Metal Cutting and Machine Tools
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Lecture-07
Mechanism of Chip Formation

Welcome viewers to the 7th lecture of the course metal cutting and machine tools. So, up till now what we have done is, we have discussed at length the different geometrical aspects of the single point turning tool. And also looked at some other cutting tools, and that we try to find out how the principles of the single point turning tool apply in case of other cutting tools. So, in this respect we have looked at the twist drill, double fluted twist drill.

We have also looked at a slab milling cutter with helical teeth, we have further had a look at taps and dies and also what you call it the centre drill etcetera, some tools of this type we have had a look. Today we are going to start the topic that is chip mechanism of chip formation, how does the chip come out? Whether it is continuous or whether it is discontinuous or whether it is segmental etcetera.

First of all we should have a thought how is it important to us? For example whether the chip is continuous or discontinuous or segmented, whether it has built up edge etcetera, what is the point of studying these things? Whenever we come across some detrimental situations, I mean some parameter causing some detrimental effect in any process if we study it in depth; we will find out what are the parameters affecting it, what are the factors responsible for it is manifestation.

And then we can ultimately try to remedy the situation by controlling those very factors, so that is why. For example built up edge, whenever the chip is coming out at the bottom of the chip surface there is some material sticking to the tool is it detrimental? Yes, because it affects the surface finish, it makes the continuous cutting rather unstable etcetera, it affects the dimensional accuracy.

So, surface finish, dimensional accuracy and steadiness of cutting all these three are affected by the built up edge formation. So, if we study built up edge formation and try to remedy it by controlling the factors responsible for it, that will be definitely knowledge addition, the constructive knowledge addition, so that is what we are going to do. So, let us start formally, so the 7th lecture is on mechanism of chip formation.

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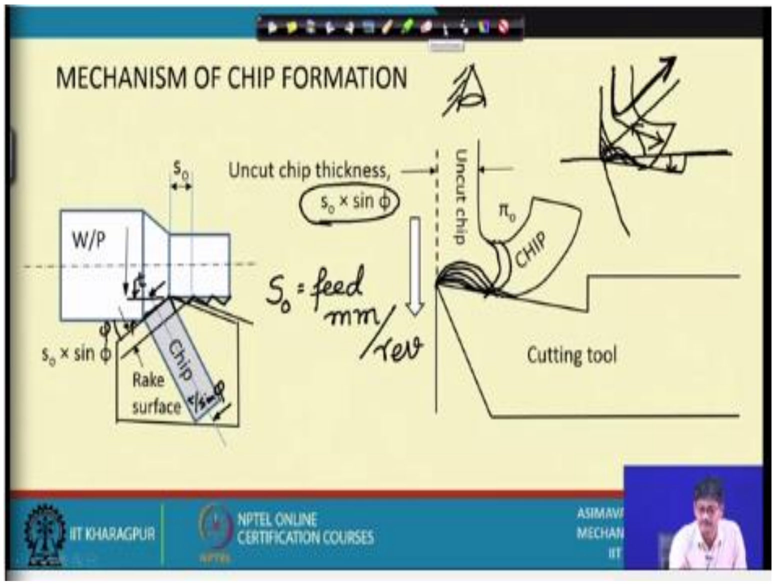

So, on 2 sides we have shown 2 situations, that is first of all looking at the tool from the top. This is the rake surface, this is the chip coming out, and this is the rotating workpiece; it is rotating this way, looking from the top it is rotating this way. So, that a person is standing here and looking at the part will be seeing that it is rotating in a clockwise direction.

s_o stands for a feed motion in millimetres per revolution, so we write s_o = feed and what is its unit, millimetres of in this case longitudinal motion per revolution millimeters per revolution of the workpiece. What does it control? It controls the roughness which is formed on the surface; this is the roughness which is formed on the surface. Successive marks left uncut by the cutting tool, so this is the chip which is coming out and we notice that this length is nothing but $s_o \sin \varphi$, what is φ?

φ is this angle; φ is called the principal cutting edge angle or a plan approach angle. So, if this is φ we can easily say that $s_o \sin \varphi$, I have drawn a figure later on which will be depicting it in much more clear manner in the other view. Here we can say this is $s_o \sin \varphi$, $s_o \sin \varphi$ is nothing but this distance. We are looking in the other view from this side; you might ask me what is this particular plane?

This is written π_o orthogonal plane, so basically we are seeing this view. It should be coming here but anyway for simplicity sake since I am drawing a totally different figure; I have drawn it this way. So, on the π_o plane uncut chip thickness appears as this distance and it is equal to $s_o \sin \varphi$. You will find if this is s_o, this comes out to be $\sin \varphi$ that is alright, what is this one? This can be derived from the depth of cut, what is the depth of cut?

Let me draw here, this is the depth of cut and let me write t. So, if this is the depth of cut the other side of the chip will be $t/\sin \varphi$. Since this is φ, this is also φ, so this distance is equal to $t/\sin \varphi$. So, I will write here, let me see whether I can use small font $t/\sin \varphi$, so we get to know what is the cross section of the chip which is leaving the cutting zone. Once we have determined these are the dimensions of the chip, what are the other things to notice here?

The other thing to notice here is the formation of built up edge, when the chip is coming out, say if we assume that it is a continuous chip here, we may find that there are layers of material I mean laminated or rather this sort of layers of material might be deposited, what is this material? What is the source of it? It is basically the chip material only highly compressed under tremendous pressure, since the uncut chip is coming this way; the material has nowhere to escape because if it tries to move straight it will be stopped by the cutting tool.

So, if it tries to move backwards further uncut chip is coming in creating a pressure downwards on this material. So, this what happens to this material is that? Since it encounters lot of pressure from all sides almost it starts bulging. At the same time there this material gets stagnated and thus it might get welded onto the tool surface under high pressure and temperature, this is built up edge. Stagnated material, we can draw another figure to emphasize the effect of stagnation. This is the uncut chip, the tool the chip is going out this way and this is a sort of stagnation.

This material gets cemented onto the tool surface and ultimately it might be taking up some shape of this type. And this might be breaking of, getting development layer by layer and then again getting suddenly removed with the chip, so it is a very unstable process. It starts interfering with the final dimension reached by the workpiece, it makes the cutting unsteady and further it increases the cutting forces.

So, that more power is expended, why does it increase the cutting force? Because ultimately you will notice here the effective rake angle which is existing occurring here, it is negative. Starting from the reference plane if you move this way it is positive rake, if you move counterclockwise it is negative rake. So, you can notice high negative rake is there, high negative rake always creates high forces, high cutting forces, it gives rise to, why?

Because since the chip is changing direction, so the higher is this change in direction more will be the forces applied through Newton's second law. So, this one is changing not much, so a negative rake forces are less than forces in case of positive rake forces are less than that in case of negative rake, high change in direction of movement. So, built up edge will increase the forces due to cutting. And in any case we would not like the built up edge to occur. So, next, let us move on to the next slide.

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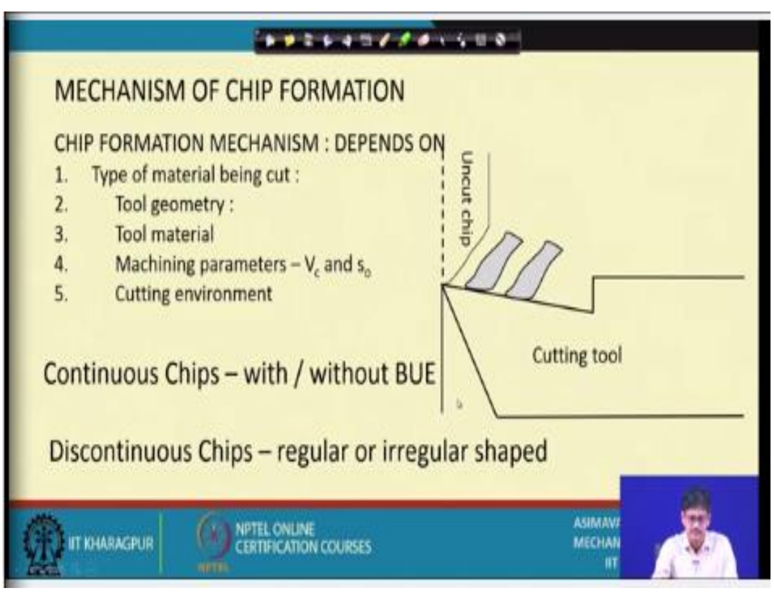

What sort of chips are there in general? We have a continuous chip which we have shown previously. We might also get discontinuous chips and also there is the case of segmental chips. But first of all what are discontinuous chips? Discontinuous chips can be of 2 types, regular or irregular shaped. I have drawn a figure in which I have shown some regular shaped discontinuous chips. So, what happens in those cases?

Suppose the material is ductile but very hard material in which the forces which are required for rupturing it is high. But once it is reached this material there is an disconnectivity between the uncut chip and the material, it removes itself, the connection is lost. So, in discontinuous chips generally the causes which are controlling it?

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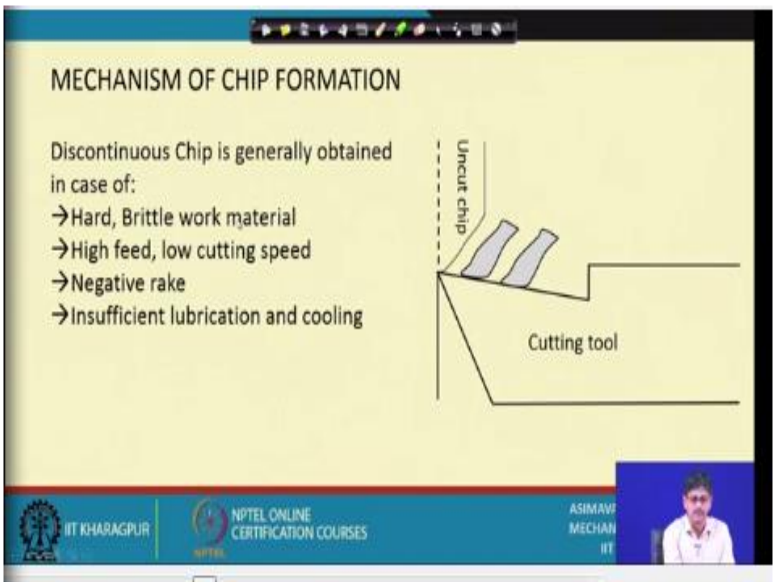

We can have a look this way, hard, brittle work material or at least hard ductile work material. An example of brittle work material will be gray cast iron. So, whenever we have a material which is not very ductile, even if it is ductile if it is hard in that case there is more chance of getting discontinuous chips. If the feed is high and the speed is low that means conditions which may create situations in which the cutting forces are high, forces involved are high there is more chance of getting discontinuous chips.

Why have not we mentioned high depth of cut because that will also increase the cutting forces? However high depth of cut even if it is taken, it is shared by the whole cutting edge length, if depth of cut is increased then cutting edge length also increases. Therefore the share of the forces per cutting edge length remains the same. And therefore the phenomenon whatever was there previously that continues to occur.

So, we have not stressed much on high depth of cut. Negative rake, as we discussed before if we have negative rake forces are going to be high. So, forces are going to be high means there is more chance of formation of discontinuous chips and last of all insufficient lubrication and cooling, if we have insufficient lubrication then forces will be high because the tool at the chip which is getting compressed between the uncut chip and the surface of the tool, so the material which is getting compressed here.

If friction is high at this particular surface chip tool interface, it will have further difficulty in moving out. It will have further tendency to bulge out because it cannot travel on this rough surface very easily. So, once it bulges out it has more chance of getting ruptured, so that helps in the formation of discontinuous chips.

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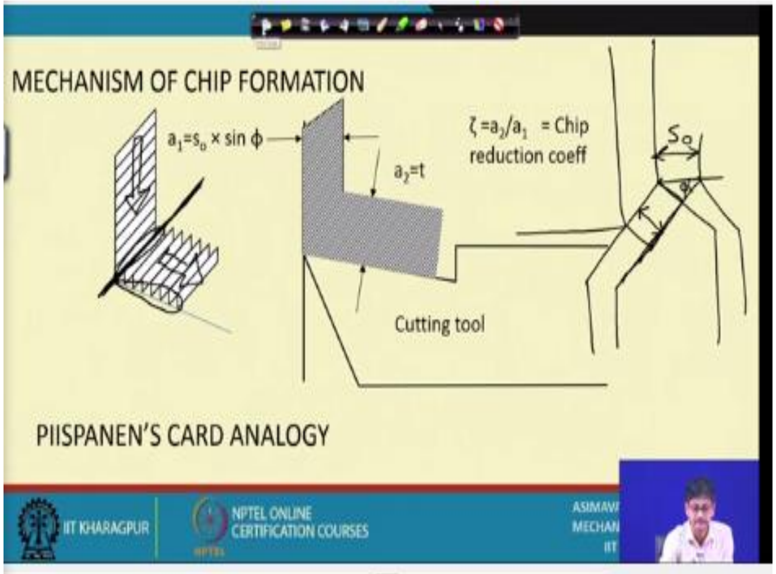

Now how does the deformation occur? Does it occur just like some kind of metal piece which is getting elongated? That is elongation the reason for deformation and what we exactly mean by deformation is it elastic deformation or is it plastic deformation the material which is coming out? The material which is coming out is generally first of all it undergoes elastic deformation definitely.

But mainly the high plastic deformation which it suffers it ultimately causes the formation of the chip. For that there is one analogy called Piispanen's card analogy which gives us an idea how this particular chip formation through plastic deformation takes place. First of all for that we will define let this uncut chip thickness which we had found to be equal to $s_o \sin \varphi$. I will just draw the figure in order to remind you.

So, if we draw this here, there is quite a lot of space here. If this is the cutting tool and if this is the workpiece, this one is that material which is coming out, and this is the uncut chip thickness a_1, let us call it. So, a_1 we have written as $s_o \sin \varphi$, this is s_o, feed while $s_o \sin \varphi$ is this value because φ is this; sometimes it is called the true feed actually in the direction of the chip flow.

So, $s_o \sin \varphi$ being equal to this uncut chip thickness equal to a_1, a_2 is the chip thickness. So, if a_2 is the chip thickness, we will always notice that a_2 is greater than a_1, which shows that the material which is coming down and ultimately coming out in the form of a chip it undergoes deformation. It undergoes an increase in this particular dimension, which means that it must have been deformed.

So, naturally people said that if I measure a_2 by for different cases of machining, if I divide it by a_1, I will get a ratio. So, if deformation is high a_2/a_1 must be high, so with that idea chip reduction coefficient has come into being. Chip reduction coefficient means to make an estimate of the amount of deformation which is suffered by the material in the formation of a chip.

So, whenever we are talking of chip formation mechanism, this particular index gives us a very clear idea of the degree of deformation, how much deformation is taking place? So, chip reduction coefficient will be used by us in a number of cases. But to come back to the analogy, what was this analogy about? It was first of all viewed as that is the uncut chip material coming down, it was viewed as a stack of cards at a particular angle coming down towards the cutting zone.

What was the angle of this particular stack of cards? That we will come to later on, but first of all once the material comes out in the form of a chip, it was assumed that material is undergoing a slip or shear at this particular zone, which is called a shear zone. So, it is not that the material is coming straight down and streamlines of the material are coming out. No, the material if you notice here it is undergoing a relative motion in this direction with its just adjacent succeeding layer.

So, that it starts getting oriented in motion in this direction, so a shear is assumed here. By this analogy we are coming to the conclusion that shear deformation at this zone which is called the primary deformation zone is the main mechanism of formation of the chip from the parent material. So, once we come to this conclusion we will assume that almost I mean the complete deformation of the material is occurring in this particular primary deformation zone.

But you might say what about the friction that we mentioned here. If these cards are they are oriented in this angle and they shear from this parent material maybe they are still connected. Because they undergo plastic deformation but they are connected with the material, even if it is connected with the material they are oriented this way now and they are gradually going to flow out but the problem is they will undergo heavy friction here.

So, a secondary deformation zone is also assumed here in this place. So, we will say this is primary deformation and this is secondary deformation. In this secondary deformation, the role of friction between cutting tool and chip will be the dominating physical phenomenon. So, once we are clear about this one, we will have to deal with analysis of this primary deformation in the form of shear and this one friction.

Next, so this is what we have drawn in the Piispanen’s card analogy, cards are coming at a definite angle and getting out, how do we make an estimate of this angle? That we will be doing through calculations which I will be showing you.

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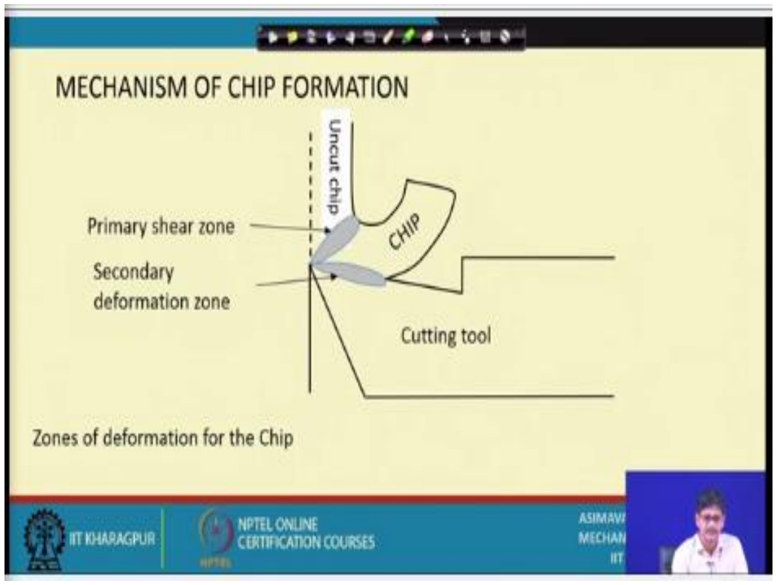

This is what we discussed just now, that is if this is the primary shear zone, if this is the uncut chip, this is a secondary deformation zone. We can write here primary deformation zone and the main dominating feature is shear as we discussed from the card analogy. And this is what is ultimately causing the final outcome of the chip. So, this gives us an idea where the zones of deformation for the chip are lined. You might ask me what is this particular cross section that we are seeing, up till now only until and unless we state anything else we are looking at the orthogonal plane.

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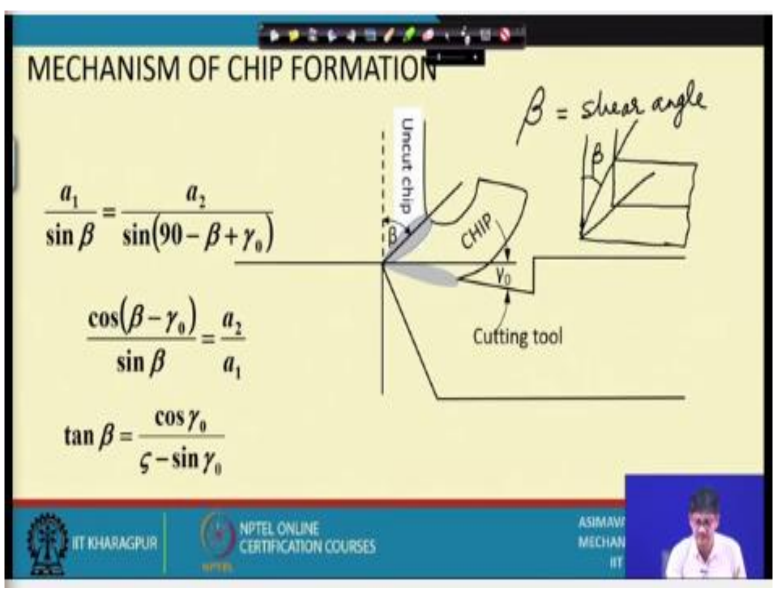

Now for some relations between these particular parameters in order to get a mathematical estimation of the angle which we said is the angle at which the deformation of shear deformation is occurring, the primary shear zone. Generally, β which we have mentioned here it is given a name, β is called the shear angle. You will notice that if β is high, let me draw a figure here, this is the uncut chip thickness.

If say β is very low and this is β is very high obviously it points to the fact that the chip thickness will be higher if β is low. So, if the chip thickness is high, deformation is higher and β is lower. So, the value β can also give us an estimation of the machining performance. That means how much energy are we expending to get how much deformation. Is deformation in the chip good or bad?

The answer is if you can get the work done with less deformation, it is always good, so let us have some geometrical relations between these terms. First of all we notice that this length, let me just create some.

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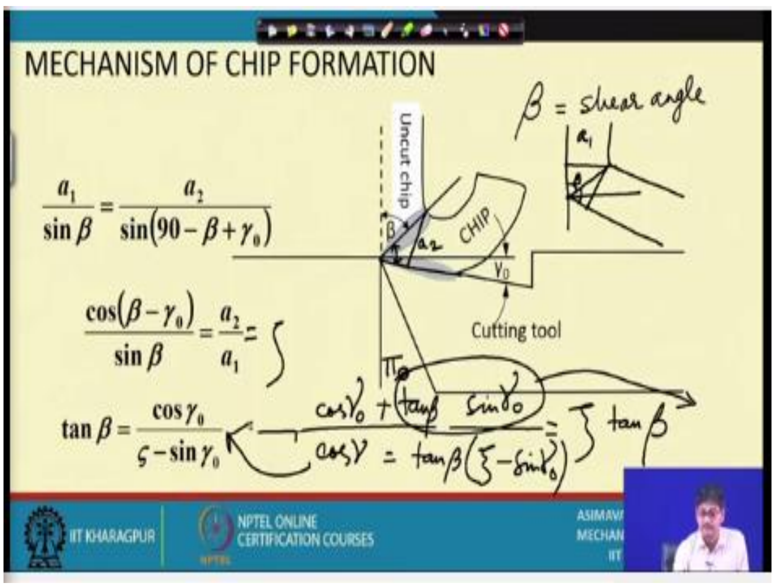

If we notice here $a_1/\sin\beta = a_2/\sin(90^o - \beta + \gamma_o)$, what is γ_o? So, first of all let me write here this is π_o plane orthogonal plane, so the rake angle which has been shown here is the orthogonal rake. So, we are simply saying that if the chip is coming down and if it is taking up this particular path, we have a geometrical equality between these 2 geometries as the equality of this line.

This line is being shared by the down coming uncut chip and the outgoing chip, this length is can be related, this must be equal to a_1. If this is a_1, $a_1/\sin\beta$, a_1 why because this being a_1 and this being β, $a_1/\sin\beta$ is equal to this distance, the hypotenuse. So, this hypotenuse on this side it is equal to once again if you take say this angle, how much is this angle?

This must be equal to 90º minus this one I draw and therefore this one is $90^o - \beta + \gamma_o$. So, once again this distance let us call it say x, x is equal to on this figure nothing but chip thickness a_2 divided by sine of this angle. So, this is equal to $90^o - \beta + \gamma_o$, I have made 1 or 2 errors here, yeah, gamma is already there. So, this distance is the chip thickness a_2, this is γ_o and this is 90º-β, so we are talking about this angle.

So, a_2 divided by $\sin 90^o - \beta + \gamma_o$, so a_2 by $\sin 90^o - \beta + \gamma_o$ is equal to this particular length once again, so they are equated. Once they are equated we take a_1 to the other side, so that we have a_2 by a_1 which is equal to as we know ζ or rather this is not written this way, it is given this sort of a sine is equal to ζ. And on this side we convert sine to cos and therefore we have cos $(\beta - \gamma_o)$, which means that tan β can be defined as, this is $\cos\beta \cos\gamma_o + \sin\beta \sin\gamma_o$.

So, if you divide it by $\sin\beta$ you will get all these things, how do we get it? Let us quickly have a look, $\cos\beta \cos\gamma_o + \sin\beta \sin\gamma_o$ and that is divided by $\sin\beta$ and that is equal to ζ. So, on this side what we can have is if you go on dividing by $\sin\beta$ you will have $\cos\gamma_o$ divided by $\tan\beta + \sin\gamma_o = \zeta \sin\beta$, just a moment let me see whether everything is it can be done more elegantly, yeah, $a_2/a_1 = \zeta$. So, we will have oh! good, yes, instead of working that way if we take $\sin\beta$ to this side $\sin\beta$. If we now divide the whole thing by $\cos\beta$, what happens?

Cos β vanishes from here, we get $\tan\beta$ here and we get $\tan\beta$ once again. So, we are dividing the whole thing by $\tan\beta$. So, which means that $\tan\beta$ can be taken common. So, you take it to that side, take $\tan\beta$ common, you will get $\zeta - \sin\gamma_o$, so $\cos\gamma_o$ here remains the lone term here $\cos\gamma_o = \tan\beta$ common $\zeta - \sin\gamma_o$. Because we are taking the second term to the other side, this one is taken to the other side. So, from here this is a one step, so with this we come to the end of the 2nd lecture, I mean 7th lecture, thank you very much.