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 geometric features related to the deformation. So, now we are well poised at the end of the 7th lecture to look at the mechanics of the material cutting process. So, the 8th lecture let us formally start.

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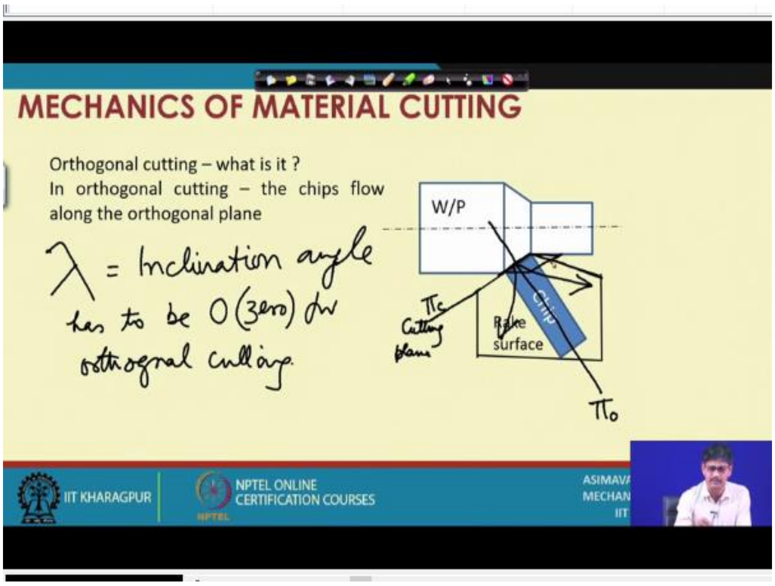

So, here first of all we see a chip coming out of the cutting zone in a particular direction and you will notice that roughly I have indicated that the chip is coming out in the orthogonal direction. What is orthogonal direction? This one is the trace of the cutting plane seen from top, cutting plane or π_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 I mean coming out of the cutting zone by moving along the orthogonal plane. Now you might raise a question what is the reason for which we assume make this assumption should be at least logical, that is okay, logical to make an assumption we do not have the full picture. So, now come across a term called orthogonal cutting.

What is orthogonal cutting? Let us address it this way that 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 and the major reason for which the chips might not flow along the orthogonal plane is that the inclination angle might not be zero.

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 endpoint here towards this side is appraised with respect to the cutting point or it is slightly down. In that case inclination angle is existing and in such a case we will find that the chip will be deviating from the orthogonal plane moving slightly away by how much may be very close to λ, 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 cutting is something special. Orthogonal cutting is a occurrence 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 orthogonal cutting talking from mathematical terms the forces 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 need for identifying situations where it may be otherwise.

First situation was λ 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 this sort of a material it is removed by the cutting tool by the combined action of this cutting edge and that cutting edge.

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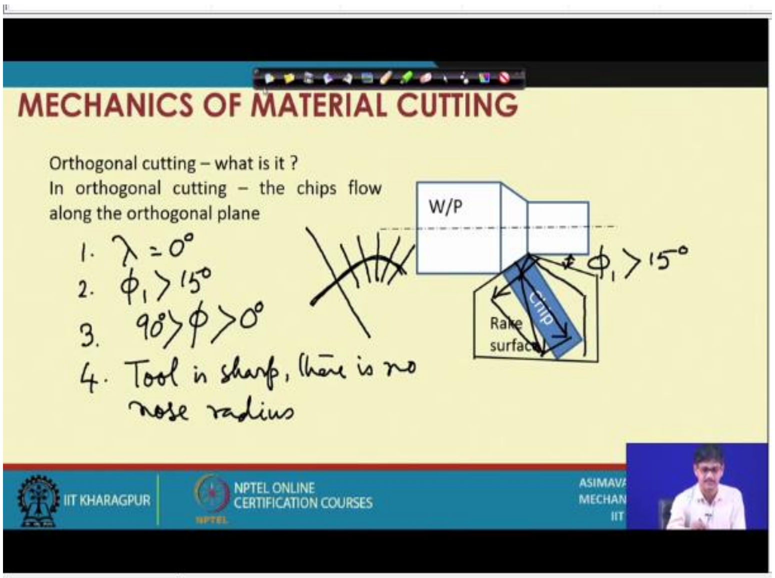

So, the auxiliary cutting edge also does some cutting and if the chips emanating due to that cutting effect they will have a chip velocity in this direction while the component of velocity from the main cutting edge might be higher than that but they will combinedly define a particular direction of resultant chip flow. 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 considered negligible, if φ_1 is higher than 15º, so that it is so much away from the actual profile that its cutting effect is much less.

So, this we define the conditions one by one; $\lambda = 0$, second $\varphi_1 > 15º$, third this plan approach angle should be between 0 and 90º, $90º > \varphi > 0º$ and of course there are other conditions like tool is sharp, there is no nose radius, if nose radius is present it will make the cutting edge it have different orthogonal rake orthogonal planes at different points.

And they will contribute to the respective 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 nose radius and the tool is sharp. There is no edge rounding also.

Once 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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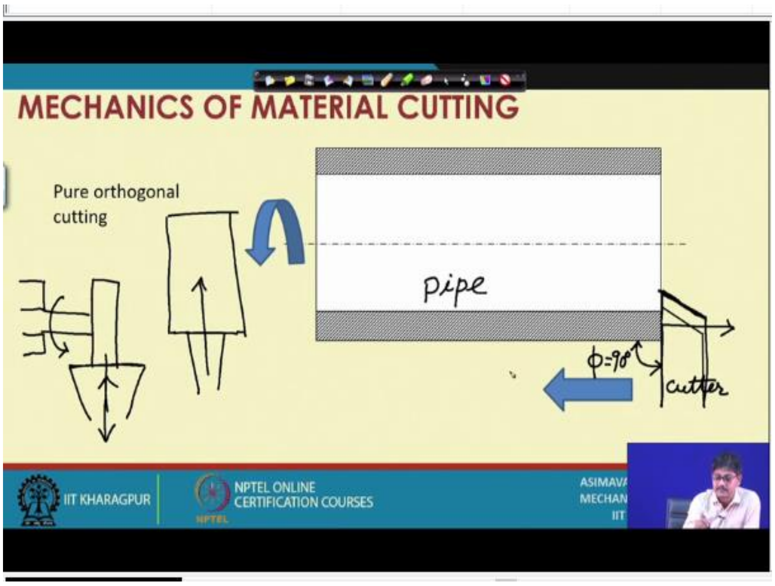

We sometimes refer to some cases as pure orthogonal cutting. What is pure orthogonal cutting? If we completely remove the auxiliary cutting effect I mean the cutting contribution of the auxiliary cutting edge if it is completely removed from the picture in that case and also the other effects which are 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 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 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 $\varphi=90^o$. So, λ is 0^o, $\varphi=90^o$ 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 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 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 90º 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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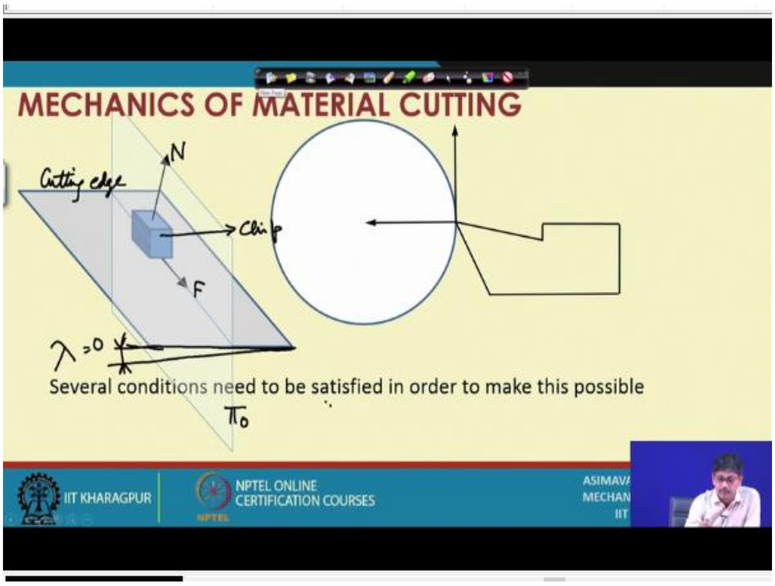

So, next when the chip is coming down the orthogonal plane and when there is no angle on this side this is orthogonal rake angle, if this is 0. So, that means sideways there is no tilt, in that case the pull forces of this body coming down the inclined plane is only defined by the normal reaction and 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 one is the orthogonal plane, orthogonal rake is 0, 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 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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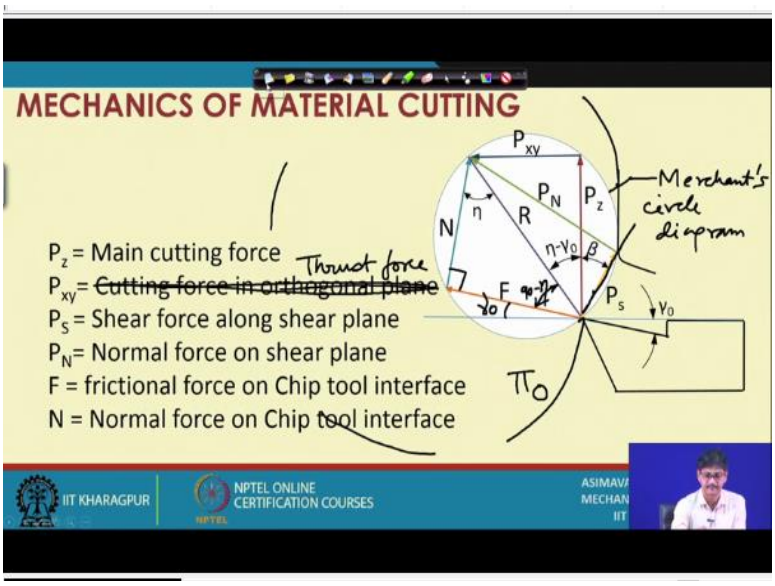

So, having agreed about that let us come to the different relationships which now exist for the resultant forces on the cutting tool. What do we mean by the resultant forces on the cutting tool? On the cutting tool the forces which are being applied by the chip they are normal force and frictional force. 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 π_o on the orthogonal plane we are having the resultant force that is the resultant of all interactions. Resultant force if this is R 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 machine axis. This is the Z axis and this is the force in the XY plane. Since the forces are restricted on the orthogonal plane apart from the component in the Z axis the 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 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/N is a resultant force.

The resultant of P_z and P_{xy} 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 interpretations about the phenomenon. So, let us have a quick look at the angular relationship. We are having is considered γ_o to be positive and this γ_o angle it is equal to virtually opposite this angle.

So, this is equal to γ_o and what is this angle equal to this angle is equal to $\eta-\gamma_o$, η is this angle. So, when we, look at this one what is this angle equal to this is 90^o and this must be equal to $90-\eta$. So, let us write down $90–\eta$. So, let us have a quick check. $\eta–\gamma_o+90–\eta$. How much is that? η, η cancels, $90-\gamma_o$.

Yes this is $90 - \gamma_o$. 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 main is called the main cutting force. P_{xy} is the thrust force when you are doing longitudinal turning in that case this force tries to push the job from away from the cutter if φ is between 0 and 90^o.

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 Merchant’s circle after the name of the scientist who establish this relationship Merchant’s circle diagram.

So, we come to the conclusion, so P_{xy} is called the thrust force, next so after that P_s is the shear force along the shear plane as we discussed P_N is 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 go, move on to the relationships between these forces.

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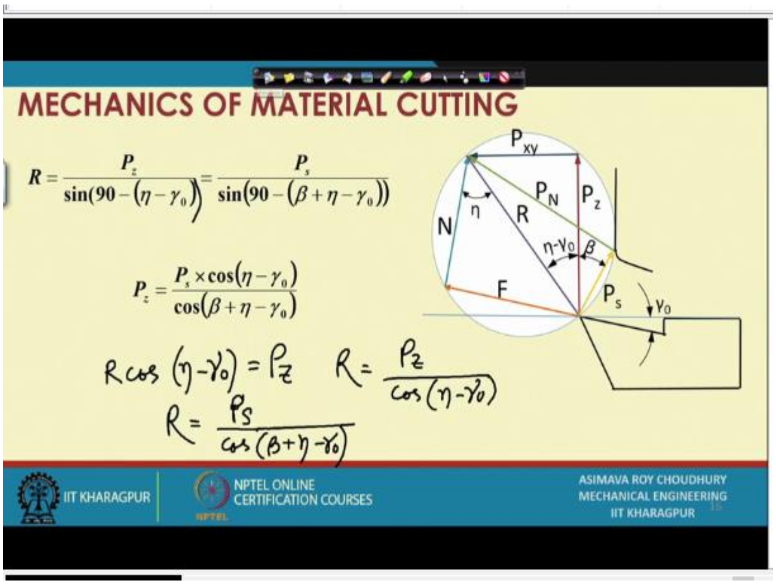

First of all we can establish a relationship between the resultant and some of these components in this manner. We can say the resultant force multiplied by cos $(\eta - \gamma_o)$ is equal to P_z. So, how do we establish that, let us see this is $\eta - \gamma_o$ and we are writing I think we can do 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, so we have a used that particular formula a 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 $(\eta - \gamma_o)$ is equal to P_z which means $R = P_z / \cos(\eta - \gamma_o)$ and next we could have also expressed the same relation between $R = P_s$ shear divided by cos $(\beta + \eta - \gamma_o)$.

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**.**

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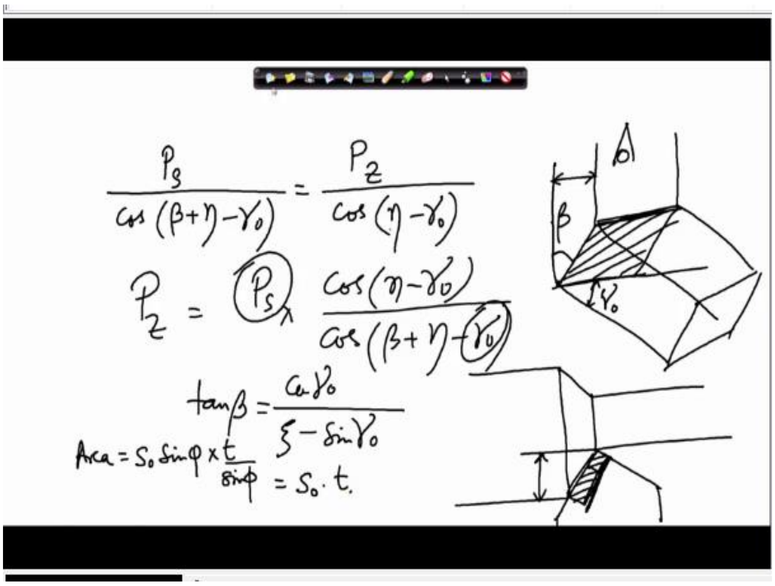

If we combine these two we get this relationship $P_s / \cos(\beta+\eta-\gamma_o) = P_z / \cos(\eta-\gamma_o)$. From here we get an expression of $P_z = P_s * \cos(\eta-\gamma_o) / \cos(\beta+\eta-\gamma_o)$. So, you might ask me that where has all this led us to, it has led us to an estimation of the main cutting force in terms of the shear forces occurring in the shear plane and some angles.

Now do we need do we or know all these angular values γ_o I know, I know the value of γ_o, its the orthogonal rake, but if someone asks me how do I estimate β, how do I estimate η etcetera, if you remember in the last lecture we had established relation between tan β and ζ, tan β and ζ it was something like if I remember correctly $\tan\beta = \cos\gamma_o / \zeta - \sin\gamma_o$.

So, in one way at least I have an estimation of β, but if you ask me what is the value of η do I know this? So, in order to completely estimate the expression of the cutting forces in terms of the different tool 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 assume that P_s must be equal to the stresses which are 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 β, what is this angle, this must be equal to η, if you remember η_o.

So, 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 be the tool I hope it is visible, yes, this is the section that we are talking about 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 this one?

We have this to be equal to $t/\sin\varphi$, what is this distance? This distance is this one, $S_0 \sin\varphi$. So, $S_0 \sin\varphi$ multiplied by $t/\sin\varphi$ gives me the projected area of this particular part. So, we can write that initial projected area is $S_0 \sin\varphi$ multiplied by $t/\sin\varphi = S_0{*}t$. 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.