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 you know taps and dies and also what we call it the center 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 you know detrimental situations I mean some parameter causing some detrimental effect in any you know process if we study it in depth we will find out what are the parameters affecting it what are the factors responsible for its you know 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 continues cutting rather you know unstable etcetera it in it affects the dimensional accuracy. So, surface finish dimensional accuracy, and steadiness of cutting all these 3 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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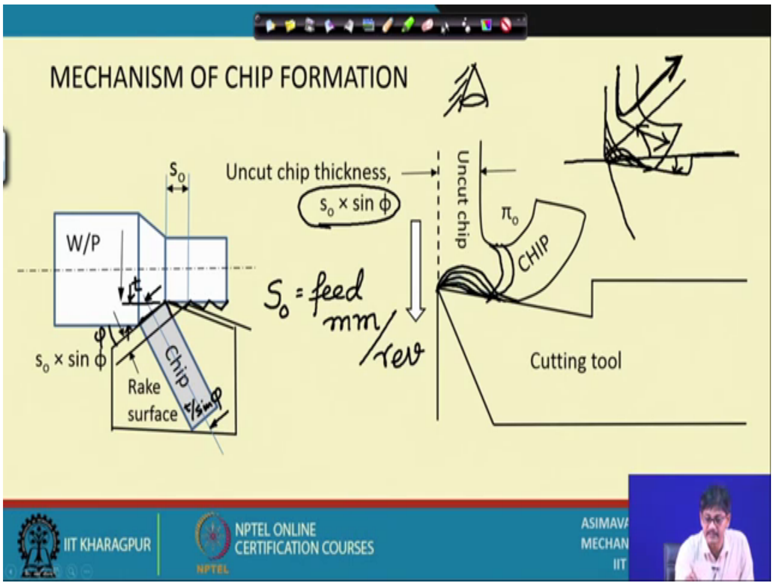

On two sides we have shown two situations that is first of all looking at the tool, looking at the tool from the top. This is the rake surface, this is the chip coming out and this is the rotating work piece, this is the rotating work piece it is rotating this way looking from the top rotating this way. So, that a person's standing here and looking at the part will be seeing that it is rotating in a clockwise direction s o stands for the feed motion in millimeters per revolution. So, we write s o is equal to feed; and what is its unit? Millimeters of in this case longitudinal motion per revolution, millimeters per revolution of the work piece.

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 0 sin phi. What is phi? Phi is this angle, phi is called the principal cutting edge angle or a plan approach angle. So, if this is phi we can easily say that s 0 sin phi I have drawn a figure later on which will be you know depicting it in much more clear manner in the other view here we can say this is s 0 sin phi. s 0 sin phi is nothing, but this distance. We are looking here from the, we are looking in the other view from this side. You might ask me what is this particular plane this is written pi o orthogonal plane, basically we are seeing this view. It should be coming here, but anyway for simplicity say since I am drawing a totally different figure I have drawn it this way so on the pi o plane uncut chip thickness appears as this distance and it is equal to s 0 sin phi you will find if this is a 0 this comes out to be sin phi that is all right. This is the what is this one? This is you know 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 by sin phi since this is phi this is also phi. So, this is equal to this distance is equal to t by sin phi. So, I will write here let me see whether I can use small font t by sin phi. 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 will we may find that there are layers of material, I mean laminated or other 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 is 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 back 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 you know emphasize the effect of stagnation, this is the uncut chip the tool the chip is going on 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 off developing, getting develop development layer by layer and then again getting suddenly removed with the chip. So, it is a very unstable process it starts you know, it starts interfering with the final dimension reached by the work piece 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 its negative starting from the reference plane if you move this way its positive rake if you move counter clockwise 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 sorry, 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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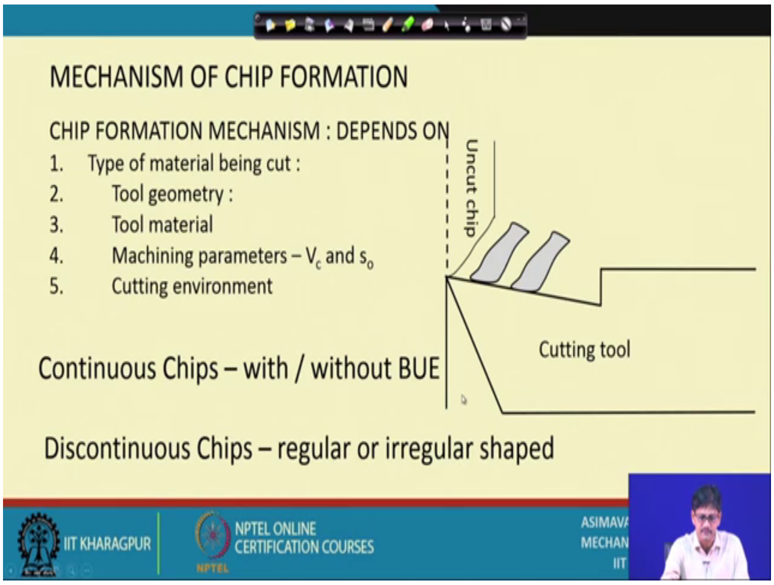

What sort of chips are there in general? We have a continuous chip which I which we have shown previously. We might also get discontinuous chips and also there is the case of segmental chips, but first of all what are discontinuous chips. Discontinuous chips can be of two types regular or irregular shaped 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 it is very hard, ductile but very hard material in which the forces which are required for you know rupturing it its high, but once it is reached this material gets discontinuous I mean it gets in 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 we can have a look this way - hard, brittle, work material or at least hard, ductile work material.

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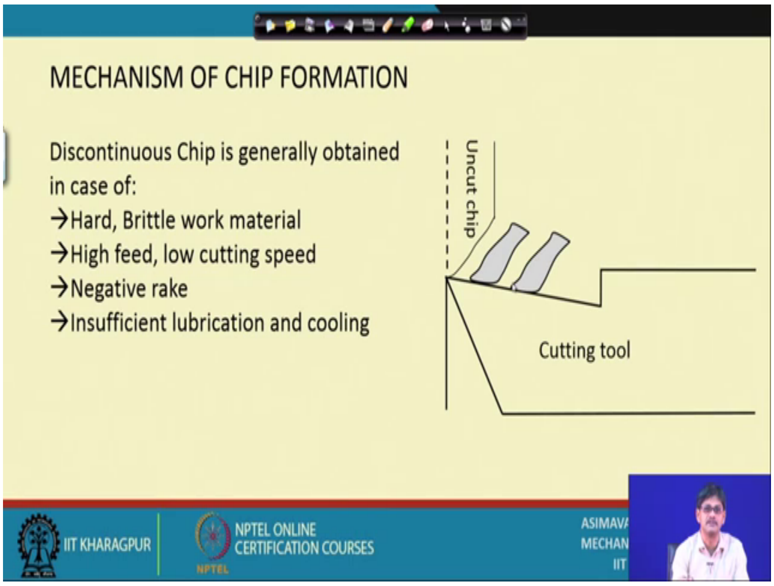

An example of brittle work material will be gray cast iron. So, whenever we have a material which is not very ductile even if it is ductile, if it is hard, in that case there is more chance of getting discontinuous chips. If the feed is high and the speed is low; that means, conditions which may create 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 shear 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 the chip which is you know come getting compressed between 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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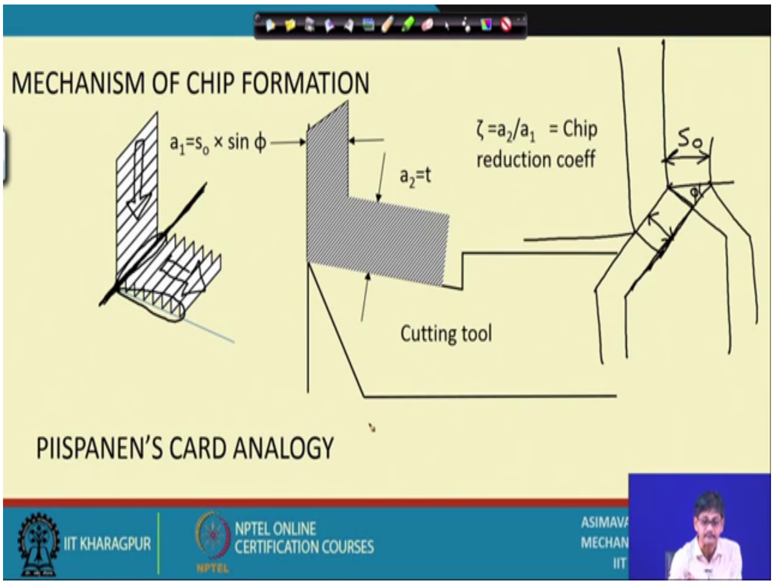

Now, how does the deformation occur? Does it occur you know just like some kind of metal piece which is getting elongated that is elongation the reason for deformation and what we exactly mean by deformation? Is it elastic deformation or is it plastic deformation the material which is coming out? The 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 you know 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 0 sin phi 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 work piece, this one is that material which is coming out and this is the uncut chip thickness a one let us call it. So, a 1 we have written as s 0 sin phi this is s 0 feed while s 0 sin phi is this value because phi is this sometimes it is called the true feed actually in the direction of the chip flow. So, s 0 sin phi 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 you know from for different cases of machining if I divided by a 1 I will get a ratio. So, if deformation is high a 2 by a 1 must be high. So, with that idea chip reduction coefficient has coming to 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 you know 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 you know viewed as that is the chip uncut chip material coming out 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 is undergoing if you notice here its 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 the conclusion the 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 guards are you know they are oriented in this angle and they shear from this parent material the maybe they are still connected because they undergo plastic deformation. But they 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 you know the dominating physical phenomena. So, once we are clear about this one we will have to deal with analysis of this primary you know 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 is, that we will be doing through calculations which I will be showing you.

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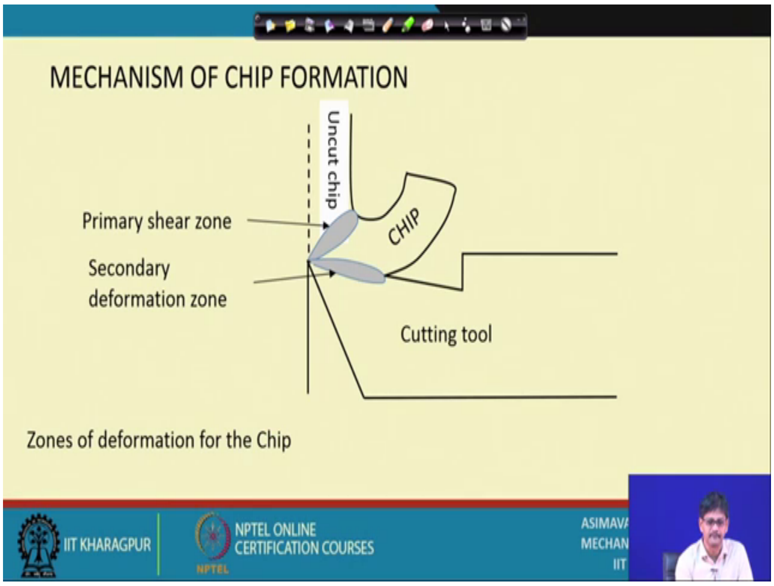

This is what we discussed just now, that is if this is the primary shear zone if this is uncut chip. There is a secondary deformation zone we can write here primary deformation zone and the main in the dominating feature is shear as we discussed from the card analogy. And this is what is ultimately causing the final you know outcome of the chip. So, this gives us an idea where the zones of deformation for the chip are line. You might ask me what is this particular cross section that we have seen. Up till now until and unless we stayed any anything else we are looking at the orthogonal plane, we are looking at the orthogonal plane.

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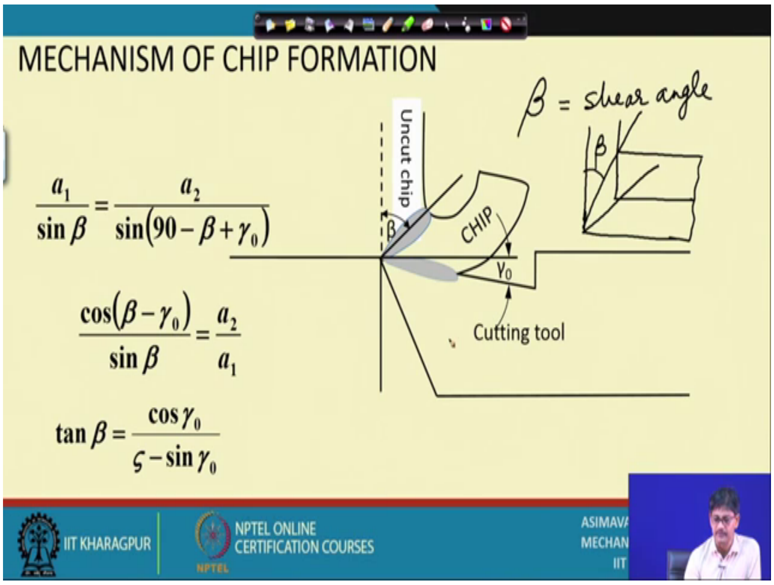

Now, for some relations between these you know these particular parameters in order to get a mathematical estimation of the you know angle which we said is the angle at which the deformation of shear deformation is occurring, the primary shear zone.

Generally beta which we have mentioned here it is given a name, beta is called the shear angle. You will notice that if beta is high, let me draw a figure here this is the uncut chip thickness; if beta is say beta is very low and this is beta is very high; obviously, it points to the fact that the chip thickness will be higher if beta is low. So, if the chip thickness is high deformation is higher and beta is lower, so the value beta can also give us an estimation of the you know 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.

Now, so, let us have some geometrical relations between these terms. First of all we notice that this length let me just create some. If we notice here a 1 by sin beta is equal to a two by sin 90 degree minus beta plus gamma o gamma 0. What is gamma 0? So, first of all let me write here this is pi o plane, orthogonal plane.

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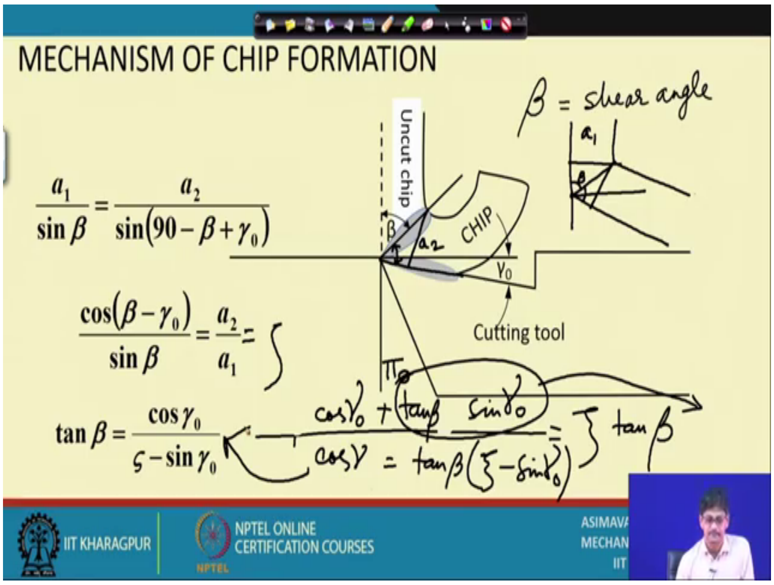

So, the angle rake angle which has been shown here is the orthogonal rake. So, we are simply saying that if the chip is coming down and if it is taking up this particular path we have a geometrical equality between these two you know geometries as the equality of this line. This line is being shared by you know the down coming uncut chip and the outgoing what you call it chip. This length is can be related this must be equal to a 1. If this is a 1, a 1 by sin of beta a 1 why because this is this being a 1 and this being beta a 1 by 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 it is how much is this angle this must be equal to 90 degree minus sorry this one I draw and therefore, this one is 90 degree minus beta plus gamma ok.

So, once again this distance let us call it say x, x is equal to on this figure nothing, but chip thickness a 2, chip thickness a 2 divided by sin of this angle this is equal to 90 degree minus beta plus gamma o; sorry just a minute I have made one or two errors here yeah gamma is already there. So, this distance is the chip thickness a 2 this is gamma o and this is 90 minus beta. So, we are talking about this angle. So, a 2 divided by sin 90 minus beta plus gamma o. So, a 2 by 90 sin 90 minus beta plus 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 zeta or rather this is not written this way it is given this sort of a sin. Sequel to zeta and on this side we convert sin to cos and therefore, we have cos beta minus gamma o which means that tan beta can be defined as this is cos beta cos gamma o plus sin beta sin gamma o. So, if you divided by sin beta you will get you know all these things. How do we get it? Let us quickly have a look cos beta sorry cos beta cos gamma o plus sin beta sin gamma o and that is divided by sin beta and that is equal to zeta.

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 plus sin gamma o is equal to zeta sin beta, oh my god just about let me see whether everything is it can be done more elegantly. Yeah a 2 by a 1 is equal to 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 beta vanishes from here, we get tan beta here, tan beta sorry and we get tan beta once again. So, we are dividing the whole thing by cos beta 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 minus sin gamma o. So, cos gamma here remains the loan term here cos gamma o is equal to tan beta common zeta minus 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 second lecture, I mean 7th lecture.

Thank you very much.