Metal Cutting and Machine Tools
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Lecture-10
Numerical Problems and MCQ

Welcome viewers to the 10th lecture of the course metal cutting and machine tools. In this particular lecture we will be discussing some of the numerical problems which cover the subjects of the second week. That means starting from mechanism of chip formation and then cutting forces, calculation etcetera, all these things as far as possible we will be covering. And if required I will also upload a few questions and answers in text form. So, that you can watch it offline, that is whenever you are not watching the lectures you can still open them up and have a look. So, let us move right away.

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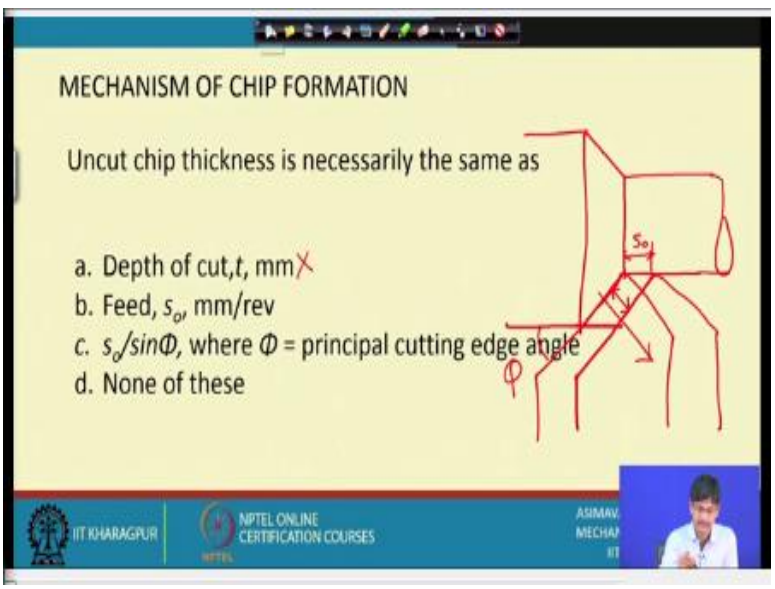

So, mechanism of chip formation, uncut chip thickness is necessarily the same as depth of cut t in millimetres, feed S_o in mm/rev, S_o/sin φ, where φ is the principle cutting edge angle and none of these. So, if we quickly have a look at the figure just to remind you, this is one position of the tool, this is the finished cylindrical part, this is another position of the tool and therefore this is the feed S_o, this angle is φ.

And therefore the uncut chip thickness looking from the top, this is our chip volume which is coming out, it ultimately comes out this way, so this is the uncut chip thickness and obviously which is equal to S_o sin φ.

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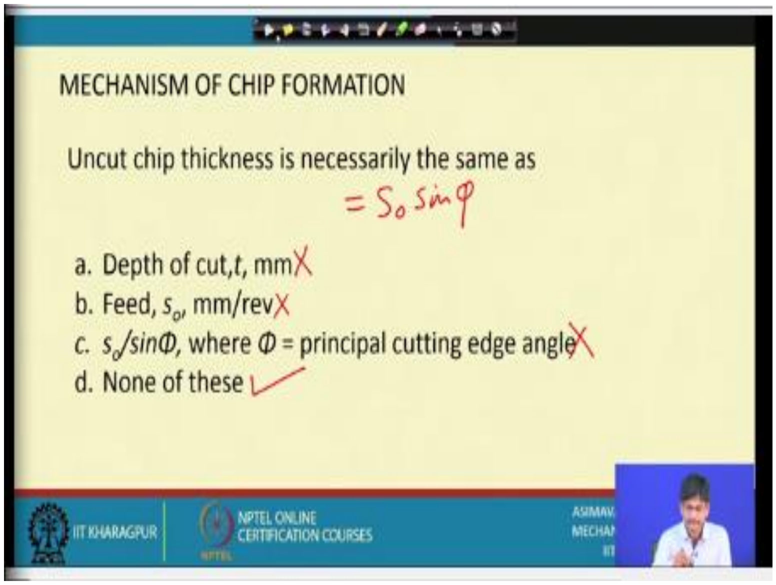

So, this is not correct, just a moment this one is not neither this, neither this one, because this is S_o/sin φ, so the correct answer is none of these because uncut chip thickness is equal to S_o sin φ. So, let us move on to the next one.

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Built-up edge, built-up edge necessarily means a tool with cutting edge built up by layered manufacturing. Cutting edge of indexable insert, material from chips cemented over the tool cutting edge and the cutting edge of a tool which is built up as assembly of several sub parts. Actually built up edge, actually if you have a look at the built up edge, if you have the tool this way and if you have the chip going this way.

Built up edge is cementing of layers of chip material which suffers stagnation and it gets almost welded with the tool rake surface and thus it covers the cutting edge, it deteriorates the cutting action, so this one is correct. A tool with cutting edge let us just check whether any of these fit by chance. A tool with cutting edge built up by layered manufacturing, it means that if you build the tool by layered manufacturing, in that case the cutting edge is called the built up edge.

No, this is not correct, even if you build up tools with layered manufacturing technology; some work has been done in this direction definitely. Especially hollow tools in which you can preferentially leave hollow spaces inside for either for lubrication or for some other purpose maybe for damping, so those are not being meant here. Cutting edge with indexable insert, no, it is not called a built-up edge or a tool which is built up with sub assemblies, the cutting edge of that particular tool, No, so C is correct.

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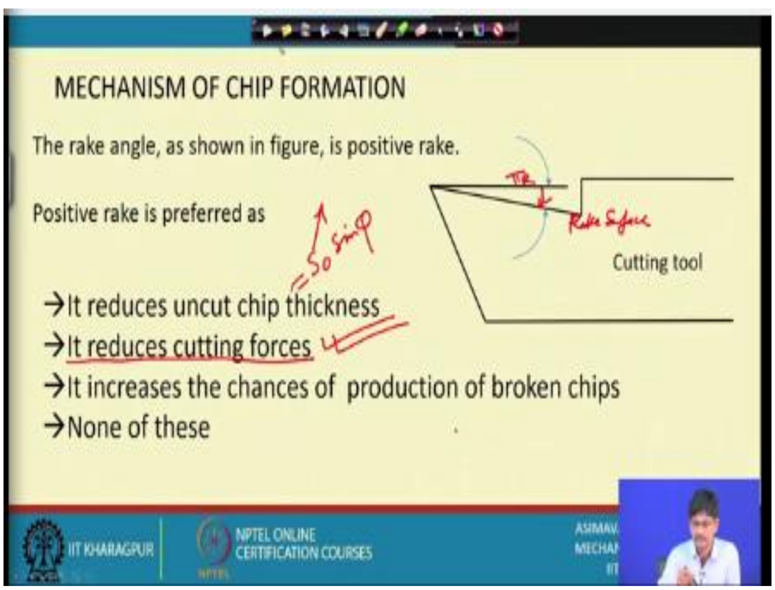

So, the rake angle as shown in the figure is positive rake, if this is the trace of the reference plane, if we go clockwise from the reference plane we reach and if we reach the rake surface, this is the trace of the rake surface then we are calling this rake angle positive. So, a positive rake is preferred as it reduces uncut chip thickness. No, uncut chip thickness is equal to $S_o \sin \varphi$ and it has simply no relation with rake angle.

S_o is something we are setting completely independent of rake angle. It reduces cutting forces this is correct, let us see whether there are other correct answers. It increases the chances of production of broken chips, just the opposite. If you have higher rake it increases the chances of getting a continuous chip, none of these. Therefore, this one is the only correct answer; let us move on to the next problem.

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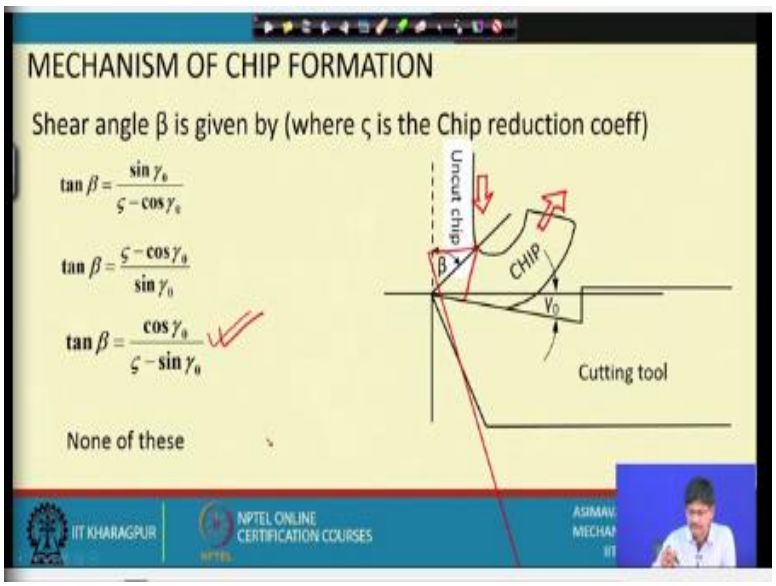

Shear angle β is given by where ζ is the chip reduction coefficient and we are given several expressions and for the tangent of the angle β, let us see what is β. Here comes down the uncut chip down with cutting velocity and it goes out as a chip with whatever velocity the chip is having, the chip velocity. This is the place where we are considering in a single plane, we are assuming in a single plane across a single plane the whole of the deformation of the chip is taking place.

Some deformation of course takes place in the secondary deformation zone, but here we are considering across a plane the primary deformation is taking place, this is angle β. And we have to find out the tangent of angle β, this one if you remember we have already derived in the class, and this happens to be the correct answer. What do you do if you do not remember the expression, it is very frequently happening that whatever we do by heart in the exam hall, we do not recall it. In that case the derivation is very simple, I will just give you the basics, drop 2 perpendiculars here one here and one there.

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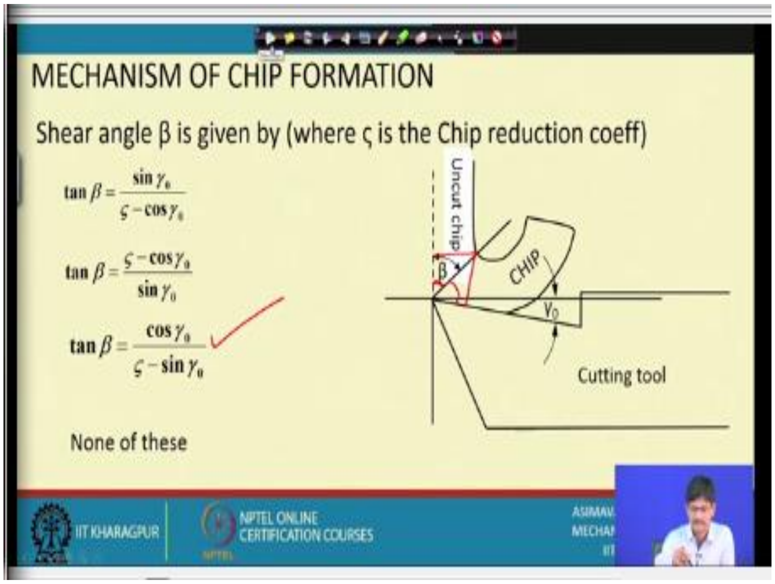

So, in these 2 perpendiculars I mean right angle triangles the hypotenuse is shared. And therefore the hypotenuse can be expressed in terms of 2 angles, one is this β and this one happens to be γ_o , and therefore this one will be 90º - β + γ_o. And from there we can get a relation that is hypotenuse is equal to uncut chip thickness divided by sin β, and it is also equal to chip thickness divided by the sine of this angle.

So, this way we can easily establish the relationship, I am not going into the derivation because it is already done in previous lectures. So, we just move on with this particular statement that only this one is correct, the others are all wrong. So, let us go on to the next problem.

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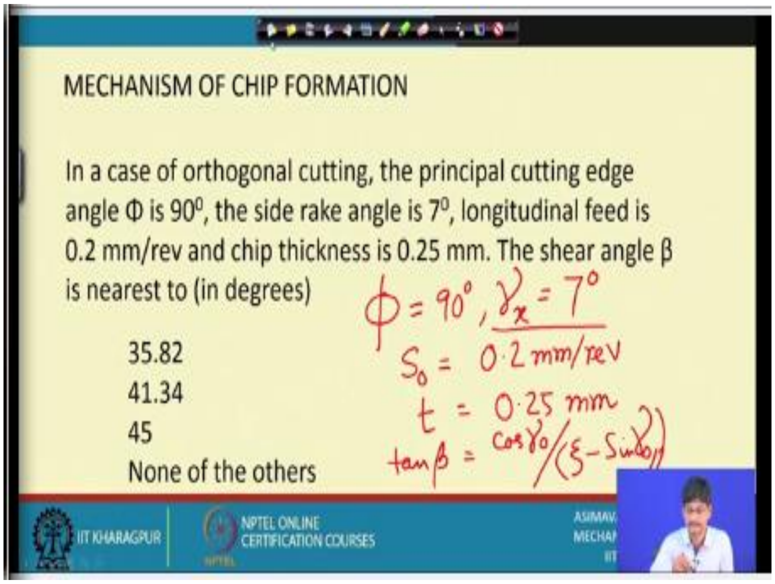

In case of orthogonal cutting, the principle cutting edge angle is 90º, φ is 90º, the side rake angle is 7º. So, φ the most important thing to be what is the data? It is given φ=90º, γ_x=7º, longitudinal feed S_o=0.2 mm/rev of workpiece, and the chip thickness t happens to be 0.25 mm. The shear angle β is nearest to in degrees, so we have to find out the value of the shear angle, how do we do that? If you remember we can use the previous expression, so these options among them let us use this data but herein come the catch.

I mean the problem, what is the problem like? Side rake angle is given while in the expression for the shear angle which we have as $\tan \beta = \cos \gamma_o / (\zeta - \sin \gamma_o)$, this refers to the orthogonal rake. Now do we have to painstakingly find out the expression of the orthogonal rake from the side rake angle certainly not, why? Let us see.

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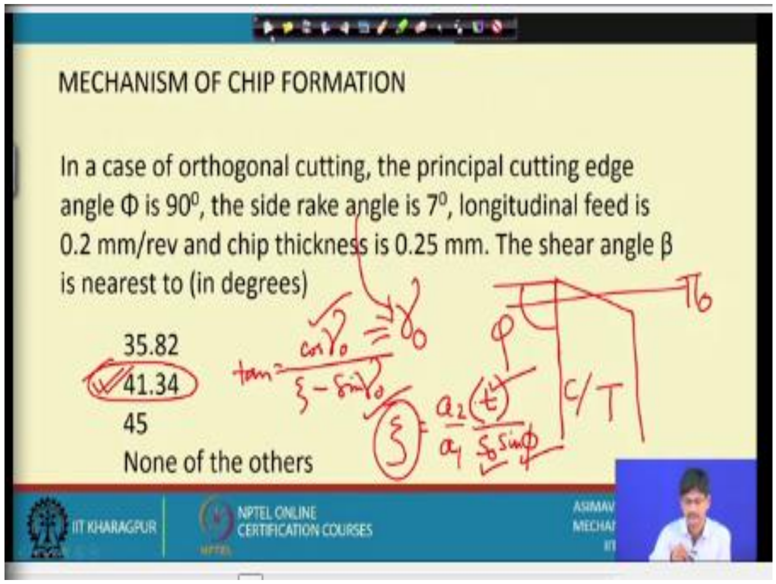

Oh! What is this? In this case what we can do is that let us draw the cutting tool and immediately something will become very clear to us, $\varphi = 90^{o}$, that is it. This is the cutting tool; I am writing in short cutting tool; this happens to be the angle φ. And therefore we can say that the orthogonal plane is here, this is the trace of the orthogonal plane seen from the top. And therefore side rake and the orthogonal rake they become the same angle, therefore we can use this value as the value of the orthogonal rake, side rake is equal to orthogonal rake.

So, our principle problem is solved. Now can we find out the value of ζ? Because as we wrote down $\tan \beta = \cos \gamma_o$, now this is taken care of divided by $\zeta - \sin \gamma_o$, this is taken care of, we can easily find it out, cos 7^{o}, sin 7^{o}, ζ. ζ is equal to if you remember it is equal to a_2 by a_1, where a_2 stands for chip thickness which is t, and a_1 stands for uncut chip thickness which is S_0 or $S_0 \sin \varphi$, φ is given, S_0 is given.

Therefore, everything is given, chip thickness is given, S_o is given, φ is given we can find out ζ completely. I have carried out my calculations, I am sure you can do it now, because it is simply algebra. If you have a calculator handy with you, you can do it within seconds. I have got this one to be correct, please check your respective calculations. This one happens to be the correct answer, the shear angle, you will get the tangent of the angle and then you have to find out arc tan or you would find out inverse tan whatever software or whatever calculator you are using. So, please check up.

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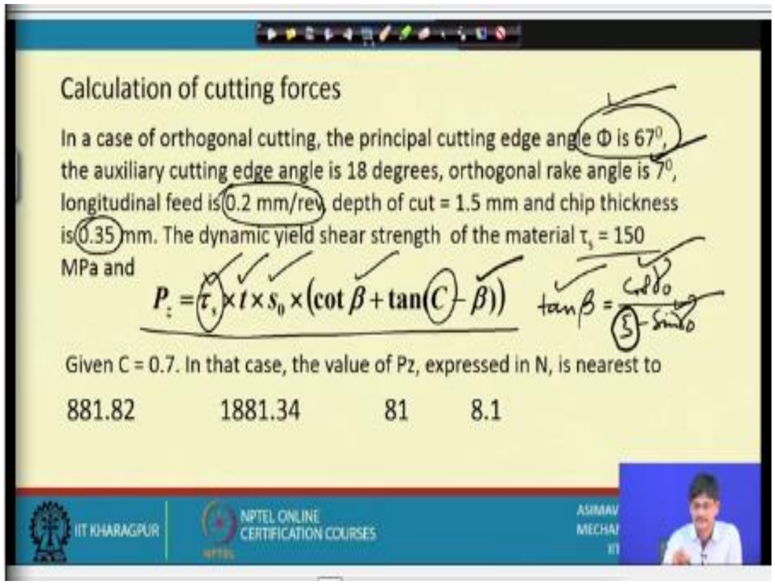

Calculation of cutting forces, in a case of orthogonal cutting the principle cutting edge angle φ is 67º, the auxiliary cutting edge angle is 18º, orthogonal rake angle is 7º, longitudinal feed is 0.2 mm/rev, depth of cut is 1.5 mm and chip thickness is 0.35 mm, the dynamic yield shear strength of the material τ_s = 150 Mpa and P_z is to be taken as with in agreement with Merchant's second proposed model.

P_z is to be taken as $\tau_s * t * S_0 * (\cot\beta + \tan(C - \beta))$, this we have derived the last day, given C = 0.7 radians. In that case the value of P_z expressed in N, is nearest to 881.82 N, 1881.34 N, 81 N and 8.1 N, now how do we proceed to solve this sort of problems? First of all, let us check whether all the data which is required here, it is provided or not.a

So, first of all if we have to find out P_z we need τ_s, is τ_s provided? Yes, so I put a tick here, I need the chip thickness, is chip thickness provided? Yes, chip thickness is provided, I need the feed, is the feed provided? Yes, feed is provided, I need β, is β provided? No, but I can find out β, what sort of equation am I going to use? We have solved it just now.

So, I just write it and I understand that we can solve it, $\cos\gamma_o / (\zeta - \sin\gamma_o)$. But this raises a question, are all these things provided? We definitely need orthogonal rake, orthogonal rake is given, so this is all right and what else? ζ, ζ is once again a_2 by a_1, so do we have depth of cut?

Yes, do we have feed? Yes, and do we have principle cutting edge angle? Yes, so we can find out tan β, so this part is solved.

Last of all what is C? C is given, so it is completely we can find out this expression completely. And what are the answers? Let us see I think I might have solved it myself in subsequent pages.

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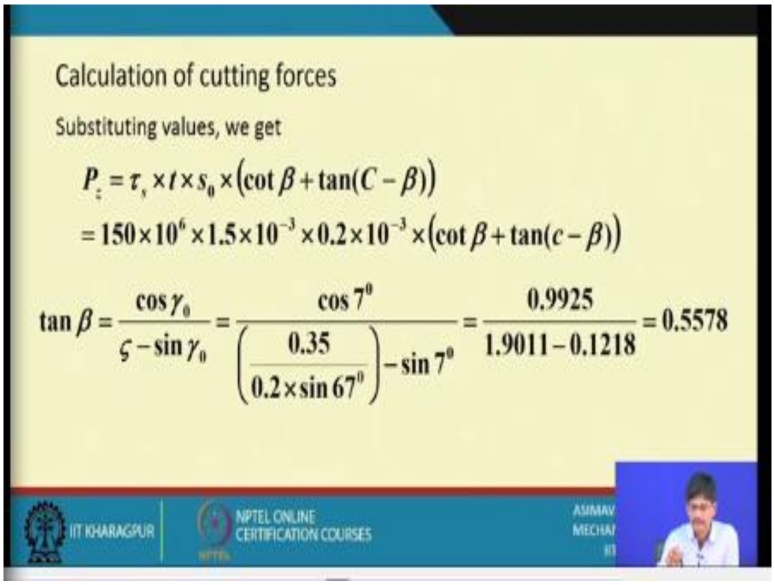

Calculation of cutting forces, first of all we are substituting values 150 * 10^6, t is to be expressed, everything to be expressed in meters. When everything is expressed in meters 150*10^6 Pa, next t is 1.5 mm * 10^{-3} m, S is 0.2 * 10^{-3}, cot β tan β has been founded as by the method that we had talked about, so this tan β is coming to be 0.5578.

And that corresponds to an angle roughly 30º, so we will pull the value of 30ºhere. And we will put the value of β here as well in radians and then convert the whole thing to degrees, if your calculator is degree compatible.

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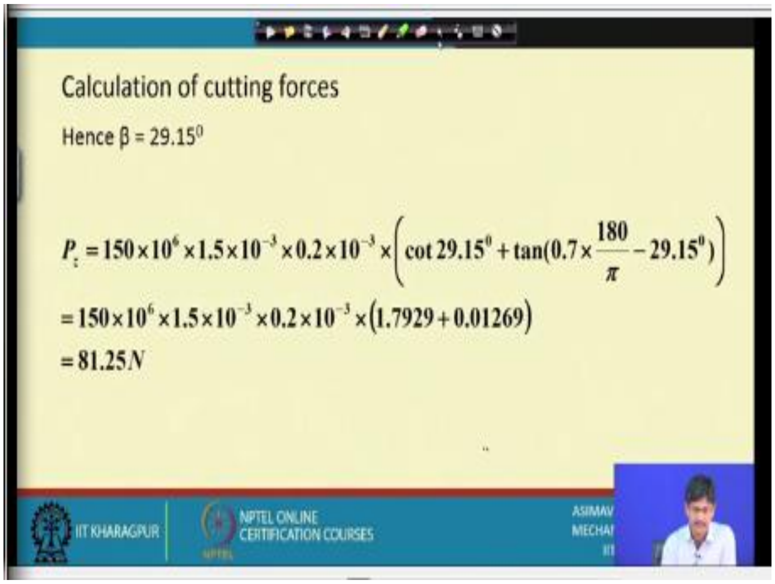

Now let us see what we found, hence we found out the value of β and after that we have put here cot β + tan C we have converted this to degrees. And therefore we can retain the degrees here and therefore by the multiplication I have found the answer to be 81.25 N. So, if we go back, just a moment this is the correct answer, it is nearest to this value.

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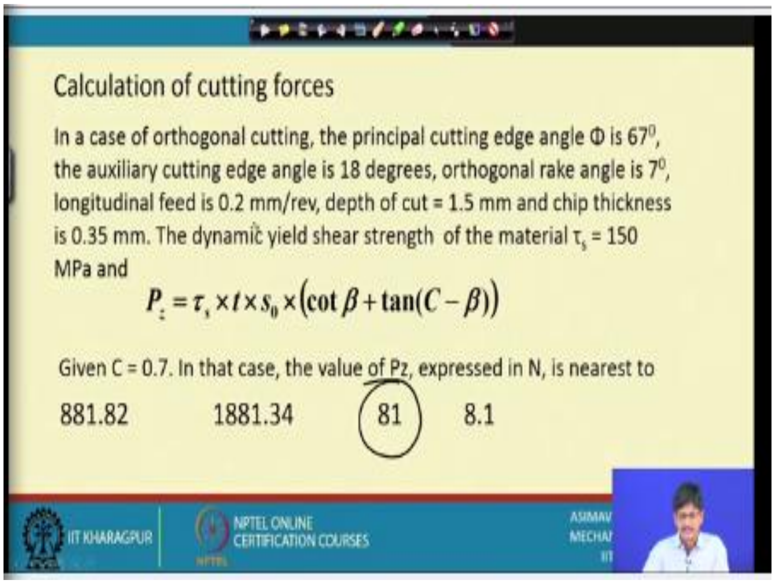

This is the correct value 81 N.

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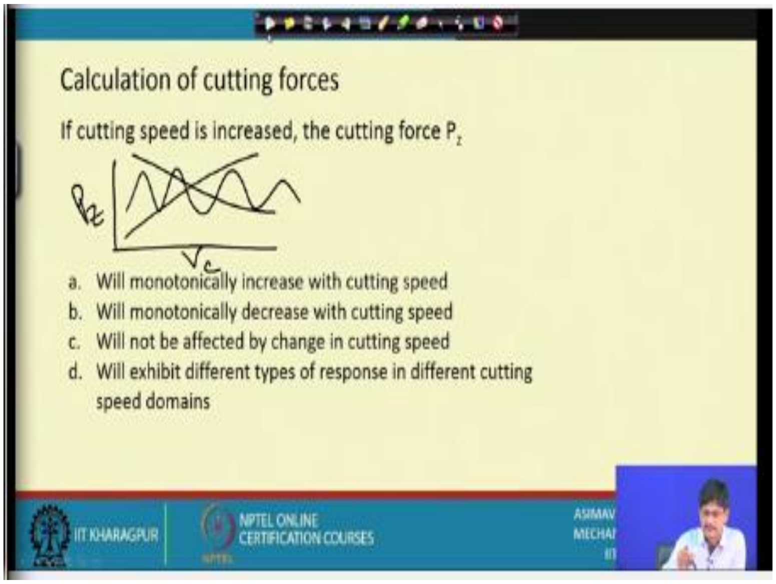

Next, if cutting speed is increased, the cutting force P_z will monotonically rise with cutting speed. That means what we are suggesting here is this, that if we plot say P_z for the time being and this is V_c. In that case we will find that if cutting speed is increasing, P_z will in monotonically increased with it. And the second option says, no it will be monotonically decreasing, third it will not be affected by change in cutting speed, fourth it will exhibit different types of response in different cutting speed domains maybe it means this, which one is correct? That is quite interesting, let us see.

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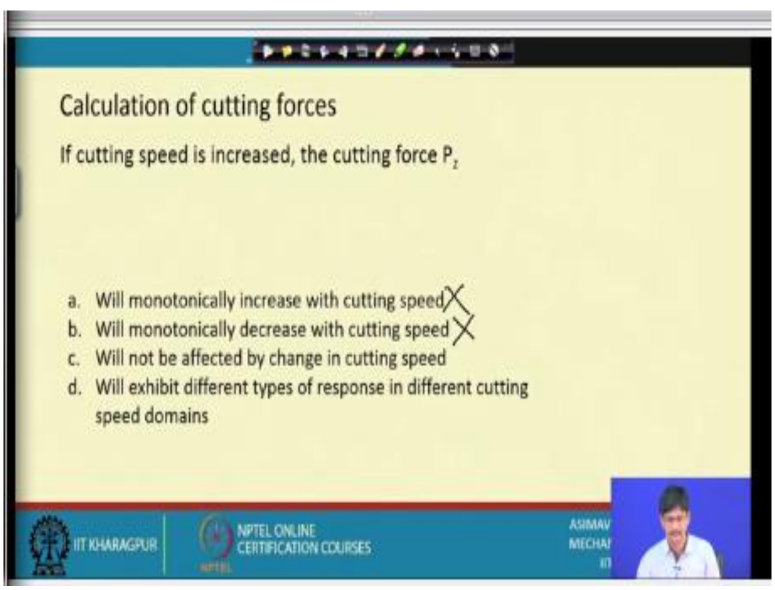

Monotonically rise increase with cutting speed, this does not happen. Monotonically decrease, this also does not happen, then what does happen? Is it not affected by cutting speed? No, it is affected, let us see.

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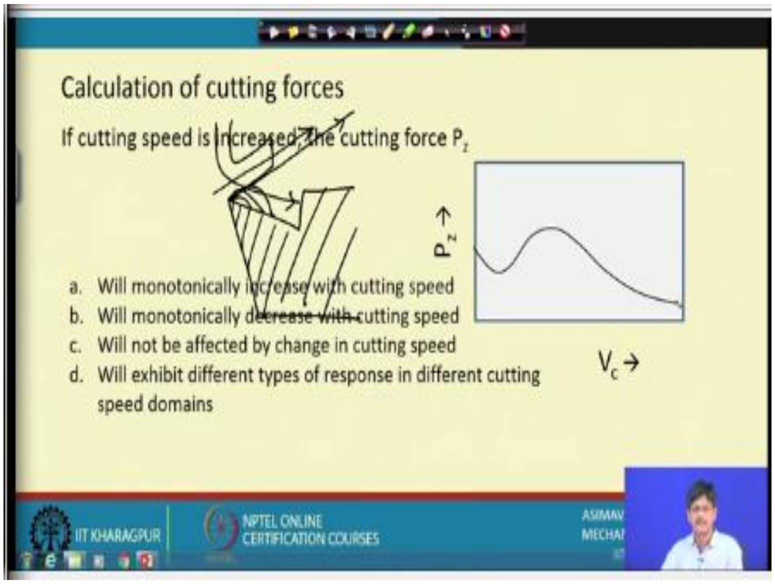

This is the typical response of P_z with respect to V_c, cutting speed and the main cutting force. When the velocity is very less, as the speed increases, with that we find from a higher value at static friction. As gradually the speed increases the cutting force goes down, because the effect of change of static friction with dynamic friction. However, after that the onset of the phenomenon of built up edge sets in at very low speeds built up edge is not there.

After that when built up edge forms, it gives it sort of changes the behaviour of the cutting tool in such a way that as if a positive rake is changed to a negative value of rake. Let us have a quick look, what actually happens? If this be the tool, if this be the built up edge, this is the resultant direction in which the chip has to move when a built up edge has formed.

And therefore instead of flowing this way, instead of sensing the actual rake which is there on the surface of the tool, it senses a much higher negative value of rake which means that forces are going to be high. So, as the built up edge goes on getting established in the medium level speed, the cutting force rises and reaches a maximum. But after that with the onset of higher speeds the built up edge becomes unstable and it gradually collapses. So, that we again have a reduction of the forces.

Finally, the effect of softening of the material with higher temperatures attained at higher velocities, that sets in and we have a reduction, monotonic reduction of the cutting speed. So, ultimately when you are free of any other special effects, then the phenomenon is like this that cutting force will reduce with higher speeds in the high speed domain.

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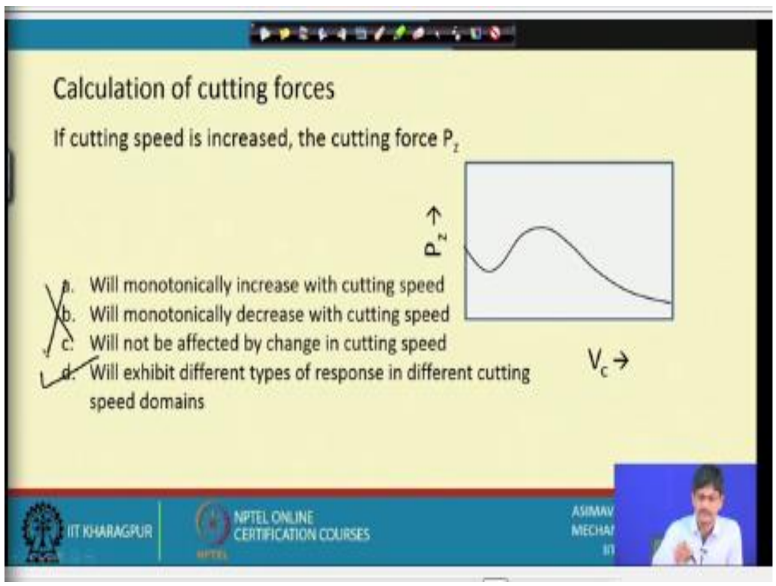

So, I should mention here one thing that is in the high speed domain this is one phenomenon. That is the cutting speed is going to the energy of cutting that is going to manifest it itself by higher temperatures, attainment of higher temperatures will soften the material. But at high speed cutting takes place with the accompaniment of higher strain rates. At higher strain rates we will find that there is an expression which predicts that the shear strength of the material is going to rise.

If that happens, if the shear strength rises there will be an opposing effect, that there will be higher forces experienced, so these 2 are contradictory. From the point of view of higher strain rates will have higher forces existing. And from the point of view of temperatures attained we will have softening of a work material leading to lower forces. And ultimately we can see here that the softening of the material is dominated. So, the answer is it will exhibit different types of response and different cutting domains this one is correct. Now let us move on to other questions.

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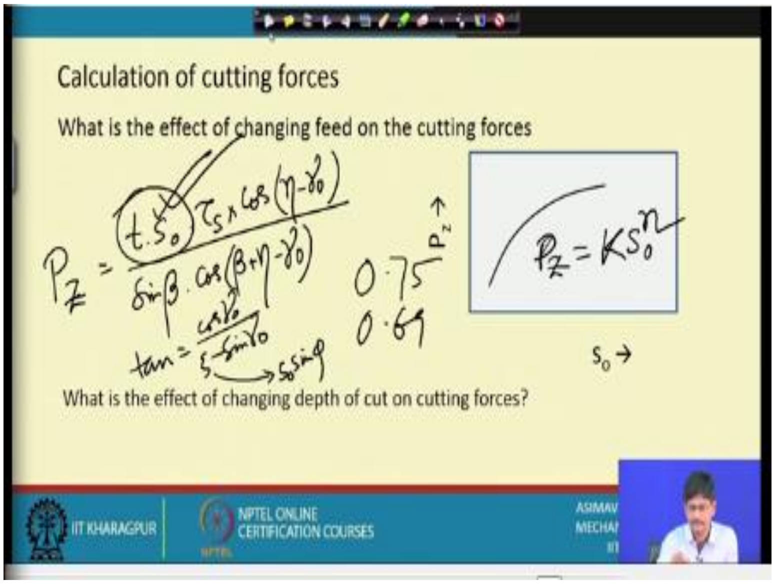

What is the effect of changing feed on the cutting forces? If the cutting forces are I mean if the feed value is changed, if we go from low feed to high feed definitely by pure even by pure guess a student can say that yes, the cutting forces are going to increase. But let us see in what way? The expression of P_z tells us $P_z = t * S_0 * \tau_s$ into $\cos(\eta - \gamma_o)$ divided by $\sin\beta * \cos(\beta + \eta - \gamma_o)$ etcetera.

And if you take P_{xy} or other expressions you will find that these things are there in cutting force expressions. Therefore, we can say, yes, it is going to be directly proportional but, no, we find that the relation between P_z and S_o has a relation of this type. That means it suggests that P_z will be equal to some constant multiplied by S_o to the power some constant say let us call it n for the time being and n is obviously less than 1.

And by experiments it has been found it generally it is around 0.75 to 0.69, this range, why does this happen? This happens because feed is not only present here but it is obviously present in β. Because tan β is containing $\cos\gamma_o/(\zeta - \sin\gamma_o)$ and ζ contains $S_o \sin\varphi$ in it is denominator. So, simply for this reason itself alone, for this reason alone we can say that it is not going to be a proportional relationship and it comes out actually this, so this is the answer. This the effect of changing feed will have this sort of a response on the cutting forces.

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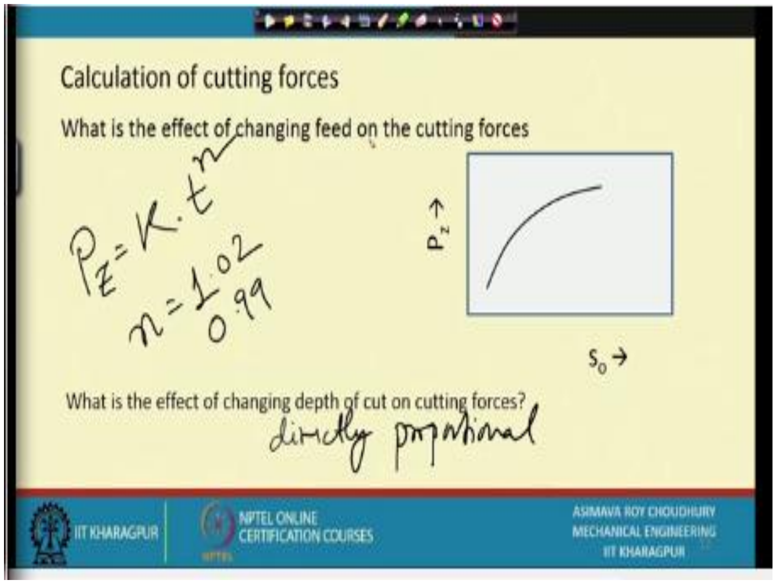

Now let us see the last part, what is the effect of changing depth of cut on cutting forces? If you change depth of cut, it will be found that more or less if we express P_z as equal to K into depth of cut to the power n, n will be roughly 1 maybe in some cases 1.02 or 0.99 etcetera for different forces. So, it is more or less proportional, if you double the depth of cut you can express more or less the cutting speed will be doubled.

So, this one is directly proportional we can write for all practical purposes, directly proportional and this one to the power roughly 0.75 to 0.69. So, with this we come to the end of the discussion of numerical problems and small thought provoking problems. I expect to give you some textual problems by uploading them and keeping them on the website, so that you can open them up. And enrich your knowledge and share our discussions later on, thank you very much.