Introduction to Mechanical Micro Machining
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Lecture - 60
Sensors and metrology for micro machining

Good morning again to our course on Introduction to Mechanical Micromachining, today we are going to learn our last topic that is related to sensors and metrology for micro machining operations. We have seen till now lot of different operations and we have seen there are different components also in the machine tool, but ultimately everything comes down to the measurement system. Because once you do machining at a micro scale our objective is that how to track down all the movement of the cutting tool that is at the micro scale and once the machining is over, we have to also do some type of measurement that whether the part is exactly as per the dimension or not.

So, we are dealing with 2 or 3 different type of systems, one is the related to the cutting tool because our objective is to monitor the cutting tool throughout the machining operation and at the end we have to also say that whether there is still any life available in the cutting tool or not.

So, that we can either use it for the next operation or we can discard it. Another thing is the work piece because, once the machining is over our objective is to measure the dimensions that is impossible on the machine itself, because if you remove that component again you have to mount at the same location and that creates lot of problem. And third one is the machine tool itself, because we know that there are lot of different components on the machine tool, those are connected with each other and if any there are problems and that problems will actually replicate it or it will be reflected on to the component or the cutting tool.

So, we have to put some sensors for monitoring the health condition of the machine tool, then monitoring of the cutting tool and work piece also. And after that we have to use some metrology something like that cameras or microscopes or some type of other techniques, by which you can measure the dimensions and do some type of characterization of the cutting tool in the work piece.

So, let us see that what things we are discussing in the this new topic.

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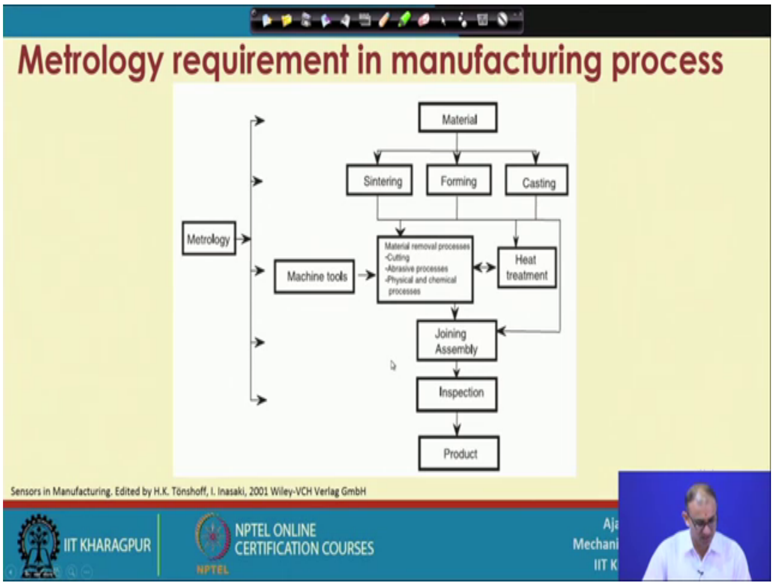

So, now this is the metrology requirement, now if you see we are starting with some material now you have a blank that blank is actually fabricated or the made by a sintering process forming process or the casting process and every stage you need a metrology, because first you see the metals are equal for material. So, here what you do that you see that what are the composition of the material and then you have to a monitor this particular process.

So, that there should not be any type of deviation in the composition of the material and that composition will be strictly monitored or strictly maintained during that manufacturing process. So, monitoring is metrology required here also and once you have a blank or the rough component then what you do that? You use a machine tool, then you do some type of cutting operation, abrasive process or chemical process by which you do some type of machining operation and after machining operation you do some heat treatment also.

If you want to improve the surface properties of the different components, so here also you need a metrology and once this thing over then by chance you are making some small small component then you need assembly also. So, during assembly also you need a metrology so because, you have to make sure that all the parts are aligned according to their required dimension and required locations and once this thing over then you have to inspect the complete assembly that there should not be any type of loose component or the lower any type of unwanted movement between the 2 different joint components.

So, here also you need a inspection and finally, the product. So, you can see here this is a routine things it is not actually specifically used for the micro machining, but this is the complete sequence of the product starting from the raw material to the final product and metrology is required at each and every stage. So, you can understand that, how what is the importance of this metrology to make sure that final product is as per your desired dimension and the desired properties.

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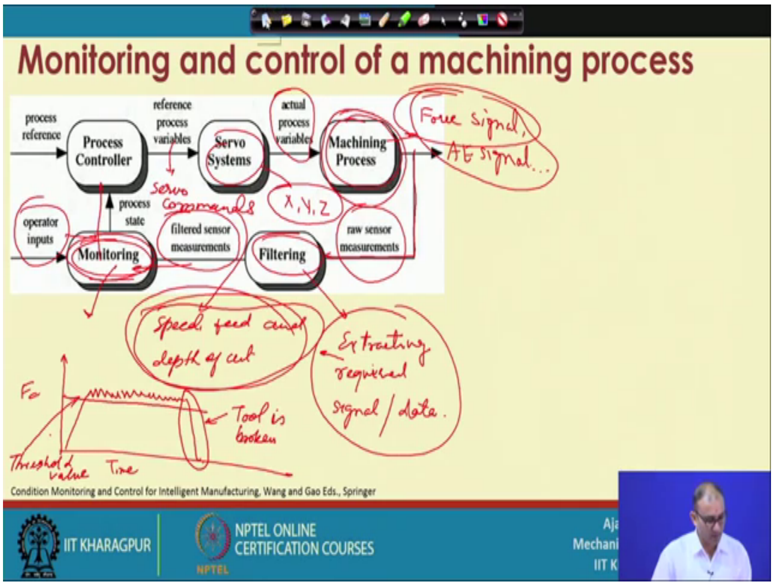

So, how do you monitor and control the machining process, now what is the first thing the process control plays important role, where you have to put the process references. Process references means what is your tolerance level and what are the different type of properties are required onto the machining part, that is low what how many components are required those things actually fed to the controller and once controller get all this information then what is the reference process variables are available.

So, this process reference process where your variables are mostly the the servo command. So, row command so this is related to the speed feed and depth of cut right. So, you have to set this parameter other than that you to provide coolant and here we hold the parameter, so once you give this command to the servo controller. So, servo control you are the x y n z motion, so right now let us restrict our self put the 3 axis machining center only. So, once you give a servo command then what happens that it will drive all the 3 axis to do a machining operation.

So, this is called the actual process variable. So, here what you are getting here you are getting a force signal, then acoustic emission sensor signal and there are many sensor whatever a sensor you are using for monitoring of this particular manufacturing process. So, once you do actual machining what happen this particular sensors will get some data.

So, those data are raw signal raw signal; that means, it will get all the data whether you require those data at the later stage or not, it is actually mixture of all the required data as well as unwanted data then what you have to do to filter. So, here what is that filter part that you filter what happened that you are actually removing the unwanted data or you are actually extracting required signal or data right. So, that is by which you can do filtering.

So, you are actually now extracting only those things which is important to you and then filtered sensor data will go to the monitoring system. So, now here what you are doing that you are actually monitoring those things and then based on this monitoring system now suppose you are using a sports signal right. So, you are doing a force signal and now it force signal is always in the time domain time domain and this is the force.

Now, let us see it is a cutting force right. So, initially it is starting from here and then you are doing turning operations it will maintain this particular thing and later on what happened that you will find that it is suddenly goes down in these case. So, what is this particular thing? That this particular thing will tell you the tool is broken correct, because now you are not getting any contact between the cutting tool and the work piece.

So, it is going down so here you those things are you are monitoring now if you tell the system that if your force is going below a certain level, so this is you consider a threshold value. Now suppose it is a closed loop kind of thing then, what you can tell that you provide one program in such a way that and tell that program that if the force is reducing below this particular threshold will you then stop machining.

So, in that case what you can do actually you can actually reduce the unwanted time here because if you do not give this thing your machining will still continue, but there is no contact between the cutting tool and work piece and all the thing will be wastage at the later stage. So, here once you get those data this is all one of the ways of doing that thing or at operator will actually men look into this monitoring system or the whatever data you are collecting and then according to that that it will actually again said this forces controller.

So, what you are doing that you are again refining the speed feed and depth of curve and other parameters, in such a way that you can actually increase this particular see efficiency of this particular machine tool.By that way you can actually continuously monitor this system and you make sure that there is no any type of problem during the machining. So, by that way you can control the machining process by monitoring the signal coming out of the different type of sensors right.

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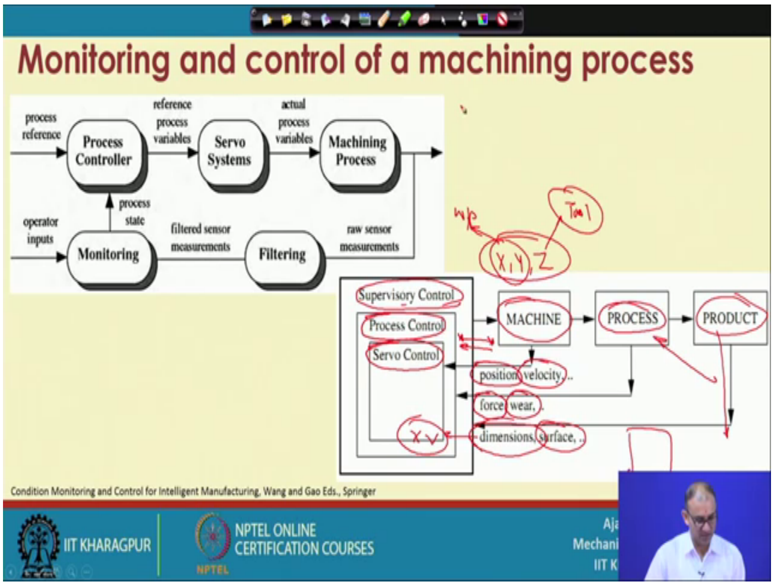

So, what are the different type of controls? now there are 3 different type of controls if you see from the machine. So, let us start with the machines or how machine will behave. So, machine objective was machinery to give the x y and z motion. So, what we do with the machine that we actually move the 3 different axis x y is most related to the work piece and z is mostly related to the tool right.

So, by moving this all 3 axis you do a cutting operation. So, when you do movement at that time these two things will come into picture, so that is the position in the velocity. So, what is the initial position and where you are going that is the 1 thing and how fast you are going. So, those things are related to the position and velocity so that is done by the servo control.

So, once the machining part is over then it is operating this x and y direction and or z direction, then what it is going to do that it is removing the material; that means, it is physically touching the component and then it is removing the material. So, when it is removing the matter what things come into picture that is the force in the tool wear right. So, that is related to the processes. So, now that is called the process control and once everything is over that you have moved the compound component and the tool in xyz direction you have performed a cutting operation and now finally you have a product.

So, once the product you have then whatever the supervisory control comes into xn that it will measure the dimensions and it will see the water the surface characteristics and then it will they said that whether this is acceptable or not, so these are the 3 different controls.

So, now you can see here that you need sensors at all the 3 location. Now supervisory control if you want automated performance automated performance of this thing, then what you do you have to add some type of microscope with a robotic arm. So, whatever component is machine here the robotic arm actually directly goes to the machine and then do the measurement or you remove this product out of the machine and then there is a separate table or the separate station available for inspection, where you do all type different type of inspection is a true dimension in the surface topography.

So, here you need 3 different controllers for complete monitoring and the control of a manufacturing process and we will see that what are the different controls to be perform out a different different locations.

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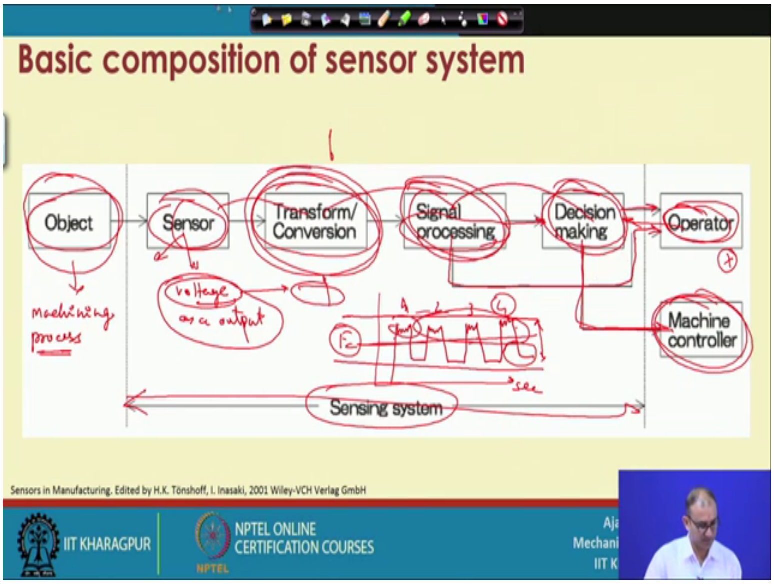

Now, basic component the sensors, so now you can say that these are the difference of words first is the where our object; object means our machining process, let us consider this is a machining process. Now, we have added some sensor to the machining process, now sensors are getting our a lot of data that is raw data including everything whatever you are giving the signal in terms of force signal or current signal voltage signal whatever way then there is a transform or the conversion because, most of the sensor will give you a voltage as a output as a output that is what our objective is not the voltage.

Because, finally whatever you are using the dynamometer for sensing our object is to get a force reading nor the voltage ready. So, it will do all the transformation; that means, conversion from the voltage to the force reading or some type of current reading to current reading to force reading or there are different other sensors available which will do conversion from a mechanic a electrical signal to the mechanical signal or mechanical signal to the electrical signal and then conversion is required to make sure that you are getting the required result in terms of your own variable not in terms of the voltage.

So, once you get the result conversion then still it is in the raw data because, whatever voltage raw data was there same raw data you will get the in terms of force. So, now you need a signal processing, so now you have to process that signal whatever signal you are getting from this sensor that signal processing is required here; that what is required out of that whether you need a average value you need a highest value lowest value or what other things are required.

Now, suppose consider this is the force signal cutting force signal and what happened that you are getting some type of signal like this right and this is the second. Now you want to say that how many times it has crossed this particular value, so it is showing 1 time, 2 times, 3 times, 4 time. So, these are the different techniques by which you can actually do some type of post processing on to the signal, so that is called the signal processing. You want a peak only or you want to average value of this signal, you want to say that how all the values are falling in which particular range of this force signal, that also you can do the measurement in terms of different type of post processing operations. So, that is called the signal processing.

So, once signal processing is over that means, you now you have a required data whatever your intended data or where you want to do some type of analysis or you want to do some judgment those things are available. So, now next step is the decision making right. So, now decision making sometimes whatever it comes under the sensing system because, you have given 1 type of rule base that suppose your force reading is more than this particular value then stop machining or do some type of other correction into the object; that means, in terms of speed feed and depth of curve you change the rpm or you change the feed rate by that way you can do lot of fully automated monitoring or the control of the matching process.

So, now once you get this signal now you have to do it decision making there what to do now. So, now there are 2 ways that one if it is a semi automatic; that means, operator comes in to x and that means, from whatever graphs are there here their operators will read those graphs and then operator will decide that what is the next step. If it is a fully automatic or a close look then what happen the close or decision making is done by the machine controller, that you have a say a troll be that if this thing happens then change the rpm.

If this thing happened then the change the feed rate, then must in controller itself will take the decision an operator will not play any role in that case right. So, in that way you can actually get the things done and signal processing can directly go to the operator also you do not require any decision-making in between these 2 decision making is required, when you are using a machine controller.

So, by signal processing you can get the things done that, by decision making you can get the operator will take the decision or from the signal processing itself will operator will take the decision, that what should be done in the machining operation or during the process. So, this particular thing is the sensor system, so this part is common form almost all the sensors by which you can get the raw data then you have to transfer and conversion then you have to signal processes a processing need to be done and then you take the decision right.

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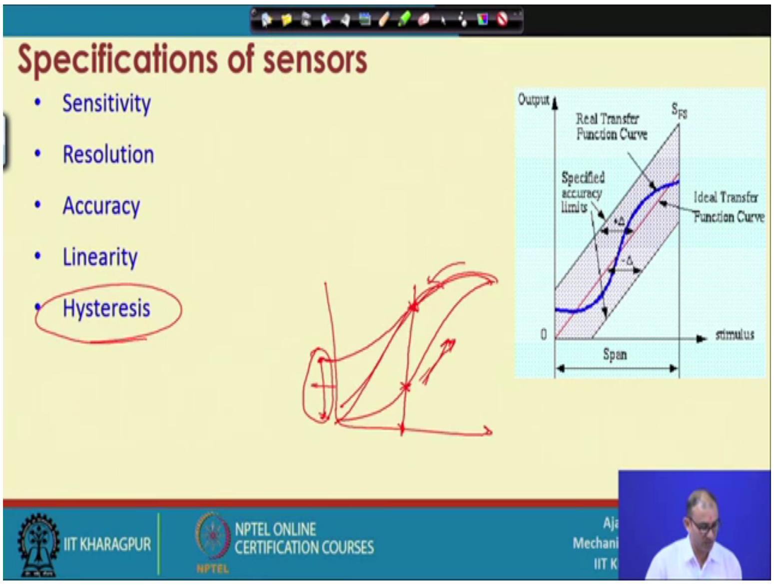

What are the specific is now when you want to buy some sensor at that then you have to specify those sensors there, what are the requirements of those sensor during a operation. So, now first thing is the sensitivity, sensitivity means suppose you are giving one input whether your sensor is sensing that input or not right.

So, you with a given input what is the output from the sensor so that is called the sensitivity resolution, we have seen already that what is the smallest measurement it can perform; accuracy that means, how far it is close to the dimension or what how far close to the desired location. Linearity that means, if you if you want to plot something with respect to your linear function then this is called the linearity, then how much it is matching with the linear fitting of the curve.

Hysteresis is very important because sometimes what happens your input graph and extra output graphs are different support. Now this is your suppose it is going into the highest location and then when it is returning at that time it is not attending to the original position. So, now you can see this is your input location input location you are getting it to output at one location here in one location here, so this is the ongoing and this is coming back right.

So, this is something which is actually the what we can say that this is a read and reminisce value; that means, this much should not be there it should come directly to the 0 value, so this is called the hysteresis loop. That means, what going means signaling when it is a response at that time it is going to one particular path and when it is returning back to it is original position it is actually taking under path. So, at that time you are end up with the hysteresis where you will get the two input output value with respect to one input value. So, those things should be reduced as much as possible drift.

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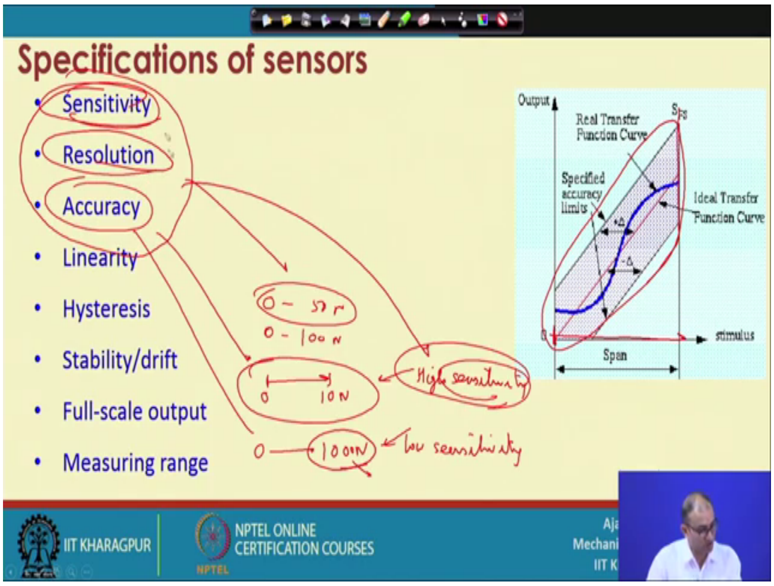

Drift is actually something which create problem with respect to the aging of the component because, we know that if you buy a new system today it will perform better, but after 1 year or 2 years you will get some type of problem, so that is related to the drift full scale output. So, this is the full scale output what it is showing that you start with the minimum possible value whatever is a sensitive will a value and then go with the highest value and then analyze that what you are getting out of the particular full scale output signal.

What is the measuring range that is very important here because, we know here in micromachining that our range most of the forces are very small right. So, suppose you want to measure some force here, suppose this is starting from range here it is considered that starting from 0 to you want to measure only 10 Newton right. So, now you consider that your all the force measurement everything comes within the 10 Newton then you can actually increase the sensitivity to a very very high value.

But if your measurement value is from 0 to the 1000 Newton, then your sensitivity will be less because now you have to make your system; in such a way that actually it can measure a 1000 Newton. So, for measuring a 1000 Newton if you make system very very sensitive then what happened that sometimes you are getting end up with the garbage values. So, those values are not importance to you and that is why the when you are looking with a very very small range at a lower scale, then you can get a high sensitivity here; but that is not the case here you have to sacrifice with the sensitivity because, that is the same yes same stringently cannot be achieved when you are looking with a very very long range.

So, you have to part out something like that then you can go with the 10 to 100 Newton or 10 0 to 50 Newton or something like that in that different different range you can actually state the different parameter. So, these particular parameters are actually connected with the, what is the range on which you are working. So, smaller the range higher the sensitive resolution you can get it, because we have seen in the linear motors and everything where your stroke of length is very very small.

If the stroke length is small then only you can get the result as a sensitivity resolution and accuracy are very very high that is at a sub nanometer level, but when you are talking at a millimeter scale those things you have to sacrifice at the later stage and then offset is important because, it is there from which location it is starting the measurements.

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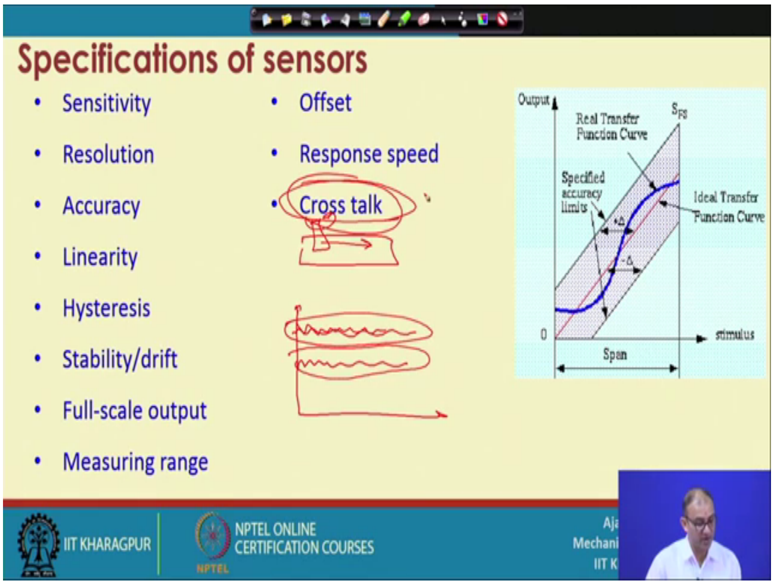

So, those offsets should be accountable when you do final calculation of the actual forces, response speed that means, once you get a v ray signal after how much microsecond or millisecond your sensor is responding to that particular stimulus. So, that is an important faster the response bit faster is the sensitivity; that means, your that directly responsible with respect to the data acquisition system, that what type of systems using for capturing all those signals.

Cross talk that means mixing of 2 different signals right suppose you are doing machining, now suppose you are doing a machining with a end mill cutter and you are cutting a slot right your end mill cutter is here and it is rotating and then you are moving in this direction correct. So, you are getting to signal one signal is for the feed rate and that is one signal is here and there is one signal here that a 1 is the normal force and another is the tangential force.

Now, things is that that these 2 signals should be separated; that means, it should not mix with each other. Sometimes what happen that if your measurement location; that means, sensor which you are using whether it is a strain gauge based type (Refer Time: 22:01) meter or piezoelectric based dynamometer. If this signals are actually mixing with each other then whatever you will not be able to capture the real condition of the cutting forces, so crosstalk should be minimum as much as possible. So, that you can get the independent output without mixing of 2 signals overload characteristic.

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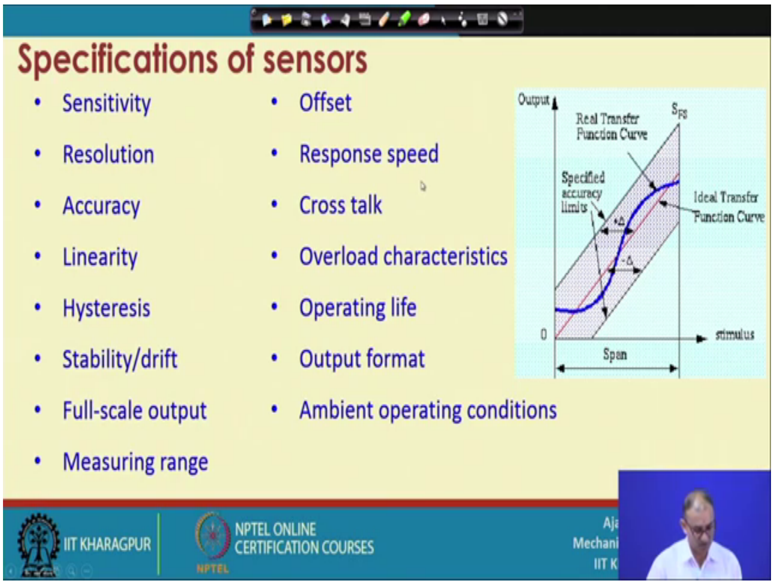

Because sometimes what happen that your system is actually rated for a 1 particular input only; that means, suppose you are for dino meter is rated for a 100 Newton only and you are giving a 110 and 10 Newton of force. So, what whether your dino meter will perform some operation or it will means break down completely without giving any type of signals, so that is called the overload characteristics.

But up to what overload it can operate within safe zone, operating lab that is important because that will directly related to drift also that in a different different environment; how much life you can extract from a sensor because, everything is a finite life you cannot use a same sensor for a lifelong. So, these all these different parameters will tell you that which particular sensor is useful for your operation. But when you talk about micromachining what our important things are sensitive resolution accuracies are very very important and these 3 parameters many times what upon the it will decide rest of these parameters, because if you set this parameter very very high then your measured measurement range will be very very small, you cannot measure for a very very large variation and the output format.

What is the output format that is also important because, ultimately what we need we need everything on the computer screen right; rest of the things whatever from raw data to the conversion then conversion to the signal processing everything is done by a computer controlled program by which this particular software or the sensors are completely a matched with a particular environment.

So, our objective is to find a particular graph suppose you are measuring a force with respect to time, then we need force respect to time only we do not require voltage with respect to time. So, what our output is coming that will decide that whether it is exactly what we required that is the output or we have to further refine or further convert that output into the under required output. So, that will also be a 1 of the specification of the sensor and the ambient operating conditions.

Now, we know that in versioning what we do that we use a coolant also then there are chip coming out of it and those chips are very very hot also. So, again we have to find out what are the sensors which are completely ineffective in this type of environment. So, they will not create any problem, when you operate when you install those sensors into this type of environment where the coolant is available and there is a high it zone available and sometimes forces are also accept in terms of vibration.

So, we have to make sure the way what are the sensors which are suitable for those type of environment and then only select the these different parameters. So, that you do not actually end up with some type of wrong signal or the wrong output and what are the sensor this slide we have seen long time before.

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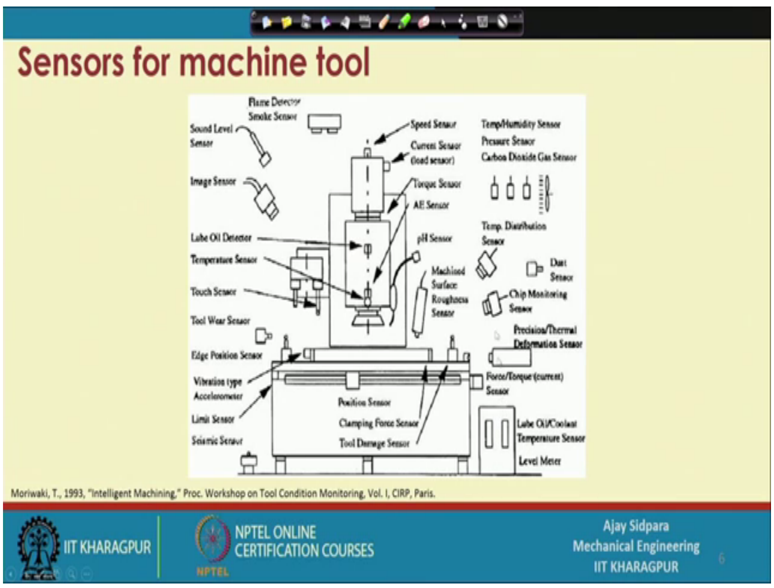

But still this slide is relevant to this particular topic because, this slide is telling you that what are the different above sensors you can use for monitoring and control of a manufacturing process.

Now, it is a vertical milling machine now you can see here that there are different we have already discussed, so I am not going to discuss those sensors again. But you can see that it is starting from monitoring the machine tool they are monitoring the machining operation and monitoring the work piece condition and also the coolant and everything and climate also it can monitor throughout the surface.

So, by this way you can understand that how this particular machine tool sensors are useful, but you also know that all sensors are not required that again depends on the what is your requirement depending on you select, the sensor which are more suitable for your application. Now coming to the different type of measurement approach one is the direct measurement approach.

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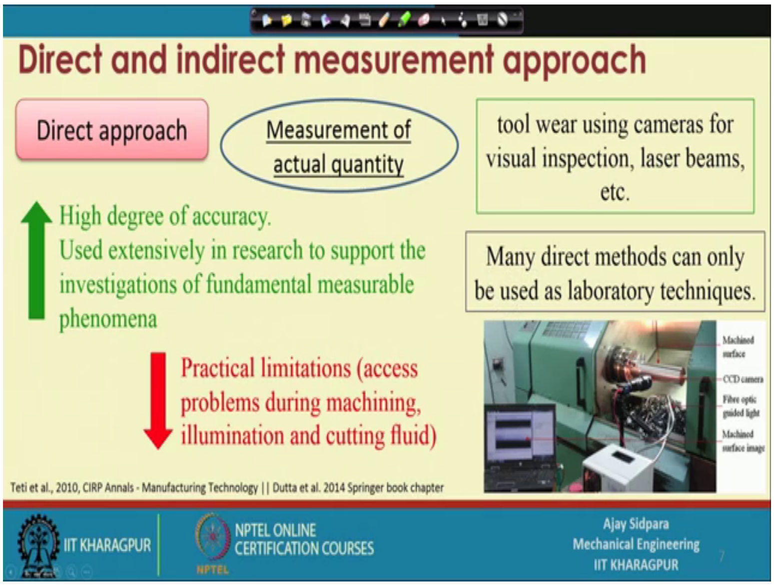

What is the direct measurement approach that you do machining and measure the required quantity directly there itself, you do not want any conversion between the 2 different ways we will use, so that is the measurement of actual quantity.

Now, suppose you want to measure the surface toughness here, then you do not want to convert that poor signal into the surface roughness and then you find out some empirical formula, you directly put 1 camera here and then capture the images right. So, based on that you can get the surface machine surface image and then you decide or when then you do some type of decision making whether it is correct or not right. So, tool we are using camera for visual inspection laser beam actuator forward placement accuracy in everything. so these are called the direct approach because, you are measuring directly what is your intended intention.

But what is the problem that many direct methods can only be used as a laboratory technique because, here what happened that if you put many things here and there then machining operation actually you cannot perform in a much better way because, these things will occupy many of spaces and you do not have liberty to say at the work piece and then again do the setting of this parameter right.

So, there are advantages of this the high degree of accuracy because, now you are measuring what you require directly there is no conversion between the 2 different values and used extensively in research to support the investigation of fundamental immeasurable phenomena because, initial stage when you want to do some type of fundamental research you do ot want any type of any accuracy in the measurement right.

Later on you can actually come move to the some other part, but right now you are to need you do not require any type of noises in bit in between the measurement and the signal what you are getting. So, this is what very advantages in this thing but practical limitations are there because, these things are mostly at the laboratory or not at the production level. So, excess problem during the machining illumination and cutting fluids there are many things are there which make those, but this particular direct approach very very inefficient in handling the actual or practical situations.

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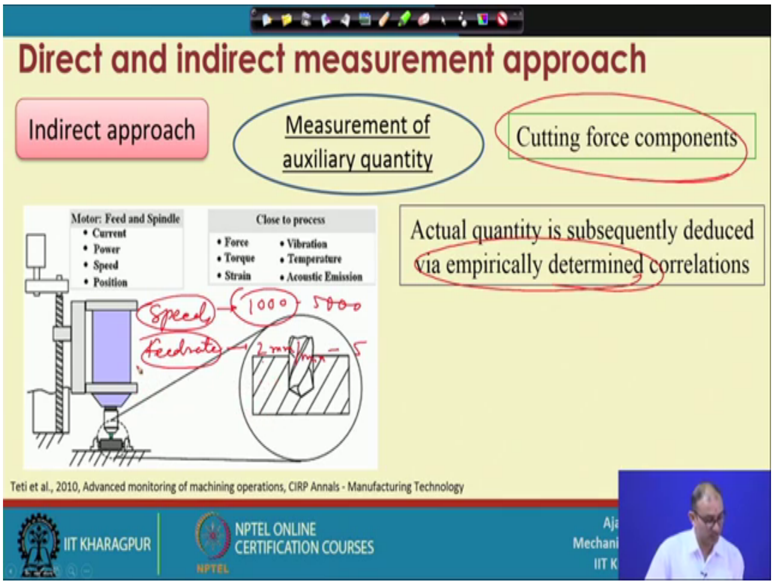

So, we do go with the indirect approach, what is the indirect method that you do measurement of current power speed and position and based on those things you do some how you calculate the condition of the cutting tool graph piece or the some other component of the machine tool.

So, it is indirect means you are measuring some auxiliary quantity and then oxalate contact once you measure, then you correlate those auxiliary quantity with respect to the actual parameter. So, suppose you consider cutting force component, that is the cutting force component has nothing to do with the machining yes it is just measuring the what are the forces acting between the cutting tool in the work piece. But by getting those signal you are getting many useful information related to the cutting tool work piece in the situation of the different different type of alignment problems.

So, actual quantity is subsequently used by a empirical determined correlations. So, here what we are doing you measure the cutting force and by changing that to different parameters suppose you are changing the speed speed you are changing and then changing the feed rate. By changing this parameter you are changing this things up for thousand rpm to the 5000 rpm 1 at a time and then you are changing fluid within 2 mm per minute to 5 mm per minute.

So, you select this parameter and then you do changes 2 3 4 5 like that and every time you get one force signal and then you create a one type of empirical formula; that if you do operate this particular feed speed and depth of curve and then these are the force reading and based on that after that you do measurement of a straight or the cut tool wear and all this thing and then you again find out the how forces are related to the cutting tool wear and how the forces are related with respect to the alignment of the work piece, whether it is a cutting in a straight line or it is cutting in a taper turning kind of thing then every time you will get a different reading. So, by that way you have to measure in a indirect way right.

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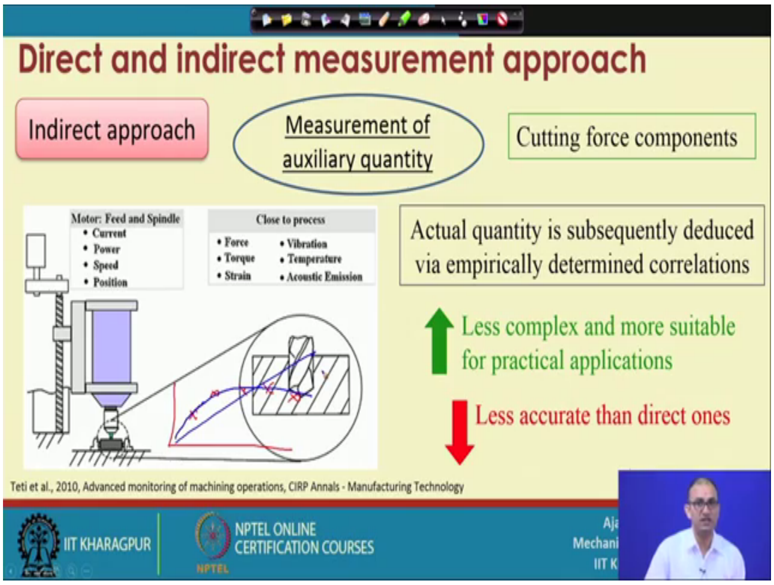

So, it is less complex and more suitable practically that is the reason the dino meters are most widely used compared to those type of direct approach, where you put a camera and do some measurement and it is a less accurate than the direct measure. But problem is also that because ultimately everything comes under the empirical formulas, then how what are the fitting of this formula with respect to the cutting force measurement.

Now, you consider that suppose you have a some type of data here suppose this other indium data and then what you have to do to do a fitting of one curve here and that curve will tell you that how far it is fitting if it is a polynomial curve then probably it will pass through this all the points depending on the what is the power of that if it is a straight line then some of the points will be missed and you are not getting the exact value. So, these are the two different approaches by which you can do measurement of the different type of signals. So, let me finish this class here we will continue this lecture in the next class.

Thank you very much.