Introduction to Mechanical Micro Machining
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Lecture - 30
Errors in machine tool (Contd.)

Good morning everybody, and welcome to our course on introduction to mechanical micro machining. In the last class we have seen some of the parameters which will affect the movement of the different axis in X Y Z direction. We have seen that what is the straightness, what is the flatness and how the smoothness also affect the machining performance and we have seen some of the examples of the problem of the tool workpiece location and the contact positions. So, we have seen those things and let us continue further in this.

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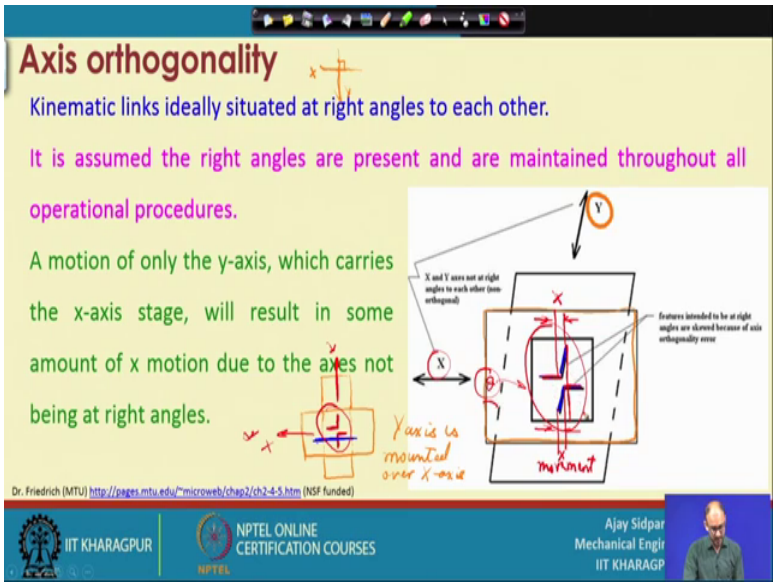

So, this is axis orthogonality. So, what is axis orthogonality; that means, we know that our X-axis and Y-axis are perpendicular to each other, correct? So, this is the X-axis and this is Y-axis. If that is not the case then what is going to happen, right? Let us see those things.

So, kinematic links ideally situated at right angle to each other that is what you have seen here, that is X Y and Z all thing should be right angle to each other. It is assumed that the right angle are present and are maintained throughout all the operational procedures.

Now, there are 2 ways that if machine is static condition we can get this particular thing done, but when it is in motion at that time what happened with these additional forces and the vibration, which may create some additional problem and you may not get the straight line, even if it is straight line there may be a some variation within that straight line. So, that creates a problem. So, what is this particular thing? Now here, this example tells us now this is the X-axis.

So, whatever we are showing here this is the X and this one is the Y only problem is that Y is not perpendicular to X. Our actual thing should something it should be something like this suppose this is the X one and this should be the Y one, correct? So, this is the actual configuration this dotted line dash dash line it tells us that X Y is actually mounted over the X-axis, right? In this case Y-axis is mounted over X-axis, correct? This is what is showing

Now, you want to create 2 futures yes. So, this is the tool path it is showing here correct? So, this is the tool path. What is our objective? Our objective is to create a component or the machine something like this. This is our objective that is only full fill if your X and Y-axis are perpendicular to each other. Now, what is problem? That your X is it correct that is perfectly fine, but it has a problem in the Y Y is little bit shifted with a some degree of angle that is theta. So now, what is problem? That if your workpiece is moving in X direction only no problem because, if you want to just cut a straight line here in this particular case.

Let us see that that suppose your cut is in this direction you want to cut something in this direction at that time it will not create any problem. Because, you are just moving a X-axis in this direction, but if you are cutting something in Y direction what happens? The now, if you see this thing X direction X direction things are both are straight along with the X direction, but when you are cutting something in Y direction. Now, this is the path it fallow.

Now, what is problem in this path still it is parallel to the Y-axis, but that is not the case there is one problem. Because, when you do when you draw one line here, from here to here and from here to here, it has a movement in the X-axis also. Now, if you see this thing this is the X movement, correct? When you are moving in X direction at that time we can see that there is movement in the Y-axis, but when you are moving in a Y

direction because, Y-axis is located in the this way at that time you are getting extra motion because, X is located on the Y. So, wherever Y is moving your X will also move. So, and that condition your X is getting extra motion where actually you do not want anything else your future is something like this, but you are getting this particular feature.

So, this is a problem which we have to ever. So, orthogonality is creating problem because, we have seen that all axis are coupled with each other if you are create getting a problem in one axis that will be propagated or, it would be transferred to the another Y-axis or the X-axis or the Z-axis depending on the motion of your tool or the workpiece. So, this should be avoided at any cost otherwise you are getting a wrong cutting or the wrong feature.

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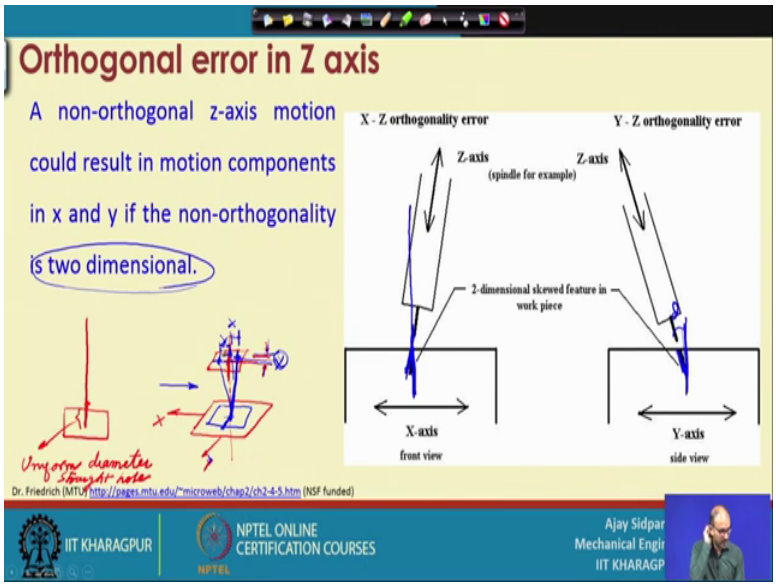

Now, coming to the orthogonal error in the Z-axis. Now, we know that our Z-axis is always vertical we assume that thing correct? And when you are want to cut something or jub suppose consider now, you are not considering X and Y direction. So, let us consider about the drilling only. So, you are drilling a hole here.

So, when you are drilling with a straight line we assume that this is a straight cutting; that means, it is uniform diameter, correct? That is only possible when your axis is a perfectly straight or uniform diameter, or the straight diameter straight wall, correct? So,

non-orthogonal Z-axis motion could result in motion component in X and Y if the north non-orthogonality is in 2 dimensional now, what is mean now this is the condition.

Now, let us see in a little bit isometric view. Now, consider if suppose this is your work piece, and this is the point through which you want to do a drilling operation. This is your X-axis this one is your Y-axis and your tool is located at the top. And when you see from the top now consider, this is a straight line. Now, let us create 1 plane here this is the straight line here and now, your tool is incline with the some axis here suppose your tool should be here, but your tool is located somewhere here at this location. So, it has a location error in X and Y direction both the things now see, this whatever this deviation so, this deviation is in that is in Y direction. And whatever this deviation this deviation is in X direction, correct? Right now, a tool is looked at here.

Now, if this location is and you are getting it at this location, correct? So now, what happens if you put this particular plane here, directly same plane then, because of this alignment problem your were hole you are drilling at this direction note exactly at the straight location. So, this is what this figure tells us. So now, we are looking at the X and Z plane. So, we are looking from this particular plane at this direction when you are looking from there because now, there is alignment problem.

So, you are tools is located incline so, instead of a straight line. So, you are location is here, so you are tool everything should be something like this. So, in a hole should be it should come like this, but because of that problem in the or alignment problem with the X direction with Z direction you are actually drilling a incline hole. That is your looking from that a, but if you look from this particular direction right now, we then you can get the another axis problem so, you are drilling in this direction. Actually, it should be in this direction because this is the angle theta which is additional or that is the error because, between the X and Y and Z-axis. So, this is what is problem.

So, now, you can understand that if your problem in X or Y direction this is a 2 dimensional because, it error occurs in the 2 dimensional. But suppose your tool is located this location or this location then, what we can tell that if it is located here then actually it is in the no problem in the X direction, but it is a axis problem or the deviation in the y direction only. If your tool is located here and then it is drilling at this location then, there is no problem in the X direction, but it is a problem in the Y direction

because, this particular things are in the Y direction X direction not y direction. So, in that way you have to find out that out of this particular thing where your tool is located, what is the tool location then only you can get the thing. So, we have seen the orthogonal error problem in the X and Y direction and Z direction also.

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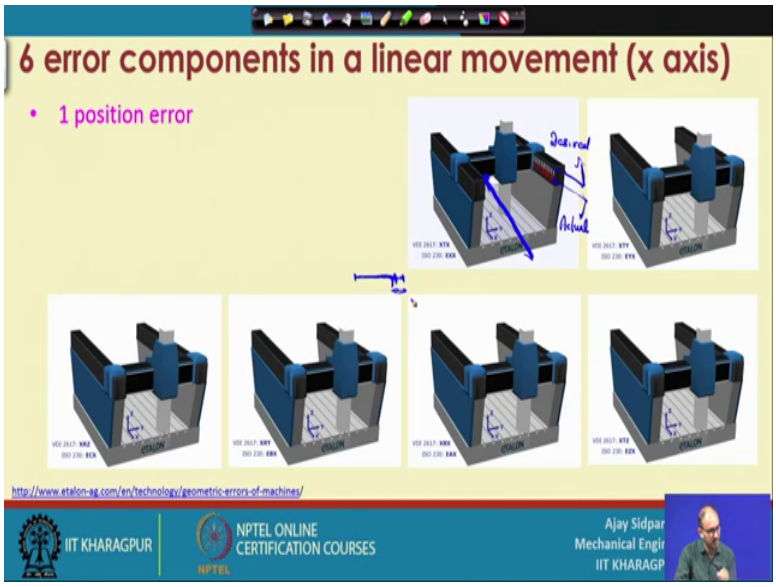

Now, let us see what are the different type of errors in different axis. Now, you consider the X direction only right now let us see X direction. So, this is the X direction now notations are given here at this. So, you have to pay attention to this location, right? So, each 6 errors are because of the deviation in the X-axis, correct? So, what are the this errors. So, first one in the position error. Position error means, right now you are talking about X-axis only.

So, your tool or whatever this particular motion control it is perfectly fine in the Y direction and both the directions. But now, consider this thing that it has no problem in the Y-axis and X-axis. So, you are your tool is always in a straight line means, there is no deviation in this particular part, but only thing that when it is moving now consider that it is moving now you will find tool scale here. If you see this particular location one is the white colour one, and another one is the red colour one. So, white colour one is the desired one this is the desired and this is what you are getting.

Now, how these things are different? If you see the spacing between all the Y lines are uniform that is called constant, but if you say spacing between the red line these are very,

very random. So, what is problem that is what we are talking about the stiff and sleep phenomena. So, sometime it is very, very easy to move then suddenly you are getting as a very stick phenomena friction is very, very high, and then sudden movement is there. So, you are not able to move your X-axis very, very uniformly. So, that is the position error that you are not able to find a one particular location.

Suppose you are moving from here to here your target location is this one, but when you are moving and you encounter the stiff sleep phenomena, because of the stiff sleep you are actually end up a little bit ahead of this particular point. Because, suppose you are reaching very close to that and your you are we want to do this to this location or target location, but because the distance is very, very small and friction is very, very high you actually provide little apply little more force. Because of that more force your movement will be little bit more. So, that is the problem in the position you are not able to get to the same location where you intended ok. So, this is what is happening in this particular case. So, your particular position error is this one.

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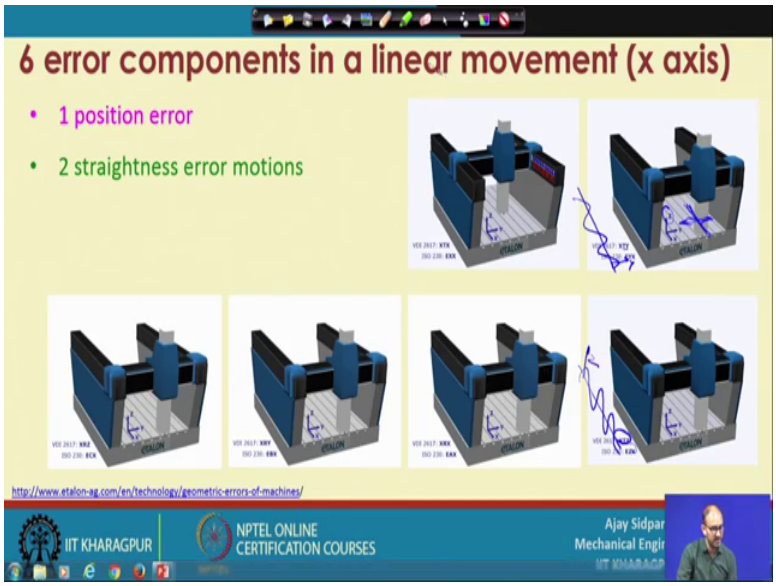

Now, second is 2 straightness error straightness error. What are the 2-straightness error? Because, we know that we have a 3 axis perpendicular to each other. So, what are these straightness errors? So, one straightness error is you consider this is in error in the Y direction. So now, what is going to happen that you will get this particular straight error you will get all the Y same this particular red colour and the white colour same, but what

is going to happened here? Z Y yours this particular movement it is in Y X-axis, but it will actually move in Y-axis also, right? If you see this particular location you can understand that it is moving in both the direction. Now, if you see this location it is little bit coming in this direction and this direction. So, your motion is actually in this direction. So, instead of a straight line what you are doing actually you are cutting in this direction. So, this is the first straightness error in the Y direction. So, still we have one more axis that is called X-axis Z-axis. So now, this is the error in the Z-axis. So, this is the moment in X-axis, but error in the Z-axis, right?

So, now, see this is moving up and down correct. So, this up and down motion will again create a problem. Because here, you are getting a this type of motion but here, what you are getting you are getting a this type of motion. So, this is in the Z direction and this one is in the Y direction. So, one is the position error because, you are not able to position your workpiece at one; that means, uniform motion was not possible. Another one is it is moving in a sinusoidal wave, but in the same plane, and another one is the moving in the sinusoidal wave, but in the vertical plane. So, that is called the Z-axis problem.

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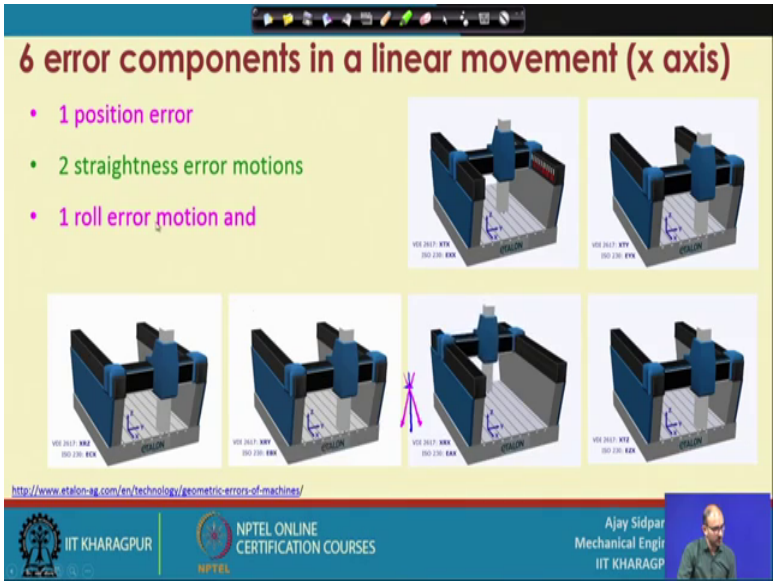

Then one is the roller roll error motion. So, this one is this one. So now, this is called X roller motion. So, earlier it was a translation X t X. So, motion in x direction, but error in X direction translation here motion is in x direction, but error in Y translation here

motion is again X direction and error in Z, but in translation error, but now it is r X it is a rotational error.

So, let us see how it is rotational error. So now, you can see that it is moving along the Z-axis, but it is swinging around the Z-axis. So, how this is happening here so, this is your X-axis and this is your point of contact are that is the centre point of that, and then your axis is moving in this direction and this direction. So, this is your movement if you see it again you can realize it, correct? So, this is going down up going down up. So, this is how it is moving. So, this is the one roller error motion.

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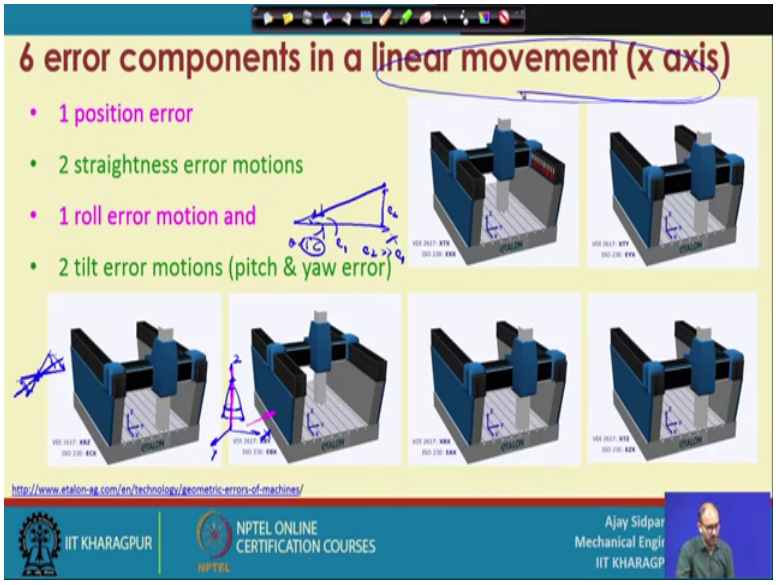

And again 2 tilt error motion pitch and yaw. So, this is X now, we can see the X rotation around X, it is X rotation around y and this is X rotation around the Z-axis.

So, now let us see, this one now see it is swinging in the Y-axis direction, correct?. So, this is something like so, if you are looking from this side. If you are looking from this particular direction then, your spindle axis is this one and then you are actually swinging in this direction and this direction is the Y-axis and this one is the Z-axis, correct? This we are looking at this particular plane. Now, this one is X-axis and this is the Y-axis from this particular plane. So, this is the Y-axis. So, movement is along the Y-axis a same way you can see this is third last one also here.

So, this is along the Z-axis, correct? So, this is the rotation around the Z-axis. So, when you see from the top one looking from the top. So, this is the location and consider this is our path then you are all axis is moving in this direction, correct? So, this is moving in this way. So, these are whatever we are so, seeing here right now it is actually at a very, very highly exaggerated view, but a small was an we know that we are working at a micron level. So, even a small micron here because we know that easily, if you see this particular thing that suppose we have a very, very small amount of problem here. So, this is this axis should be straight consider X-axis and this is one degree of slope whatever theta is 1 degree.

So, if you are machining at this location what is a problem that you are actually working with this particular error only. So, this is the error1, but if your tool is located here at this location then your error is very, very amplified depending even though it is a 1 degree angle the far away from the so, or so, location of this error your amplification will be very, very high. So, this is the e 2. So, e 2 is very, very higher than e1. So, if you see in this condition every or this rotational error everywhere your movement is very, very small, but it is very if it is very close then it is very less, but if it is very far away from there then it is a very, very high. So, that is called yaw error that is mostly will find in the vernier caliper. So, this is about the movement in the linear direction right now we are talking about linear direction.

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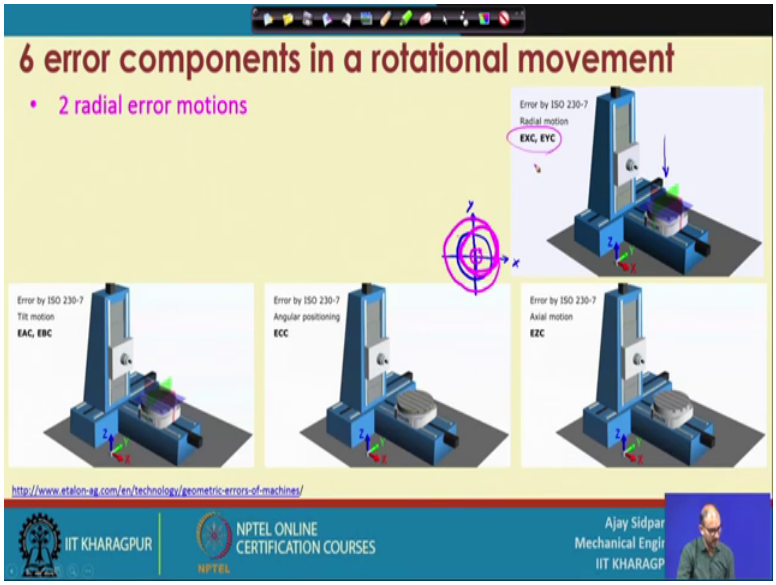

Now, coming to the rotational axis. Now, we have seen that linear axis X Y Z all 3 will play important role in the machining, but suppose we have mounted on the 4th axis that is the rotational axis. So, how rotational axis will work? So, there are 2 radial error in the motion. So, total there are 6 error earlier case also there were 6 errors, but here there are 2 radial. So, let us see this first 3 2 radial. So, this is the error in X direction circular error and this is error in Y direction circular error.

So, here this particular chock is given and chock has the 2 plane, one this green colour plane is one there 3 plane another is blue colour is at the bottom so, it is a plate surface and this red colour is the perpendicular to the both the planes. So, these are the 3 planes. So now, when it is moving at that time you can see that it is actually not moving exactly at that centre only. So, it is moving in both the direction X direction and Y direction. So, how you can see that thing? that suppose the real looking from the top so, this is the actual location.

And now consider this Y is this one. So, let us considered this one is Y-axis and this one is X-axis what you are looking at from this only. So, instead of that what it is doing that it is rotating something like this. So, it is centre is shifted to one another location that is all. If that is happening then what will happen? That it will rotate in both the deviation. So, you have a deviation in the X direction also and Y direction also, correct? So, in that way if you are centre is here then, sometime what was centre also rotation this direction then whole path your tracing path will be something like this a big circle now.

So, in that direction you will get the magnified error in the all this condor 1 2 3 all condor you will get that error and that is called the error in the X and Y direction during the radial rotation.

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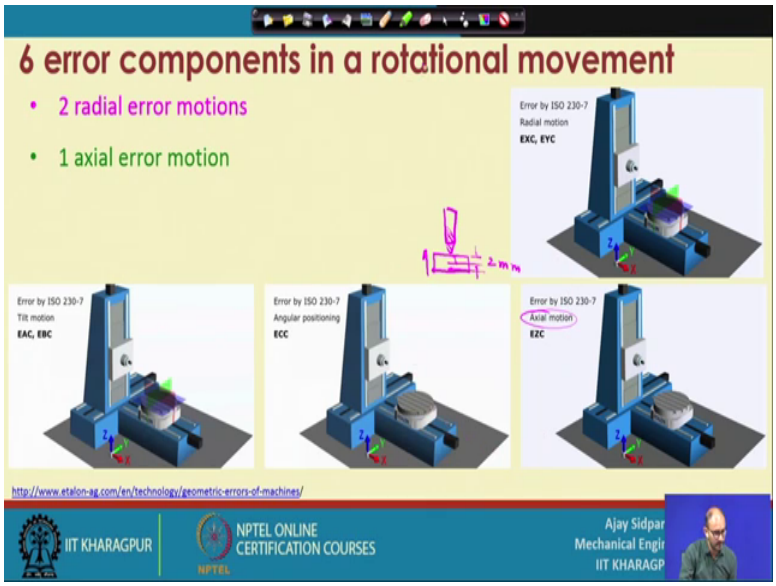

And another is the axial rotation motion. So, axial means what we are talking here it is a rotation around the Z-axis. So, this whole thing will move up and down.

Now, see this is called up and down motion. So, it is not in the same plane. So, this blue colour plane is there. So, it is not rotating in the same plane so, it is moving up and down. So, your Z is always changing in that direction so, what is the problem of this particular thing is suppose, this is your tool and consider that you want to drill it. So, this is your drill and this is your workpiece, correct? And you have said that you want to go a do a shallow cut or the all drilling.

So, this is suppose you want to go with a 2 m m, and if this thing happen that your workpiece is moving up and down in this location what will happen instead of 2 you may go up to 3 also because, now your depth is not able to controlling that. So, that is the problem in the actual motion you are not able to control the depth very, very properly.

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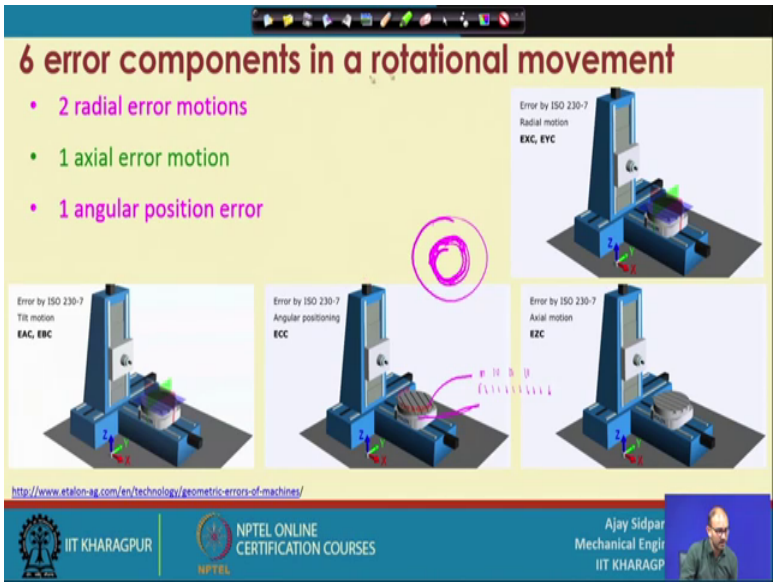

Now, coming to third 1 angular position error. So, this is the angular position error. So, what it is showing us that now, you can see here that there are 2 different mark earlier we have seen in the earlier graph that those 2 marks were the white colour and the red colour. So, here this black colour is the desired path; that means, all the things are uniformly space and what motion you are getting here, you are getting something like a and something like this. So, this uniform this thing are uniform or the smooth motion is not achievable in this particular case.

So, when you are cutting a slot by this particular thing then, there are problems suppose you have circular workpiece and you want to cut a slot something like this, this is the slot which you want to cut ok. So, instead of giving the motion in X Y continuously what you are doing you are doing a cutting in the rote by rotating this particular C-axis. So, in this case what will happen that you are not able to move your tool uniformly throughout this particular circle, and that is the reason that you are encountering a very, very large amount of force for a longer time, and suddenly there is no force or suddenly there is no movement. So, at that time tool failure will be very, very high.

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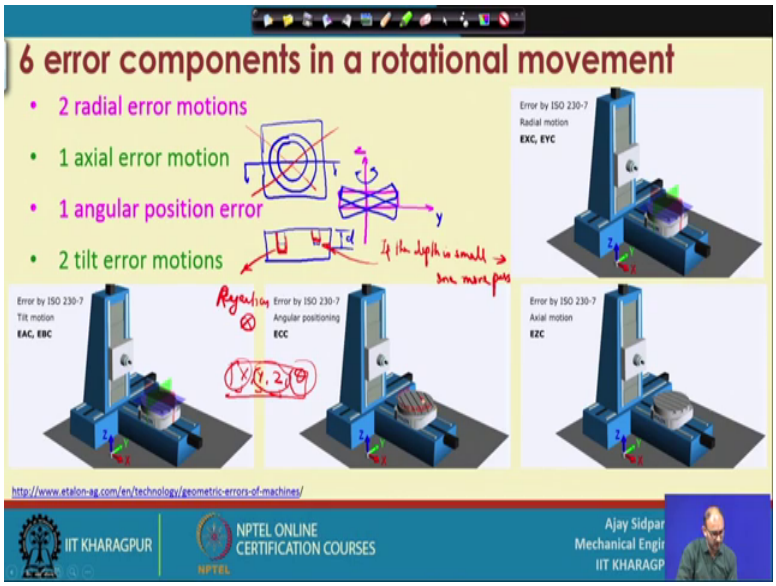

And this one is the 2 tilt error motion. So, now, again now wherever we are finding there is a radial error or the tilt error then, all the 3 plane is coming into picture. So now, tilt error are is the error in the A with circular that is means along the X-axis along the Y that is a B axis along the Y-axis and then you are getting a circular error. So, let us see that how it is there. So, here you can see that it is moving out of the plane in this particular case, correct? So now, how it is showing that thing now, your slide or that particulars chock is located at this location and this is our Z-axis. Consider this one is our X-axis and Y-axis is perpendicular to both of this.

So, first let us see the EAC. So, what is this EAC that you are this particular thing is now rotating in this particular way. So, this is the angle with respect to X direction. So, your rotation is a continuous that is; obviously, there, but it is rotating in this particular directions so, in this way or in this way. So, this is the problem with the X direction, same way if you change it to Y-axis then you are getting the same axis for the Y one also.

So, this is considered this is the Y one then you are getting the same motion here. So, what is problem here? This suppose same let us take the same example here, that you have a square circle and this is the slot you want to cut, and if you are taking a cross section of this one what you are getting here?. This is the thing and here this is the slot with a uniform depth, correct?

So, this depth should be same, but if you are end up with both this particular thing is what will happen? In some cases your depth will be very, very large wherever you do a cutting operation whatever plane you cut from here ,you will get a different depths maybe dif they are high is very large here it this maybe even smaller than what is required, it is higher than what is required.

So, in this type you can get the different different type of shapes and different different type of errors. And sometimes what happen that now, if this is the condition suppose in all the cases you are getting a them smaller than what is required then, there is a chance that you can do re working here. If the depth is small is small then you can do one more pass, correct? But if depth is more then you cannot do anything here it is a pure rejection, correct?

So, what is the objective of understanding this error component that we have error in the 2-different direction. Total means total in 3 direction X direction Y direction Z direction and this rotation also that is in theta direction. So, all the 3 axis are important in this way we have seen X example, we will see Y and Z example in the next class and theta this example we have seen here, and this is the way actually you can understand what are the problem in the motion error of the axis.

Workpiece machining and those thing will come later, but first we have to make sure that our motions of all the axis are perfectly fine, and there is no deviation or if there is a deviation it is within the allowable limit of the specification of the component, which we are going to cut out of that machine.

Thank you very much let us finish this class here, and we will continue this topic further in the next class.

Thank you very much.