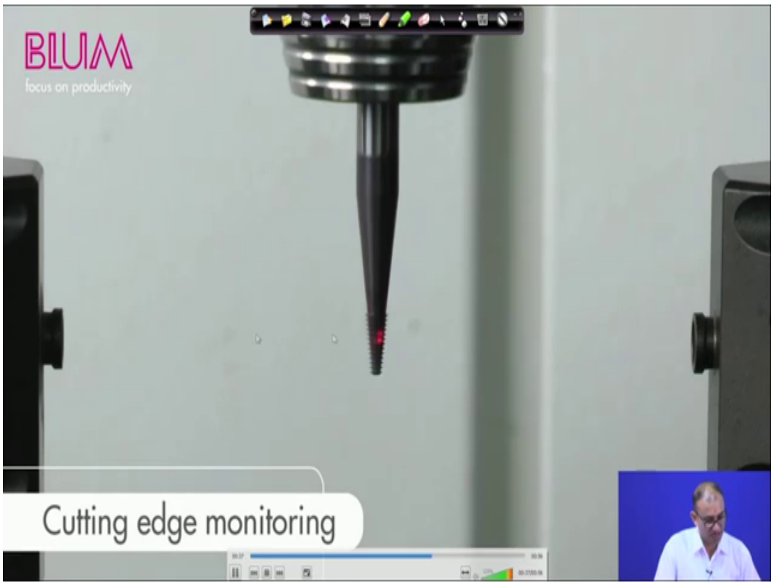

So, cutting edge monitoring now it is going one by one on the top surface and based on this laser transfer from one location to other way, you will get the edge monitoring also.

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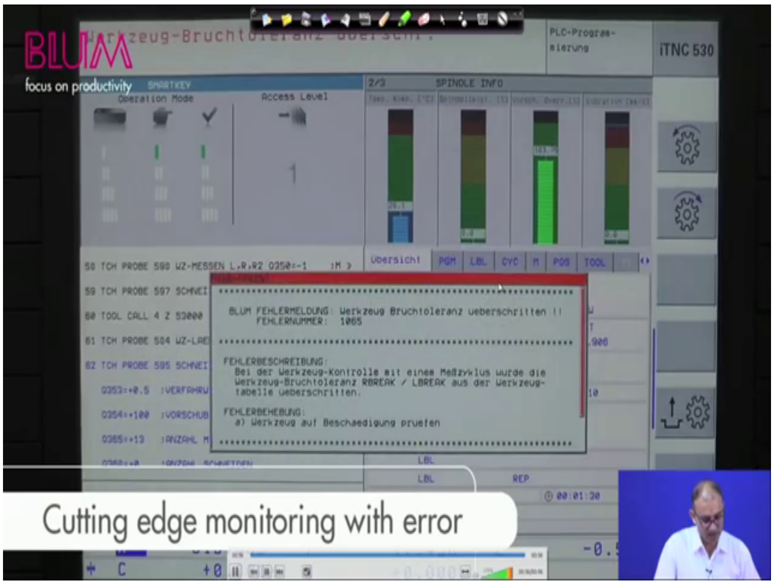

Right; so, this is the one of the ways by which you can do some type of corrective action also by including those type of cutter we are. And this is the machining operation where you can do all the measurement within the system.

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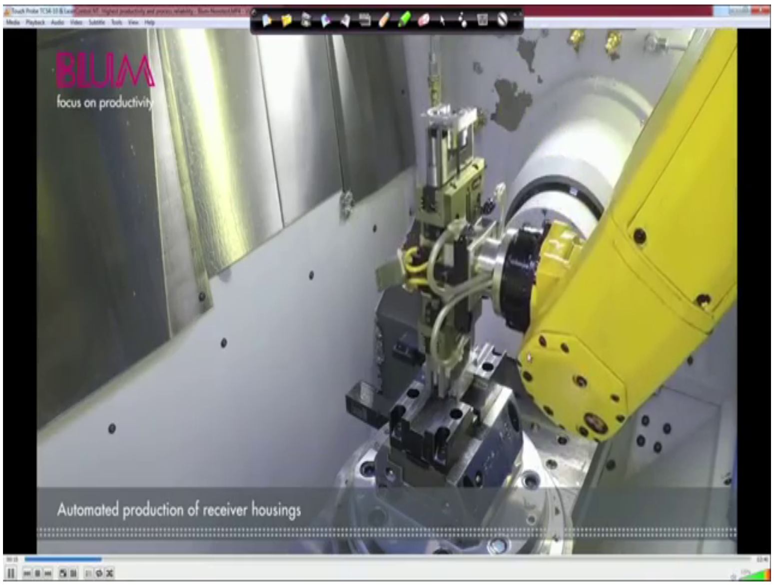

Ah. So, initially this is the setting of the component where you are putting this part and this is the cleaning of that. Now it has cleaned the surface and then you are putting this part.

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And now, there is a touch probe available. So, this is the touch probe by which you are sensing this position that where it is located exactly; whether it is a there is a deviation in the measurement or not. So, by this way you can do all the measurement; so, this is a wireless completely you do not need any hard wire also for measurement of that. So, this is the workpiece location measurement. So, once that part is over then you do machining operation here.

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So, machining operation also after machining what you have to do? You to do measurement of the cutting tool whether the tool is wear out or not right. So, this is that laser part again; so, you put the laser here and then you do measure still it is useful.

Then do the second operation slot milling then this system is available here that location now again do the measurement here. So, you do not need to worried about any type of secondary open that you do not need to remove the tool itself, everything is done here. So, now, this is the part this is the laser system available here at this location.

After each and every operation you do the measurement of the cutting tool position and then perform the different machining operation right. This is the same way and now this part is over then you can move this part to some location take another part and do the same operation again. So, now, you can see that this is the these are the some of the ways by which you can improve the productivity and use the efficiently use the different type of sensing element for making your system more robust. Now coming to microscope now till now what we have used?

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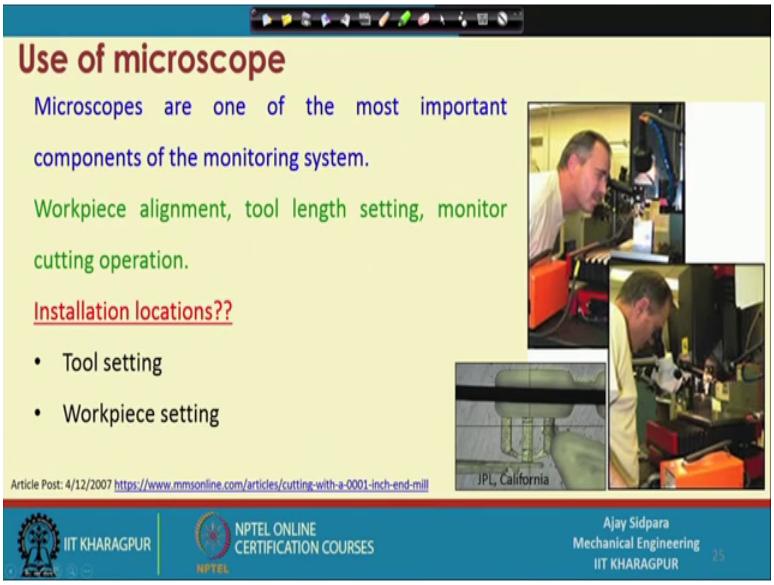

That we have you sensors by which you can get some datas, but microscopes are also very important. So, it is very one of the importants components for measurement system or monitoring system. What you can do? You can do workpiece alignment, tool length setting or monitoring and cutting operations.

Where do you install these things? That because we are worried about two things one is the tool setting and another is the workpiece setting. So, first one microscope we have to ensure in such a way that you can do measurement or the tool setting measurement; another we have to put like something where you can do some measurement on the workpiece.

So, these are the two different situation by one is the located on the axis of the cutting tool; that means, Z axis and another is mounted little bit on the side. So, that you can monitor the cutting operation and this is the cross hair available on the microscopes for the alignment purpose.

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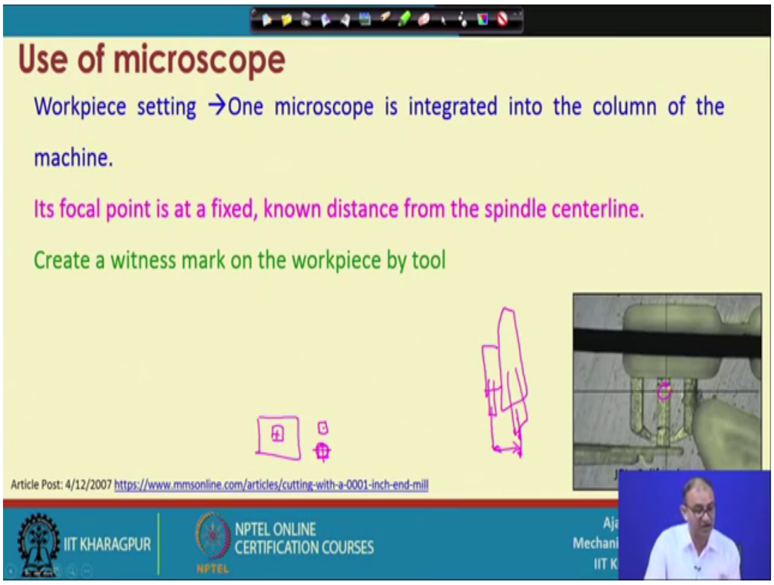

We will see how you can use those thing; for workpiece system one microscope can be integrated into the column of the machine. So, here it is a focal point; so our this is what is the focal point its focal point is fixed and known distance from the center spindle center line right. Suppose you have one system here; so, this is your spindle and this is your cutting tool and now you install one microscope here some location here rights and this located is.

So, you know this distance how much is distanced from each other and then once you create one indent mark here and then move this microscope here and then you find out what is that indent mark right. So, create a witness mark on the workpiece by the tool; so now, this is the workpiece right. So, you create one witness mark here and that is by cutting tool and now you know that this is the situation of the cutting tool your cutting tool is located here and your workpiece your sensor is located here according to this particular situation.

This is your cutting tool and this is your sensor. So, now, you have cut measured this particular part and then move this particular microscope this particular closure to this location. So, you by that way what you are doing? Actually you are monitoring the situation of the workpiece that from where you are starting the machining operation.

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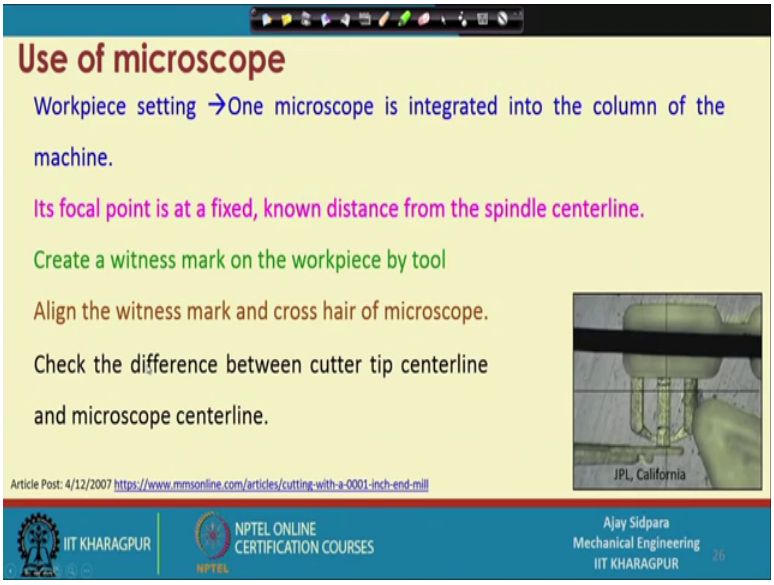

Ok and align the witness mark and crosshair of the microscope. So, wherever you have created that witness mark; you align with this thing and check the difference between the cutter tip centerline and the microscope centerline. So, remember that value and when you do machining operation then what you can do that, every time you know that what are the difference. So, you can find out all the dimension with respect to that particular reference point. So, that is the advantage of using one microscope for the Z axis.

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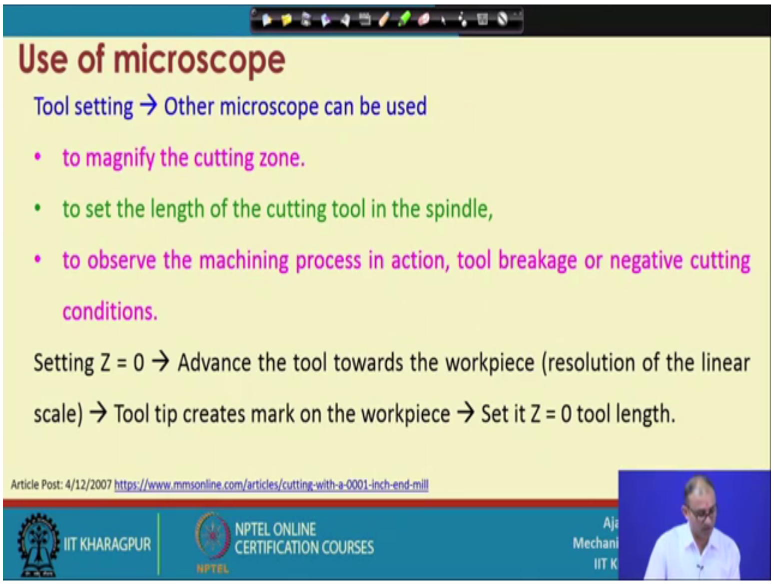

For the tool setting what you can do? That other microscope can be used for tool setting to magnify the cutting zone, to set the length of the cutting tool with the spindle and to observe the machining operation in action. If cutting tool is broken then also you can find out because it is a direct view of the actual operation; you do not need to do any type of confer transfer or transformation from one parameter to another and negative cutting conditions also can be measured.

How you can do? The for setting up a Z 0 what you do? That you move tool slowly down and once that depends on the resolution of the linear scale; whatever we are using 0.1 micron or 1 micron and when the tool tip creates the 0.1 because you are contains looking from the microscope; when it creates the mark you can understand this is the Z 0.

This is routinely used for the some machines where you are not using any type of probe system; whatever probe system we have seen in that video it is fully automated you do not need to worried about this particular part. Because it knows that where is the Z 0 location of the workpiece and based on just calculation of the cutting tool by the laser system or laser sensor you do not need to perform with this thing.

But this is the machines which are modified for getting the operation of a micro machining job. Because every time you do not need to purchase the separate machine, sometimes you can modify your existing machine in such a way that you increase the

RPM of the spindle, you put a linear axis, linear scale and then you add the some type of systems such that you can get the required things done at the bigger small machine also.

So, this is we are talking about the system which is not fully automated or not actually cropped with the lot of sensors. Now coming to the surface measurement because once you do measurement of a once you could do machining of the component; then you have to do lot of measurement, dimensional measurement and then you have to do measurement of the surface roughness then burr formation many things are there.

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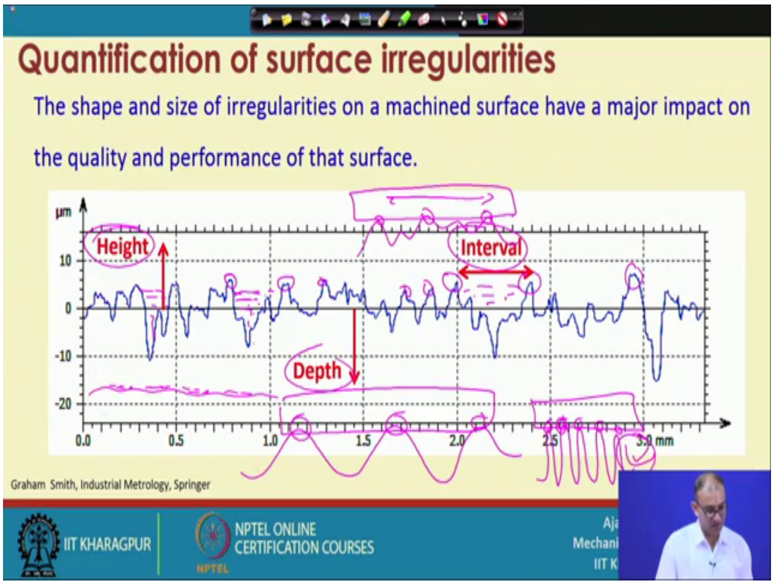

So, this is the routing graph which you can get which you can get from the surface profiler. The shape and size of irregularities on the machine surface have a major impact on the quality and the performance of that surface.

Because now if you say that if this is the roughness profile and then you can see that it is very very rough surface; if you considering this variation is the plus or minus 10 micron. But if you see one graph is here something like this then this surface is much better than the earlier case. So, by that way you can do lot of measurement or lot of understanding about the final use of that component where it is going to use.

So, what things we do measure here? We do measurement of the height after how once you get this a particular graph then how do you may get some information out of it the;

first you do measurement of what is the height right. So, what are the heights here? So, these are the heights these are called the peaks peak of the surface roughness profile.

So, higher the peaks what happen? The these surfaces are very very bad in the sense because if there is a relative motion then what happen that most of the loads are taken by those particular few locations only. And when it is moving here and there their view of this components very very large and because of that you are not getting a very very required operation out of it. Second thing is the valley that what are the different valleys? How this valleys are important because now suppose you are putting some liquid here the liquid will float here right.

So, whatever valleys are there that will be completely filled up here; if it is a corrosive liquid or corrosive fluid then what that it is detrimental to this part. So, at that location if you are putting this particular component with this roughness profile and you are putting in some environment some corrosive environment anything staying on this particular valleys or depth; it will create a problem.

So, better to have a very very smooth profile so, that your liquid or the corrosive liquid will not stay on the surface that is very important. And third one what we are looking here is the spacing that how these peaks are separated from each other right. So, that is also important; height is important, depth is important, the interval is also important right. So, if you see that you have one surface like something like this and you have another surface something like this with the same amplitude.

Now you can see here the load if you put some load here; this load is taken by 3 points only, but if you put same load here this load is actually taken by many points here right. So, this surface will play very important role because for peak you are getting a very less amount of load because it is equally divided more peaks that will be more divided by that way. So, in this way it is also important throw liquid how much liquid is filled up in this that is also important. So, depth height and intervals are very important for the surface.

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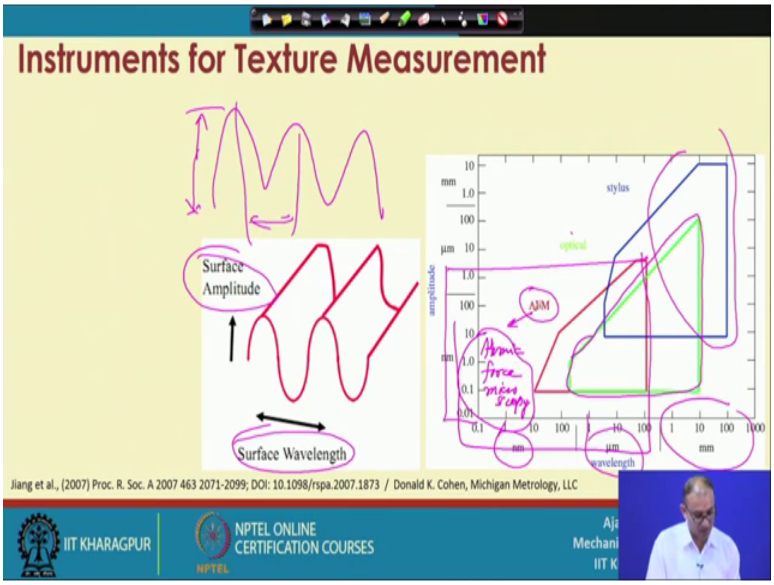

Right; so, what are the stylus type is one instrument one is the optical this is stylus means contact type whatever graph we have seen earlier class earlier slide that is captured by the stylus type.

Optical type; that means, noncontact type and AFM it is Atomic Force Microscopy. So, that is called Atomic Force Microscopy. So, you can see that you can get very very small amount of dimension or something that is considered the 1 nanometer 1 micron to down to the angle less than 1 anglestrom also and it has a very very small range.

So, you have to find out something which is very if you if you are looking at a very very large scale you go with a stylus base; if you are looking with a something which is optical that is noncontact then you can go with optical atomic force also you can find. So, how these things are different with each other? They are different with each other with respect to amplitude and the wave length.

Amplitude is here; that means, how much what are the peaks it can measure. So, these are the amplitude and how they are separated from each other. So, these are called the wavelength how they are separated; so, this is the wavelength. So, looking at a millimeter scale you have one instrument at micron scale, you have another instrument and a nanometer scale you have one more instrument.

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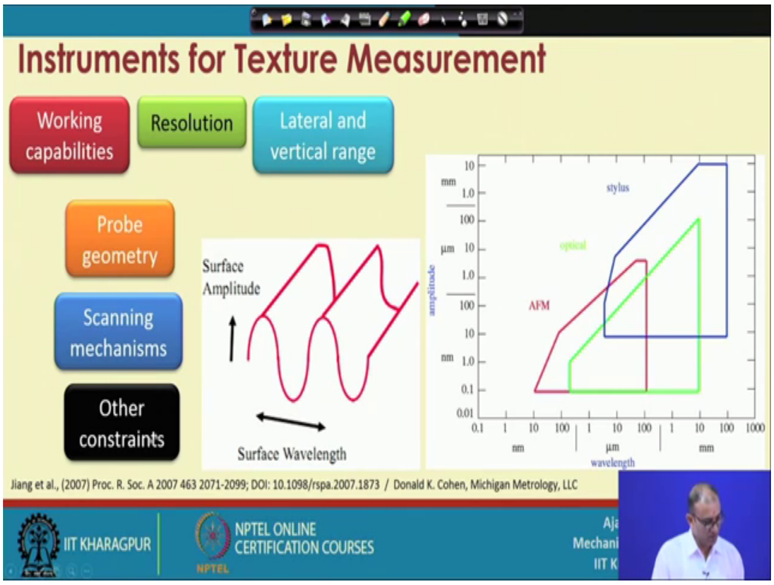

So, how you can select this thing? You the you have to select instrument based on the working capability that which way which principle it is working optical it is sometimes very very tricky because it has very less amount of depth of focus.

Resolution what is the smallest dimension it can measure? Vertical and lateral and vertical range; so, within a one measurement what is the measurement area? Suppose you want to measure something in a 5 micron by 5 micron; then better to go with a atomic force microscope. If it is a 1 millimeter by 1 millimeter you can go with the optical if it is a 10 millimeter by 10 millimeter; you can go with the stylus type.

Probe geometry that is mostly related to the stylus type and atomic force microscopy; that means, the sharper is the probe; you can get the more realistic picture of the cutting tool about the surface. Scanning mechanism which way it is scanning the surface it is a light flooded with that or it is interferometric base or it is a contact type. Another constant related to temperature where you are putting this instrument; you need some type of climate conditions also or not, humidity is also one of the parameters by that way you have to select the instrument.

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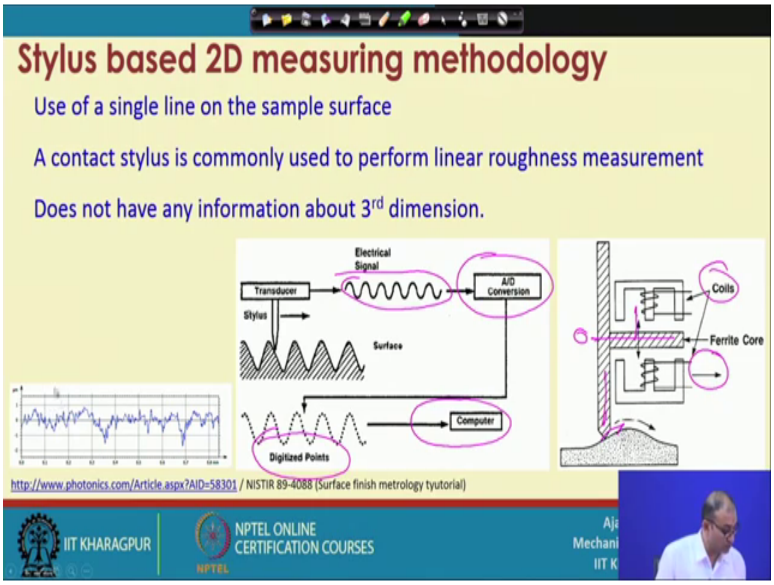

Now, let us see the stylus step; so, this is the stylus step you have surface this thing. Your stylus is moving up and down here and that will create a signal. So, this is the LVDT Linear Variable Differential Transformer and here right now it is exactly located at the center location.

Now, when it is moving up and down what happen? This particular ferrite core will move upside or downside based on that this coil will get a different different signal here. Because right now it is at the center. So, you are getting a 0 signal here it is not moving towards any of these coils and when it is moving up and down; you will get a signal and that signal resolution is at a sub anglestrom level.

So, whatever way the stylus will up and down; it will create electrical signal based on this difference in the coil power. And then you have to convert analog to digital signal then you are getting everything in a digital pattern in a computer right. So, this way you can do measurement of a part in a 2D part and this is the profile what you get routinely in a from this stylus based kind of thing. So, use of a single line sample surface, a context stylus is commonly used to perform linear measurement but it does not give any information about the third dimension right. So, here what happen that what is on the depth wise you are not getting that information. So, what we have to do that? We have to go with a 3D measurement right.

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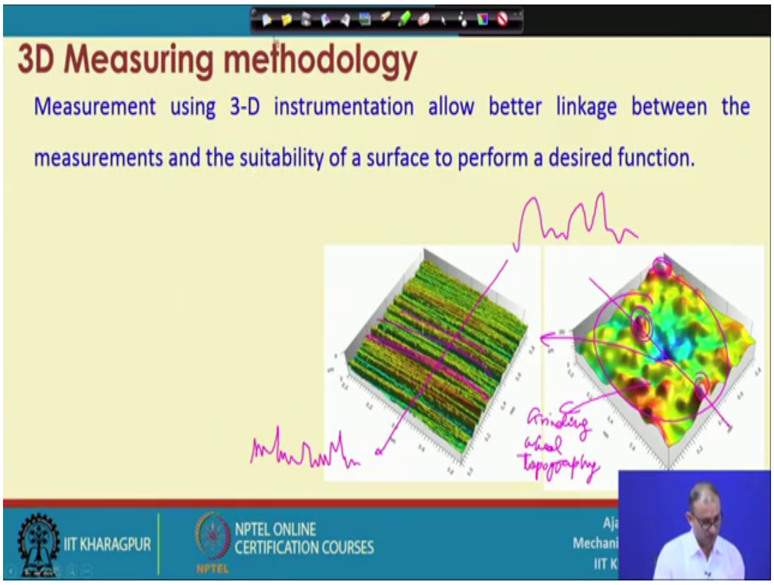

So, 3D measurement measuring, using 3D measurement allow better linkage between the measurements and the suitability of a surface to perform the desired operation. Now you can see the these are the two images; this is the topography of the grinding wheel.

Now you can say these are the abrasive particles; this information you cannot get in the 2D view whatever you are getting you will get some type of peaks here and these type of thing, but you do not know that what are the total area available here. And this is the machine surface by this grinding wheel now you can see that you can find all the grinding waves here; if you get a cross section here what you will get? You will get something like this. So, this is the line graph, but you will not get the actual view of the surface. So, that is why 3D measurements are much better.

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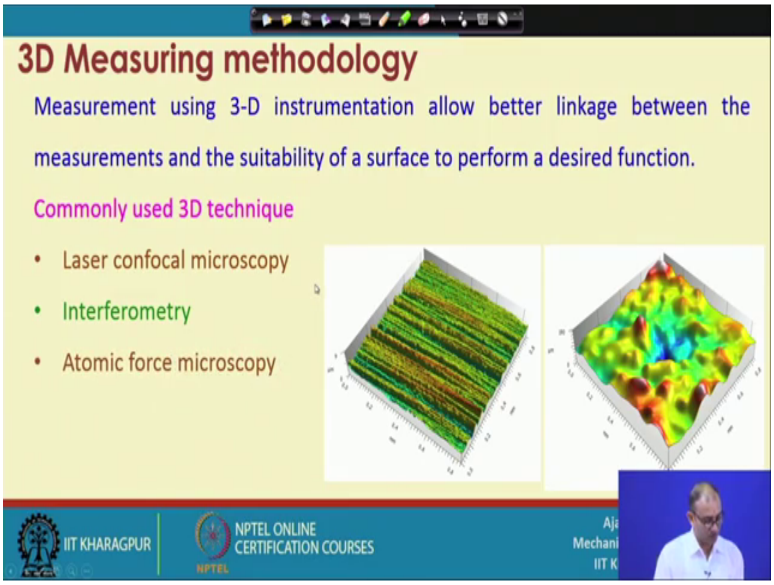

What are the commonly used? There are many techniques available right now we are discussing about a very commonly used; that is a laser confocal microscopy. You take the you take the image at a different different light and then actually you combine all the things.

Interferometry based; so, these are measured by the interferometric base. Atomic force microscopy, what we have discussed in the last slide.

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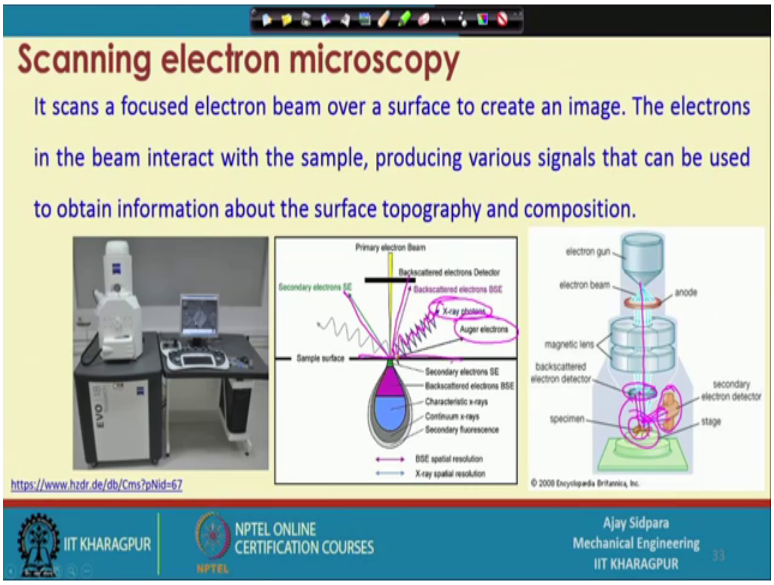

Scanning electron microscopy is also very important because here what we do that we do some type of measurement in terms of a very very high magnification microscopy that is mostly not possible by a optical microscope. So, what it does here? That it scan a sense of focus electron beam over a surface to create an image. The electrons in the beam interact with the sample and producing various signals that can be used to obtain information about the surface topography and the composition.

So, this is the full photograph of that part surface and this is the initial way. So, now, the when the electrons is passing through here and it interact with the surface what happen? That it actually generates the secondary electrons. So, there is a detector available which will capture this secondary electron and this is the back scattered electrons; so, there is one detector which will actually capture this back scatter also.

If you see the more inside view of this is the surface and these are the secondary electron here; back scatter is here it also actually transport the x ray by which you can do elemental analysis that what are the elements available here auger microscopy can be also done here. So, here you can see that by this particular interaction of the electron beam with the workpiece; you will get a different different signals and those signals are very very useful to understand the what happens to the surface.

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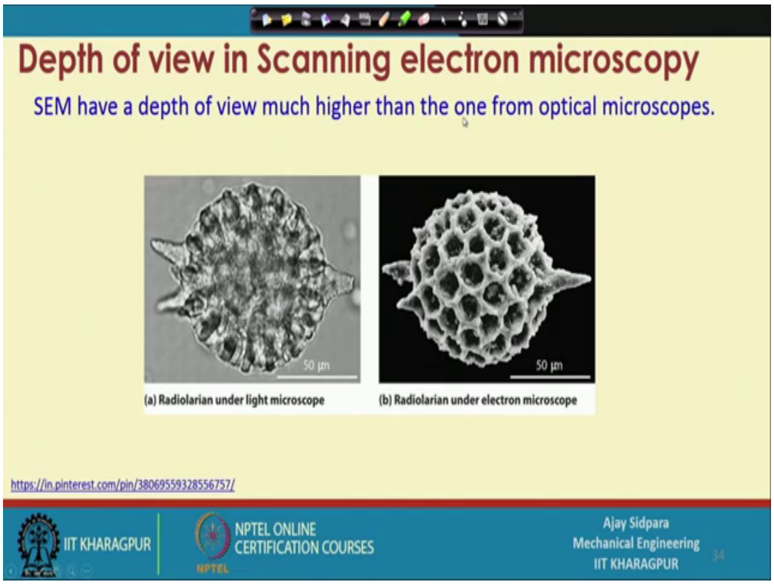

Here what is there? This is showing the depth of focus of that; that means, up to what depth you can actually do measurement; this is measured by the light microscope or optical microscope, both magnetic concerns are same but here what is the things that you actually get the plane only.

Now you can see here on this particular plane whatever things are that you can actually capture, but here depth of focus is more. Because here not only that plan you can get a different different plane here; one plane here one plane here and there is a one plane here also you can get the information. So, you are more depth of cut means it will give a more realistic view of the system or whatever may dimension you want to measure that is possible in this particular case. So, that is the advantage.

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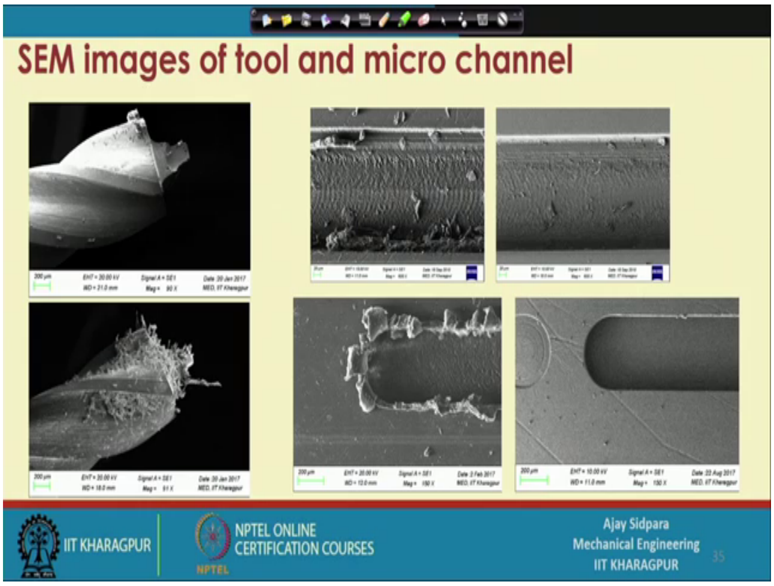

And what you can do? That in my machining part you can see that these are the this is the view of a cutting tool that we have fabricated in our lab. Now you can say this is the end mill cutter on the end mill cutter we have fabricated a very small tool here. So, this diameter this diameter from this side is the 100 micron here and you can do machining with this particular part only.

If you do machining with a some type of polymer material what is happening that lot of chips are actually stayed onto the cutting tool and now this is what you are getting into the chart. So now see if you want to study these type of thing then what you have to do that you to use SEM only because scanning is that optical microscope and other microscope with a light microscope kind of thing; you will not get this type of very clear view of that.

Even though you can mount a very close to the part, but here what happen? That SEM is also limited in terms of the size of the component which you can put into the system. And also you need some type of preparation of the sample for conductive material no problem for non conductive material you have to do some type of coating in the surface so, that electron can be reflected from the surface.

So, this is the condition before machining and after machining you can see this part and this is the some these are some channel photograph machine on a PMA motor you know polymer material and you can see there are lot of different different type of things available. So, these are some residual available onto the workpiece surface. So, these are the some chips actually again reentered into the zone and these are the chips which are separated from the machine zone.

So, if you optimize the process parameter and then what you can get? That you can get a clean surface also; so, by that way you can actually see the difference between these two surfaces by which you set the different process parameter and dimension of this particular channel is 500 microns.

So, if you see this thing it is 500 micron right. Now this is the machine channel; if you see the another view of that now you can say these are the (Refer Time: 28:37). So, if you work with a very very low RPM and very very low feed rate, high feed rate then you are end up with this type of burr formation. Now getting the information of this burr formation is very very tricky because this is you can see that this dimension is very very small here 200 micron 300 micron is the dimension here and these chips are very difficult to captured by a normal microscope.

So, you have to move this component to the SEM and then you have to do some type of gold coating on the top of that. Because polymer are non conducting material mostly; so, in that case you have to do coating; so, that you can get the required information. So, once you get this information and then what you do? That you optimize your process parameter you increase the RPM or you increase some of the coolant by which you can actually force the chips which can flooded with this particular.

So, this is called tool loading; so, you reduce the to loading you apply the put and coolant force in such a way there it will remove all this cutting material which are entangle into the flute of the cutting tool. And if you optimize the thing now you can see the how clean you can get the surface. So, by different different process parameter setting that this is the same channel machine at a different process parameter and now you can see the how clean is the surface from each other.

So, by this way you can mostly do measurement of a 2 dimensional because here you can see mostly it is 2 dimensional, but now there are software's available by which you can take the image with a different different angle and those software actually combine those images and create a 3D image. So, you do not need to use some type of interferometric base which we have seen in that earlier where what the view of the grinding wheel topography and the grinding machine surface those type of surfaces you can get by SEM also, but you need some dedicated software which are available in the market.

So, SEM 3D topography measurement by the interferometric base or the laser confocal microscopy; these two instruments and the microscope at a very very high magnification; let it be a different what we can say that a different less depth of card, but still they are useful for monitoring the system of the different different machining operation.

So, let me close this course here; so, this was the last slide and our course is over by this lecture. And I hope you have enjoyed this course and all the best for the different subjects in these matters.

Thank you very much.