Mechanics of Machining
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Lecture - 10
Mechanics of Oblique Cutting

Hello students welcome to the course on Mechanics of Machining. This is the 10th lecture of this course we have almost reached now midway. So, today I am going to talk about mechanics of oblique cutting, perhaps you may find that this is the toughest lecture of this course why because we are mostly discussing 3 dimensional geometry and you know that it is becoming very difficult to explain 3 dimensional geometry by means of the blackboard or by means of screen.

However we will try to get something in this hour, that there are some books on this you know textbook of GK Lal book on machining science can give you some information about the mechanics of oblique cutting and you have to visualize a lot you can make your own models and after that you can understand that how what is the oblique cutting mechanics, this you have to do by means of making some models.

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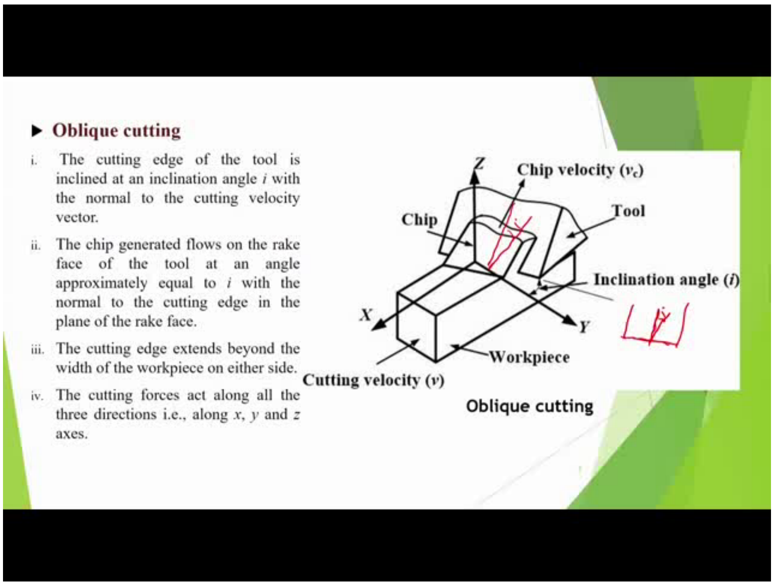

So, let me just review again that concept of the oblique cutting, here I have made a 3 dimensional picture of the cutting process there is a work piece and tool is moving in the X direction, so X direction can be called as the cutting velocity direction. Now here in the orthogonal cutting, cutting edge is perpendicular to the X axis; that means, it is perpendicular to the velocity direction. But in this figure if you are seeing that the cutting edge is inclined at an angle from perpendicular direction; that means, this is X direction if the cutting edge would have being along Y direction then we would have said that it is a orthogonal machining.

But in this case it is inclined at an angle I this is called inclination angle and as a result of that when the cutting process is taking place, then the chip is also flowing at certain angle it is not just a at 90 degree to the cutting edge it is on that plane it is going in this direction. Cutting edge of the tool is inclined at an inclination angle i with normal to the cutting velocity vector the chip generated flows on the rake face of the tool at an angle approximately equal to i with the normal to the cutting edge in the plane of the rake face.

This is also one type of observation by stabler that he found around 1950, that it is the chip which is flowing that is inclined at approximately equal to i. So, suppose this angle is i and I draw a perpendicular to the cutting edge on this plane then the chip will make angle chip flow will make angle i from here ok.

So that means, chip is going normally suppose you have that is the cutting edge then the chip 90 degree to this is this line, but chip does not flow like this rather it gets inclined and that inclination angle is i. Cutting edge extends beyond the width of the work piece on either side that we are assuming here that it is extending, so that we can understand that it is only shearing action. Cutting forces at along all 3 directions that is along X Y and Z axis X direction also you have that is called cutting force or power producing force and then along Y direction also and along Z direction also, so this is cutting force is acting on all 3 directions.

Whereas in orthogonal direction if it is pure shearing operation, then there is no force along Y direction there is one force that is called cutting force that is along X direction and there is a thrust force that is along the Z direction. So, this but here we have to get 3 components in a space, so you have to consider all these components and you have to do that complicated analysis.

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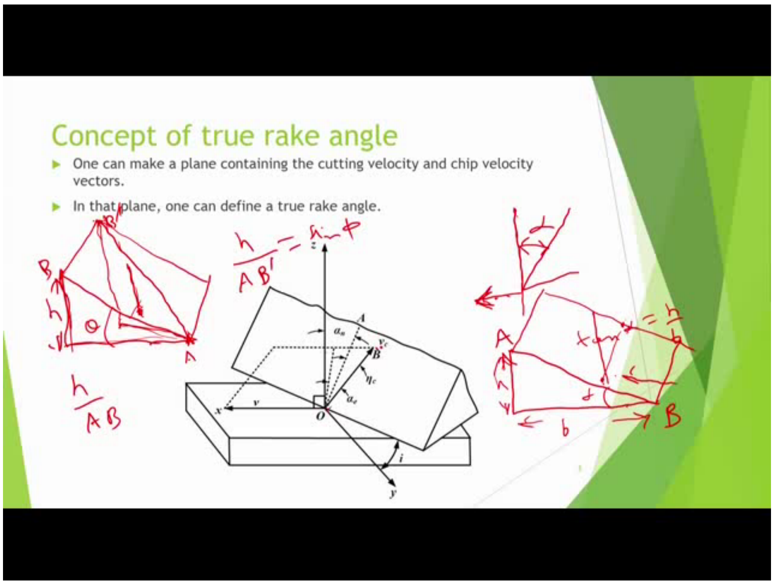

Before moving further, let me explain that some concepts of the true rake angle, you see that rake face is inclined like this and in the orthogonal cutting there is a rake face and we say that it is there is a reference plane that plane is making an angle of 90 degree from cutting velocity. That means, if the cutting velocity direction is this, then reference plane is this that means, normal to the reference plane is nothing but the cutting velocity vector and this is making an angle alpha from here.

So, this is alpha that is only one rake angle we defined in orthogonal cutting, but in this case there can be several cutting rake angles, that we have discussed in the previous classes also we told about the normal rake angle, we told about orthogonal rake angle, we told about side rake angle in American standard system. So, here we are going to tell you something more that here if you define suppose you take one plane which is perpendicular to the cutting edge, perpendicular to the cutting edge if you make a plane that plane will be called normal plane ok, normal plane that need not be orthogonal to the reference plane. So suppose you are making that one that is normal plane on the normal plane, if you show that inclination of surface from the perpendicular to the cutting velocity then that is called alpha n, that you already know that means slope of this is alpha n.

We can also have that one plane which will contain which can contain that orthogonal that is orthogonal plane that which can contain the cutting velocity vector. At the same time it will be orthogonal to the reference plane and in that plane we define orthogonal rake angle or sometimes we call velocity rake angle. But in this, I am going to show one more plane that plane is containing the velocity vector V and also it is containing the velocity chip flow velocity V c.

So, V and V c both are contained you make a parallelogram like this and in this if you show that this and now you can see that in this plane that we are showing eta c eta c is the chip flow angle we call and in this one if I show the inclination of the surface on this plane that is the we say 2 rake plane, in this if we show then that is called 2 rake angle. So, you understand that what is a 2 rake angle that it is going here and then it is making from it is vertical that line here projection this one it is making that alpha e. So, alpha e is called true rake angle and many people believe that. In fact, true rake angle make you the better indication it may be you know logous to the in rake of the orthogonal system. So, here you have to understand that I again in precise that you may think that in 3 D how it goes, usually suppose there is a sloping surface suppose there is a sloping surface. Let us say that A B is the sloping surface.

If I say that find out the slope of this surface you know, it is very easy you know that how much it is sloping, when you are moving B to A in this direction then how much you are lifting up vertically. That means, this height may be h and how much you are going in the base direction, so we say this angle tan alpha is equal to h by b that is how we do and we talk about only one slope. But suppose think about the 3 dimensional case in that case suppose the surface is like this I am designating; that means, this is a (Refer Time: 09:35) I have shown that isometric type of view.

Now, you are moving on the surface if you are moving on this parallel to this that means so that parallel to the vertical plane, then of course that your slope is h by b only. But suppose you are on this plane you are moving from this point to this point then slope is what it is 0, because you are going from here to here vertically you are not lifting up. So, that surface inclined in this direction but the surface is not inclined in the other direction, similarly you can think that suppose you are moving from here to here like this diagonally type thing then your slope will become different. So, this slope will depend on in which plane you are measuring, suppose I cut a vertical plane cross section, then you get that what you make in the diagram in the books in solving mechanics problem you just simply make a slope or something like that.

But if you make a horizontal cut you get a different one. So similarly you can here also you have to see this that you have to visualize this one, that here you are having alpha n normal rake angle in the normal one. But I am now talking about this plane which is containing the chip velocity and it is also containing the tool velocity and in that particular plane what is the slope if there is O and B 2 points are there. So, how this O and B when I am going from O to B, then how much I am going from in the horizontal direction and how much I am going in the vertical direction like that.

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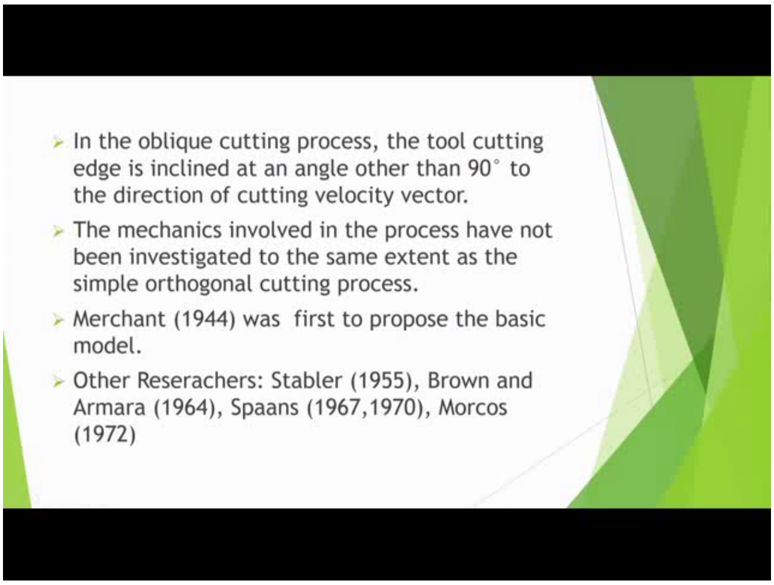

So, this is alpha e and this one, so in the oblique cutting process the tool cutting edge is inclined and at an angle other than 90 degree to the direction of cutting velocity vector. The mechanics involved in the process have not been investigated to the same extent as the simple orthogonal cutting process because, that is obviously difficult merchant in 1944 he proposed a model for the first time other researchers are stabler in 1955. I was talking that he gave relation that chip flow angle eta c is equal to the inclination angle that chip flow angle eta c, that will be equal to the inclination angle that he observed.

Later on he said that it may be equal to 0.9 i that means chip flow angle may be 0.9 times this thing, but more or less you can say it is 1 and Brown and Armara in 1964 also did Spaans 1967 1970 and then Morcos in 1972 have done this type of analysis.

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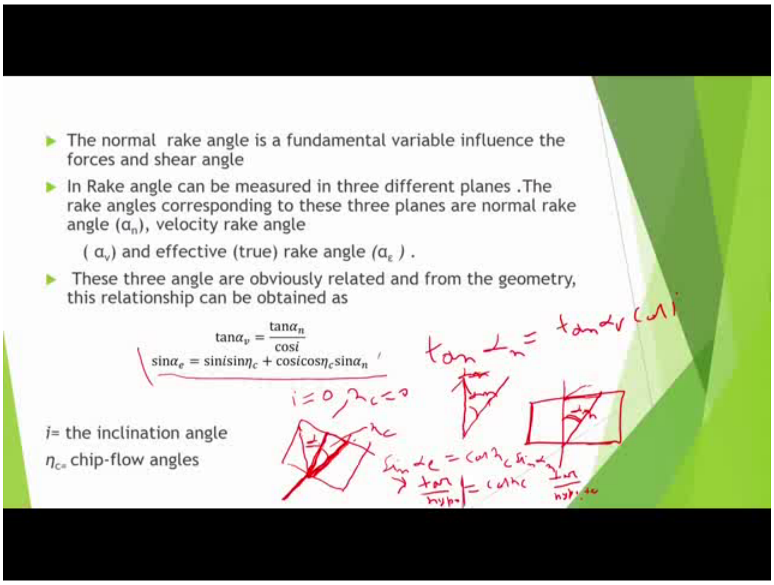

Now, the normal rake angle is a usually many authors believe that normal rake angle is a fundamental variable influencing the forces and shear angle; they think that it is better to take the normal rake angle. In fact, you take that normal rake angle because one there is one paper published in 1967 in (Refer Time: 12:50) journal here it is stated also that we make that to apply the oblique cutting, the results of the large amount of orthogonal cutting data you will (Refer Time: 13:04) it is necessary to select a rake angle in oblique cutting which corresponds to the unique rake angle of orthogonal cutting.

Now, the previous investigators are at odd say as to which rake angle alpha n that is normal rake angle alpha V velocity rake angle or orthogonal rake angle or alpha e that means 2 rake angles should be considered. That means, there is a dispute among the researchers there is no proper agreement, however in recent work stabler shows that the power consumption in oblique cutting is directly proportional to normal rake angle. He does concludes that the normal rake angle is the only fundamentally correct way of measuring rake [experimental measures by Bound and Armara Rego also suggest that alpha is the controlling rake angle.

So, this is what that many consults have done like this so you have to consider normal rake angle, I mean that you can do the analysis similar to orthogonal type of analysis. In fact, once I have given some hint about that when we were solving a turning problem, but many people will believe that no 2 rake angle or effective rake angle alpha e should be taken. So, rake angle can be measured in 3 different planes the rake angles corresponding to these 3 planes are normal rake angle, velocity rake angle that is orthogonal rake angle and effective rake angle alpha e.

Now these 3 angles are obviously related from the geometry and these relationship can be obtained as this tan alpha V is equal to tan alpha n divided by cos i or tan alpha n is equal to cos i into tan alpha v. In fact, we have discussed this also in one class that how it goes that you know that this one again. I can give some sort of hint that suppose you have it is something like this tan alpha n is equal to tan alpha V into cos i. That means, a tan alpha if normal rake angle will be somewhat less and this will be more so it is like this.

So, if we make some sort of that some sketch then we can appreciate that thing that you have some you have some cutting edge like this and there is a normal plane that on that particular plane. If you have got alpha n this is alpha n and this one is this is something like vertical direction is this and this may be the surface of that tool. So, it is something like this so in this there is a alpha n this angle was suppose alpha n in normal angle and that means suppose I make one sketch like this one plane I should show some orthogonal view, suppose this is the vertical one and suppose this was some line on that normal plane and this is alpha n.

So, naturally alpha n becomes tan alpha n becomes what this divided by this vertical height. Now suppose you incline that plane to an angle I suppose this inclines, so you have to take it is projection. So, in this case this on that vertical height merely means same but if you incline it by i, then this base may reduce by cos i factor. So that means, base becomes cos i times the previous base and height remaining same therefore this tan alpha O will be tan alpha n divided by cos i. Similarly you can find out that true rake angle will be sine alpha e is equal to sin i sine eta c plus cos i cos eta c into sine alpha n.

Generally eta c is a chip flow angle eta c is equal to sin i itself and if we say that sin i is basically same sine if i 0. That means, orthogonal cutting in that case sine alpha e becomes sine alpha n, that means the velocity this true rake angle is nothing but the normal rake angle that simply it goes like this and in fact all 3 angles becomes same. So, this relation was reported by stabler first and slowly you can derive. If you make projections and if you do that in a slow manner then you can understand that how this is related may be, at the end of lecture we may discuss little bit more on this. But this relation you can note down that sine alpha e is equal to sin i sine eta c cos i cos eta c sine alpha n.

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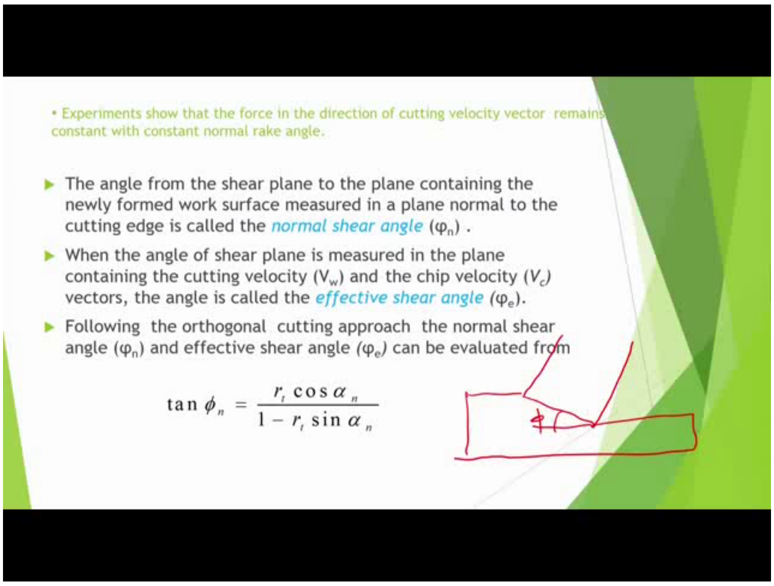

Experiment show that the force in the direction of cutting velocity remains constant with normal rake angles, so again I am emphasizing the point that normal rake angle is more important and the angle from the shear plane to the plane containing the newly formed work surface measured in a plane normal to the cutting edge is called the normal shear angle. You have known the shear angle in 2D it was very easy for me to explain it was like this and simply this one and I was telling that chip is flowing like this and this angle was phi right.

But it is in 2D there is only one plane that is a plane of paper, but here I defined normal shear angle that is in a plane which is normal to the cutting edge. Same thing we are measuring in that plane then it becomes phi n and when the angle of shear plane is measured in the plane containing the cutting velocity V w and the chip velocity V c, that means that 2 plane, then the angle is called the effective shear angle. So, we get effective shear angle also and like in the orthogonal cutting we can get these relations also, normal shear angle phi n can be evaluated as tan phi n is equal to r t which is the cutting ratio into cos alpha n divided by 1 minus r t sine alpha n this you can very well do that.

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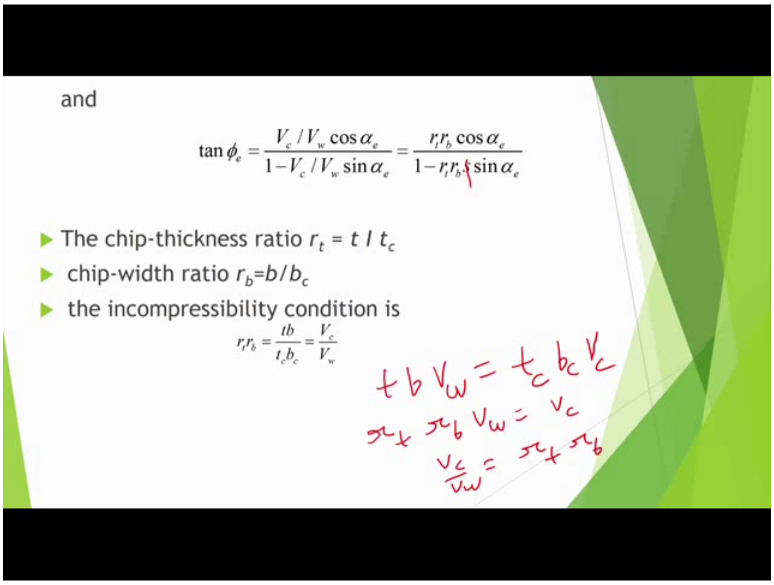

And tan phi can be like wise can be derived as V c divided by V w V w is the work velocity and this is cos alpha e 1 minus V c divided by V w sine alpha e and this can be V c by V w can be written as r t by r B, what is r t by r B r t into r B r t is actually the chip thickness ratio. So, r t is equal to t divided by t c and the chip width ratio is r b, r b is equal to b divided by bc.

Usually in the orthogonal cutting in merchant's analysis we assume that V was equal to V c. So, r b was always one but in general you may have some width also, so by incompressibility condition that means what will have, that if we say that this one that we will be having this type of relation r t means t times t times b and V w. That means, work velocity or something and this is the chip velocity t c times bc and this will be V c that means chip. So, volume remains constant no doubt whether it is 2 D machining or 3 D machine volume of the metal remains same.

So, what it gives me that t by t c is r t so that means this is t by t c, if I bring t c this side then it will be r t and b by V c is r b r t r b and this is V w into is equal to V c, so therefore V c by V w is equal to r t and r b right. So, we can put this also we have put here like this r t r b cos alpha e 1 minus r t r b and sine alpha e this has come extra s sine alpha e and so incompressibility condition is giving me this, so this also this relation you have understood.

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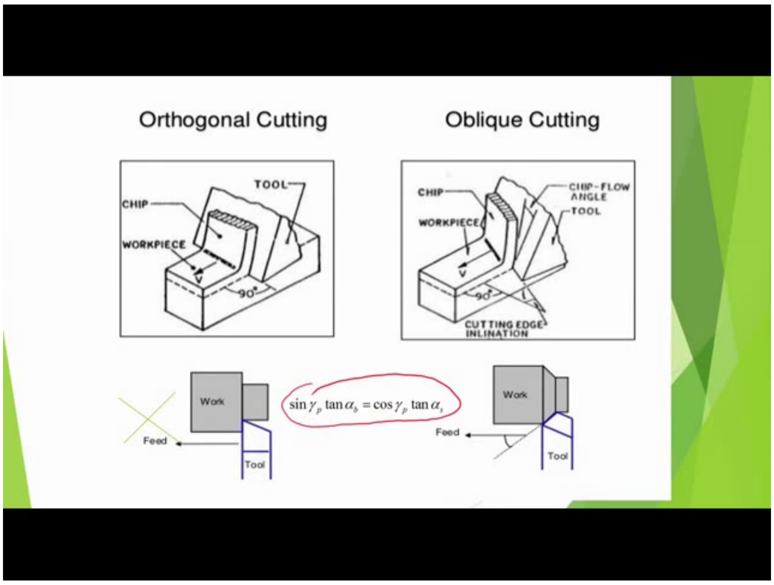

Now, in this case I am again explaining that difference between orthogonal cutting and oblique cutting. Orthogonal cutting is like this that cutting edge is at 90 degree to the velocity this one V this is work piece going like this and in the oblique cutting that cutting edge is inclined at an angle i and this is 90 degree here that 90 degree line is this. So, velocity vector is making angle actually from here this is this one and this chip is flowing like this. So, I draw it here so suppose normal to the cutting edge is this line, but the chip is flowing like this that is chip flow angle.

Many books are sometimes people define like this also that, this is orthogonal cutting that the in rake machine tool is moving like this and they say if the tool is moving like this is orthogonal cutting. But it is actually should not be correct definition, in fact this type of turning operation is not orthogonal at all unless you are doing the machining of the tube.

Because here in orthogonal cutting another thing is that the edge tool edge should extend beyond the job also this should be that should be, but many people say this is pure orthogonal cutting and you call this also as orthogonal cutting. But many books will not agree to this so you have to be careful they say that this is oblique cutting, but this is orthogonal. But I have earlier showed this also that for if it is orthogonal cutting, that means tan gamma p into tan alpha B will be equal to cos gamma p into tan alpha s, gamma p is the is what principle cutting angle. That means, in this case gamma p is equal to suppose we say gamma p is equal to 90 degree because gamma p is side cutting edge is 0.

So, in this case tan alpha b but this is 90 so tan alpha b 0, so that means in this case back rake angle should also be 0 that is also condition to be satisfied. That means, you have to have you can say first of all it should be tube machining only, so that cutting edge is extending beyond this one. Second thing is that there should be only this slope of this surface in this direction; there should not be any slope in this back this direction ok. That means, it should not be coming it down that means top rake should be 0, so this type of confusions is there but you have to be careful.

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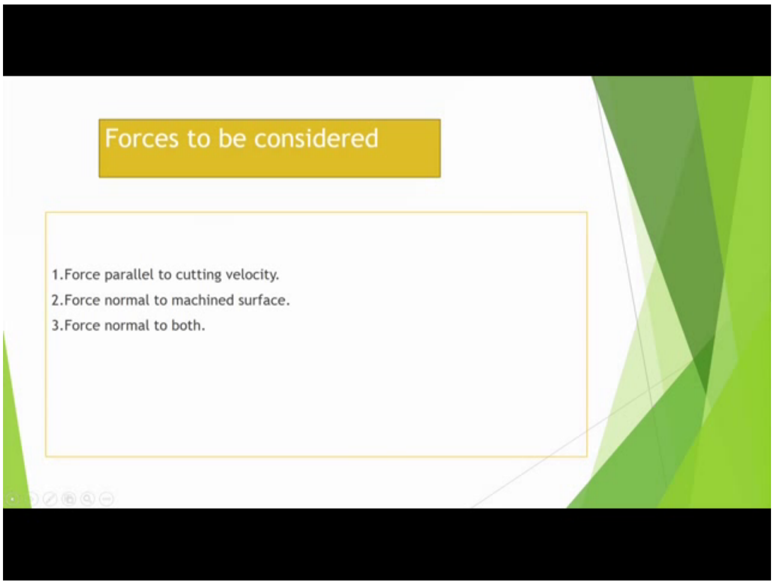

Now, we do the we find out forces we do force analysis, we want to find out the forces, so we can consider force parallel to cutting velocity that is active force that basically machining and we need to calculate it for finding out the power, then there is a force normal to the machined surface and then the force is normal to both. So, force normal to machined surface like in the lathe machine you have one is the cutting force that is tangential to the direction of motion job is rotating and it is tangential to that then we have in the feed direction one force and one force is of course in the radial direction also that has to be this one and we need to find out the forces per proper design of the our machine and process.

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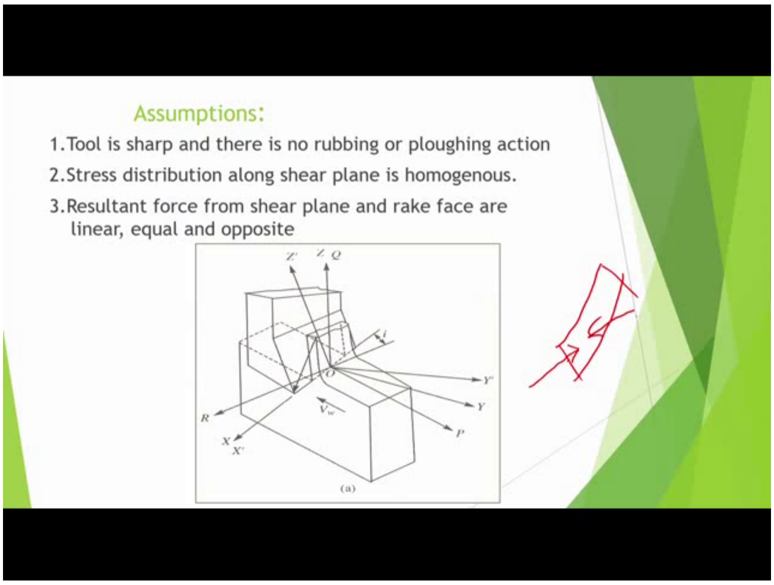

Now, what are the assumptions in the analysis, assumption is that tool is sharp and there is no rubbing or ploughing action ok. Then stress distribution along shear plane is homogenous that is also we are assuming and then resultant force from shear plane and rake face are linear equal and opposite, this is also one assumption like in orthogonal cutting, we will say that there is chip and the chip is supported from 2 sides by the forces.

Once it is applied by the rake surface friction portion normal and another is from the work material across the shear plane and both are equal and opposite, but we as we have already seen that these need not be equal and opposite and that is why there is some chip curling is there In fact, this so this concept is one thing that here you have that assumption is there that these are linear equal and opposite.

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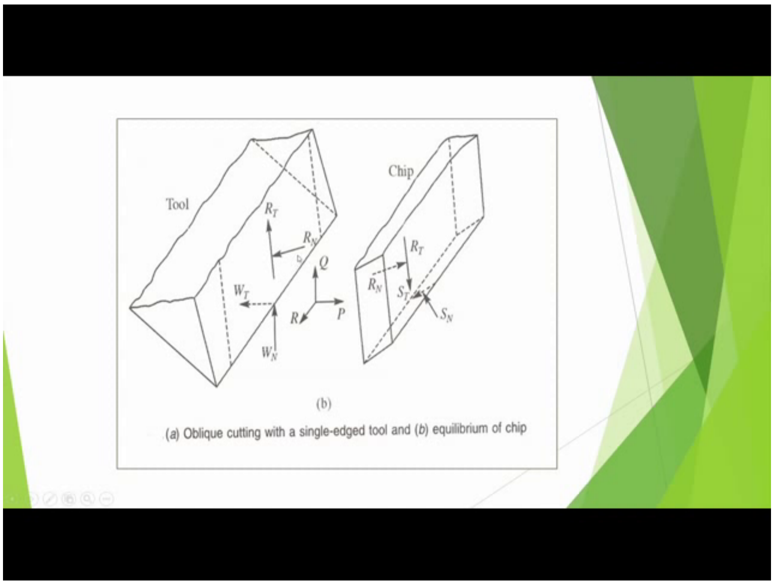

Generally if we have oblique cutting with a single edged tool, then the on the tool you get these type of forces tangential and normal forces like this and on the chip also you get the forces in other directions. And if we say the resultant of all the forces is R, then R can be resolved in 2 components.

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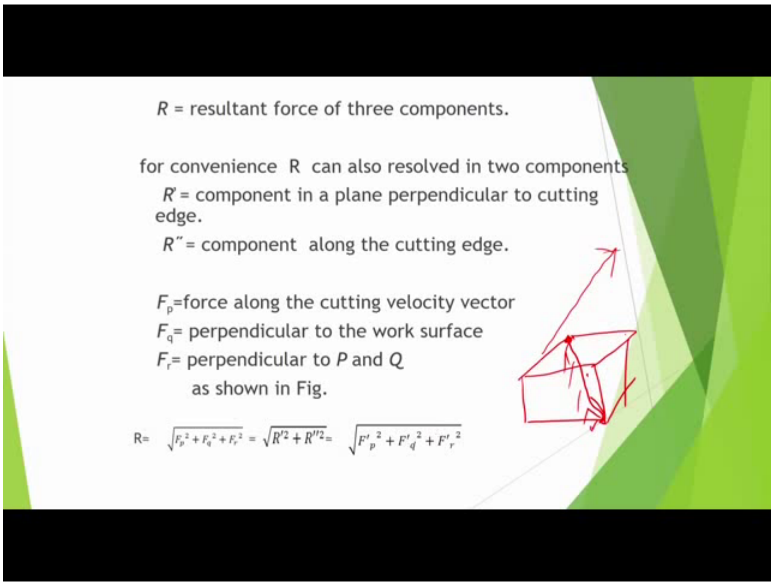

Suppose you have got a force you know a particular force in 3 D. If I have in Cartesian Euclidian system then that force can be resolved into 3 components, one component will be called F X other one is F Y and other is F Z that you very well know that the force we will have 3 components. But it is also possible to resolve the force into 2 orthogonal components provided the forced line is passing through a plane.

So, for example if you have I make a cube type of thing a box type of thing and if I show that my one force is from this 1 2 other diagonal corner point like this, naturally it has to be resolved in 3 components on all sides of this. But if I take a diagonal plane like this passing through this and this then you can have only 2 components this point has to be understood. So, component in a plane perpendicular to the cutting edge and component along the cutting edge I can take.

So, then it can be resolved in 2 components also and then Fp is the force along the cutting velocity vector FQ is perpendicular to the work surface and FR is perpendicular to both P and Q as shown in this one next figure. So, resultant will be square root of Fp square plus FQ square plus FR square and same thing can be called as R dash square plus R double dash square and if I take a rotated coordinate system in that, I can have this type of relation that can be done ok.

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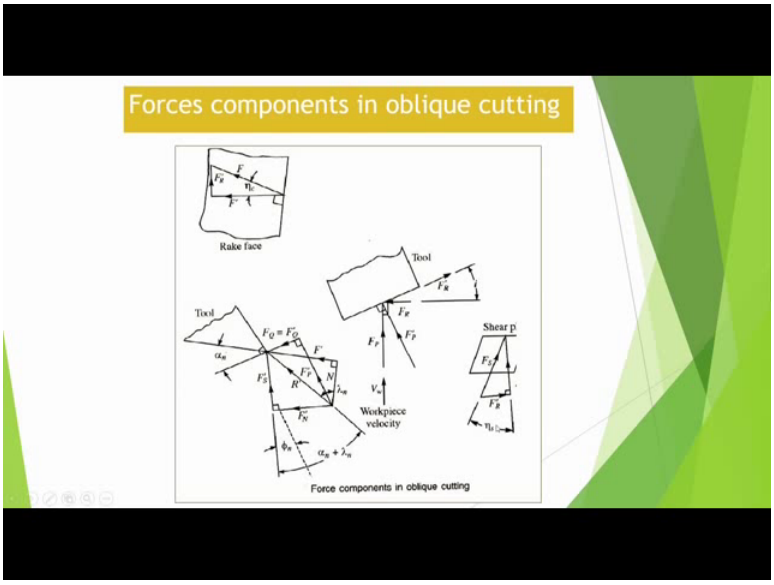

Now, I am just this is a figure GK (Refer Time: 29:01) machining. In fact, merchant has done this type of you know analysis for the first time, so from that you observe that suppose we make different views, this is a rake face in which there is a chip which is flowing in this direction. So, this is the force on the chip rubbing force friction force, but this is making eta shear a angle from here this angle is 90 degree here and this is eta c chip flow angle which can be resolved this force can be resolved into 2 components that is F dash and this can be F dash R.

So, this is the rake face and similarly other views shown suppose 2 is inclined like this and work piece velocity direction is this. So, work piece so perpendicular this is Fp perpendicular to that it would have been FR, but I am showing that perpendicular to this cutting edge. So, this becomes F dash p, that means angle between Fp and F dash p is i and similarly this becomes F dash R and this angle is i. Similarly in the other view you can see FQ and this is the tool and you can see that velocity is in this direction, this is alpha n and this becomes F dash s shear velocity and this is F dash n and here we define that this angle has phi n and this is R dash.

So, you can see that this angle becomes alpha n plus lambda n, where lambda n is the normal friction angle lambda n is defined with respect to that there is a F dash, that means if it is going F dash here and the normal force is n. So, ratio of this projected force to this will be called this one, actually 2 friction angle is basically F tangential goes is F but this we can show it here and then we can have here also this is eta a c is also the shear angle in another plane.

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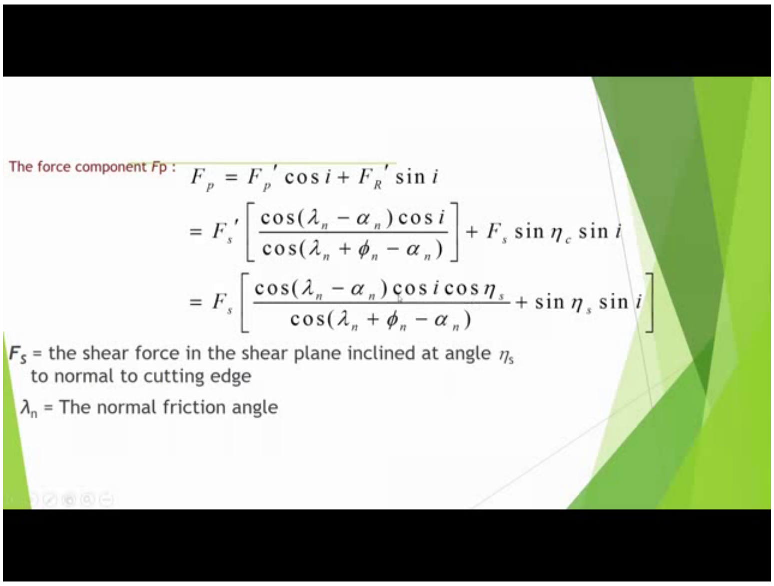

So, total force component Fp can be written as Fp dash cos i plus FR dash sin i and if we put in terms of this one like orthogonal shear force in the shear plane inclined at an angle eta s to normal to cutting edge, that means it is inclined at an angle eta s to normal to cutting edge and lambda n is the normal friction angle. So, like by merchants analysis type things you get this one F s dash, but F s dash a F dash F s dash itself is written as F s times this one cos cosine i.

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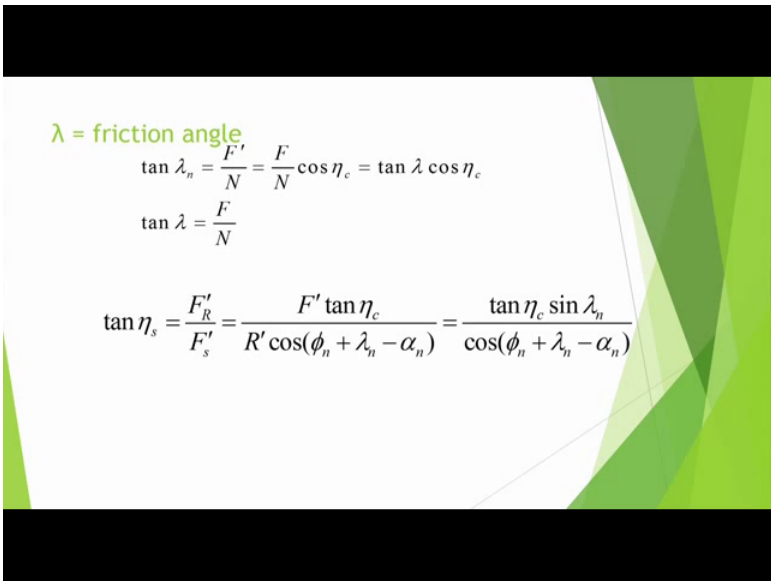

So, it gives so ultimately you are getting this type of relation you can work out this and lambda is the friction angle. So, in this case tan lambda n becomes F dash by n, but F dash is basically F times cos eta c chip flowing in. So, this becomes tan lambda into cos eta c. So that means a lambda l in this will be what it will be slightly different from friction angle by this relation, tan lambda will be equal to tan lambda into cos eta c where tan lambda is equal to F by n and tan eta s will be basically F dash r divided by F dash s that is shear this one and this can be written as F dash tan eta c and multiplied by this will be R dash cos phi n plus lambda n minus alpha n.

So, tan eta s will be equal to tan eta c into sine lambda n divided by cos phi n plus lambda n minus alpha n. So that means, you will be getting this type of relation here and about this one.

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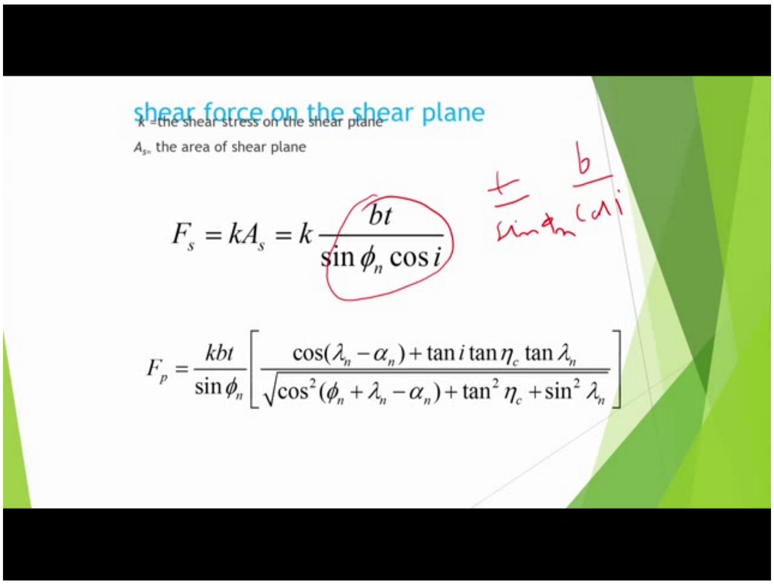

So, now here K if we consider K As the shear stress on the shear plane and As is the area of the shear plane then F s becomes equal to K AS and what is As, As is the shear area so K is the shear yield shear stress of the material. So, this is K and this is b t sine phi n because b is the b b As is actually As is actually like this t by sine phi you used to do, now in this case it will become thickness will become t by sine phi n and b means width that will be related by b by cos i.

So that means, this is so relationship that area a s has become bt sine phi n cos i and it has become K times this one and if we put these values from the previous one K bt Fp is equal to K bt sine phi n and you will get this type of relation here from the previous relation ok. That means, Fp F p is equal to F F dash p this relation is already there in that you substitute and put that relation you will be getting this type of relation and FQ will be naturally equal to FQ dash that in the figure you can see FQ is equal to F dash Q, that means this remains same that perpendicular. That means, vertical component type of thing that you know this is along the reference plane.

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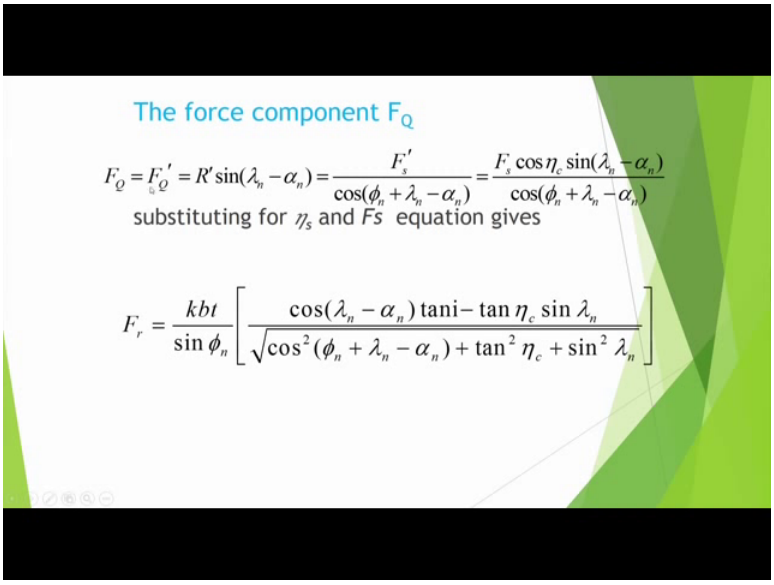

So, F dash Q is same and then you will get this type of relation FQ is equal to FQ dash is equal to R dash and this becomes sin lambda minus alpha n and this can be written as F dash cos phi m plus lambda n minus alpha n and this becomes F dash s is F s cos eta c sine lambda n into this one and substituting for ns and F s equation u u, ultimately by some algebraic manipulation you get FR is equal to K bt sine phi n and this u type of thing you get. So, these are basically the force relations they are given in your book of (Refer Time: 35:33) plus at many other places. So, there is no issue that expressions are well known it is documented in the papers but only thing is that you have to understand.

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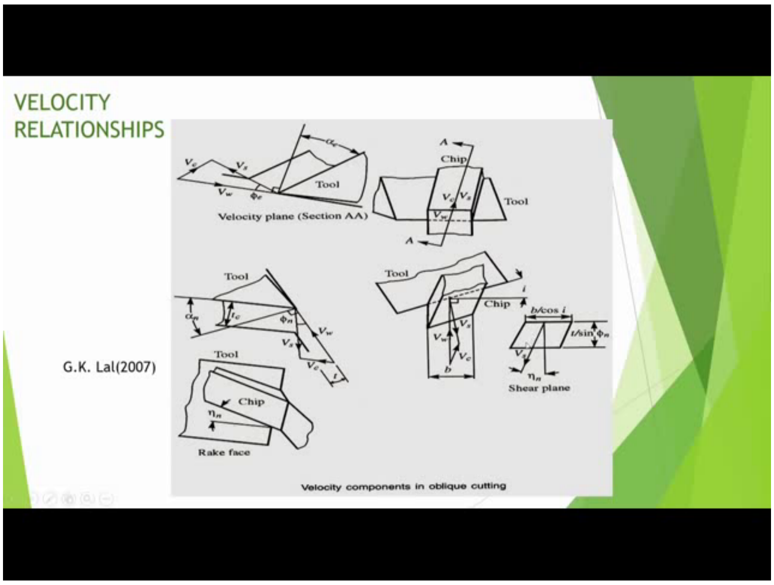

So, understanding is one similarly you can obtain the velocity relation also, we are showing this diagram this is tool and in this one we are taking some section about that suppose V w is the velocity of this one, V w is the work piece velocity and V c is the velocity of the chip though. If I take a plane which contains V w and V c both then V w and V s that is shear velocity on the shear pane that becomes V s ok. Like previous one that there is V w suppose the some job is moving on that and on that it is sliding by V s that chip. So, resultant velocity it has become V c and this angle means this slope of this surface on this plane will be denoted by alpha e that means, how you will measure the slope from V w you draw perpendicular.

So, that this is along the reference plane and from this angle is alpha e that we have been calling as 2 rake angle and then here in this few they are showing these chip and they have taken the section like this and then this is rake face and they are illustrating that basically eta n. That in this chip flow in this plane norm on the normal plane that this is eta n and this is alpha n normal rake angle this is t c and this is phi n here shown Phi n has been shown here V w V s and this was basically Ri and this one is here they are showing V s V w and V s and this is chip and they are showing that on the shear plane there is a b by cos i.

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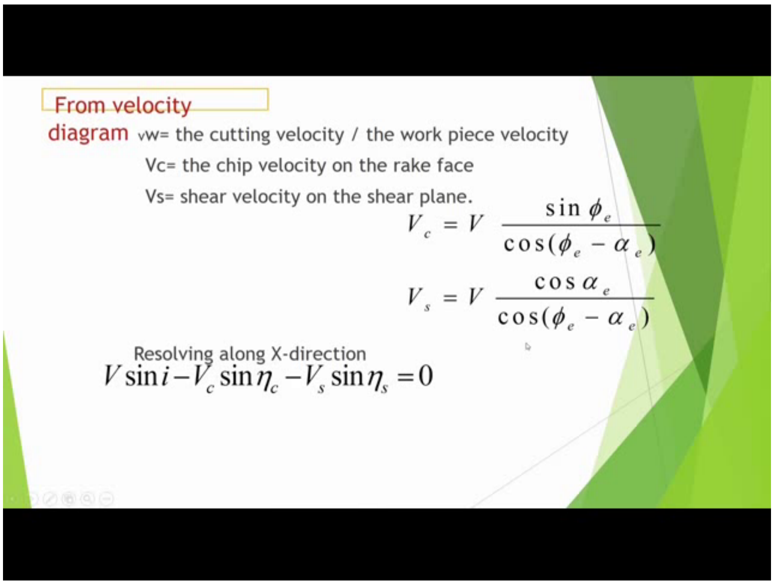

This relation is also there we will discuss about this in the next slide that now we seen that diagram V w is the cutting velocity or it can be work piece velocity and V c is the chip velocity in the rake face and V s is the shear velocity on the shear plane. Then you have got this type of relation like you have got in the merchants force diagram that V c is equal V time sine phi e cos phi e minus alpha e, but now these values are 2 valued. That means, 2 rake angle and similarly if you resolve the components along X direction then you get this type of relation.

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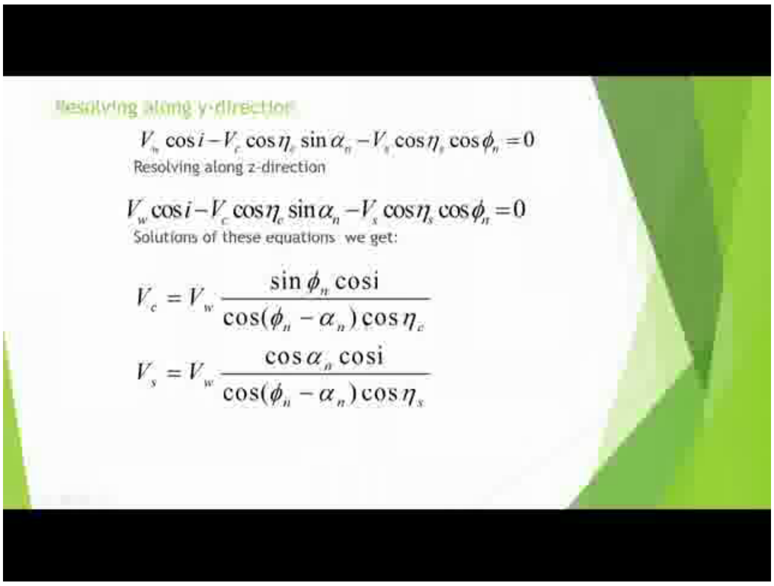

And then resolve along the Y direction you get this relation and if you resolve along Z direction you are getting this type of relation and solution of these equations, we can get V c is equal to V w sine phi n cos i and cos phi n minus alpha n cos eta c and V s is equal to this will be cos alpha n cos i cos phi n minus alpha n cos eta c.

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And tan eta s is defined like this tan I cos phi n minus alpha tan eta c sine phi n divided by cos alpha n and we can have shear angle relationship from here and if we put that these values. In this case that tan eta c minus this one some relation is there, then you get from geometry this type of relation.

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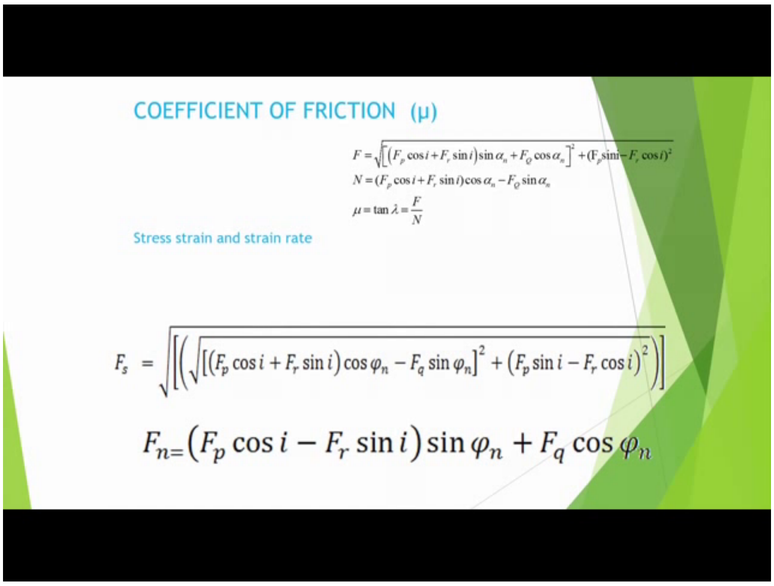

Now, coefficient of friction mu for that first you find out the F, F is equal to square root of F t Fp cos i plus FR sin i sin alpha n this quantity and n is equal to this much, then mu becomes equal to tan lambda by F by n and for shear strain and strain rate you can find out this relation Fs is equal to this type of expression and F n is equal to Fp cos I minus FR sin i into sine phi n plus FQ cos phi n.

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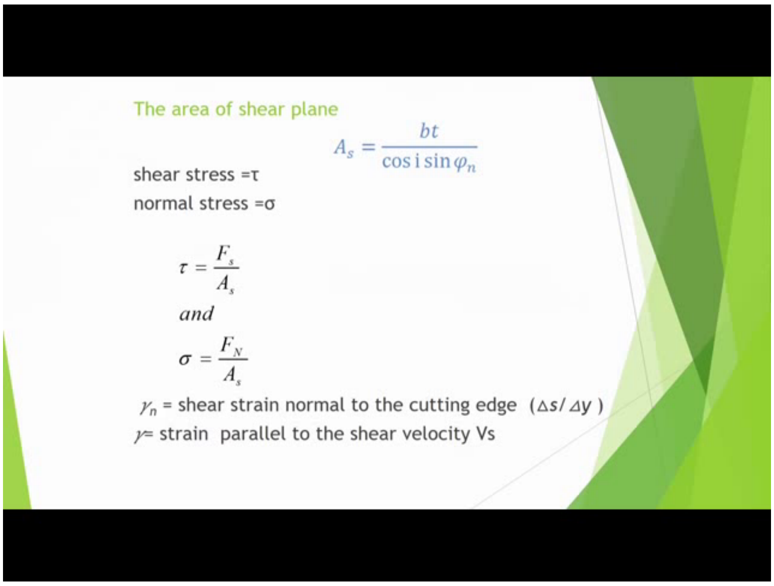

And then the area of the shear plane is in fact As is equal to bt divided by cos i and sine phi n, i is the inclination angle and phi n is the shear angle in the normal plane. So, shear stress is tau and normal stress is sigma so tau is equal to F s by As and sigma is equal to F n by As and gamma n is equal to shear strain normal to the cutting edge, so that is basically delta s by delta y. So, this is as we have done in orthogonal cutting and gamma is strain parallel to shear velocity V s ok.

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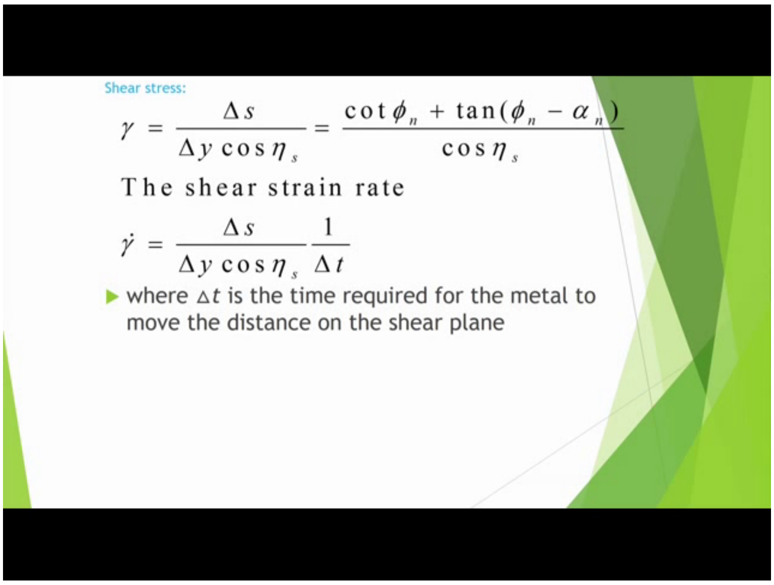

So, this one so gamma is delta s by delta Y cos eta s. So, gamma in shear strain normal to the cutting edge but this is strain parallel to this shear velocity, so both are related by this type of relation. So, gamma is the strain parallel to the shear velocity and that is called cot phi n plus tan phi n minus alpha n divide by cos eta s and shear strain rate then can be found as this gamma dot is equal to delta s divided by delta Y cos eta s, this is 1 by delta t delta t is the time required for the metal to move the distance on the shear plane this one.

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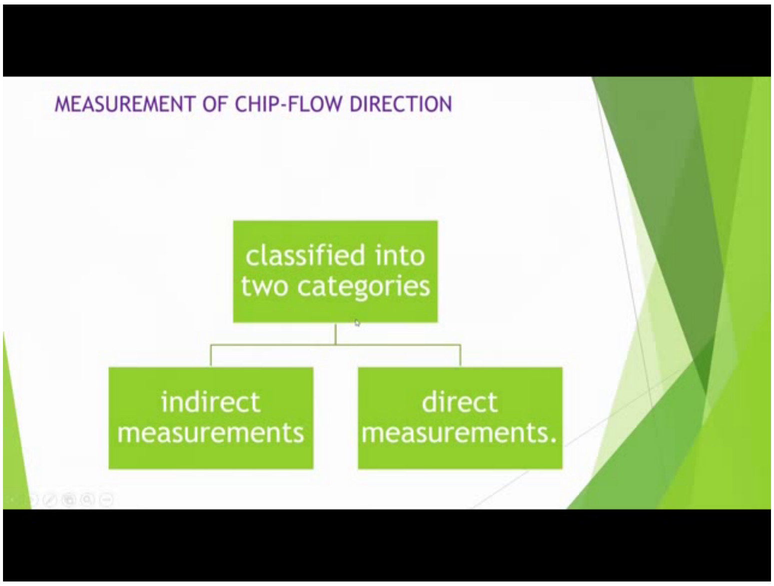

So, these are relations, I hope that you have understood, but do not get scared if you do not understood properly these expressions are also you need not memorize. In a exam if somebody gives any problem then he will give those expressions and these you have to be basically visualize there are various ways to visualize. That means, you can make the orthogonal use or you can use 3 D coordinate geometry, then things can become clear to you and I will give that you will understand that how the forces are obtained that is the derivation, each of that work was one separate paper by various authors.

Now, what is of course you are studying that in the books in 1 or 2 pages, but this is this is not so easy to understand also and there as I told there is a controversy also. So, that whether I should take the normal rake angle or true rake angle these type of things are there. Now I am talking about something about that measurement of chip flow direction that means how we are assuming that the chip is flowing chip.

In the orthogonal cutting is just flowing perpendicular to the cutting edge, but here it is not moving in that direction it is inclined, so it is measurement of the chip flow can be classified into 2 categories one is the in the indirect measurement and other is the direct measurement.

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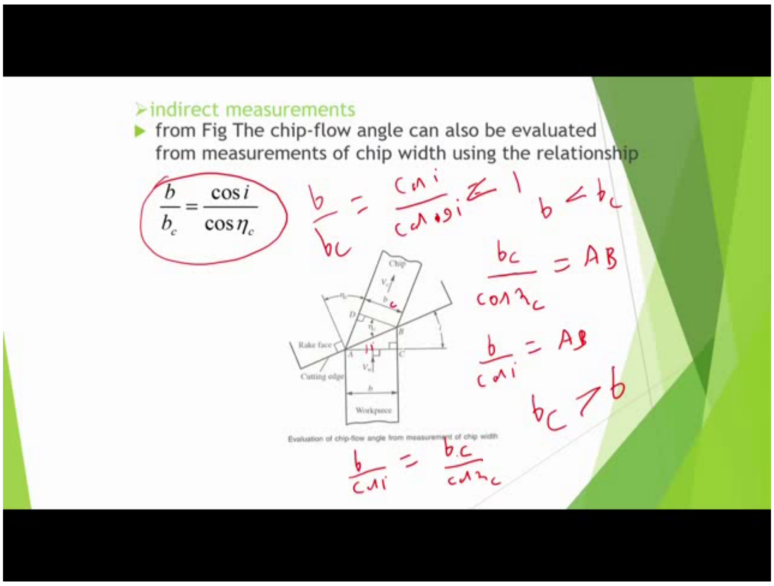

So, here indirect measurement suppose you from figure you see that this one it is a work piece and this is the cutting edge, you see cutting edge is this and V w is this work piece velocity is in this direction. So, this angle is basically i and this is the rake face and on the rake face I can draw one line which will be perpendicular to the cutting edge. So, this is just perpendicular to the cutting edge on the rake face ok; that means, the rake face it is a figure like this. So, this is rake face that this is like this one and but your chip which is flowing in this direction, so this angle is eta c on the rake face.

Supposing it is going like this and this chip width comes out to b then from this geometry suppose this is eta c then perpendicular to this will make eta c from here. So, b by b this is b and this will be b, suppose we say b divided by cos eta c b divided by cos eta c will be will give us a b u ok.

So that means b and here it will be sorry it is it is not b here there is a mistake here it should be bc this is b. So, suppose we say this bc b c from this diagram b d by bc divided by cos eta c that is equal to AB right is not it. But here another diagram is giving me this angle is i, so what is happening that here A C is B, so b divided by cos i is equal to also A B so equate both the things. So, you divide b divided by bc so basically you get what you get b by cos i is equal to bc by cos eta c.

So, that means b into cos eta c is equal to bc into cos I, b into cos eta c is equal to bc into cos i so you get this type of relation, that b divided by bc is equal to cos i by cos eta c; cos i is known to me because that is by geometry inclination of the cutting edge, that you know at which angle you have set you yourself have set it. So, you know it so this is cos i and this is cos eta c.

So, suppose you measure b and bc then you can get idea about eta c, stabler observed that most of the time it is basically eta c is that almost same as i in that case b by bc will be same. That means, chip width even in oblique cutting will remain same, otherwise in the later on he did some photographic study and by that (Refer Time: 46:22) study he found that that eta c is in fact about 0.9 times phi. So 0.9 times I means 90 percent of i so cos of i, so other these values cos i and this is cos 90 percent of i. So, this is smaller means this portion is bigger means b is bigger and bc becomes a bit a b by bc ok.

This is a smaller so b by bc is equal to suppose I say cos i divided by cos 0.9 i, so that means this is suppose one value. So, this whole thing will be because cos 0.9i will be more than cos i because smaller the cosine angle, more it is. So that means this quantity is more therefore this entire thing is less than 1 so that means b is less than bc.

So that means there is some chip so that means chip width may increase a bit ok, chip bit may increase actually we see that chip thickness also increases due to deformation, but the length reduces but here it is showing that here bc is greater than b. So, suppose bc is greater than b that means the chip will also widen also a bit, that means it will spread also a bit.

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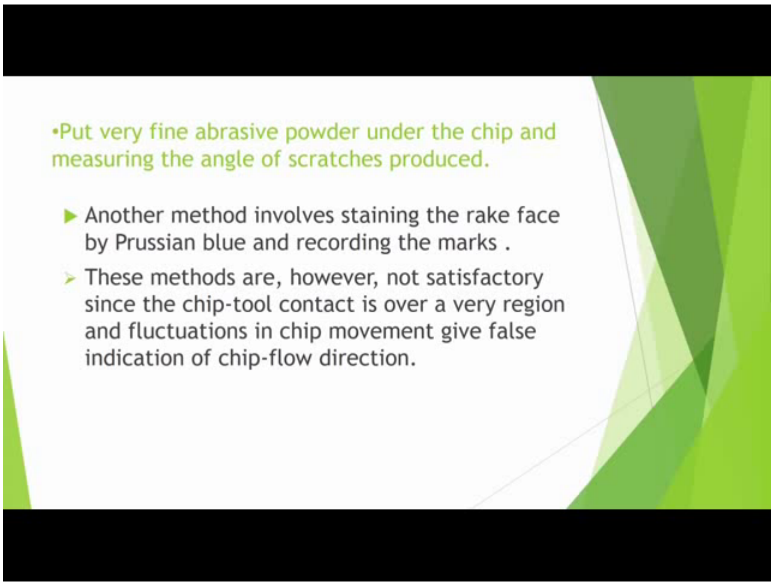

So, that type of relation is there from here you can obtain and how you can measure it experimentally. So, one method is that put very fine abrasive powder under the chip and you measure the angle of scratches produced under it, that type of thing can be done abrasive powder will sketch another method is in was staining the rake face of by Prussian blue and recording the mark.

We can put Prussian blue on the top and these methods are how your not satisfactory, since the chip toll contact is over a very region and fluctuations in a chip movement give false indications of chip flow directions. So that means it will basically there can be chip flow fluctuation and you may have difficulty.

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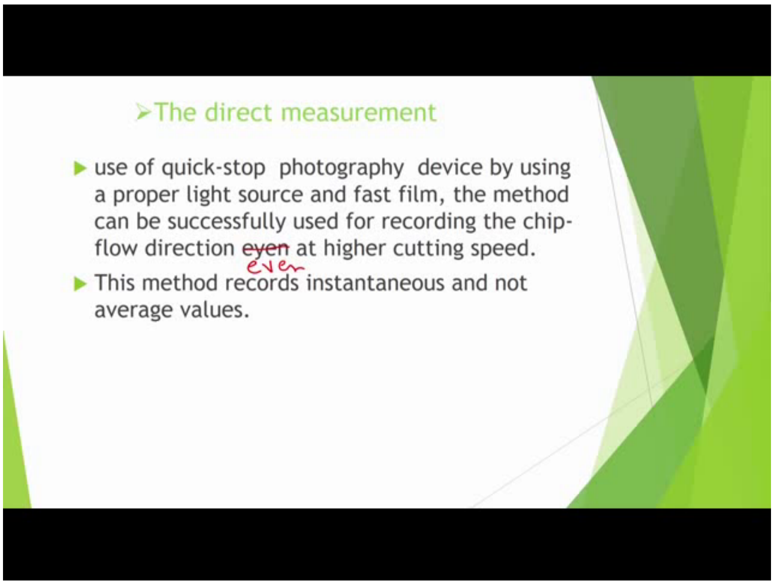

Another method is that use of quick stop photography as I have described in my previous lecture, proper light source should be there some fast film should be there and method can be nowadays today we have high speed cameras these high speed cameras also can actually provide these thing. So, they can give the recording and flow direction even at high cutting speed. So, that is what this method records instantaneous and not average values, but you record instantaneous but you do not record average value.

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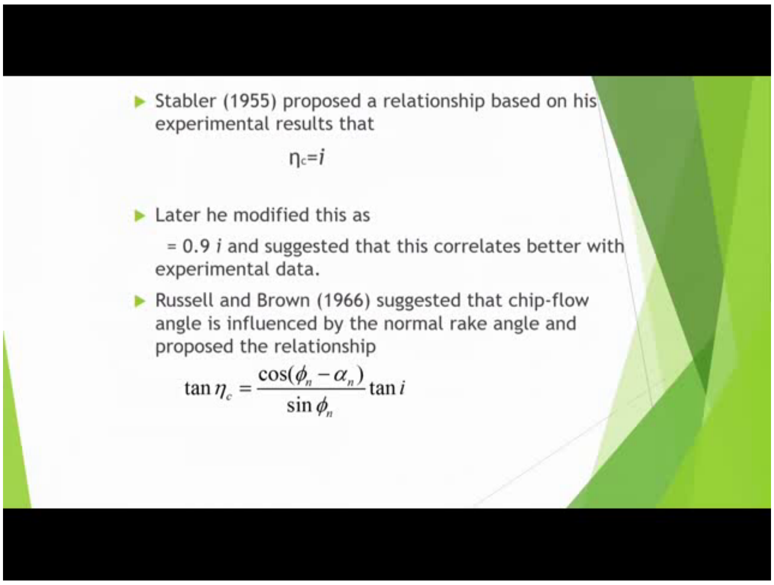

Now, stabler in 1955 proposed a relationship based on his experimental results that eta c is equal to i that chip flow angle is same as the i and later he modified this as is equal to 0.9 i approximately and sometimes between 0.9 to 1 and suggested that this correlates better with experimental data Russell and brown suggested that chip flow angle is influenced by the normal rake angle and they proposed the following relationship, tan eta c is equal to cos phi n minus alpha n divided by sine phi n into tan i. So, they have actually proposed this type of relation that cos phi n minus alpha n divided by sine phi n tan i.

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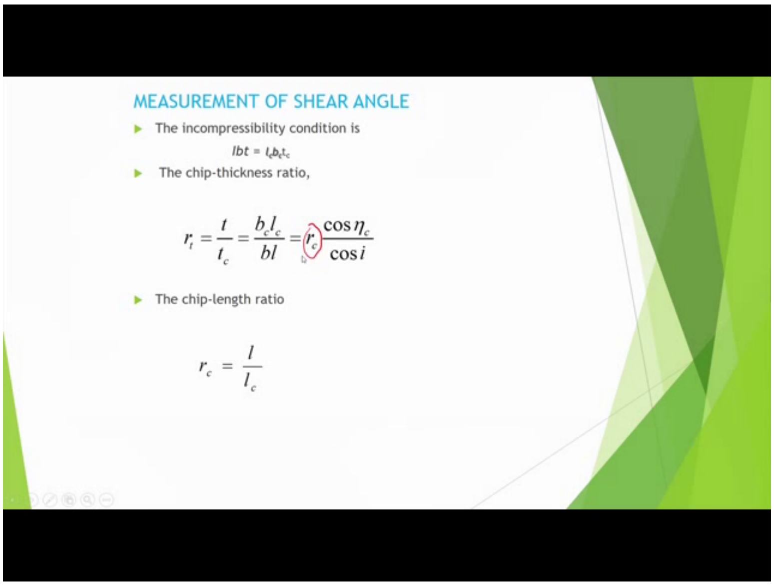

And then incompressibility condition can be used to measure the shear angle, now we know that lbt is equal to l c bc t c and chip thickness ratio r t is equal to t by t c and that is bc l c divided by bl and this bc by b can be written as bc by b is suppose we write as r c ok, r t is equal to t by t c and then this no this l c by l this will be bc by b can be written as cos eta c by cos i.

Suppose you have got this one cos eta c by cos i, so here this will be t and r t is equal to r c divided by this one. So, if we say if we define the chip length ratio as r c, r c is equal to l by l c. So, this is this already I have done in this figure just remember this b by bc is equal to cos i by cos eta c. So, b by bc is equal to this one so bc by b is cos eta c cos i, so this becomes r c and this becomes cos eta c and divided by cos i. So, the chip length ratio is actually becoming l by l c that and if we assume that basically eta c chip flow angle is same as the inclination angle then we will be getting this type of relation from the previous relation.

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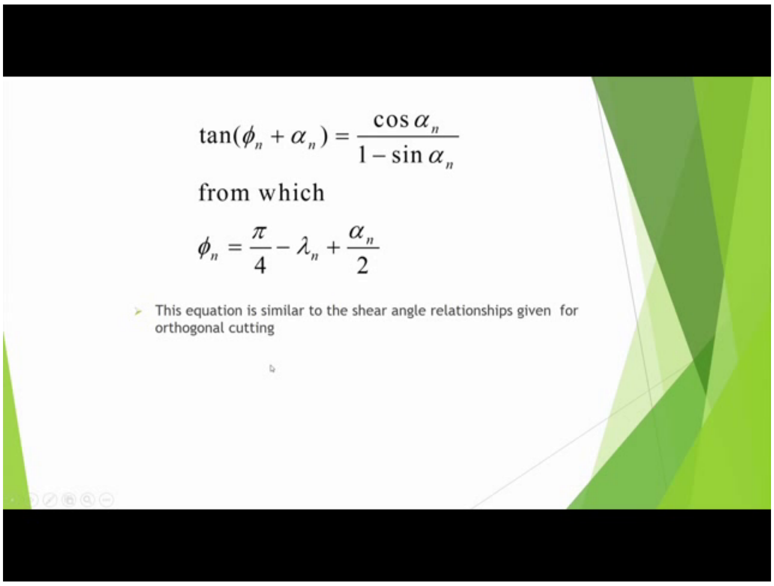

Suppose tan eta c is equal to tan I, then we get basically tan phi n plus alpha n is equal to cos alpha n divided by 1 minus sine alpha n. So, from which we get actually phi n is equal to pi by 4 minus lambda n and then you get and plus alpha n by 2. So, this equation is basically similar to the shear angle relationship given for orthogonal cutting, that means automatically then you will get this type of relation.

So that means if we believe in the stablers analysis, then in that case phi n will be actually equal to pi by 4 minus lambda n plus it will be alpha n by 2, so this type relation will be coming and this will be done. So, this much thing I have told about this one and I will now just go back draw your attention, if you want to really understand proper derivation you have to understand each and everything very slowly.

First of all you see the observation that tan alpha n is equal to tan alpha V into cos i because, you are having some if inclination is there. Suppose you have something in the normal plane in the orthogonal plane that angle is going to increase here and here sine alpha is equal to sin i sine eta c cos i cos eta c into sine alpha n.

Assume that one case in which supposing, supposing you say that I is equal to 0 and eta c is equal to 0, in that case this relationship gives nothing but it gives alpha e is equal to sine e alpha n You can have another possibility also that suppose you have inclination angle equal to 0, but your eta c is present actually eta c is present that means what is the situation here. That means, this is a true rake surface may be this is a true rake surface and tool velocity is like this, this is normal to that one where no inclination is there. So, it is like this this is the velocity type direction and this is the normal to that thing, but you are having this one eta c you are having eta c here the chip is flowing like this.

Now, you want to say that I want to find out alpha e, that means basically when you are moving from here to here that means you are moving here to here, how much is this slope of that surface. So, this type of relation will give you sine alpha e is equal to here cosine i is 1 that means cos alpha cosine e eta c and into sine alpha n right. That means, I am going to get this type of relation.

Why so can you derive this first that means, in a before moving to the complicated relation first you can derive this one and if we talk about cos eta c here then cos eta c is basically this divided by this type of thing ok; cos eta c no sorry this line divided by this that is cos eta c and this was sine alpha n. So, sine alpha n will be measured here that in the normal plane and this will show the slope of that and you can make use of the 3 D coordinate geometry and you can visualize that how do you measure sine alpha n.

Suppose this is you are at some vertical height and now your surface is sloping, that means how the surface is going towards opposite side so that is why you are getting here alpha n. That means, if some surface is just vertical then there is no sine alpha n so that means that will be there is no slope alpha n is 0. But surface is tilted so that means this is this divided by this now same thing if you are now going to in this particular direction, then you are moving getting that some extra type of thing. That means sine alpha n is this vertical so suppose vertical height is this and this was that something diagonal height. So, now this diagonal length has increased a bit so sine alpha n is equal to perpendicular divided by hypotenuse.

So, hypotenuse has increased by a factor of cos eta c, that is why you are getting cos eta c into this one so that is why you are getting that this relation about this one. So that means sine alpha e is basically perpendicular divided by hypotenuse, hypotenuse in that one plane and this is cos this is basically in that 2 2 plane and cos eta c is cos eta c is that is again perpendicular and divided by hypotenuse in the normal plane. If I to take the perpendicular strain then you can very well understand that there is a difference of this hypotenuse so that means this slope. So, this is something these relationship you can properly do if you understand that my analogy when I told earlier slide also, so that here is you are having some slope in the 3D plane like this you have to visualize that what will be the slope of the surface.

Slope of the surface is maximum in this direction, but in this direction it is 0 and in other direction you can find out this slope. In general how do we find the slope of the surface if I move from A point to B point then if I know that how much I am moving vertically; that means, this distance and then I know this distance then I can say that sine alpha tan alpha is equal to this by this. Similarly if I am moving let us see inclined way so that means I have gone, so let us see this point and now I have gone in inclined manner this thing know.

So, A to suppose B dash point now when I moved here to here, how much slope I encountered, so we can actually find out here also we can draw a perpendicular we can draw in this one. So, we can say there is a vertical height I moved the same because height is edge, but this way now I clever to moved distance in a hypogenous direction. So, my sin i sine will difference suppose here sine theta, so sine theta in this case was what this was h h divided by A B. But suppose I am moving from here A to B dash in that case my sine height was same h.

But this will be A B dash this was A B dash so sine phi is equal to h by A B dash. So, naturally A B dash is more so that is why you will encounter that less amount of angle now the slope will be less. So, basically this same type of concept is there if you try to visualize if you see slides again and again then you yourself you will understand because it is a 3 D that is why it is very difficult to visualize people make various type of models. But whatever best possible I have tried to explain through screens and 3D pictures I hope that you will understand and the next time we will talk other topics.

Thank you very much.