Introduction to Mechanical Micro Machining
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Lecture - 61
Sensors and metrology for micro machining (Contd.)

Good morning everybody and welcome again to our course on Mechanical; Introduction to Mechanical Micromachining. In the last class we started our topic on Sensor and metrology for micro machining operation. And we have seen that there are different type of sensors which can be used for monitoring of the machine tool itself, monitoring of the work piece and monitoring of the cutting tool.

So, let us continue this topic further; so, last structure we have seen that there are two different approaches by which you can do measurement of a different type of signals.

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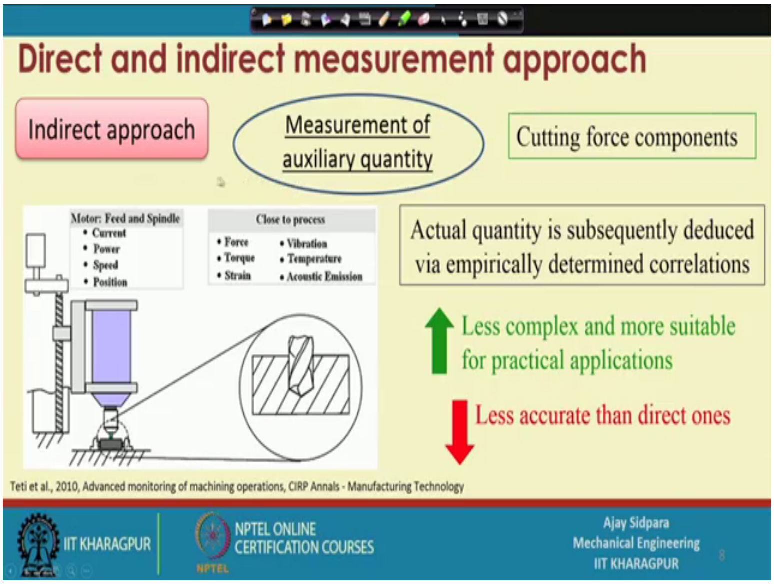

So, one is the direct approach and this one was the indirect approach.

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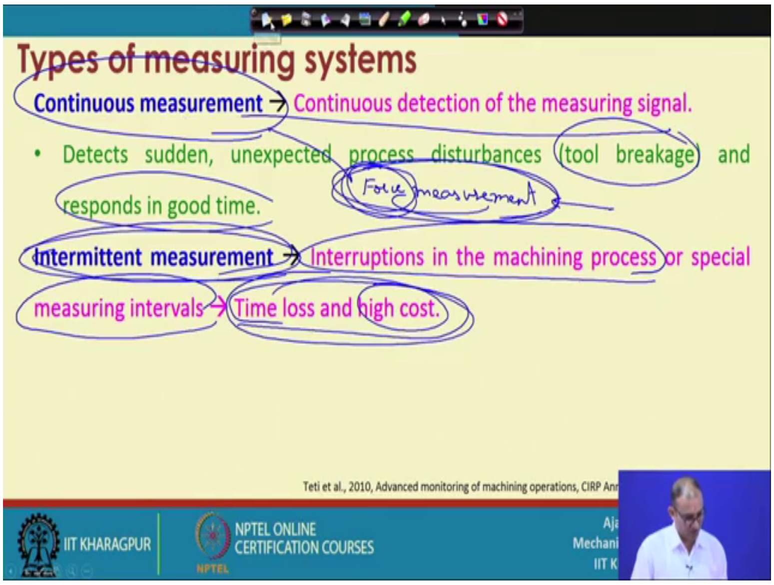

So, there are different type of measuring systems also; one is called continuous measurement; what does it mean? That; that means, that you are continuously detecting the measurement signals that is called the force signal right. So, we force signal we directly measure on to the work piece or the cutting tool and then because of that continuous measurement what we can detect? That we can detect a sudden or unexpected process disturbance like a tool breakage or the response in the good time.

So, if you measure something in a continuous operation then what we can do that? We can actually stop the operation once you get some type of unwanted result or there is some type of problems in the system. So, that is the reason that continuous measurements are very very useful in the real time monitoring of the machining operation.

Another thing is the intermittent measurement that you do a machining operation, then stop the operation and then you take out the cutting tool and then do the measurement. So, what we are doing here that when you want to do these things continuous; then mostly we actually use a indirect approach right because we are measuring forces here. So, force is force measurement right, so force measure means indirect approach, but what happen by measuring the force actually you can find out the what is the tool breakage or anything.

Because suddenly decrease in the cutting tool major cutting tool force signal; then what you can tell that there is wear of the cutting tool or there is a sudden completely breakage of the cutting tool. So, by that way you can monitor continuously but if you want to do intermittent that you complete the operation and then take out the cutting tool and then you put that things under the microscope and then you do the all the studies.

So, there is interruption in the machining operation or you need a special interval in between these two. So, what are the consequence of that? You will end up with the time loss and the high cause. Because you are interrupting the machining process and you need a separate station for putting all these things and then do the measurement.

So, sometimes what happen this things is important in some cases that you do not have space available in the continuous operation. And ultimately what we are measuring? We already seen in the flashlight the force measurement is indirect measurement. So, ultimately you are end up with some type of equation calculation and that everything depends on the how accurately you are putting those equation in terms of the fitting of the curve. But intermittent what is the advantage? That you are measuring the actual quantity, but you have to stop the machine and then do the measurement, but this is more reliable it will tell you the exact position of that.

But we know that still people are using these thing because there are some advantages associate with the indirect measurement or the continuous measurement that is not possible here. Because ultimately you are end up with the time loss and the high cost that will also create a very important role in the final production.

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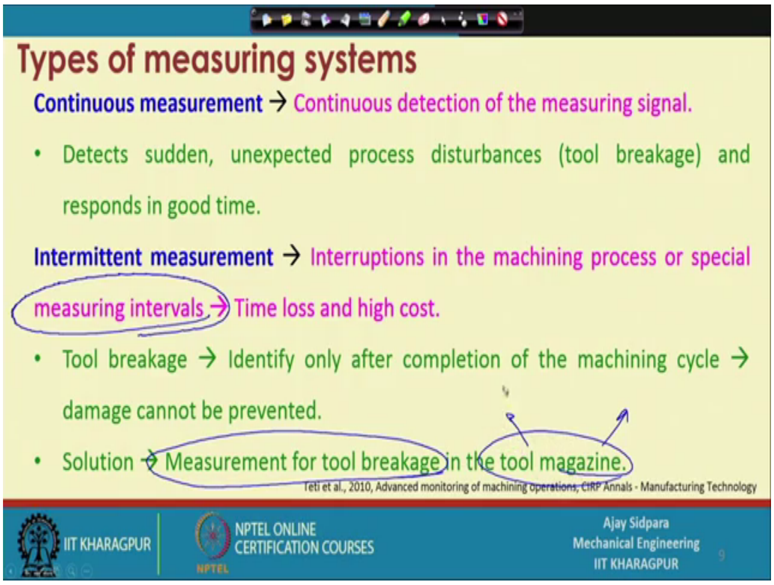

Right; so, suppose you want to measure the tool breakage by intermittent measurement it can identify only after completion of the machining cycle right. So, you do not know that at which particular location your tool is broken. And you still continue operation there and finally, you cannot dam prevent the damage of the cutting tool as well as the workpiece part.

So, that is the problem when you go with the intermittent, but there is a solution also. Suppose you are working with an automatic tool changer. Then what you do that? You do not need to provide a separate interval for this particular operation. Because whatever you are using here; what you can do? You do machining operation and then you change the cutting tool. And whenever you are putting that user tool into the tool magazine then put a sensor there itself in the tool magazine. So, while going when you are doing a machining with a another tool by that time already used tool is being monitored by a sensor system.

So, that you do not require any type of special interval between the machining. So, you continue that operation and in the tool magazine you are actually doing all the analysis of the tool geometry that what are the cutting edge available, whether it is a broken or it is a one out. So, this is also one of the solution by which you can actually reduce the time loss; by that way you can still continue with the measurement of actual quantity and still you maintain the production time without any problem. So, by that way you can actually find out there are different ways by which you can use the intermittent measurement, but still maintaining the production time.

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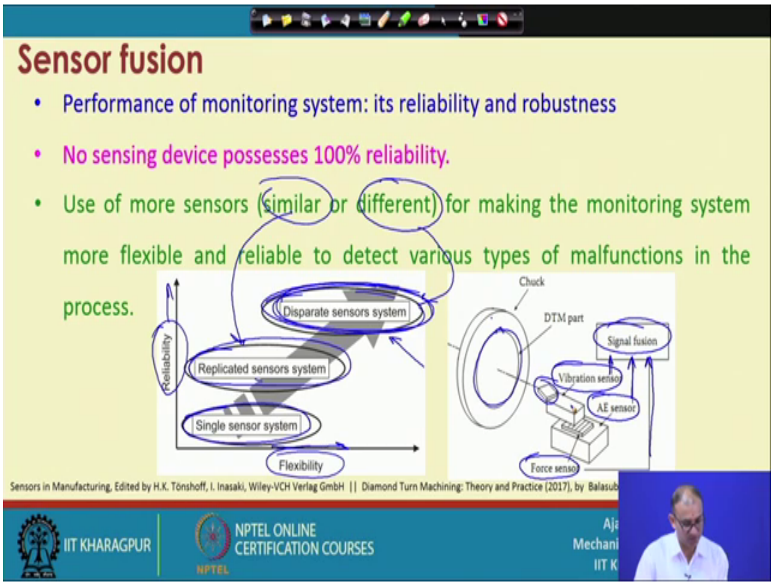

Now, coming to the sensor fusion; so, what is the sensor fusion? Now what happens that when you use any type of monitoring system in terms of sensor or some type of metrology; you think actually depends on the how much it is reliable; how much is it robust? Right? So, once you get a signal you first you have to find out whether it is reliable or not it is showing you correct results or not and another thing is robustness; that means, you are end up with a lot of different type of environment. When your depth of cut is very high or it is very small how it will respond to your in stimulation of the input?

And we also know that none of the sensing systems are 100 percent reliable right. So, what to do in these case is; so, what you have to do? That use more sensors either it is similar type or the different type for making the monitoring system more flexible and reliable to detect the various type of malfunctions in the process right. So, what we have to do? That suppose you do measurement with a one system suppose you consider you are using a dynamometer right.

So, you do measurement with a one dynamometer and you use measurement of with the similar type of dynamometer and then you check that what are the variation in the cutting forces? Or you use a different one; use a dynamometer another you use a acoustic emission sensor and then you compare the signal.

So, in that way you can actually increase the reliability of the signal. So, now, this particular graph will tell you many things here. So, what it is showing here? So, this is the reliability and this one is the flexibility right. So, this is a single sensor system. So, you are using a single sensor here and you are monitoring the system.

That whatever more a process now you are monitoring, you are monitoring the cutting tool, you are monitoring the workpiece; so, this is called the replicated sensor. Replicated sensor means you are using a similar type of sensor more than one to monitor a particular situation. And this is called a desperate system sensor system where you what you are doing? You are monitoring or you are measuring a single quantity using a different sensors right.

So, these sensors are different and those are working in a different principle of measurement and these are the similar kind of things right. So, now, what is happening that you if you use a different sensors with a different for measuring wind of the same quantity; then what happen? You are actually increasing the reliability of the measurement because we know that if one particular measurement principle is not fitting with a particular system, then what happen?

That if you are using a single may sensor or you use a multiple sensor with a similar configuration; it will not make much difference there. But if you use a different sensors working on a different principle and they are all measuring a same content then you have a large amount of data base. And then you can see there which whether your requirement or the whatever parameter you are measuring it is showing the correct trend or not and it also increases the flexibility.

So, that is the advantage of with going with a d separate; disparate sensors system. Now this is the example of a diamond turn machining operation; now you can see here. So, this is the component machine component, this is the chuck and this is the cutting tool. So, what you we are doing? We are using one force sensor here; so, if this force sensor will measure the cutting force; we are using one vibration sensor here also.

So, that is also attached with the cutting tool; so, whether cutting tool is moving with a predefined depth or what happens to the cutting tool? It will measure then we are again putting one acoustic emission sensor. Now you can see that all the three things we are putting on a cutting tool and all the three sensors will give you a signal and then you get a sensor fusion. So, by that way you are actually increasing the reliability of the system sensor system; so, that you do not end up with any type of wrong measurement or taking some decision based on the wrong ways measurement right.

So, what happens? That suppose you get the wrong measurement you do not have any problem because at least you understood that there is a problem in the system. But suppose you get one wrong signal and you are not able to identify whether it is wrong or right and you take some decision based on the wrong signal that will create more problem. Because you do not know what happens based on the final decision and you further do some type of wrong setting in the process parameter and at the end; you actually create some type of problem into the workpiece and it will be rejected at the later stage right.

So, what our objective? That you use a different type of sensor for measurement of the same quantity; that will create more useful system for measurement of the different quantities.

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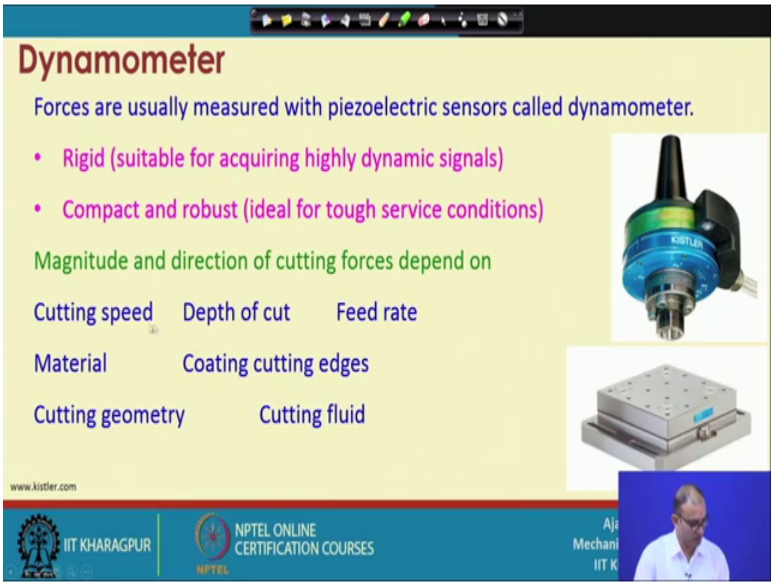

Now coming to the dynamometer; so, dynamometer mostly we use be the force measurement. So, that is called the force are usually measured with the piezoelectric sensor called dynamometer. We use the strain gauge based load cell also, but we know that when you want to measure something at a micro scale, it is better to go with a piezoelectric type of sensor. Because these things are very robust and it is very rigid because suitable for acquiring high dynamic signals.

Because even if you do machining at a micro scale, you have one particular range micro range by which you can do or you can get the signals at the micro scale also. So, these are the one this thing is called the rotating dynamometer which is attached on the cutting tool and this is called the stationary dynamometer which is at the workpiece side.

So, compact and robust because these are ideal for the top service condition because we know that we are using coolant also then that we are using there are lot of chips available coming out of the workpiece. And those chips are actually fallen down onto the workpiece in nearby area, but if you are. So, if you dynamometer is not able to cope up with this type of tough situation then you cannot use it.

So, this dynamometer based on the piezoelectric sensor principle or piezoelectric base type of sensor; then that is not creating any problem in the measurement part also. But there are different issues that thing the magnitude and directions also play important role and those things are depends on the 3 main parameter speed feed and depth of cut. Because we know that by measuring or controlling these 3 parameter most of the things you are end up with the correct measurement or correct component out of the machine. But rest of the thing that cutting tool and the workpiece material those things are the secondary parameters, but these 3 are very major will play important role into the required quality of the component.

What are the other component? One is the material; which type of material you are machining; hard material will give you more signal, soft material will give you a less signal. Coating of the cutting edge that is also important because when you do coating what happens? That you are increasing the life of that particular cutting tool and by that way you can reduce your cutting forces.

Cutting geometry is also the negative rake angle; positive rake angle if you use cutting fluid then you reduce the cutting heat effect heat; heating of the component on the tool side as well as workpiece side and depending on your cutting tool signal will cutting force signal will we will change.

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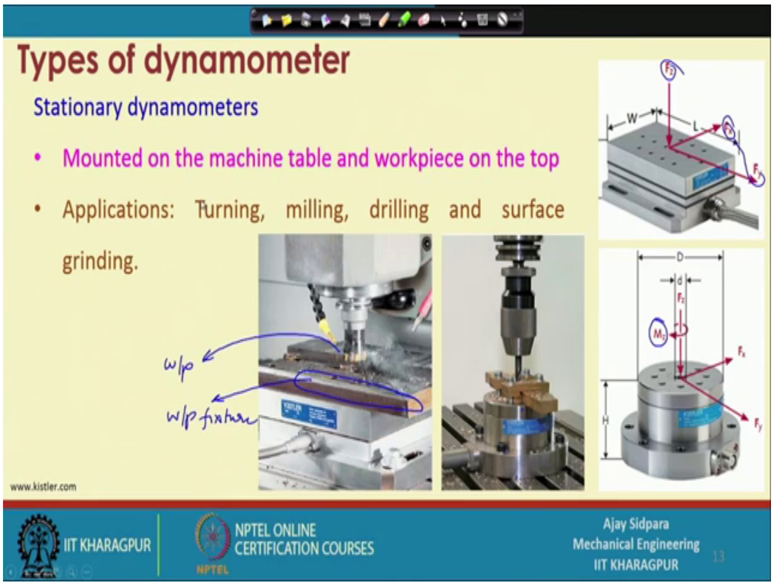

What are the different type of dynamometers? One is called the stationary dynamometer; so, this are called stationary dynamometer; stationary dynamometer means they are not in motion. And those are mounted on the machine table and workpiece on the top of that; now you can say this is the dynamometer on the top what we are doing? You are putting a fixture; this is the workpiece fixture and workpiece is on the top correct. And then you do machining and then you will get x y z whatever force you want to measure from it and this is the drilling operation. So, do you want to measure the moment also; so, this is the 4 component dynamometer other then you are measuring x y and z it measures the M z also that is the moment around the z axis.

So, do you buy there moment you can measure the torque also here. So, in that case this is the 4 component dynamometer; both are stationary type of things. So, here they it is mounted on the table and workpiece is on the top of it; alright. What are the application of this dynamometer? So, those applications are turning, milling, drilling, surface grinding, wherever your workplace is stationary you can use it by that way you can put the; in turning also what happen that? In turning it is a different way that you when you want to use a turning operation for that what happen the dynamometer; dynamometer is not attached with the workpiece.

Because we know in turning operation workpiece is rotating, but cutting tool is fixed. So, there are some provision available where you can put you are cutting tool onto the dynamometer and then you do machining. So, in that way it will give you a different results; that is so another thing is the rotating dynamometer.

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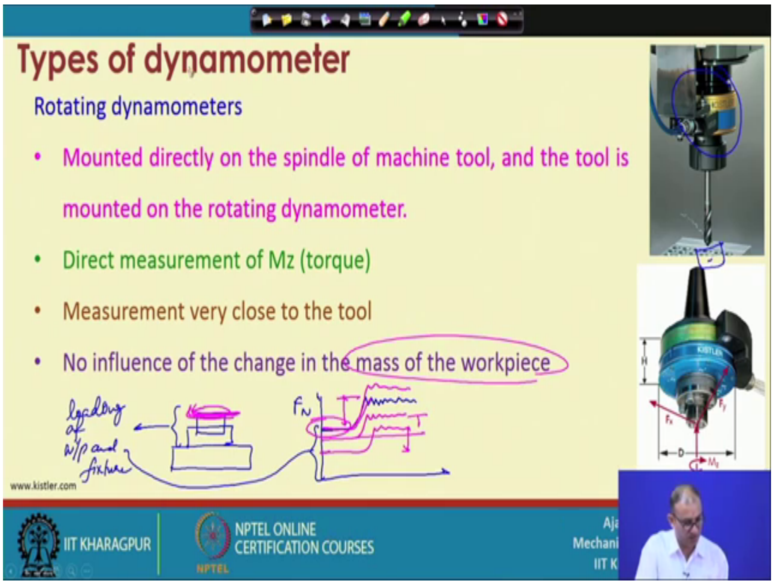

So, rotating dynamometer; that means, it rotates along with the cutting tool. So, this one is attached onto the tool side not to the workpiece side. So, this is the cutting connection, in earlier case; what was the scenario? That we are using a dynamometer here correct, there was a work dynamometer on the top there was a workpiece picture and on the top there was a workpiece.

And then dynamometer was located here but now dynamometer is located on the cutting tool side. So, mounted directly onto the spindle of the machine tool and the tool is mounted on the rotating type dynamo. So, this is the actual photograph of the cutting tool dynamometer right. So, here what is they did? They measure directly to the Mz tool. Now earlier case what was the thing? That you have to actually find out in terms of the where is that sensor is located? How far it is?

So, it is direct measurement of the cutting torque earlier that was not the direct measure by moment you are measuring the cutting force. And measurement is very close to the cutting tool. Now here that most of the times what happened that when you do measurement of cutting force by means of dynamometer our objective is to find the status of the cutting tool. But if you see that stationary type of dynamometer what was happen? The dynamometer was attached to the workpiece, but we want to measure the or we want to get information of the cutting tool. So, it was distance was very large; so, here what is the advantage here that dynamometer is very close to the tool. So, measurement is very reliable in terms of the rotating dynamometer compared to the stationary dynamometer and no influence of the change of the mass of the workpiece.

Now, if you see that earlier case what was the thing that this was the situation; your dynamometer was here, on the top there was a 4 piece picture and on the top there was a workpiece. Now you are doing machining; now what happened that when you are end; you already have some type of preloading, so this is called the load loading of workpiece and fixture. So, when you want to do measurement of a normal force that is the F N; what happens? Your starting point is this one right your force will start from here and then it will go something like this that. So, this is the force because it is already loaded.

So, this force is because of that and now you do that you are doing machining with a different depth of cut. Now you want to do some type of 2 or 3 passes; so, one pass is done, second pass is done, third pass is done. So, what is happening? That this particular graph will always try to change and then you will it will come here right. So, this is the change of the; so, whatever the mass of the workpiece you always get a some different offset after each and every pass.

So, what is the problem here? The problem is in the post processing here you will not get any problem because every time you would know that this is going to happen well ultimately when you want to do measurement of actual force; actual force is this one from these to this. So, if every time it is starting from here what happened? That you do not need to change the baseline, but every time when you do cutting of their; this much amount of operation then this much amount of material is lost. So, your graph will start from the little bit lower side.

So, now, actual graph is this one in the third grab this is the actual graph. So, post process require what? Additional step by which you can actually get the data plan very effectively, but that is not a problem in this rotating dyno because dynamometer is located on the total cutting tool side. So, whatever machining you are doing; you will always end up with this particular graph. So, this is the one graph, you start with the second graph. So, your data will never change and that is the advantage that you do not require any type of additional step in the post processing of a signal. So, that is big advantage.

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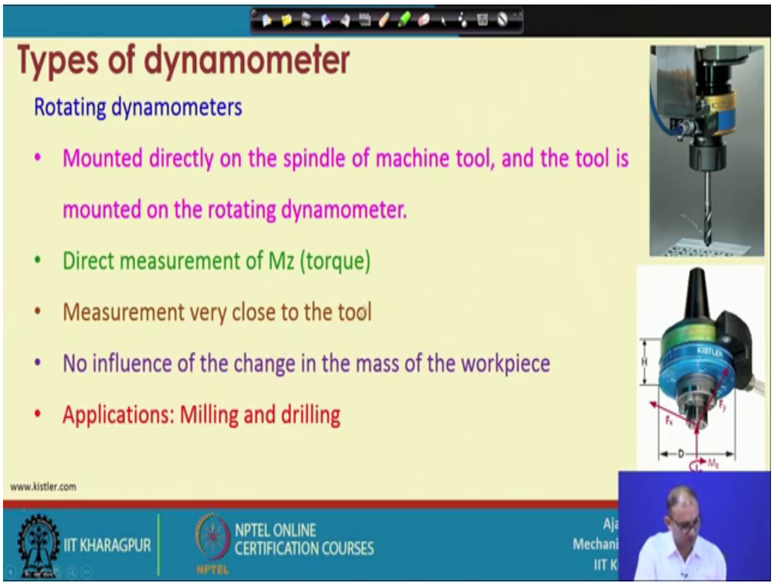

Application is milling and drilling because these are the two operation by where you can mount a dynamometer onto the tool side.

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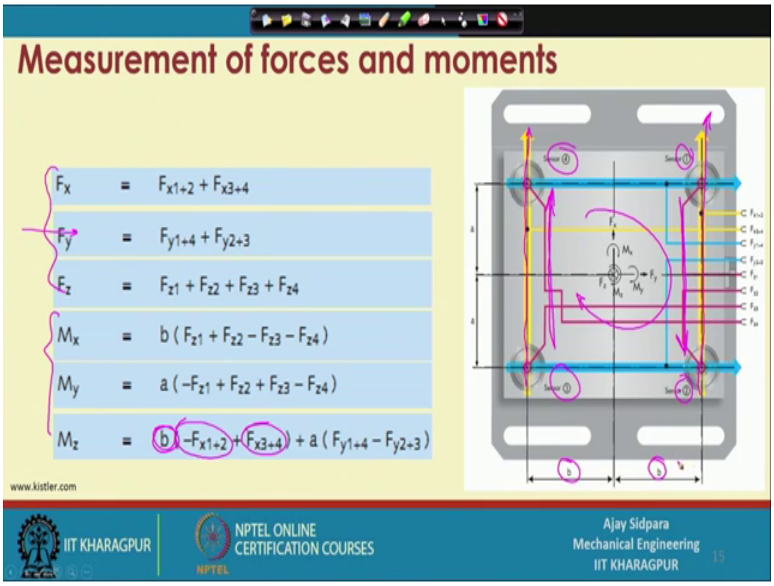

So, how do you measure? So, this is the stationary dynamometer and you can see that there are 4 different sensors available and this is whatever direction is showing. So, these are the positive direction of the force is acting in this direction that they are consider as a positive. And these are the 3 moment you see M x that is along the F x M y that moment around the F y and this is the M z force that is the moment around the F z. And these are the distance from the center point it is in the vertically if these are located a b b and horizontally they are located with the a a.

So, how dynamometer measure this all the forces? Now when it measures the force on the F x direction; so, this is called the F x. So, this is your x direction right. So, in x direction what it will do? So, it will do measurement of this part. So, this is the one measurement and this is the second measurement. So, this is the 3 and 4; so this is the sense of 3 and 4 summation of these 3; 2 forces plus of sensored signals from the sensor 2 and sensor 1. So, this is the F x 1 2 plus F x 3 4. So, 1 2 plus 3 4 by that way you can find the F x force.

Second way is the F y; so, similarly in that way. So, now, your F 5 force is in this direction; so, this is F y. So, similar to that now what you have to do? You have to do summation of this for signal from the signal of sensor 1 and sensor 4. So, this is sensor 1 and 4 in the y direction; similarly it is a sensor 2 and sensor 3 that you are getting in a 2 direction; 2 plus 3 in the y direction. Now coming to F z; that means; what we are doing here? We are actually loading from the top; when you are loading from the top you understand that all this 4 force load or sensors will actually press simultaneously with a same reading.

So, what we are doing here? That, we are directly summing the z 1 plus z 2 plus z 3 plus z 4 because now all distances are same from each other and all will be loaded with the same value; so, it is a straightforward calculation. Now coming to the moment; now what is this moment? So, now, this is M z; M z; that means, what we are doing? We are measuring moment in this direction. So, this part is the loading part and this part is the pulling part right; we are pressing only this part. So, when you press this part, this will give you a positive reading.

And we are loading from the top; that means only z will be active direction. So, when you are loading on this direction; this will give you a positive reading. So, this is 1 and 2 right. So, this is the 1 and 2 are positive and how far it is located from the sensor? These are located from the sensor with a b value correct. So, this is the b value; when you are loading from the this direction then similar where you will get the pulling from the other side.

So, when you are getting pulling; so, that is called the 3 and 4 are negative. So, these are the 3 and 4 are negative, but those are also located with a b distance from the sensor right. So, M z value you can calculate by this way right now we can see that this is the moment around this part and we are calculating those things.

So, earlier case we have seen that you can directly measure the torque in a rotating (Refer Time: 21:00) dynamometer, but here you have to do calculation. Now similar to y how do we calculate the y? So, now, this is the y; so we are loading from this direction. So, these both things are positive now that is because loading we are loading on the sensor 2 and 3 side. So, sensor 2 is positive sensor 3 is positive; these two are negative because now we are pulling from that side.

So, this is called z 1 is negative z 4 is negative and how far those are located from the sensor? Both are located at the sensor at a b distance; so, a distance sorry, so, you are getting the a here. So, these all calculations are very straightforward if you know the moment in the force direction, but still one thing is left that is called M z. So, this one is little complex now this direction is these directions, now we are rotating in a clockwise direction right.

So, when you are rotate in a clockwise direction now what happens? That we are not pressing the component right earlier case whatever we are pressing. So, everywhere you will see that these are the F z only comes into picture, but here in M z; what we are doing? We are not pressing there, but we are actually shearing the plate.

So, when you do shearing then x and the y force will come into picture. So, let us first see the measurement of a different components. Now when it is rotating in this direction right; so, it is moving in this direction let us in then it is moving in this direction right. So, when you let us consider first in the y part right; so, this is the y part. So, when it is moving in this direction now you can say this direction is aligned with this direction correct. So, this 1 4 and 1; this will give you a positive result right. So, this is the F y that is 1 and 4 are positive correct and how far it is located from the sensor? These are there are located from the sensor at a a distance.

Coming to this direction it is moving in this direction. So, this direction and this direction opposite to each other right. So, if sensor 2 and 3 in the y direction you will get a negative. So, here or this is what is happening that 2 and 3 but they are negative and how far it is located? There are located with a a distance right. So, this part is over with respect to y; now let us talk about the z x. So, now, still it is rotating in this direction; so, if it is rotating in this direction what is happening? That it is moving in this direction and then it is moving in this direction correct. So now, now you see the direction of x forces in this direction, but now you are moving in this direction; so, 1 and 2 will be negative right.

So, 1 and 2 are negative how far they are located from the center point? They are located at a b distance. So, this is the b distance and then you are on this direction this is in the moment is in this direction; your fourth directions is also in this direction. So, sensor number 4 and sensor number 3 are positive and both are positive, both are located at a b distance; so, this is a b distance right.

So, you can see that by this way you can do measurement of F cutting force in x y z direction and the moment in the x y and the z direction by this type of calculation. But you do not need to do this calculation this calculation is done by the software whatever interface we are providing ultimately whatever finally, you will get; you will get a graph only.

So, you do not need to worry about, but you should know that what thing is going on inside the sensor; so, that you can find out the any type of relation if you want to do measurement by a manual calculation also right. Now coming to the acoustic emission sensor now each and every sensor you can also take as a separate course, but we are right now what we are discussing we are discussing a small amount of introduction only then only we can cover all these things into the this course.

So, acoustic emission is also is one of the sensors which is widely used for micromachining specifically; so, that you can get the reliable signal similar to the dynamic dynamometer.

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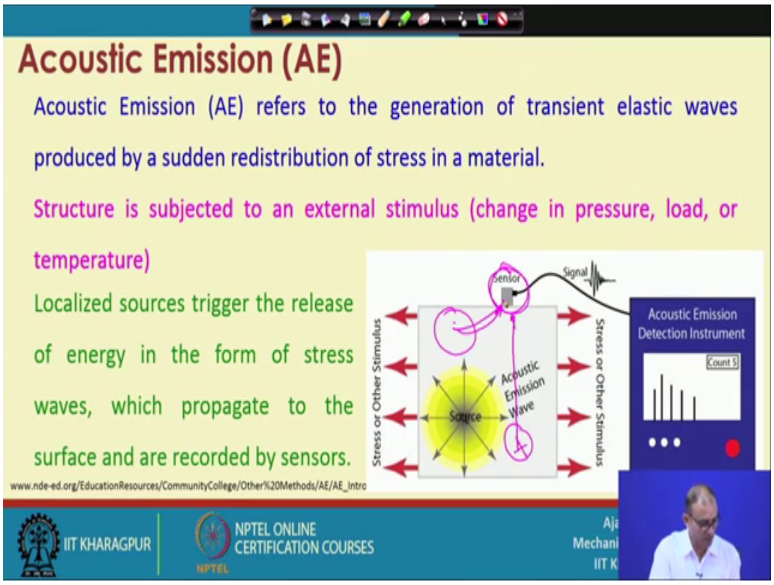

So, what is the acoustic emission? The acoustic emission refers to the generation of a transient elastic wave produced by a sudden distribution of stress in a material. Now you can see this is one of the compound one component and here some disturbances happen at this location; at source. Now what happened? Because of that disturbance what happened? That there are stresses generated in a different direction and there is acoustic emission waves which are created from this location.

So, if you put one sensor here that is called acoustic emission sensor. Our objective is to capture these particularly elastic waves, so that you can get a signal and then you can do some type of post processing or the decision making based on this sensor.

Now, wherever you will get some type of disturbance into the material or when you get some type of stress generation; there because of the stimulation you will get one signal because of the acoustic emission wave. So, this based on this principle this is very very useful sensor for specifically in the micromachining domain.

So, structure is subjected to an external stimulus change in the pressure load temperature because of that you will get a different type of signal here and localized sources triggers the release of energy in the form of stress waves. So, whenever you will get this type of disturbance here it will generate one type of energy in the form of stress waves. So, that is what we called as elastic emission waves and which propagates and to the surface and then it is recorded by the sensor.

Now it is like that that suppose your sensor is located here and your disturbance is here then there is chance that you will get a very reliable signal. Because disturbance is located very close to the sensor; now if it is very far away from the sensor then what happen? That when it travels to this part then everything depends on the metal property the how far your material is able to transfer that particular wave to the sensor location? So, location of the sensor also play important role where you are putting the sensor and if you know the location of the deformation.

And we know that if you do machining we know the maximum deformation takes place the tool and work piece interface, but we know that is also know that it is difficult to put something there. So, we have to put sensor any sense let it be acoustic emission sensor or the dynamometer; we have to put those sensor as close as the as close to the machining condition to get the reliable signal.

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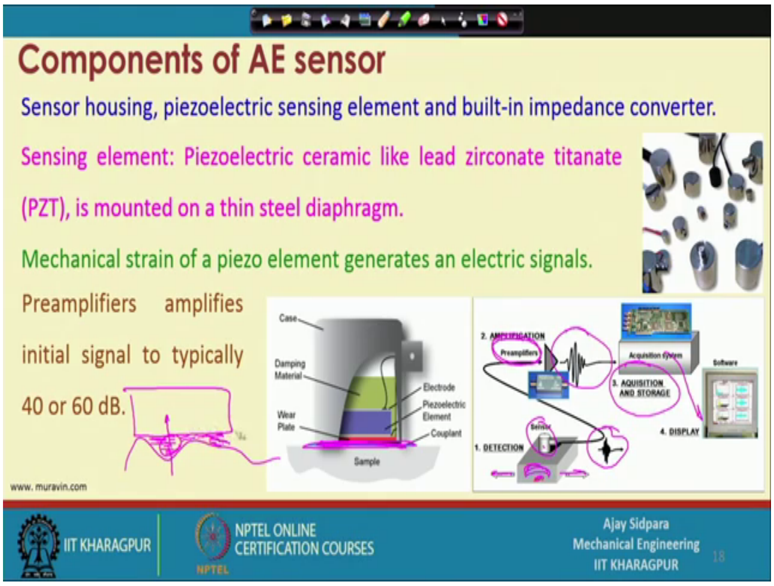

So, what are the different type of components of the AE sensor? This is the cross section or the cut to you of the acoustic emission sensor and these are the sensor; it is something like a cylinder. So, here what things are there? It is a sensor housing because you how to put housing so, that we can use this thing in a very harsh environment when cutting fluids are and cutting cheeps are also available this is separated here and there.

Piezoelectric sensing element is available that is by which you can do sensing element and inbuilt impendence converter available. Because you have to reduce the opposite flow of the current; so, that it will not create any problem at the signal strength. Sensing element mostly it is a zirconate titanate that is called the piezoelectric ceramic reduce and it is mounted on a thin steel diaphragm.

And mechanical strain of a piezo element generate the electrical signal. So, here also you will get electrical signal in terms of voltage and then convert that voltage in terms of a required quantity or whatever parameter you want to measure here. So, important thing here is that how you are putting this particular or installing this particular sensor here. So, that particular sensor the installation is very important here because now if you see this is coupling. Now if you not completely fitting or completely installing this as acoustic emission sensor to the sample if there is some air gap then what happens? You are losing some energies there and that is the big problem and let us see this particular last thing also.

So, this is what it is showing. So, here you have installed a sensor here there is some disturbance here or you are putting some type of loading here. And that disturbance will create some type of waves and that waves are creative as captured by the sensor. So, this is the rough signal here and you have to amplify it because amplifying is equal to because we know that when you do some machining at a micro scale; the strength or the magnitude of your signal is very very small. So, big to make it more readable what you have to do? You have to amplify that signal and once you amplify that signal now you can see that different components you can easily identify.

Then acquisition and data acquisition storage system available by which you can actually do some type of signal processing and then storage of data. And then you transfer to the computer screen where the software is available which will do all the different type of curve fitting related to the signal. So, by that way you can do lot of measurement of the signal and this particular what we are discussing? The coupling is very important now suppose the surface is something like this and you are putting your sensor here.

So, this is the air gap and we know that we want to actually measure the elastic wave. So, if there is a air gap available then problem is that air gap will actually consume some of the energy or it will actually not able to transfer the same energy to the a piezoelectric element which is measuring this particular part. So, by that way you have to make sure that there is a firm coupling between the work piece and the sensor and sometimes people are using different type of glue.

So, that all the even if there is some gap this gap is filled by this glue and there is no any air gap available. Or you have to do some type of sample preparation before you apply some type this acoustic emission sensor there you clean it completely then make sure that there are no any type of waviness available or the roughness at a high level and then you do different type of operations.

So, this is about everything about today’s lecture. We will continue this topic further in the next class.

Thank you very much.