

Introduction to Mechanical Micro Machining
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Lecture - 28
Errors in machine tool (Contd.)

Good morning everybody and welcome to our course on introduction to micro mechanical machining. In the last class we have seen some of the aspect of the error in the machining processes and we have seen that there are no any components which are very perfect. So, we have to indentify or we have to put some criteria, so that we can accept a particular part. So, we have seen different criteria. First one was the tolerance by which you can actually accept or reject the component. If the dimension you wanted 10 millimetre, if it is within the 10.24 or 10.9 point something, then you can accept the part.

Another thing was the roughness. If roughness is acceptable within a particular range, then you can accept that component. Third one was the shape. Because, if there is a shape deformation is there; that means, if you want a perfect spear and it is little bit deviated out of that spear, then you can reject that part. And another one was the properties related to material. If you are functionalising any material, then if you are properties are within a particular range, then you can accept those particular components.

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Cost vs. Performance in error correction

How much time/money spent to look for the sources of errors to prevent or minimize the errors.

Successful projects keep a close watch on budgets (time, money, performance)

Understanding errors in components and machines is the key to staying on the leading edge.

“Bleeding edge” designs can drain you.

The graph plots Cost (Y-axis) against Performance (X-axis). It shows several curves representing different technologies: Leadscrews, Ballscrews, Linear Motors, Stagnant edge, Bleeding edge, Leading edge, Yokes, and Creative Alternative Technology. The curves generally show that as performance increases, the cost also increases. The 'Creative Alternative Technology' curve is the lowest, indicating the most cost-effective performance.

Prof. Alexander Slocum (<http://kinematiccouplings.org/>) | Precision Manufacturing by Dornfeld and Lee, Springer, 2008

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Another thing we have seen that what are the ways; you can spend the money on to the component; that means, cost versus performance was one of the criteria. So, here we have seen that, you have to always take into this reading it; so that you can get more amount of performance compared to the cost and time you are spending into the getting system already.

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Sensitive directions

We have to ask ourselves, "when is an error really important?"

Put a lot of effort into accuracy for the directions in which you need it

- The Sensitive Directions
- Always think about where you need precision.

Prof. Alexander Slocum (<http://kinematiccouplings.org/>)

Workpiece in a lathe

Non-sensitive direction

Sensitive Direction

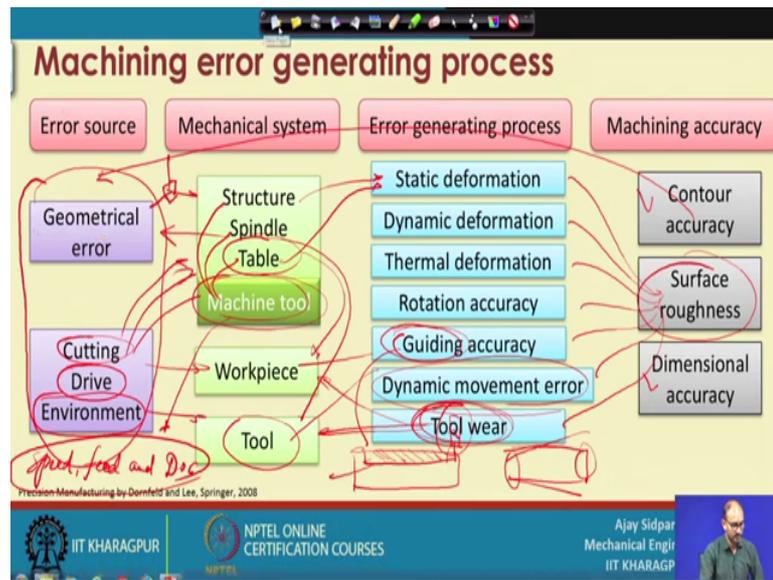
Tool

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The slide features a 3D diagram of a green cylindrical workpiece on a lathe. A purple tool is shown cutting the end of the cylinder. A yellow arrow labeled 'Non-sensitive direction' points along the length of the cylinder. A red arrow labeled 'Sensitive Direction' points radially outward from the end face of the cylinder. The slide includes a title 'Sensitive directions', a key question 'We have to ask ourselves, "when is an error really important?"', and a recommendation 'Put a lot of effort into accuracy for the directions in which you need it'. It also lists two bullet points: 'The Sensitive Directions' and 'Always think about where you need precision.' The footer contains the IIT Khargapur logo, NPTEL Online Certification Courses logo, the name 'Ajay Sidpara Mechanical Engineering IIT KHARAGPUR', and the slide number '27'.

Then we have seen that we have to also focus not only cost and time, but you to also finalise that which is the direction or which is the error which is important to remove or which it is important to minimise. So, there are many errors, but some errors can be neglected, which may not play important role during the fabrication or after fabrication. So, you pay more attention to the sensitive direction, where your machine stiffness should be very, very high.

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Now, machining error generating processes so, what is happening here? The first we have to identify the what are the sources is of error right. So, mostly sources is of error geometrical errors another is a cutting process error, driver error, environmental error. What is the geometric error? So, geometric errors are mostly related to the structure of the machine and it is most related to the machine tool. And cutting is that, when you operate a machine, at the time you are end up with some type of cutting operations so, your see as in machine dynamic condition.

Now, there forces; there salvation, disalvation of the cutting tool in different the promotion and then there high heat generation. So, those think create same problem in the error and then there are drives. So, drives means, the table and the cutting tool which is moving up and down. So, those are call drives which move this slide and all the thing. Environment most related to temperature variation, humidity variation and what things are located here climate conditions. So, those thinks are related to this. So, these are the different sources is of errors. Now, second with mechanical system that how this think errors are affected in this reaction.

So, geometrical error are most related to the machine. So, this is the machine tool. What machine tools consists of? Machine tools consists of the table, spindle and the structure in this case. So, geometrical error are mostly connected with this particular things because, this are the table and the structure is always the stationary structure. So, if you

are not getting a orthogonality between x y and z direction, then you are end up with a some type of problem. So, this are what is required in this particular direction and all the think should be perpendicular to each other. So, if those things are not there, there are some other problem, then you are end up with some geometrical errors. What are the other components here?

So, other one is the work piece. Because, we know that machine tool is a standalone component. But, there are 2 other things we are heading into the depending on the selection of the machining operation. One is the work piece. That we are adding because, we want to shape this particular thing. Why we are shaping? That we need a tool also. Because, tool and work piece this both things are the selection base and depending on the what is the specification of your machine tool and these things are already in built into the machine tool. So, cutting tool cutting error, drive error, environment error, that is directly connected with this also and it made it may be connected with this also. So, these are the error source is where this will this error can occur? Those things are this because in the mechanical system this is the only thing which were standard available.

Now, if you add same camera or you add same microscope or you add same force, since of those things are actually the supplementary things, but that cannot be considered during this particular error generation mechanism. There error generating process is what are these things? So, this is a static deformation. Because, in static deformation what happened that if you are not doing any machining operation anything, because of the age of this machine tool, then what am I there is a static deformation in the structure static deformation in the table also. In that way, you are end up with some type of problems. Then dynamic deformation, that when your machine is operation, you are cutting a work piece by a tool and then it is in dynamic situation.

So now, forces occur, vibration occurs and how your machine tool will tackle those type of dynamic situation; that everything depends on what is the error during the dynamic deformation. Thermal deformation because; thermal deformation occurs without operating machine or with; operating machine. If it is operating the machine, then heat generation will be very, very high because, your cutting a one machine in by friction or shear force and that will increase the temperature at the cutting zone. And that temperature will propagate through the different components. Other than that, once you

cut the material, cheap also carries same temperature. And that when cheap is falling at that particular location also, temperature will be very, very high.

So, you have to identify the thermal deformation or the highest temperature zone and you have to insulate what isolate those particular things, so that the temperature will not be propagated inside the system. Rotation accuracy because that is; little spindle mostly because when you rotate spindle. Mostly it should be in the eccentric with the spindle housing. If it is not like that, then what happens? There is a run out dynamic run out is there, then static run out is there. So, those particular things will create a problem and it will generate some error during the process. Guiding a accuracy guiding accuracy is mostly related the motion of the tool work is that is by means of a table because, table work which is loaded on the table and the tools loaded on the z axis. There is also guiding system, which is moving your tool up and down. So, that is call z axis.

So, there accuracy is also important because, all 3 axis should be perpendicular to each other as close as possible. So, that is also one of the source of errors. Dynamic movement error. So, when you are this is dynamic deformation that is in operation and this dynamic movement error that when you are doing machining and you are moving your work piece from one location on the location. So, this is your tool, this is your work piece and this is your tool and tool is a penetrating inside the work piece and then you are moving to cut down this much amount of material.

Let, so, when you are moving, at that time if there is some problem guiding accuracy that you are sys your all the 3 axis and not pertain to do each other at that time, your material removal rate little bit higher or lower depending on the angle at which your x y z axis are deviated. So, depending on that, you will get a dynamic movement error. And that movement error will directly affect the life of your cutting tool and the quality of the work piece which you are getting either it will be rejected or you have to do some rework to get the thing correct.

Then the tool here is also one of the thing because, you cannot avoid the tool here. But you can actually minimise the tool here by setting a optimisation optimise parameter for this particular machine tool. So in that way, these are the different error generating processes and what you are finally getting, what is our objective that we should get a

very, very high contour accuracy contour accuracy; that means, suppose you are one to you want to get a circular component or it is a cylindrical component.

So, it should be a cylinder only. It should not be a some type of contour. Or positive wear or the negative wear. So, that is call contour accuracy surface roughness is important because, we have seen that we have different criteria for acceptance of the component because error cannot be we cannot produce a perfect part.

So, contour a safe for one of the things, surface roughness was the another thing. And dimensional accuracy, that is how much what is the tolerance level. So, here we are not talking about the material property because, there is a another criteria not connected with a machine tool. So, here, what we have to do that first? We have to find out that what is the problem in our car. Suppose, you are not getting a surface roughness is not exactly the requirements, you are getting a contour is also dimensional also acceptable.

So, first, if you are getting a surface roughness, then you have to actually go back side. So, which parameter is effect in the surface roughness? So, you have to go in this direction. Suppose, you are tool is want is still you are going continue that particular machining operation, then there is a chance that tool wear is a one of the things which is creating a rough surface. Then once it is identified it is a tool wear, then go to this back side again, then which is the mechanical system which is creating a tool wear.

So, here, one is the tool, which is directly connected. Another is the work piece also there because, if the work piece is very, very hard and your putting a speed feed and debt of cut, these are the parameter speed feed and debt of cut you are selecting a very, very aggressive value of this, then what happened your tool will be very, very high. And machine tool what we are doing we are directly connected with this thing.

So, again you have to identify out of this 3 option that which one is responsible for tool here. Once you identify that thing, suppose, in all the 3 are playing important role, then you to find out that which one is more than if it is a machine tool by spend speeding speed feed and debt of cut setting you can do some changes there. If everything is fine, there may be a chance of a geometric error. So, then, you can actually they calculate in this direction find out what the source of error and then you spend time in cost for correcting this particular error source.

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The slide is titled "Geometric Errors of Machines". It contains the following text and diagrams:

- Text: "Machine tools and measuring equipment with 3 to 5 axes are widely used in fabrication and characterization of the component."
- Text: "Accurate parts can only be achieved by a controlled and deterministic manufacturing process."
- Diagram: A feedback loop diagram showing "Feed back controllers" connected to "Encoders".
- Diagram: Two 3D cutaway views of machine tools. The left one is a 3-axis machine with a table moving in X, Y, and Z directions. The right one is a 5-axis machine with a table moving in X, Y, Z and two rotational axes (A and C).
- Source: "Xiang et al. (2015) Proc IMechE Part B"
- Logos: IIT KHARAGPUR, NPTEL ONLINE CERTIFICATION COURSES, and a portrait of Ajay Sidpar, Mechanical Enginr, IIT KHARAGP.

Now, geometric errors on the machine now, these are the 2 configuration of the machine. So, this first one is the 3 axis machine and this one is the 5 axis machine.

So, why 3 axis because, now we can move table a work piece in x direction y direction here and z direction here additional 2 axis here are the one is the a axis a axis means the rotation around the x axis and the c axis. Suppose, you want to rotate your work piece not the tool rotation are already there, but the when you want to rotate work piece then, what you to do you to put another motor for rotation of that because, we know that this particular rotation is along the axis of the z.

So, that is why, it is called c axis. Now, still there is a one axis we have that is called y axis. If you are putting one more motor and if you swing this particular wall stare, then what you are telling that you are actually movie or tilt in this particular table that is in this direction. So, that is called b axis.

So, depending on the requirement, you can actually design a micro machining centres in different exists freedoms. So, accrued pad can only be achieved by control order deterministic manufacturing processes, what does it mean that, first thing is the control how you can control your thing? That suppose, you have one machine and you have lot of feedback controllers. So, if you are moving from one location another location, it is perfectly telling that your tool is moved from this to this location. So, this is your tool and it is moving from here to hear.

So, those are called the feedback controllers feedback controllers. So, what are those things those are the encoder right. So, rotary encoders are there that will find out the rotation of how many rotations are there depending on what is the translation linear encoders are also there, so that directly calculate the linear motion of that. So, those are called the feedback controllers.

So, by feedback controller, you can actually control your process even if you have some type of backlash within the driver something, then this particular encoder will take care about this particular problems. Another thing is a deterministic manufacturing process deterministic manufacturing process then, suppose, your setting a parameter for a.

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Geometric Errors of Machines

Machine tools and measuring equipment with 3 to 5 axes are widely used in fabrication and characterization of the component.

Accurate parts can only be achieved by a controlled and deterministic manufacturing process.

Ex ① Depth of cut } Material (cut) + Tool
RPM of tool }
Feed rate } → Material Component

Ex ②

<http://www.atafon-ag.com/en/technology/geometric-errors-of-machines/>

Xiang et al. (2015) Proc IMechE Part B

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Suppose you have a 3 component, that is a depth of cut then RPM of tool and feed rate at and you have a one material or the work piece and plus tool. You have selected one particular thing and you are getting one component out of this machine component machine component.

So, first experiment you are doing this thing, this is experiment number one you are doing experiment number 2 again with the same parameter and if you are getting the same thing here again, then; that means, it is call the deterministic manufacture. That means, you are not changing any parameter of the machine tool or the work piece or the tool combination every time you are getting a same component; that means, your process is deterministic.

So, in that case, if you are not putting any controller or feedback controller, still your machine in such a condition that is always give accurate part, accurate part means within the acceptable limit and so, we that we can tell that geometric accuracy of the part can be achieved either by a feedback loop through the part metrology. So, this is the feedback loop.

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The slide is titled "Geometric Errors of Machines". It contains a diagram of a machine tool with various components labeled: Machine control unit, Command lines, Ways, Column, Spindle, Work, Table, Z-axis drive, Tool, Feedback device, V-Axis drive, Lead screws, Bed Base, and V-Axis Drive. Handwritten notes in red and green highlight two points: "a feedback loop through part metrology" and "accurately calibrated machine tools." The slide also includes a URL, a citation "Precision Manufacturing by Dornfeld and Lee, Springer, 2008", and logos for IIT KHARAGPUR and NPTEL ONLINE CERTIFICATION COURSES. A small photo of Ajay Sidpar, Mechanical Engnr, IIT KHARAGP, is in the bottom right corner.

Now, if you see, so there are many different component available. This is the tool is available here and the work piece here. So, these are the main things which is connecting the old thing. So now, spindle is there. So, spindle, if you have putted we have variable frequency drive. You can get the feedback from the spindle RPM. Also, how much is the RPM of the spindle during actual operation? This are the moment in the z direction that is, the in z guide way, if you are putting a optical encoder, here linear encoder then, it will give you a signal of that thing that how much is the movement in this reaction. X axis drive is available then, there is a y axis drive.

So, this particular moment will tell you the what is the actual position of your work piece on a machine tool. Depending on that, there are different construction part is also available to this is the construction group or the structural group through which you can get the thing. So, if you have very good feedback control, then you can get the geometrically correct component. Why that is the case, then another way you can get by calibrated machine to calibrate; that means, you know that, if you have mu machine a

component that we have seen in earlier slide, that if you machine a component with fixed parameter, you continue with the fix parameter every time, you getting the same component. That means, your machine is calibrated. You do not have so much of deviation, which will reject the part or it will which will divide the path even if you have all the input condensation are constant.

So, that is the way if both the things are there it is more much better than anything else because, you are getting a feedback also through the metrology part metrology part; that means, you can measure the surface roughness. Also, in that if you have roughness tester located here. If you had camera here, directly you can actually analyse the tool we are also or what is the parts geometry. So, these are called the metrology instrument which will help you to monitor the machine tool as well as work piece.

And the tool even when it is in motion or when it is in machining condition, so if both the things are much preferred, but if one of them is upset, then you have to rely completely on the other component. You have to make that particular thing very, very strong, so that you can get the required geometrical accuracy in two parts. Now sources of geometry errors.

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Sources of geometry errors

Accuracy of machine tool is affected by many error sources.

- Kinematic errors
- Thermo-mechanical errors
- Loads
- Dynamics forces

The diagram illustrates a machine tool structure with various error sources labeled: Motion and positioning errors, Thermal fluctuation, Reaction force, Tool, Heat, Workpiece, Load, and External vibration, distortion and foundation.

<http://www.etalon-ag.com/en/technology/geometric-errors-of-machines/> | | Hernández-Martínez et al. Ing. Invest. y tecnol. vol.11 no.2 México abr./jun. 2010

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So, first, let us take the geometry error; that means, what are the sources of error in the x y z direction or the movement of the axis only. Let us not go to the other way in the tool slide or the work piece slide. So, accuracy of the machine tool is affected by many

sources. So, if you see this particular thing, now you can understand that this should be the exactly straight line. If this is the straight line, this should be also perpendicular to this part and this should be perpendicular to this one and this should be perpendicular to this one.

So, this is the this should be the actual condition, but what happens that, you have a external vibration distortion and foundation problem. So, your base of the foundation is little bit squid away and that is the problem that because of this deformation of this foundation, even if this all the 3 this thing this thing and this things are right angels to each other, but because of this problem what happened this all thing will move in the other direction. So, this whole thing will move in this direction.

Now, you one if it is contain a 90-degree part. So, this is also 90 degree. This is 90 degree, this is 90 degree, but this particular line is moved from this to this here one particular angle. So, whole thing is distorted. Now, there is a thermal fluctuation. So, if this particular thing is perfectly correct, now this is a straight line. There is no problem in that. So, old thing is correct and now thermal deformation occurs here. So, this will little bit bend and this whole thing will also expand depending on the temperature effect or the temperature part. Now, this is completely something like that and this is creating a problem.

So now, this things are not right angle to each other and that will create a problem. Then another thing, emotion and positioning error. Suppose, this particular error is the z axis and z axis is right now it is little bit incline here because, consider that your work piece is very, very hard and you are moving this particular work piece in this direction correct and your tool is not able to remove that material very, very high way, then what happens? That your tool will bend here. And when tool will bend, it will create extra force here. In this case, and few if whatever you are looking at this particular deviations, this is not so high. But, right now, very, very exaggerated view of the small deformation and that is what is important to understand here at this location.

So now, coming to that down, now once it is in works piece and this location, now consider this is all things are correct, no problem in that and then you are doing a machining operation. So, machining operation also create a reaction forces there are lot because, you have mounted a heavy work piece on the table, heavy voice is available

which is fixing the component. Then, because of that additional load, your foundation may get deformed at a micro level and when you are getting a forces again propagate in this direction, this load and vibration will propagate in this direction and then, again it will close the loop and because of this structural loop deflection, your end up with errors. So, what are the sources is of error? The first the kinematic errors that your access is a not right angle to each other that is what is required.

So, this thing should be orthogonal. That is the one thing. Second is thermo mechanical error. The temperature affect because, of the climate condition. Also, because of machining operation, these are the two different sources through which you will get a temperature different with the system loads means, it is the stationary loads also and another thing is a when you do machining forces also that will also consider as a dynamic for dynamic load which will also create problem in the spindle system as well as in the other structural component.

And the dynamic posted this load is the stationary load and this would force dynamic force you are talking this force at the reaction force or some forces which occurs during machining operation; that means, when you are machine is running condition at that time you will encounter with dynamic forces.

So, these are the different forces which will create a problem in the geometry of the machine. So, first is the kinematic error. So, what is kinematic error?

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Sources of geometry errors

Kinematic errors

Due to imperfect geometry, alignment and dimensions of machine components.

Assembly problem

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So, it is due to imperfect geometry alignment and dimension of machine component. So, suppose, you have a complete structure of the machine and if its geometry is imperfect; that means, whatever dimension you are creating, that suppose have a whatever this can your be means create sets on or it is a secular sets on it is other than any this to step, then it is dimension should be perfectly within the along. So, within the tolerance limit alignment is also a problem. Because, we know that everything should be perfectly in alignment, so that your spindle axis is always in a vertical straight direction.

No to the anything other than the straight thing and the dimension of the machine component because, that will directly depend on this alignment; because, if you are not exactly the dimension, you will not get the assembly problem correct. And if there is alignment problem, then you will not get the perfect combination of the different components. So, they are stable or changing slowly over time.

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Sources of geometry errors

Kinematic errors

Due to imperfect geometry, alignment and dimensions of machine components.

They are stable or changing slowly over time e.g.

- due to foundation drifts, ← Deformation due to age (time)
- wear or material aging and
- also collisions. ← Free machining

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Now, whatever these kinematics errors are there was sometimes what happened that, initially you are not getting those things. But they are stable also. But as the time passes, what happens? You are doing machining with different parameters setting sometime forces are also very, very high at the time whatever over the time. This will start playing an important role. So, that is because of the due to the foundation drift. What is the drift? Drift is a deviation due to age; that means, whatever is there deformation due to age or

we can say it before way with respect to time. If your machine is very, very old, then you will get a foundation drift. So, foundation drift means, if foundation is never in motion.

So, it is always in a stationery part, but because of this many things, you are doing on the foundation machining is there you are mounting a very, very heavy voice for heavy work piece on the top. Then removing it again, again you are mounting. So, those things are playing important role in the studies or the status of the foundation. What is the local current status of the foundation and wear or the material aging? Because all the materials whatever you are aging using in they of construction of the machine tool, it may get wear because of the aging messages with respect to time you are getting this material in a very, very unstable condition. So, you may get some type of kinematics errors after a long time and also by coalition because, we know that when you do machining at very, very high right.

Now, suppose you cutting tool is here and your work piece is here at this location and you want to remove this whole things. So, you start with cutting to here and then right now, you are moving from here to here there is no any type of machine. So, it is cool free machining. So, free machining and as soon as it touching this particular part, then it will do actual machining. So, from here to here as soon as is coming into contact you will get a very, very high force in sudden highest force is jumping in that. So, you have a spindle system here. So, this spindle system will this particular force will be in this direction to a spindle will try to move in this direction.

So, after your whole thing is moved here and now you want to cut another depth here so now, your location of the cutting tool is here again you have one free time here or the free machining here or haircut cutting. So, here no first and then you are student striking that this location and you are spindle system is here at the time you are cutting in this direction and then your forces will be in this direction free. If you would like here and there many times because, one day you are suppose doing settable machine and 10 parts, 100 part in it and this will be also consider as collisions. So, this particular small thing also play important role in the maintaining or the stabilizing this particular kinematic errors.

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Sources of geometry errors

Thermo-mechanical errors

Internal and external heat sources in the machine may lead to thermo-mechanical deformation of machine components → leads to kinematic errors.

α (Coefficient of thermal expansion)

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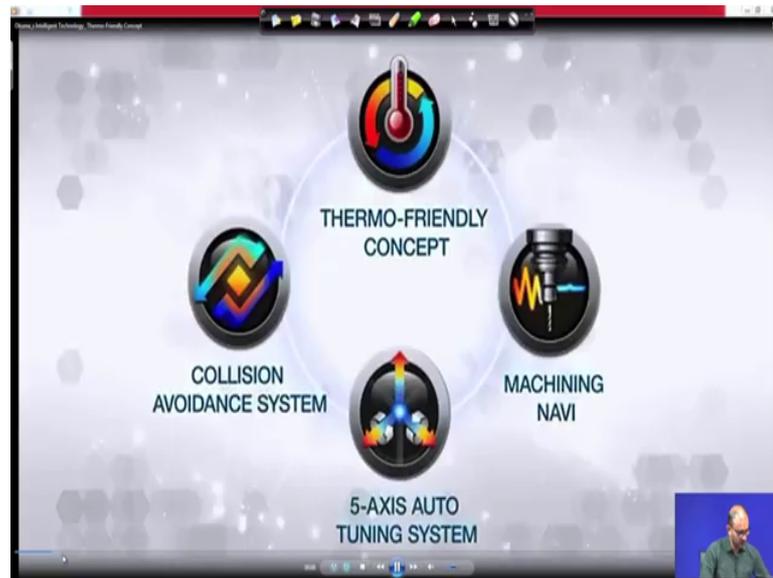
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Then thermo mechanical error. So, what are the thermo mechanical? Internal and external heat sources in the machine may lead to thermo mechanical deformation of machine component and then it leads to the kinematic error because, we have seen that we have a full construction here. That is in x y and z direction, this is the work piece, this is the tool, this is a construction.

Now, because of this temperature difference, what will happen? This particular thing is some coefficient of alpha here. This one is one thermal coefficient alpha. This one also every component has a different thermal coefficient of thermal expansion correct. So, if the materials are different than all materials of different coefficient of thermal expansion. And depending on the temperature variation, your part will expand or contract differently. So, at the end what are the location it will create a problem? So, this are the location where it may create a problem because, it may bend imposed in right side or the left side or right side. Then you are what total geometric stability will be reduced. So now, let us see one video here where it is showing that how this particular thing works.

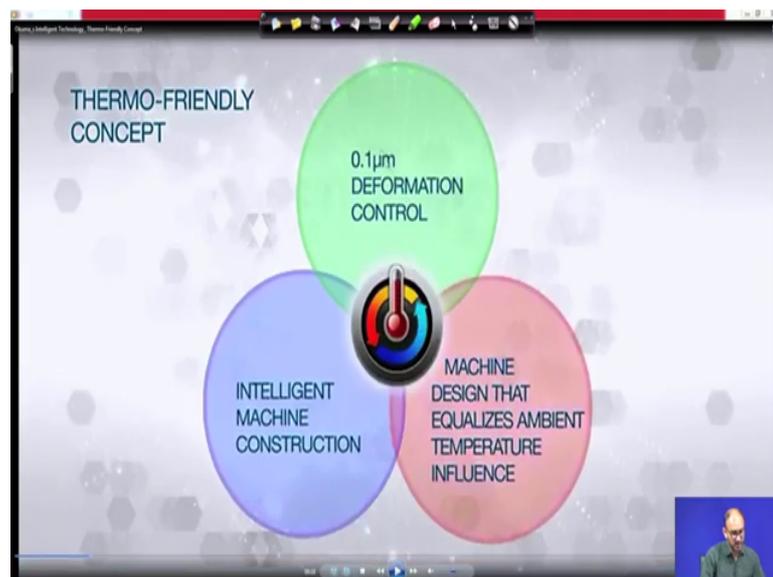
So, this is a company okuma. They are making this particular system for temperature thermo friendly concept that is what we are looking at right.

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Now, what is what is this thing; that you can actually control the deformation within a 0.1-micron; control if your tool is deviating from 1 within a 0.1 micron, then you can actually control within that part intelligent machine construction. So, construction also play important that if it is a symmetric structure. Then the deformation will be symmetric your tool will always be in the centre.

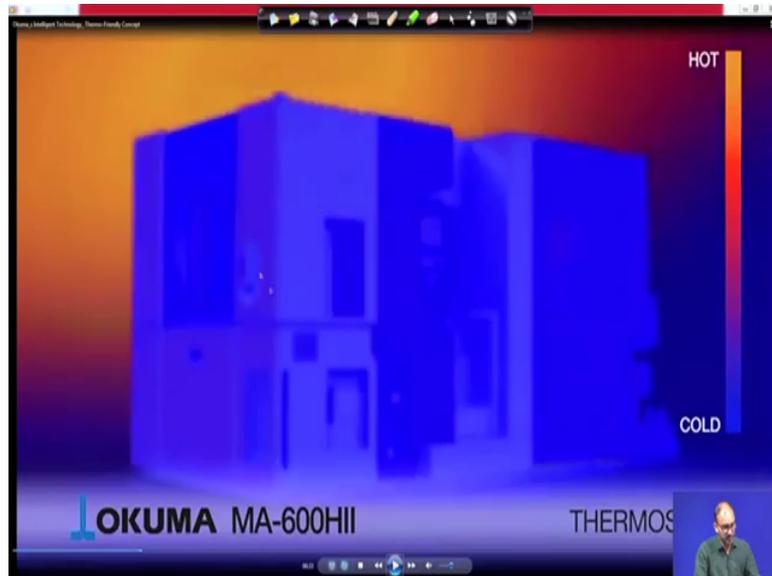
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So, temperature equalization is important because, whatever is the ambient temperature condition, your machine will actually respond to that temperature deformation. So, this is

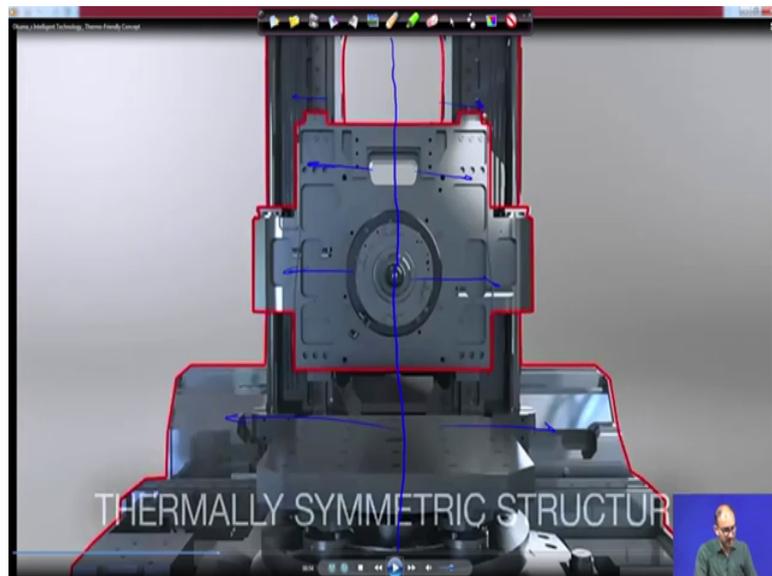
first thing that house machine will take care of this is the installation space of the machine and this is the temperature variation.

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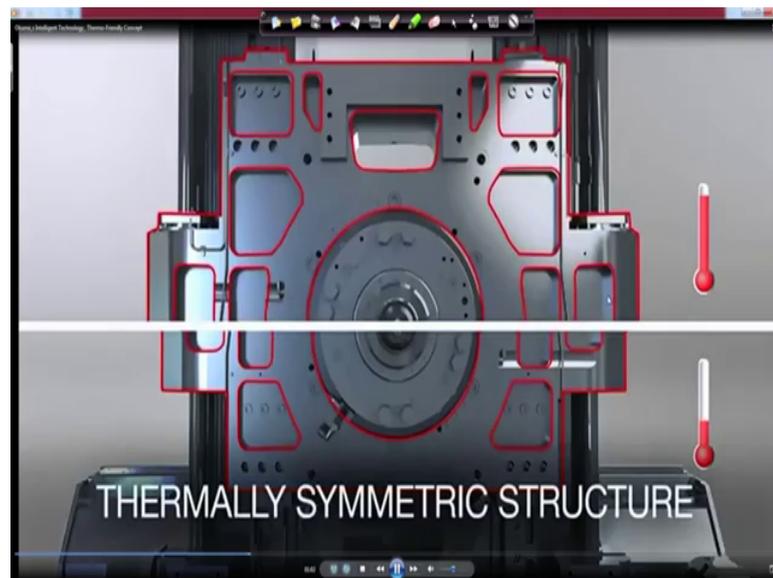
Now, if you see this particular thing, your temperature of the whole machine is within a particular joined there, you will not find any orange spot or the red spot. So, this is the external when you are changing the temperature of the climate steal your machine is in the same temperature; machine adapts to the ambient temperature changes intelligent machine construction. So, how your machine is constructing that is important here.

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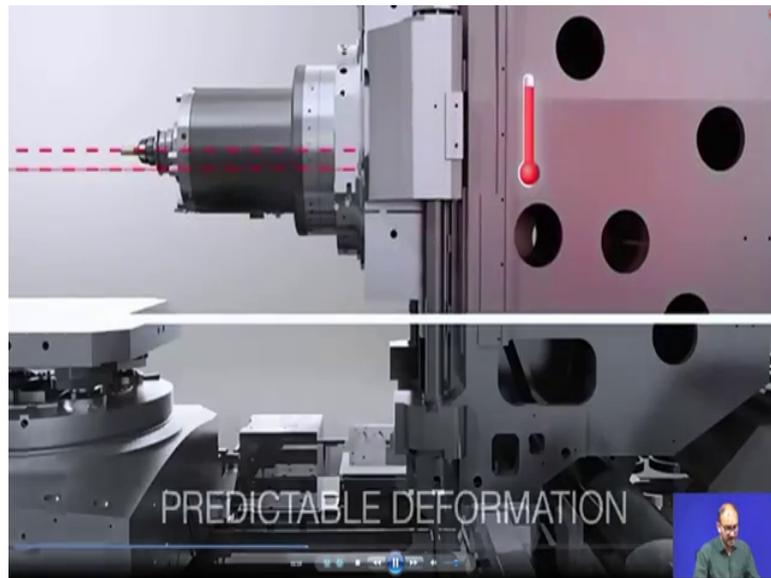
Right if you see this thing old thing, is at the if you consider this view drew one particular line form here, if you see this both the things are symmetric in this case, what is the advantage? That now even if there is a thermal deformation or the thermal expansion this particular thing will expanded in old the direction. So, your whatever is the location of this particular spindle it will not be change. So, that is the advantage of thermal symmetric structure and these ribs are important.

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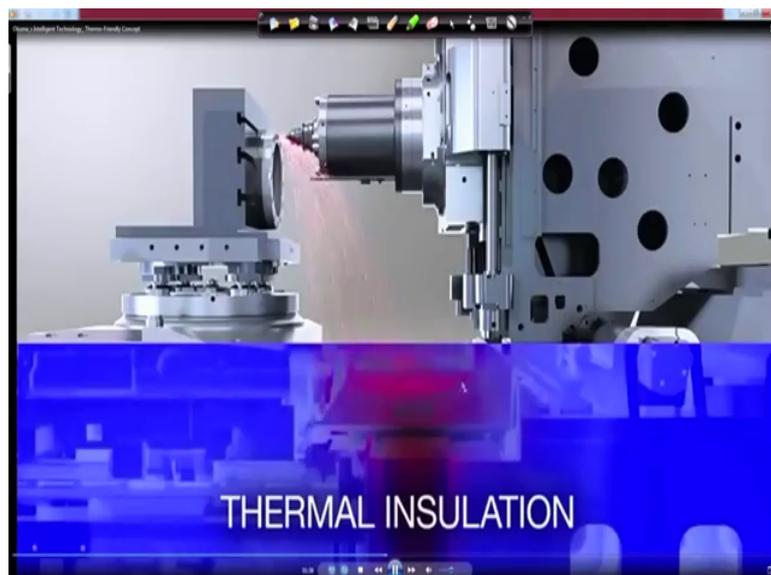
Now, see the temperature is moving up here. But still you are in the same direction thermally symmetric structure and this is the box bill structure. So, this whole thing is not a solar structure. Now if you see from the cross section, you will find lot of ribs.

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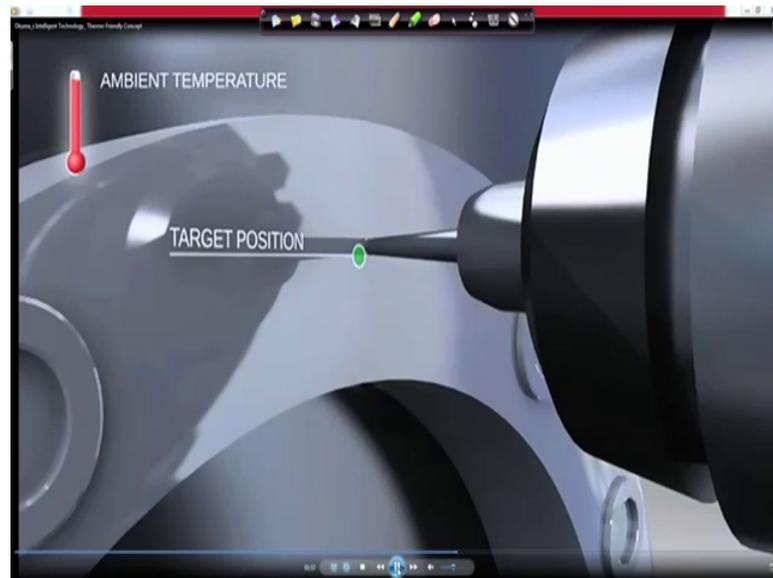
So, this will help in dissipation of the temperature because, we know the now area increases. Here in this case and that is the reason; you can actually predictable deformation here. So, whatever deformation you can predict it and this is thermal insulation what is importance of thermal insulation that when your doing machining, there is a heat generation. Some heat will go to the that, so this is the cheap which are falling here in this location and this is the temperature zone high temperature zone.

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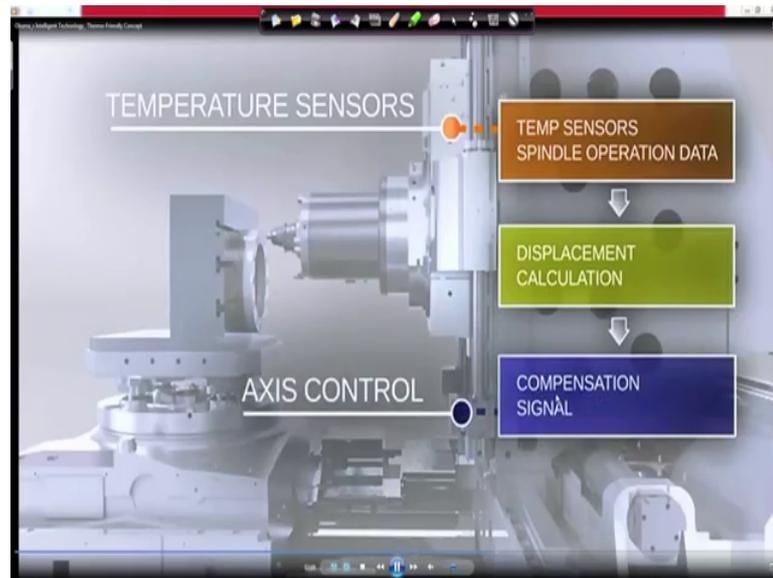
So, you end up with this temperature what you do you to provide tool insulation here. So, cheap will not be created any problem in the heating of the different component of the machine tool and then this is the last one this is the point one-micron deformation control. So, here you what you need? You need sensor which will sense the temperature variation.

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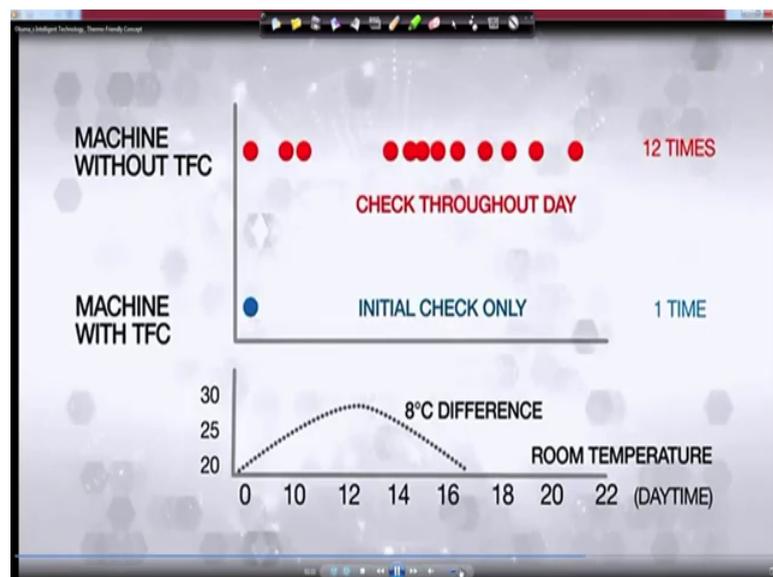
So, right now, this is your target position, but be it is in ambient temperature. Now suppose, you have various and in the temperature and because of that what is happening here that you are but target is little bit shifted hear, that is at toward the point 1 micron that is 100 nano meter. So, what this machine does that, it has a temperature sensor here. That temperature sensor will find out this particular temperature sensor spindle operation data.

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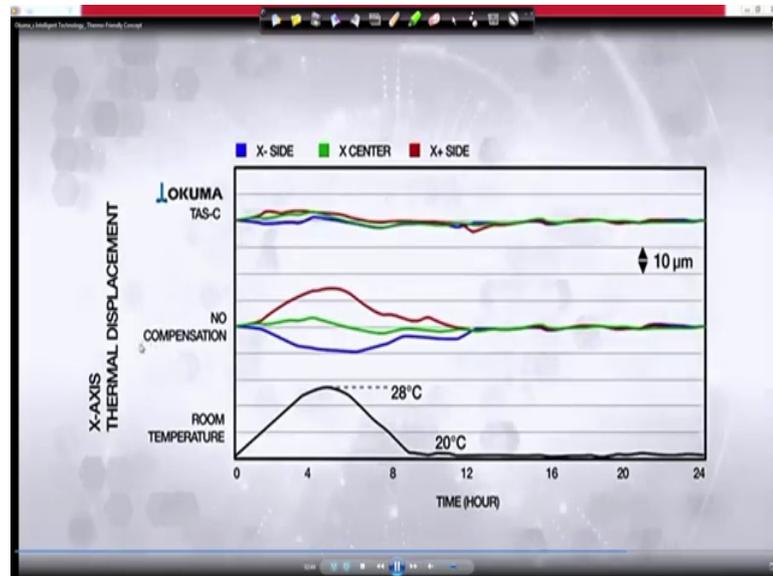
It will do calculation of the displacement. Here how much is a displacement? Because of the temperature variation, so that displacement will directly do compensation signal and that will go to the access control. And once you can get the thing, again it will calculation the original location. And then you can do the machining. So, there are lot of advantage of doing this particular thing because, you can actually reduce the total variation time.

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So, here, if it is without this thermal spindle concept, then you have to measure temperature throughout the operation. Here, we have do first measurement. Then it will take care about everything.

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You have to do one thing only here. Then this is the no composition within the composition. You can actually maintain the x axis depletion within one rage and you cannot get any type of stability problem here.

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- **STABLE MACHINING ACCURACY:**
 - AFTER COLD START
 - IN DRASTICALLY CHANGING TEMPERATURE ENVIRONMENT
 - INDEPENDENT OF VARYING SPINDLE SPEEDS
 - REGARDLESS OF WORK PIECE POSITION / SIZE
 - WITH COOLANT ON OR OFF

So, these are the different consa advantage of using this particular system. So, let me finish this lecture here and we will continue this lecture on this topic further in the next class.

Thank you.