Metal Cutting and Machine Tools
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Lecture - 08
Mechanics of material removal

Welcome viewers to the 8th lecture of the lecture series Metal Cutting and Machine Tools. So, in the previous lecture we have roughly had an idea how chips form and what are the ways in which we can estimate from looking at the chip, how much is the deformation and what sort of other physical features are observable when we are looking at a chip like built up edge formation, and what sort of analogies can be used in case of chip in order to find out where the deformation is taking place and some calculations to find out how we can find out those angles related to you know geometric features related to the deformation.

So, at the end of the you know now we are well poised at the end of the 7th lecture to look at the mechanics of the metal material cutting process. So, the 8th lecture let us formally start.

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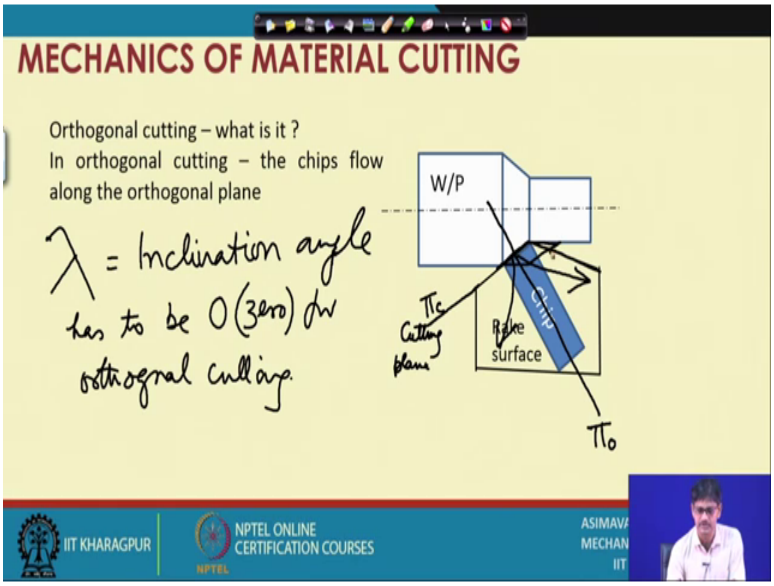

So, here first of all we see a chip coming out of the cutting zone in a particular direction and you will notice that roughly I have indicated that the chip is coming out in the orthogonal direction. What is orthogonal direction? This one, this one is the trace of the cutting plane seen from top cutting plane or pi c. This one perpendicular to it and perpendicular to the reference plane must be orthogonal plane.

So, I have drawn a figure in which I am cleaning that the chip is coming down I mean coming out of the cutting zone by moving along the orthogonal plane. Now, you might place a question what is the reason for which we assume make this assumption you know assumptions should be at least logical that is logical to make an assumption we do not have the full picture. So, we now come across a term called orthogonal cutting what is orthogonal cutting. Let us address it this way that orthogonal cutting in case of orthogonal cutting the chips flow along the orthogonal plane. Now, is there any reason for which chips will not flow along the orthogonal plane? Yes, there are a number of reasons and the most I mean the major reason for which the chips might not flow along the orthogonal plane is that the inclination angle might not be 0. So, let us write it down, that is it.

So, inclination angle means that if the cutting edge as you can see here there is the trace of the cutting edge as seen in the plan view if the cutting edge is slightly appraised. I mean inclined so that it is in end endpoint here towards this side is appraised with respect to the cutting point or it is you know slightly down in that case inclination angle is existing and in such a case we will find that the chip will be deviating from its from the orthogonal plane moving slightly away. By how much may be very close to lambda if we make some assumptions.

Now, the second point is other reasons for which or the chip might be deviating from the orthogonal plane and first of all why are we so much hung up that orthogonal plane is something other than cutting is something special. Orthogonal cutting is you know occurrence when the chips can sorry when the forces can be considered to be contained in a two dimensional plane and it is easy for us to visualize the situation and make force analysis.

So, let us come back here. So, we understand in the auth in orthogonal cutting talking from mathematical terms the forces are will be contained in the orthogonal plane. What sort of forces are we talking about? The cutting forces, the cutting forces will be contained in the orthogonal plane. So, if the chip is flowing along the orthogonal plane this is going to occur. So, now, we ended up with the you know the need for identifying situations where it may be otherwise. First situation was lambda is not equal to 0, in that case the chips will deviate. What are the other effects? Other effect can be for example, this particular auxiliary cutting edge which does part of the cutting you know this sort of a material its removed by the cutting tool by the combined action of this cutting edge and that cutting edge.

So, the auxiliary cutting edge also does some cutting and if the chips emanating due to that cutting effect they will have a chip velocity in this direction while the component of velocity from the you know main cutting edge might be higher than that, but they will combiningly define particular direction of resultant chip flow.

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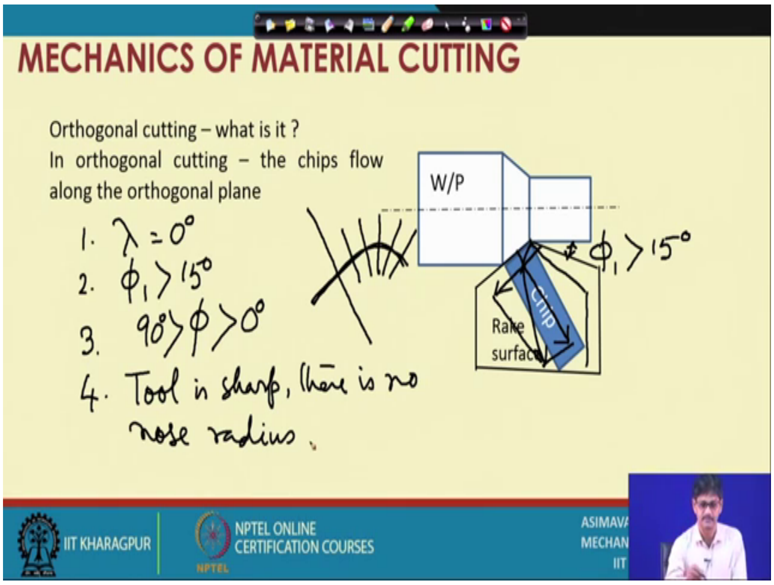

Therefore, this is another possibility of deviation of the chip from the orthogonal plane. So, what we generally see is that the effect of auxiliary cutting should be negligible for orthogonal cutting to take place. Sometimes this is referred to as restricted cutting effect. Now how can it be negligence consider negligible? If phi 1 is equal to I mean is higher just a moment, if phi 1 is higher than oh my god higher than 15 degrees. So, that it is so much away from the actual profile that its cutting effect is much less. So, this way we define the you know conditions one by one, lambda equal to 0 second phi 1 is greater than 15 degrees third this angle this plan approach angle should be between 0 and 90 degrees. 90 degree is greater than phi and greater than 0 degrees and of course, there are other conditions like tool is sharp there is no nose radius.

You know if nose radius is present it will make the cutting edge, it will make the cutting edge have different orthogonal rake orthogonal planes at different points and they will contribute to the respective speed you know speed vectors from different portions and there will be ultimately resultant direction which might not match with this orthogonal plane. So, we are assuming that there is no rays nose radius and the tool is sharp there is no edge rounding also. Once these you know these factors are accepted we can assume that the chips flow in the orthogonal plane. Let us have the next discussion.

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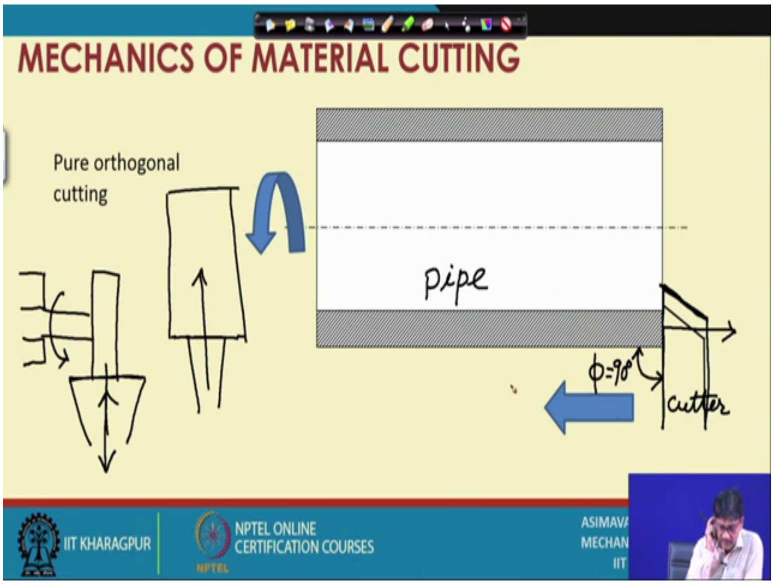

We sometimes refer to some cases as pure orthogonal cutting. What is pure orthogonal cutting? You know if we completely remove the auxiliary cutting effect, I mean the cutting contribution of the auxiliary cutting edge if it is completely removed from the picture in that case and also the other effects which are taking place if they are completely removed in that case we can have a situation in which purely orthogonal cutting is taking place with absolutely no interference from other factors.

For example, if we now consider a pipe. So, this is a pipe which is sown shown in section this is the material this is hollow it is rotating and due to the rotation this cutter I mean due to the rotation cutting is taking place and this is the cutter. As the cutter is moving forwards this way and say it its cutting edge is so large that there it totally encompasses the depth of cut. So, this material will be coming out straight and there is no contribution of the auxiliary cutting edge hence we say that effect of auxiliary cutting edge is completely absent here. So, pipe cutting and also we will notice here phi is equal to 90. So, lambda is 0, phi is equal to 90 and there is no contribution from the auxiliary cutting edge. So, this sets the stage for the consideration of pure orthogonal cutting.

There can be other situations also you know one is as we have defined second is this one our tool might also be poised to cut straight radially inside. We are cutting a sort of group say and not just like this, this is the cutting edge I mean tool and this is the reduction in radius that we are cutting on a job say this is the job held on the chuck and rotating and this is the way in which I am moving forward. So, if this is the feed direction, this is the cutting edge and therefore, the chips are flowing 90 degrees to the cutting edge because lambda is also 0. So, radially reducing the diameter or longitudinally cutting a pipe pure orthogonal cutting.

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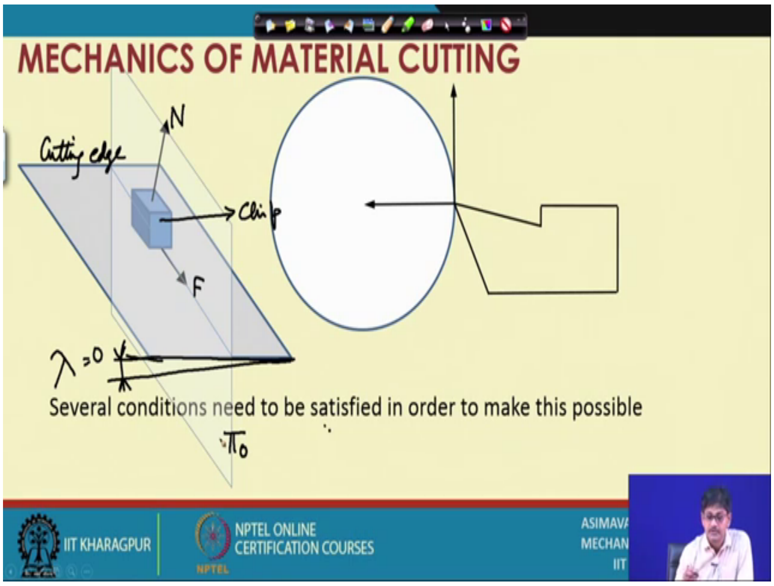

So, next, when the chip is coming down the orthogonal plane and there is no angle on this side which means sorry when there is no angle on this side this is orthogonal rake angle if this is 0. So that means, sideways there is no till in that case the pull forces of this body coming down the inclined plane is only defined by the normal reaction and the frictional force and therefore, it will be contained in this plane perpendicular to this particular plane. So, this is the cutting edge, this is our chip, this is the orthogonal plane this one is the orthogonal plane orthogonal rake is 0; sorry I made a mistake.

See cutting edge is not supposed to have any inclination, so this is 0 and in that case this is orthogonal plane the chip will be totally you know forces on the chip will be totally confined to the orthogonal plane. Frictional force which the chip applies on the rake surface, and normal force which is existing as normal reaction between the chip and the rake surface, so this is normal force and they are totally on the orthogonal plane.

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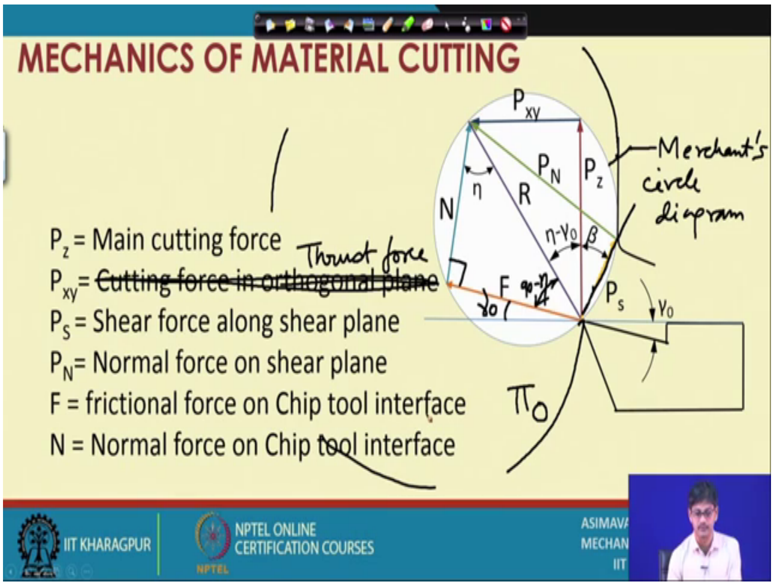

So, having agreed about that let us come to the different relationships which now exist for the resultant forces on the cutting tool. What do we mean by the resultant forces on the cutting tool? On the cutting tool the forces which are being applied by the chip they are normal force and frictional force. I mean we can break them up into such components. There is a single resultant force what we know about that force is that it is on the orthogonal plane.

So, if this is, you know if this is pi o on the orthogonal plane we are having the force resultant force that is the resultant of all interactions resultant force if this is our pointing upwards if we consider the force on the chip. The tool is applying this force on the chip and what can it be; in what components can be resolved it. We can resolve it in components in the direction of the rake surface and perpendicular to it in which case we will get frictional force, normal force representation. We can also resolve it in the standard you know machine axis, this is the red axis and this is the force in the x y plane since its seen you know the forces are restricted on the orthogonal plane apart from the component in the z axis the other and other axial components must be together in this plane. So, we are writing P xy, P XY has to lie on the orthogonal plane in case of orthogonal cutting.

In the same way when we are talking about the shear plane; that means, the plane in which the primary deformation is considered to be you know occurring restricted in the form of shear. So, we can also consider to a shear force to be occurring here which is equal to say we are writing it as P S and a force normal to it as P N. If we have such a representation all of them ultimately the resultant of F by N is resistance a resultant force the resultant of P z, and P x y will be equal to R and the resultant of P S and P N will also be equal to R we are simply resolving it in different mutually perpendicular directions and getting different you know interpretations about the phenomenon.

So, let us have a quick look at the angular relationship. We are having is considered gamma o to be positive and this gamma o angle you know it is equal to what will you opposite this angle. So, this is equal to gamma o. And what is this angle equal to? This angle is equal to gamma minus sorry; eta minus gamma o eta is this angle. So, when we look at this one what is this angle equal to? This is 90 degrees and this must be equal to 90 minus eta. So, let us write down 90 minus eta. So, let us have a pick check. Eta minus gamma o plus 90 minus eta how much is that? Eta eta cancels, 90 minus gamma o, yes this is 90 minus gamma o. So, this matches with our calculations.

So, this way we have the angular values of all these sectional segmental angles and therefore, we can further establish another relationship between all these. Let us formally define them. P Z is the mean is called the main cutting force. P XY is the cutting force in the sorry; I make I will just rub it out. Thrust force when you are doing long longitudinal turning in that case this force tries to push the job from away from the cutter, if phi is between 0 and 90 degrees there is a push perpendicular to the axis of the workpiece. You might say where is the workpiece, the workpiece is like this, this is the anchor chip this whole work thing is the work piece which we have not drawn. This circle is not the workpiece mind you, this is called merchants circle.

After the name of the scientist who you know established this relationship merchants circle diagram. So, we come to the conclusion. So, P XY is called the thrust force next yeah. So, after that P S is the shear force along the shear plane as we discussed, P N is normal to the normal on the shear plane, and F is the frictional force on chip tool interface and N is the normal force on the chip tool interface this thing we have already defined. So, let us move on to the relationships between these forces.

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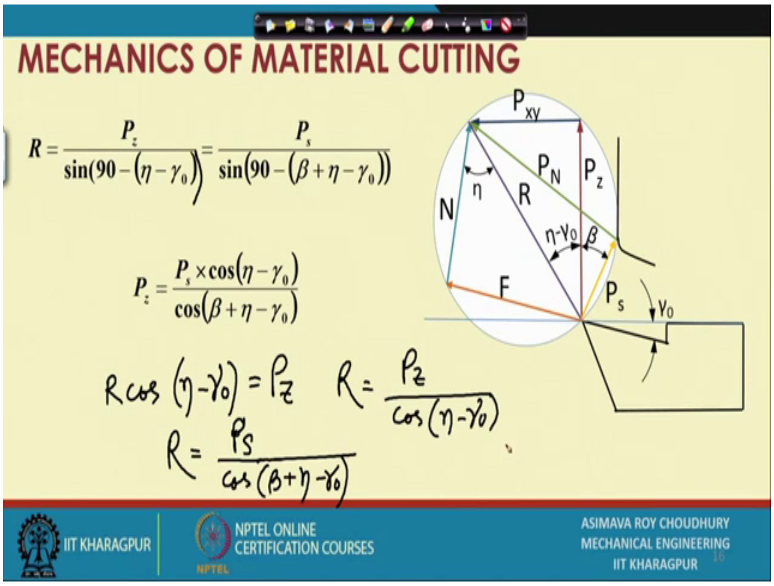

First of all we can establish a relationship between the resultant and some of these components in this manner. We can say the resultant force multiplied by cos eta minus gamma 0 is equal to P Z. So, how do we establish that? Let us see this is eta minus gamma o and we are writing o, I think we can do it in an easier manner than what is written.

First of all let us see what we have stated here. First of all there should be another bracket here. These are P Z by sin, we have a used that particular formula e by sin a is equal to b by sin b that we can do we could have also simply taken components for example, if we write from here R cos eta minus gamma o is equal to P Z which means P Z is equal to right, which means R is equal to P Z by cos eta minus gamma o and next we could have also expressed the same relation between R equal to P Z, P sorry could not be P Z, P S shear divided by cos of beta beta plus eta minus gamma o why this. So, because this is the angle this whole angle is in between P S and resultant. So, R cos this angle is equal to P S which means if we combine these two, if we combine these two we get this relationship.

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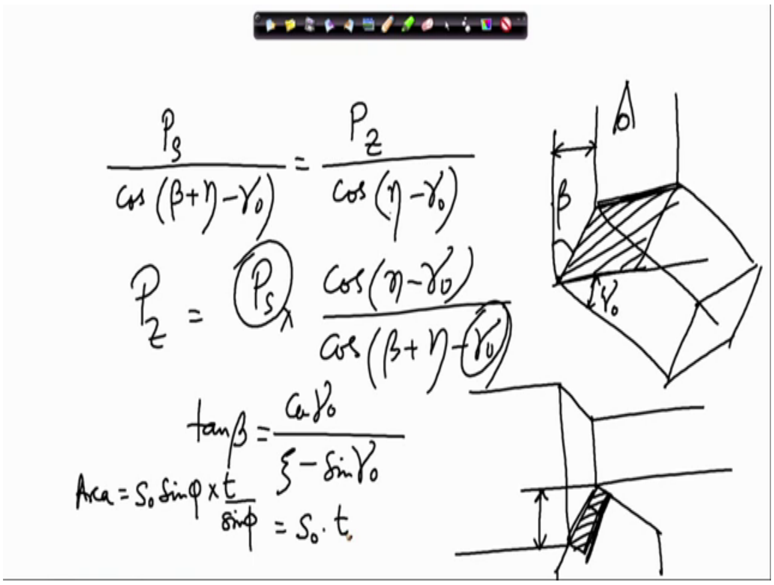

P S by cos beta plus eta minus gamma o is equal to P Z divided by cos beta sorry eta minus gamma o. From here we get an expression of P Z equal to P S into cos eta minus gamma o divided by cos beta plus eta minus gamma o.

So, you might ask me that where has all this led us to. It has led us to an estimation of the main cutting force in terms of the shear forces occurring in the shear plane and some angles. Now, do we need do we know all these angular values gamma o I know I know the value of gamma o is the orthogonal rake, but if someone asks me how do I estimate beta how do I estimate eta etcetera. If you remember in the last lecture we had established relation between tan beta and zeta, tan beta and zeta it for something like if I remember correctly tan beta is equal to cos gamma 0 by zeta minus sin gamma 0 ok.

So, in one way at least I have an estimation of beta, but if you ask me what is the value of eta do I know this. So, in order to completely estimate the cutting forces expression of the cutting forces in terms of the different you know two geometry and other parameters of cutting we need to do some more analysis. Secondly, what is P S? Do I have an estimate of P S? If I can, if I assume that P S must be equal to the stresses which are you know either equal to or crossing the shear strength of the material then only failure must be occurring. So, if I multiply the shear strength of the material with the cross section which is undergoing the shear then I might be able to find out what is the expression of P S. So, for that if you notice that the chip is coming out this way, this is the chip coming out. What is this angle for example? This is beta. What is this angle? This must be equal to eta if you remember, eta o.

So, in that case in that case there is this particular section which is undergoing shear what is this section equal to. So, if we look at the figure if this view the tool, I hope its visible, yes this is the section that we are talking about from looking from the top on this particular view the inclined section can be viewed we are seeing a component of this particular section. So, this distance how much it is, how much is it; this one, so we have this to be equal to t by sin phi. What is this distance? This distance is this one S 0 sin phi. So, S 0 sin phi multiplied by t by sin phi gives me the projected area of this particular part all right. So, we can write that initial projected area is S 0 sin phi multiplied by t by sin phi equal to S 0 into t.

So, as the time of the lecture is already over what we will do is we will continue with this thread only in the next lecture.

So, till then thank you very much. So, we continue in the next lecture.