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

Lecture - 29
Errors in machine tool (Contd.)

Good morning everybody and welcome back to our course on introduction to mechanical micro machining. In the last class we have seen some of the sources is of errors which will create a problem in the structure, and we have also seen that what are the sources of error and where this errors will occur and what is the outcome or the final product and now if you dip calculate all the things first you find out the what is the problem in the final product.

Suppose it is the surface roughness then you can find out that what are the errors by which your problem has occurred then you can go to different component of the machine tool where you have found this thing and then finally, you find the source of the error by this way you can actually control the or you can identify atleast the what is the source of the error and then which way you can control that depends on the what are the instrument and what are the things you have in the machine tool.

So, in that we have started and we found that there are different sources of error in the structure of the machine tool, we started with the structure and we have seen one video where you can do it thermal compensation in terms of insulating of the different different area because of the falling of the chip and putting the temperature sensor. So, you can control or it can calculate the deformation in the structure. So, that again it can come back to the original location or the target location and you can continue machining without any problem.

So, let us go further ahead in this case. So now, there are the 3 different 4 different forces over there and that was creating a problem in this is what we have seen in the thermo mechanical errors.

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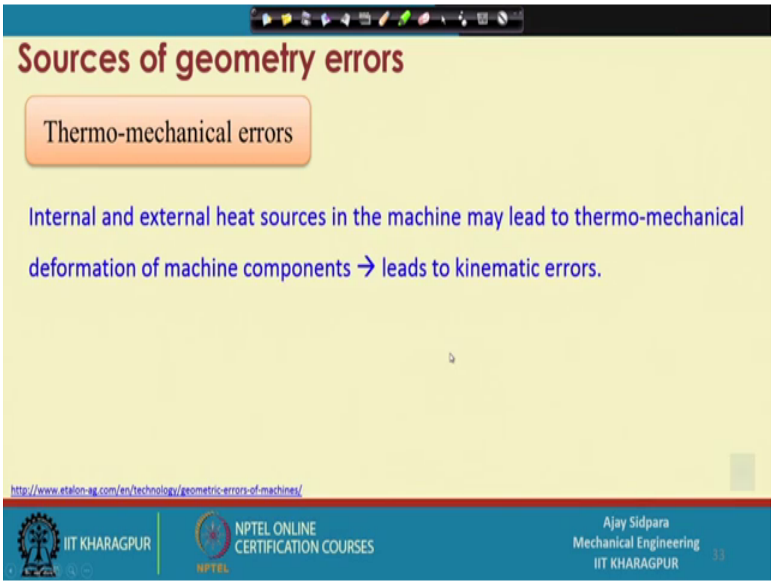

So, here we seen that video and we found that there are different machines available which can actually respond to the thermo mechanical error and your machine will be still in within the acceptable zone or acceptable limit and you can continue the machining operation.

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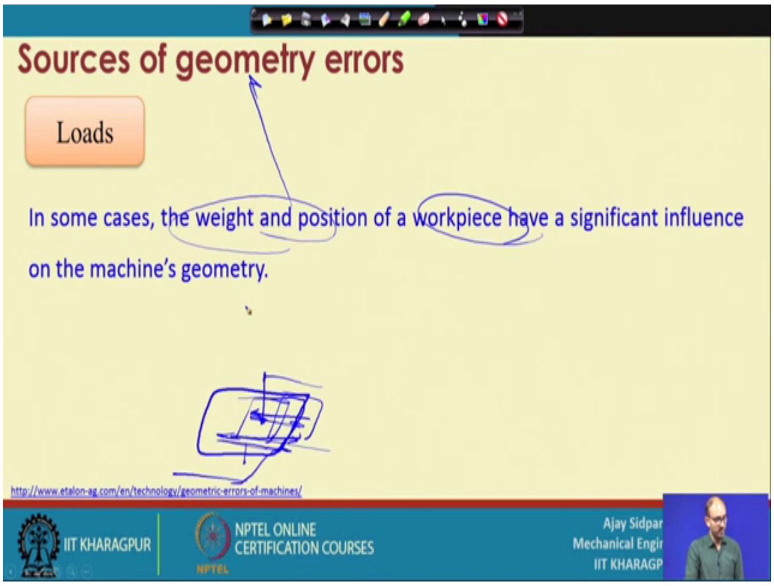

Further ahead this is a loads. So, what are the loads that in some cases the and position of a work piece have a significant influence on the machine geometry that we have seen long time before also. That suppose you have a table this is a table where you are putting the work piece. So, if you have put a very, very heavy work piece here what will happen the table is actually not the at the bottom there is always a base so base will deform because of the position of this weight.

Because many times what happened that we put we put at work piece here and then what we do we slide the work piece or the whatever we are putting a work piece we are putting we are putting a fixture or the wires of the work piece then we slide it here if you do this thing 100s of time there is a chance of that there is a wear of this particular component and sometimes you are sliding sometime what we are doing.

We are just putting on the top look at locating at the top and then you are just falling it down, at the time it will create impact and if you are sliding it will create a scratch. So, after long time if you continue in such a way that that your end up with a some type of problem in the geometric error. So, this will actually destabilize the whole structural look and that would create a problem when you do actual machining operation.

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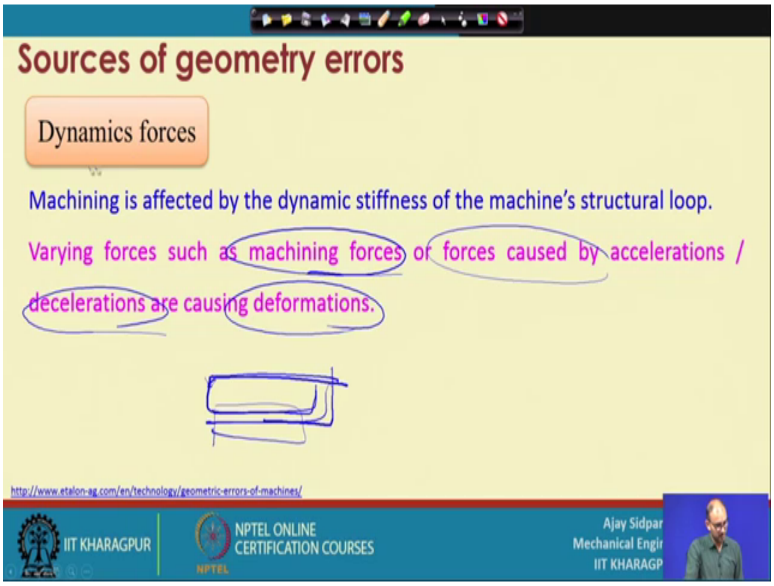

And dynamic forces those are the forces which are in dynamic condition; that means, when you do machining there are different, different forces occurred and that will create a problem. So, varying forces such as machining forces, so machining forces is one of the main source and then after that the force is caused by the acceleration deceleration because suddenly our machine because when our work piece located here what will happen suppose you want to cut in from the one direction only correct?

So, once your tool is completed this part what you do you pull out this tool and then suddenly quickly go to this location because we want to increase the production rate also. So, here we are not doing machining so it will quickly go to this location rapid travel and again it will locate to this location then do the second part. So, this acceleration deceleration also create a small amount of deformation because in the machine in the geometric error. So, these are the different source is of error by which your geometry will be problematic.

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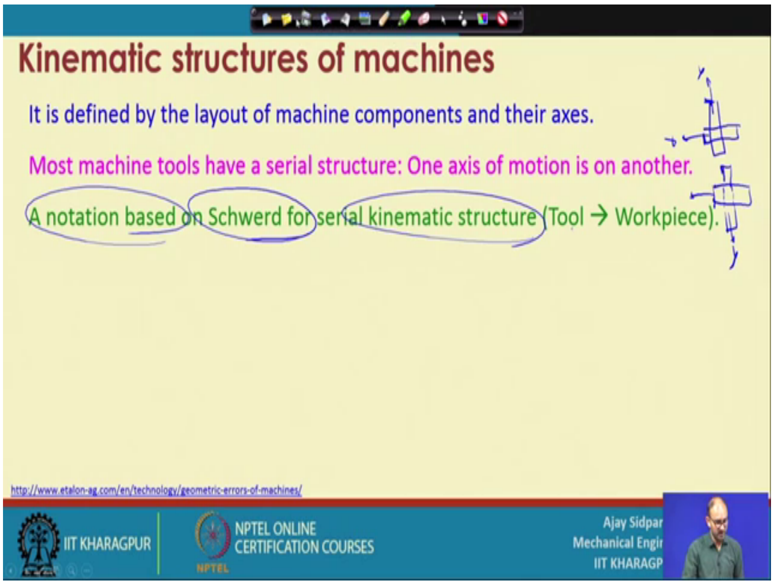

Now, coming to kinematic structure of the machine, how can define the structure? So, it is defined by the layout of the machine components and their axis how they are located and mostly almost machines have a serial structure. Serial structure means that one machine axis of motion is actually overlapped or it is built or it is mounted on the other one. And now there are different notations are also available. So, if that is also case now we consider. So, this is the where so this is suppose the X axis and that does not means that Y axis is somewhere else. So, this is moving in X axis.

So, Y axis either on the top of this X axis or it is a below of this X axis so this is X axis this is Y axis. So now, here in this case Y axis actually it is below of the X axis it is on the top. So now, there are overlapping with each other and because of that there is one person who is Schwerd who has actually provided one notation by which you can get the kinematic structure form tool to the work piece now we have to do that let as see that which way we can define those things.

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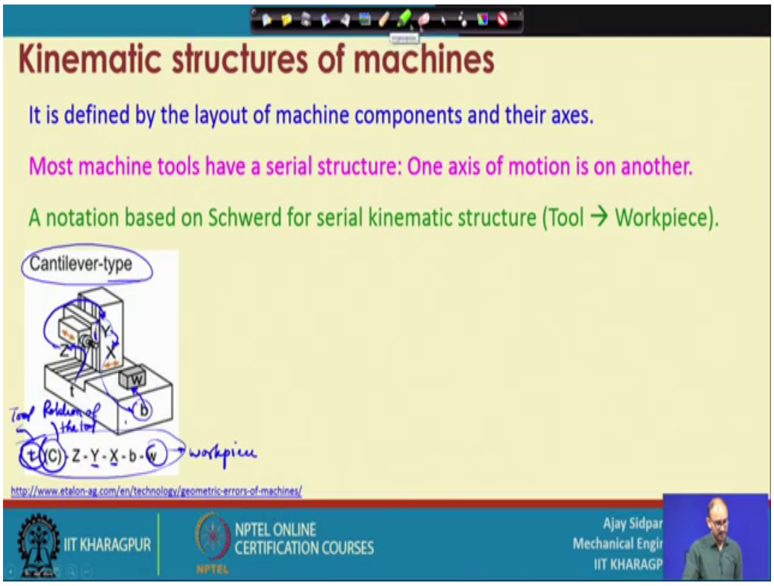

Now, this is one of the structures now here same of the notations are given. So, t is belongs to tool and w is the work piece correct? Whatever is in between these 2 these are the different, different motions which are coupled with each other. So now, if you see this t so t is located here.

Now, what comes next to t it is the c axis that is the rotation of the tool. Now where this spindle axis is located this is located on the Z axis now third one is the Z1. Now where Z is mounted all the thing all the things are mounted with this location. So, form here to here it is there form here it is moving to the y so now, next on is the Y, where Y mounted? So, Y is located here this is the Y motion Y is connected with the Z X 1. So now, form Y to x. So, we are getting Y to X and X is mounted on to the base. So, it is directly connected with the base. So now, this one is the base and from base we are putting the work piece. So, this is called the cantilever type configuration and where we can notice given notation something like this.

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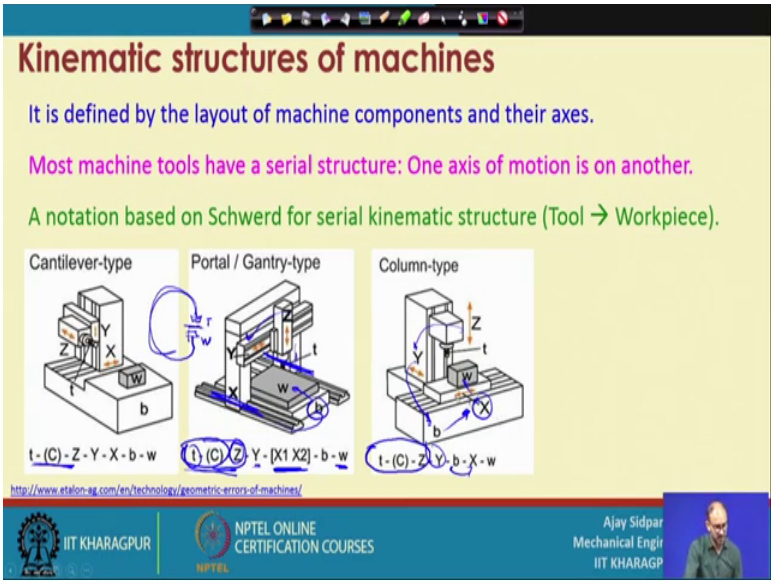

Now, this is the second structure now this is a gantry type of structure. So, here again let us see same way. So, these 2 things are always fix mostly you will get you can get Z also because tool is rotating and rotation is always in the Z axis. So, this 3 are mostly common in all the cases w is always at the end because this is the only location where you are coupling the older thing. So, because right because we know that this is the work piece and this is the tool, this is the tool and this is work piece and this both the things are only the open link out of this full loop rest of the things are connected with each other.

So, after Z now, you can say this is the Z and Z connected with the Y. So, Y on is there now it is gantry type of thing. So, it has a 2 player from. So, here is a one another is the Z this one. So, that is why it is given X one and X 2, but both things move we assume both thing are moving parallel and there is no any type of late in the motion. Then both the things are located in the b and then b to the work piece. So, this is classification of another case this is the column type. So, here also so tool work piece tool r p m in the Z axis are common for that and then Z is connected with the Y then Y is connected, now here it is different if you see here Y to X everywhere Y to X and then it is on the b, now if you see here why it is going to the b because Y is connected with the base and X axis is mounted on the base. So now, there is a shifting or inter change of the X and b position and form X your putting a work piece on the top. So, that is another way and this is another 5-axis machine so

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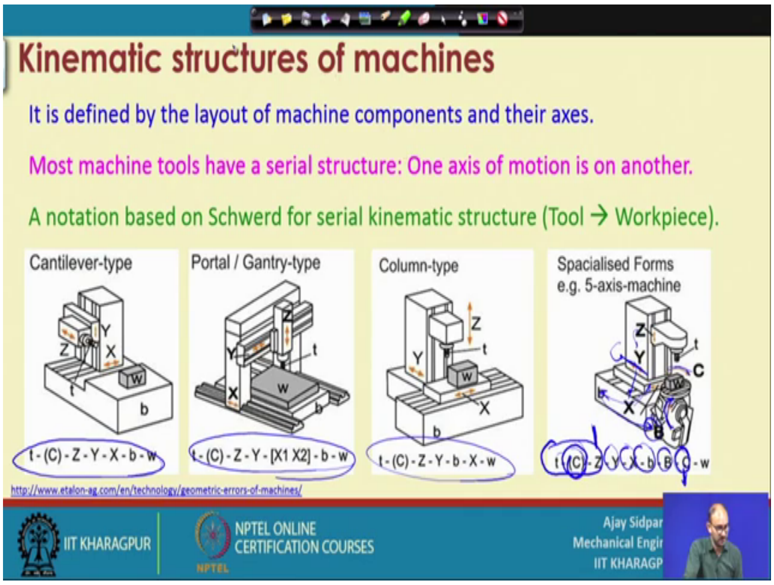

Now, you have to add one extra axis here. So, here again the same thing here t c and Z available t c and Z available. So, here is a one c and Z is on the y so it is coming to the Y then Y is mounted on the X. So, that is the X, X this is the X on whatever we are showing here this is a X then X is mount it is on the base, from base we are putting a b axis b axis is the rotation around the Y axis. So, this is the Y axis rotation this is the Y axis rotation Y axis is here.

So, we have rotation around the Y axis that is why B is coming into picture. Then we have rotation the work piece along the Z axis. So, that is why another C has come here. So, this C is always appear here because it is a rotation of the tool and this is and that is the rotation of the tool along the Z direction, this is a rotation of the work piece along the Z direction. So, this one has a another name for this is only C which is at this location now by looking at this particular notation we can see that which way our tool or the kinematic structure is configured. So, depending on that you can find out what is the structural loop and what are the problems associated with the different, different axises. Description of the geometric error.

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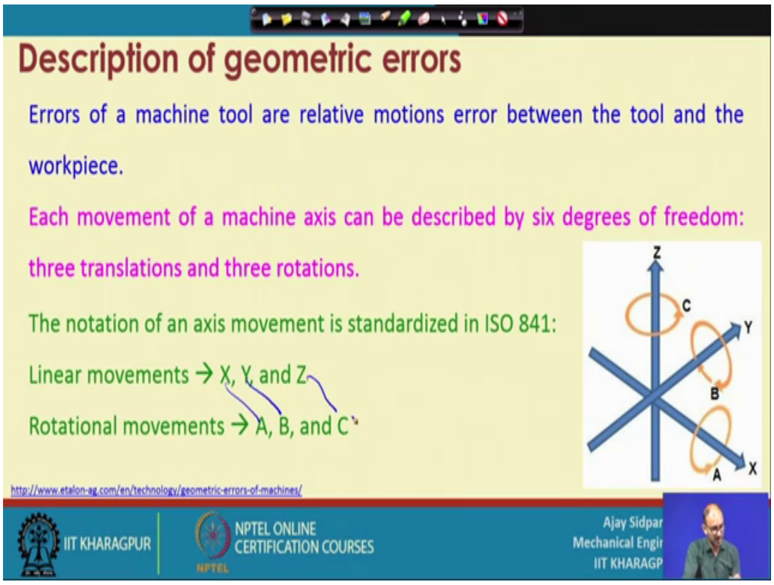

So, error of a machine tool are relative motions error between the tool and the work piece now each movement of machine axis can be described by 6 degrees of freedom, 3 translation and 3 rotations. So, that we have seen here. So, this are the 3 axis X Y Z all are perpendicular each other. So, if there is a linear motion that we consider the X Y and Z are the linear motion and rotation around the X Y Z we can consider those thing as a rotation around X is a A axis rotation of B is a Y axis is the B axis and rotation around the Z axis is the C axis. So, this are the nomenclature we have seen this thing long time before.

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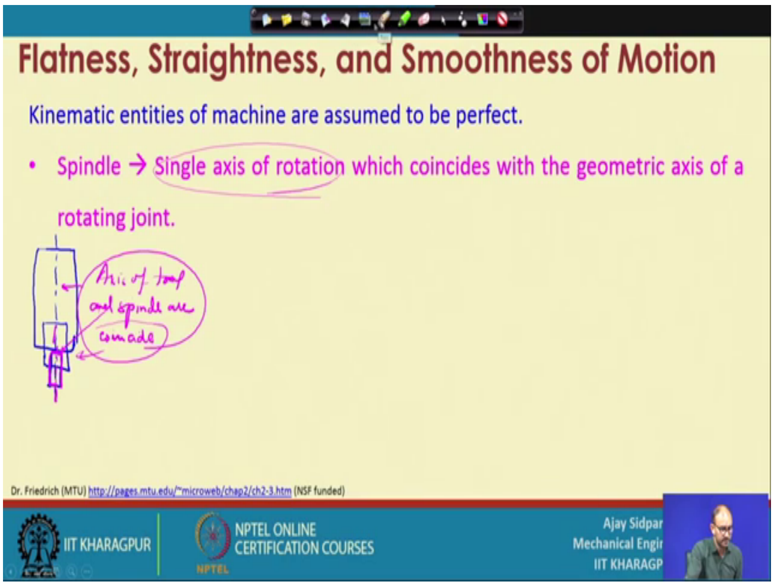

Now, coming to the flatness straightness and the smoothness of the motion, because all this 3 are important flatness will ensure that you are getting a flat surface on the component. Straightness will ensure that you are not getting any type of if it is a component is flat, but you are getting error from the side then it is a problem and the smoothness means; that means, there is no any type of fluctuation of the motion, you are getting a uniform motion it is not like that jerk type of motion or something called as stick slip phenomena.

So, kinematics entities of machine are assumed to be perfect, but mostly it is not the case. What we assume that spindle if you consider spindle we assume that single axis of rotation there is no any other deviation which coincide with the geometric axis of the rotating joint. So now, what is; that means, that suppose we have a spindle so spindle has one axis. Then we have qualette in the qualette we are putting a tool correct. So, this are the small, small sub-assemblies and we assume that whatever is the let me give different colour to the tool.

So, this is the tool and tool has is also one axis correct. So, assume that rotation of the this is a single axis this axis and this axis are coincide. So, axis of tool and spindle are coincide right? That will be assume, but many a times what happens it is not the case you have to be very careful in selection of the tool holder.

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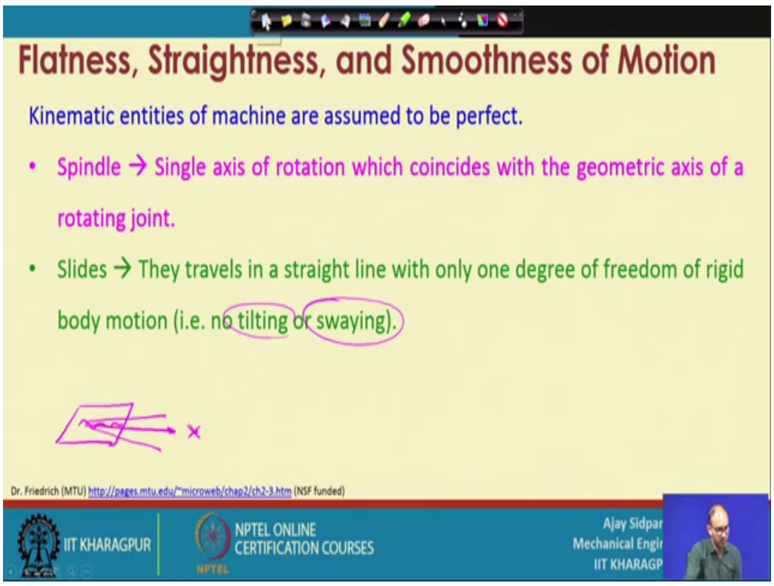

And if you consider slide what we assume that they traverse in a straight line, with no with only one degree of freedom. So, if you consider that your table support this is your table you are moving in the X direction we assume that it is not moving in this direction not moving in this direction or not actually creating any problem in this particular direction.

So, that is we assume that that is no tilting or swaying in the motion. So, this is our assumptions, but when you make a construction of the components are all degrees are all axis are orthogonal to each other there is there may be some problems by which, but you are not able to get the required motion. So, you have to be very careful in calibration getting same machine component out of this type of problematic errors.

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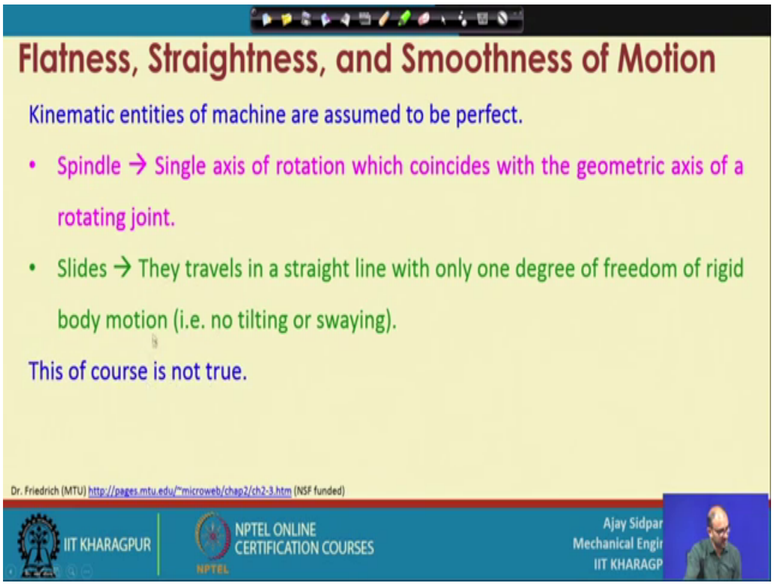

So, but this is not the correct thing because we assume all the things are perfect, but this is not correct. So now, let us take this example that which way we can tell that

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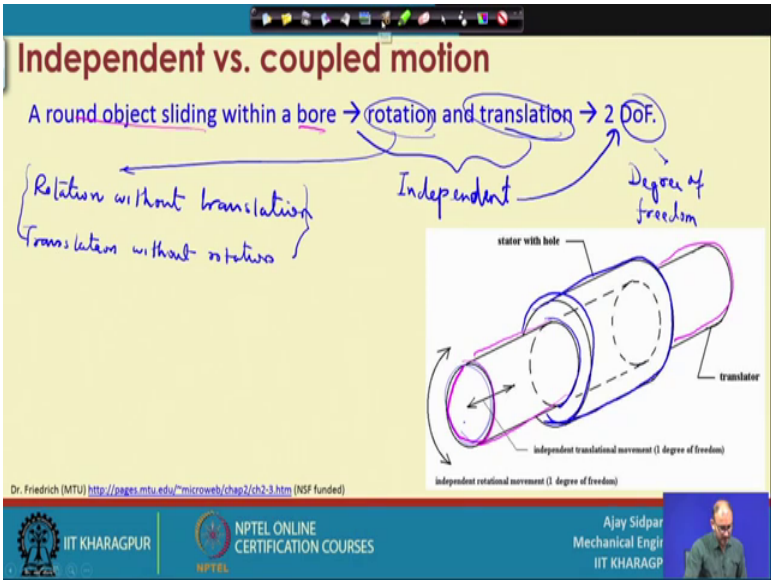

So now consider so this is one component. Now what is this component so here it is a round object sliding within a bore right. So, this is round object whatever is this, this is the round object and this one is the bore. So, whatever is this one, this one is a bore correct? Now you consider that you when you are rotating this particular thing this is if you are rotating the bore then what happened that you can actually rotate without translation right? So, what are the ways you can get this motion rotation without translation right? It is possible and if you want translation, translation without that is also possible.

Now, if you are moving just this way translation direction then it is possible; that means, you are just moving to and fro direction without rotation that is possible. If you do not want to move in to and fro direction you fix at one location you rotate the particular this middle part that is called the round object then it is also possible. So, both the things are independent. So, these things are independent correct? And that is why it has a 2 degree of freedom so this is called degree freedom. Now let us continue further.

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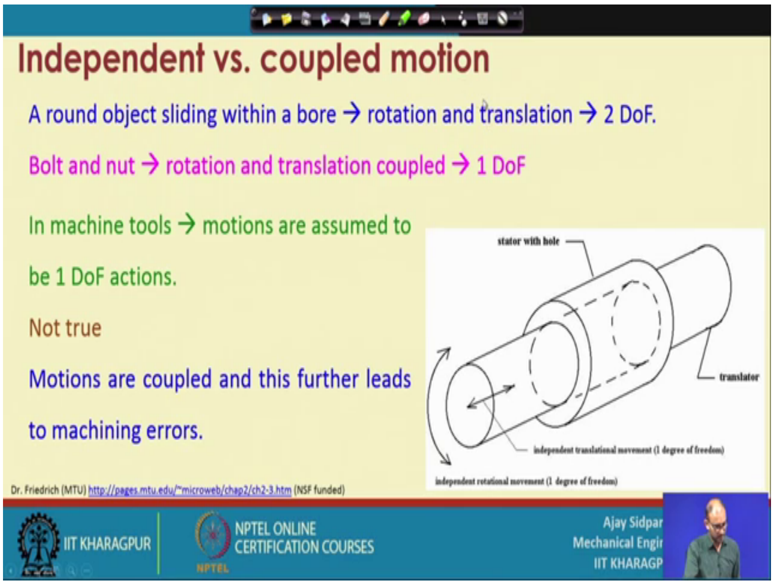

Now, consider we have same thing now here, but instead of this what we are doing that we are putting a thread here. So now, only difference is that we have thread on the both the side consider this one as a bolt and this one as a nut. So now, if you are rotating it translation will occurs automatically because now both things are coupled. Only what we have done that we have just put thread only nothing else

So, now, we can tell this is only single degree of freedom because you cannot get independent motion and if you want to rotate without translation it is not possible because when you rotate automatically it will translate inside it and if it is just a translation is not possible because you have to rotate to get the translation motion. So, those both the things are coupled with each other and that is why it is called the one degree of freedom.

So, how this thing is connected with the machine tool? Because in this machine tools motions are assumed to be one degree of freedom only, because we understand that when you are moving a cutting tool in X direction we assume that it is moving in X direction only and if you are moving in Y direction Z direction whatever way you assume that this is a single degree of freedom.

But that is not the case every time your motions are coupled, if you are problem or if you have a error in one axis it will be actually reflected in the other axis also and that is why it is more problematic in a machine tool. It is not the true because motions are coupled this further leads to the machining error. So now, let us see some examples that how these things are coupled in which way it will create a problem in the machine tool correct?

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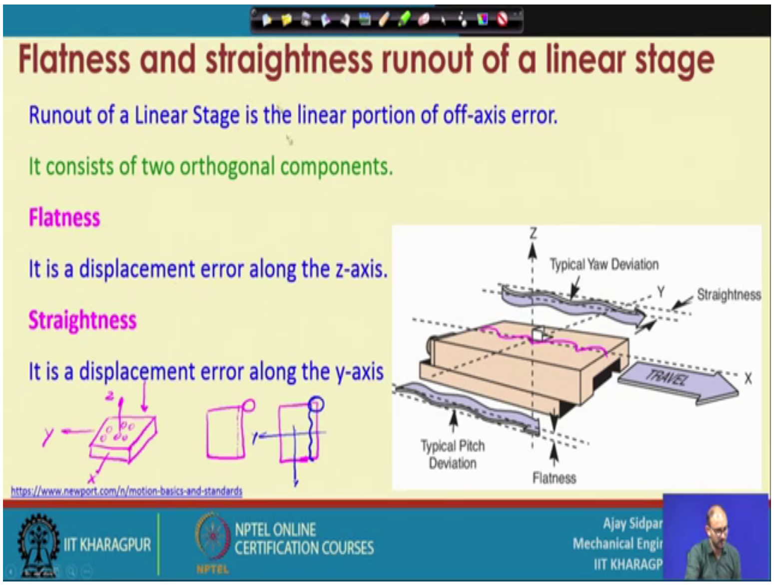

So, this is a flatness and straightness error in the linear state, now if you consider this particular diagram your whole table is moving in the X direction. So, this is at the direction of the X motion.

So, now, there are 2 errors one is a straightness error another one is a flatness error. So, how you define the straightness error and flatness error. So, run out of a linear stage is the linear person of the off-axis error. So, off axis means we intended moving in the X direction, but it is moving in X direction along with the some deviation in the Y direction and the Z direction.

So, first one is the flatness let us see this what is the flatness. So, it is a displacement error along the Z axis. Now see consider this is the table now table you want to move in this direction, but your table is suppose moving in this direction suppose there is a little bit of problem. So, this is the problem so whatever is this problem in the X direction; that means, it is moving up and down and then it is moving in this direction. So, that particular displacement error called the flatness. So, your surface is not flat completely so, you want to do a cutting suppose you this is the work piece you want to cut a flat surface here this is the surface which you want to cut.

Now, consider your Z axes; that means, your tool is located here and your X axis is travelling in this direction because of this flatness error what you are getting instead of that, this is your work piece against same what you are getting, you are getting a some type of this type of things that is because of the flatness error let it be at a micro level, but that is still enough to get rejected during the inspection so that is called flatness error.

Second one is a straightness error, what is the straightness? Error the same displacement error, but not in the Z direction, but is in the Y direction in this direction. So, here what it is doing here your table is not moving along the X direction, but it is actually moving in the Y direction. So, where it is creating a problem, now if you consider that suppose your work piece is this one correct this is your Y axis this is your X axis and this is your Z axis you want to flatten out this particular surface, this surface because you have references position or some other com different type of features which you have found or which you have calculated based on the reference of this particular surface.

So, you are cutting this particular surface to make it completely flat. If you see form the top now this is our work piece and our tool is located at this location right. So, what is our object that we want to remove this material up to this this much amount of material we want to remove and it should be straight line, but what happens what we are getting here that because of this problem you are getting a some type of unevenness because that is because of the problem in the Y axis. So, this is still our Y axis this is X axis and from through the page Z axis is located. So, our tool is located here. So, this are the 2 problems because of the problem in the flatness and straightness run out of the linear stage.

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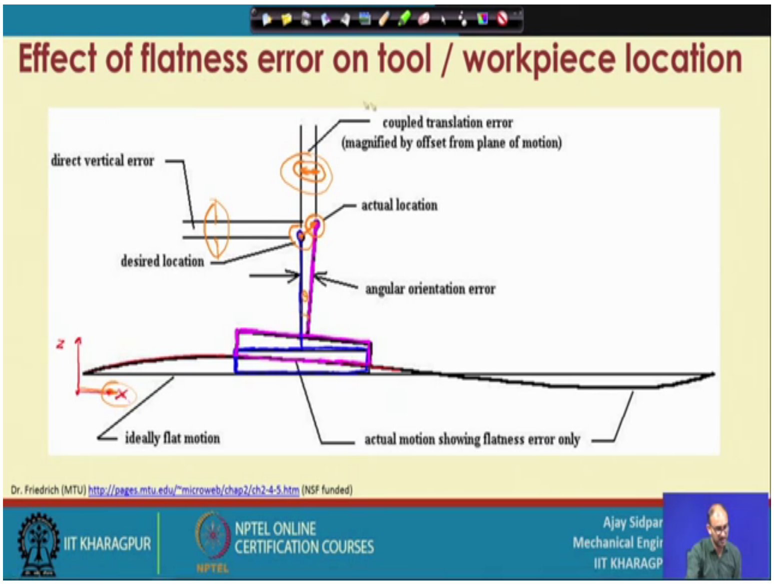

Now, let us take this example so now, this particular thing this is our ideal flat surface, whatever this straight line is there this is our ideal flat surface and what is our error surface. So, this one is a error so now, this is the problem the surface is not flat, but instead of this flat your end up with a one type of other surface.

This is your surface now we can understand this thing that our error is in X direction only, now suppose you consider this is the X direction and this is the Z direction correct? So, we have error in X direction and this is our original location of the component our component or the work piece should be located here. So, this is the location of the work piece. If the surface is flat, but surface is not flat here we know then our work piece is here.

Now, it is location is this one, this is location for work piece. So, if in first case that this is the actual location of the tool suppose you have a tool position this is the actual location of the tool, but because of this flatness in X direction what we are getting we are getting a shifting of this particular axis and this is the actual position this is a desired location, but because of this flatness error in the X direction you are getting this problem. Now what is the problem here? That even though there is a problem there is a deviation in the X direction. So, what we are getting here?

That we are getting a shifting in this particular direction. So, this is in X direction. So, let us our error or the deviation in dimension should be on X direction, but if you see that this dimension change is also then a this dimension is also this for you have vertical error also because he this is displace at this location because of this angle theta and because of that you are end up with a 2-dimension error because one is in vertical dimension another one is horizontal direction.

So now, what is the conclusion of this thing, we have seen in earlier slide that motions are coupled with each other, even though you are getting a error in the flat direction or in any one direction actually your getting error in 2 different direction. So, it is better that you first identify which has the error and then you actually do a program because if you do not consider this flatness variation here your end up with not only wrong dimension at one location you are end up with the wrong dimension at 2 location. So, this is what it explains about the flatness error at the tool or work piece location.

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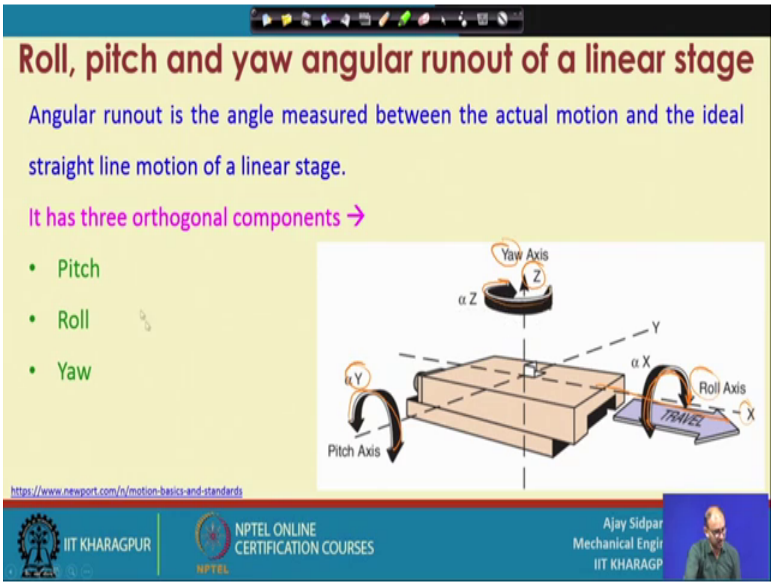

Now, roll pitch and yaw angular run out of the linear stage earlier we have seen that there was the flatness and the straightness error but now consider suppose there is a rotation also. So now, that is the angular run out is the angle measured between the actual motion and the ideal straight-line motion of a linear stage. Now this is our linear stage this is the travel and view where rotating in this direction also that is the rotation around the X axis.

So, if that is the case then what will happen that Z axis will create another rotation here suppose it is not exactly at the flat direction then it will create a pitch that is the rotation of the Y axis, yaw is called rotation of the Z axis and the roll is called the rotation around the X axis. So, it has a there orthogonal component one is the pitch another is the roll and another one is yaw. So, not only the translation motion, but you are also end up in the getting a error in the 3 rotational axis that is of the pitch roll and the yaw motion. Coming to the smoothness of the motion.

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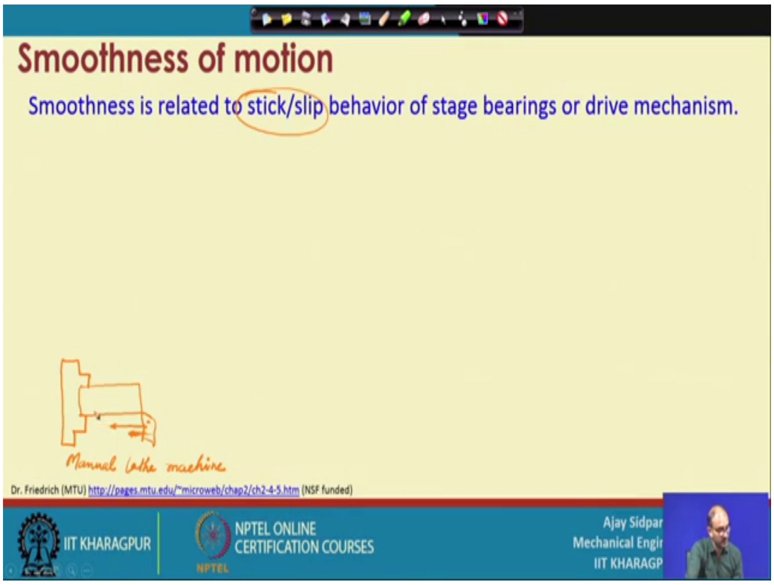

Now, we have seen the straightness flatness, but smoothness is also very important in the micro machining because smoothness is related to the stick slip behaviour of stage bearing or drive mechanism because if you have seen manual machine if you are operated the turning machine and if you are doing a operation now consider. So, this is your work piece this is the truck and this is your cutting tool and you are moving in this direction.

So, when you are moving in this manually this is let us consider manual lathe machine. When you are doing in this direction at the time what happened it is very difficult to get a uniform motion right, when you rotate a carriage wheel at the time it is very difficult to give us continuous motion and because of this is because the stick slip behaviour because there is a friction between the different components and you have to overcome that friction uniform length that is very, very difficult when you operate at manual operation right?

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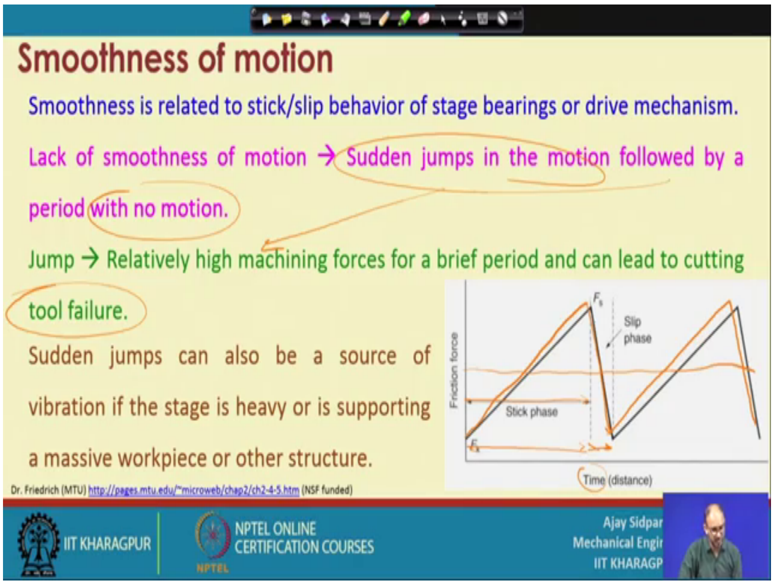

So, this is what is happening this is a frictional force. So, frictional force will increase initially. So, you are actually not able to get a continuous motion.

So, this is a stick phase and as soon as you actually overcome that frictional force suddenly you are able to move it and then this is called slip force. And once that motion is over again the same psychology repeat again you will get a stick phase and the slip phase. So, your motion is actually not uniform what we need here in this case that we need a continuously this type of friction that your friction force should be uniform. So, you can get uniform motion out of this particular motion, but that is not the case. So, what happened because of the lathe or smoothness the sudden jump on the motion followed by a period of no motion correct?

So now, if you see this particular thing that this is the time so within this particular time you have very difficult to move in this direction, but after that you are not getting a friction in suddenly you are moving that part again it is coming to a slanting position. So, you are not getting uniform motion and because of that non-uniform motion what happened that you are getting a very, very high relative forces for brief period, because whenever you are getting a sudden jump in this case at the time your forces are very, very high force. And when you are getting a no motion at the time at the time there is no any type of failure because at that time there is no any type of forces in that or forces are very, very less. So, this type of high fluctuation of the forces are there then what it will directly late it will lead to the failure of the cutting tool right?

So, because our objective is to make sure that there is uniform and very less amount of forces acting on the work piece and the tool during operation, but because of the stick slip phenomena you are not getting uniform motion. And sudden jump can also be a source of the vibration if the stage is very, very heavy or a is supporting a massive work piece or the other structures because we know that friction is direct connection with the normal force, because if you are things which are very, very heavy onto the stage at the time you have to spend more amount force initially and as soon as you are crossing that particular frictional force you are getting a jerk motion and again your end up with the roll motion.

So, because of this smoothness or stick slip phenomenon what is happening that you are not able to get a smooth motion and that is real thing in the abnormal machining operation and the failure of the cutting tool. Let me finish this lecture here and we will continue this topic further in the next class.

Thank you very much.