Mechanics of Machining
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Lecture - 16
Practical Machining Operations(Milling and Drilling)

Welcome to the 16th lecture of the course on Mechanics of Machining. In the previous lecture we discussed about turning process and in this lecture we will discuss about Milling and Drilling process.

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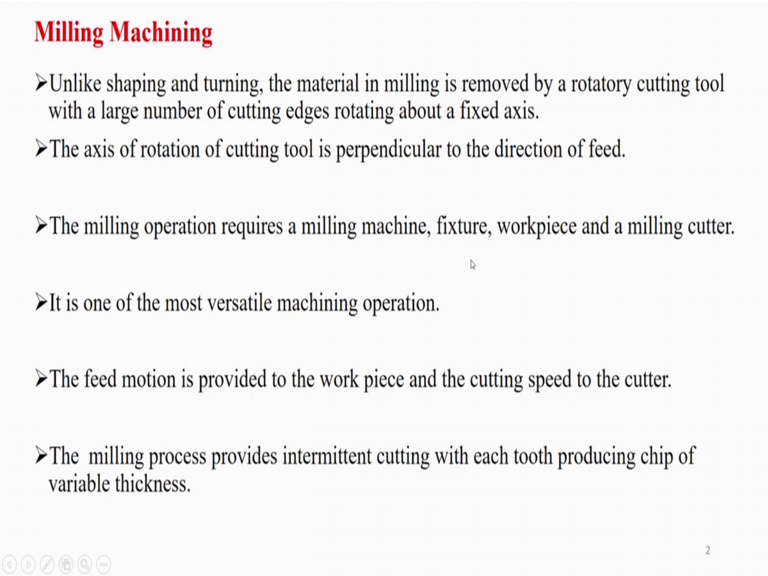

So, machining by milling is different from shaping and turning, in the sense that material in milling is removed by a rotatory cutting tool with a large number of cutting edges rotating about a fixed axis. So, there is a cutter in which there are number of teeth. The axis of rotation of cutting tool is perpendicular to the direction of feed and milling operation requires a milling machine, fixture, work piece and a milling cutter. It is one of the most versatile machining operation for producing flat surfaces, curved surfaces, mostly we can machine the rectangular jaws also. The feed motion is provided to the work piece and the cutting speed is provided to the cutter.

In the turning operation the work piece rotates, but here the work piece stationary related to the rotating cutter. Milling process provides intermittent cutting with each tooth producing chips of variable thickness this is essential difference between turning and shaping and milling because, in turning and shaping there is a continuous chip production, but here there is a intermittent cutting.

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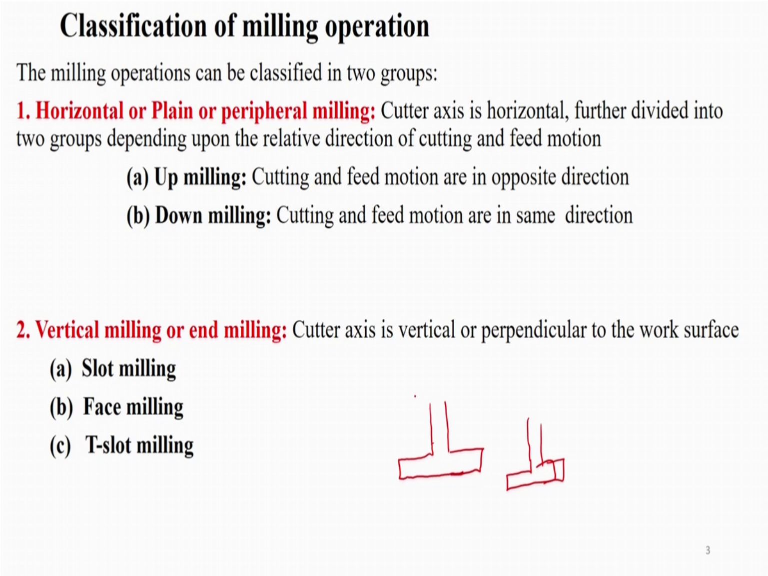

So, we can classify milling operation in various ways; one is depending on the machine, so one is horizontal or plain or peripheral milling. In these cutter axis is horizontal, it is further divided into two groups depending upon the relative direction of cutting and feed motion. One is called up milling. In the up milling cutting and feed motions are in opposite direction that is up milling and in down milling cutting and feed motions are in the same direction.

Then we have vertical milling or and also end milling. In these processes cutter axis is vertical or perpendicular to the work surface and it can be classified into slot milling if we want to make a slot, it can be face milling if we just want to facing of the surface we want to remove just like in the turning operation we do facing also by a cutting tool.

Similarly, here in the face milling also we can do facing; we can make the plain surface on the top, then T slot milling in which if we want to make one T slot. What is a T slot? You know it is like this like this and it is a in which you can fit a T volt. So, this type of slot is generally made, you might have seen a milling machine table in which these type of T slots are already made and various other places like in a planar also sometimes.

So, T slot is used for fastening, there will be a T volt which will have this type of hat it can be slit inside the T slot, so T slot milling is also there which makes T slot.

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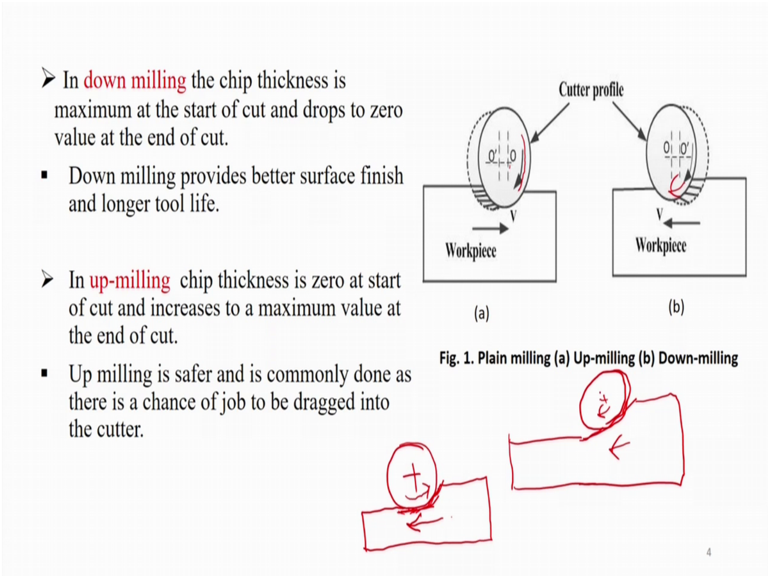

Then let us discuss about down milling and up milling; you see that in this figure there is a plane milling plot is shown. So, part a is showing up milling in which work piece is moving in this direction from left to right and the cutter is rotating like this. So, therefore, peripheral speed of the cutter with respect to work piece in opposite direction to that work piece actually this one. So, that is what is happening and in the down milling work piece is moving in this direction peripheral speed of the cutter is also in the same direction, so both are essentially moving in the same direction and it is going like this.

See here in this case, O initially it was this is the centre of the work piece O and this has gone O prime that means, relative to work piece you can say this has moved from here to here ok, relative to work piece otherwise work. Similarly, in this case it is centre is here and then it has it goes there. So, that means, up milling and down milling these processes have been shown here. In down milling, the chip thickness is maximum at the start of the cut and drops to 0 value at the end of cut. So, in the down milling because down milling may be like this here I am just showing that very schematic type of thing suppose this is job and this is cutter is moving like this. So, in the so it is both are moving in the same direction so first you encounter a larger chunk of the material and then it goes.

So, that is why in the beginning the chip thickness is more and after that it gradually draft to 0 in up milling. So, therefore, because of this down milling provides better surface finish and longer tool life in up milling chip thickness is 0 at the start because in up milling. Suppose you have the cutter like this and then it is going like this and it is it is it is like this here that chip thickness is 0. So that means, this cutter if it is rotating like this and then you have it is moving movement is like this work piece movement is like this. So, in the beginning it encounters edge this one flat surface 0 type and after that chip thickness keeps increasing.

So, chip thickness is 0 at start of the cut and increases to a maximum value at the end of the cut usually you know that even in turning operation finishing cuts are generally taken of a very small depth of this one and initially the cuts are high, but here you have got different type of situation. So, that is why this way may not give that much good surface finish, now up milling may be sometimes considered safer because it is there is a chance to be dragged into this one cutter.

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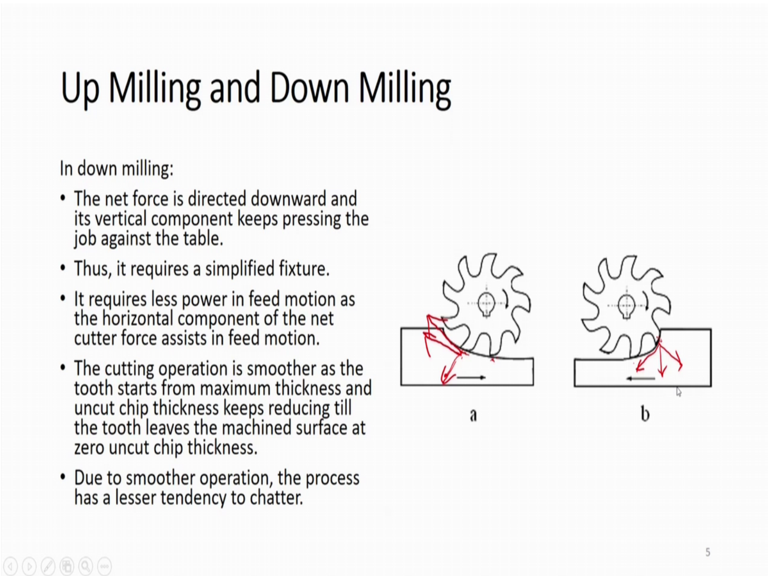

So, this is what happens that here in this case let us see that some more advantages and disadvantages of this one, suppose here you have got up milling and then there is a down milling here.

Now, in the up milling this is job is moving in this direction and cutter is moving like this let us say that cutter is stationary. So, that table is actually relative motion is in this direction relative to the cutter it is moving in this one or if the table is fixed then naturally the cutter moved, but we are considering that suppose cutter is fixed at this location and this job is moving in this direction. So, you see that initially that cutter encounters this flat surface and as job is moving it is getting more and more bite actually here and in the down milling it is moving in this direction job is coming. So, initially it is getting a big chunk here it has to cut that material and gradually it reduces.

So, in the down milling net force is directed downward let us see this is down milling b is down milling and if we see that it is if you are seeing that job is moving like this and therefore, there will be one motion that it is cutting. And that means, cutting force on the job is going in this direction and at the same time there is a this one that means, it is the radial direction there is a force like this and therefore, resultant is like this. So, resultant components is downward inside, so it gives the pressing the job against the table. So, therefore, it requires the simplified picture fixture in this case in up milling what will happen that if we see that it is a putting. So, it is like this you are having suppose, suppose you have force coming like this and then there is a that force it is it is like this here and then this will be in the down milling also suppose this is the force on this and even if there is a radial force like this. So, even then its component radial force direction can be shown like this one.

Let us let me show a first because suppose it is cutting like this, so cutter is moving like this so cutter is a pressing because, because one component by tangential wise it is coming this way and it is this way and radially because there will be like this way ok, so this is. So, therefore, resultant is here in this case it is like this and radially, suppose it is this. So, that resultant is somewhat this now it is it is in this direction cutter is moving like this in this case cutter is moving in this direction ok. So, force is component is like this and in this case the force component will be like this it is it is having this way and it is in more, more component is this direction. So, it is more inclined towards that that resultant is actually towards this, so it has tendency to lift it up.

So, that is why you requires strong fixture here, so down milling requires simplified fixtures. It requires less power in feed motion as the horizontal component of the net cutter force assist in the feed motion see job itself has tendency to drag it and it is going in that direction. So, less power is required cutting operation is smoother as the tooth starts from maximum thickness and uncut chip thickness keeps reducing till the tooth use the machine surface at 0 uncut chip thickness. So, it is smooth variation of the forces due to smoother operation the process has less tendency to chatter or undergo self-excited vibrations, so these are the advantages.

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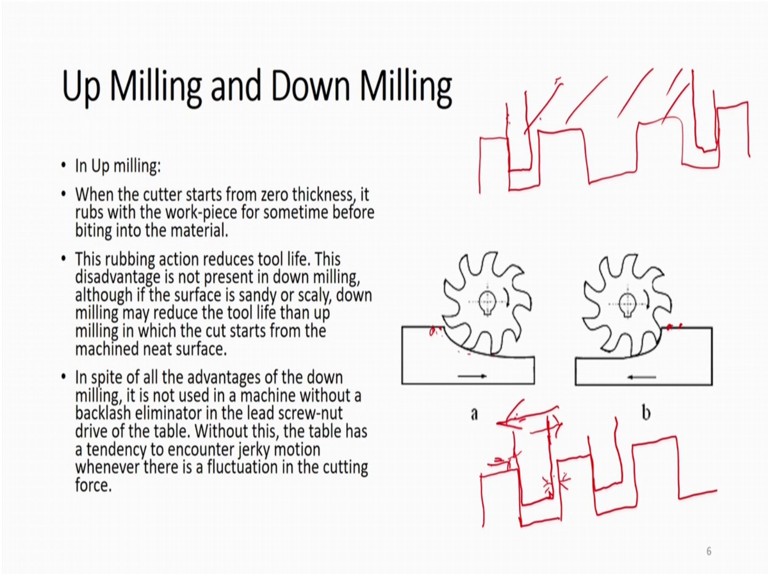

In up milling, when the cutter is starts from 0 thickness like here, it rubs with the work piece for sometimes because here there is a hard turning depth of cut, it is just rubbing and for sometimes before biting into the material.

So, this rubbing action reduces the tool life. This disadvantage is not present in down milling although if the surface is sandy or scaly then down milling may reduce the tool life than up milling, because here if it is sandy suppose there is a sandy surface sand is there. So, initially this surface will come in contact whereas, in the down here even if there is a sandy surface, but we are cutting from this which is machined surface. So, it will go and it will buy this time it will reduce the big chunk, so that problem is not there. So, tool life in sandy surface will be less in down milling, but otherwise in general the down milling will provide more life.

So, but in spite of all the advantages of the down milling it is not used in a machine with a backlash eliminator in the lead screw nut drive of the table. Because there is generally a backlash that is why up milling is always preferred in favour of the down milling because without this the table has a tendency to encounter jerky motion whenever there is a fluctuation in the cutting force. Let me tell you what is the backlash type thing I am showing in a very schematic way simplified way suppose this is lead(Refer Time: 14:53) these are the gaps and this is corresponding nut portion.

So, you know that nut thread will engage with the screw thread like this like this it may be usually there is always a gap between them. Ideally thickness of the this gap in a screw will be equal to the thickness of the teeth of thread of this one nut, but use that cannot be done because if you make very precise then it may jam and it will not have free movement and due to thermal expansion also we need some space.

So, we deliberately provide some gap between them backlash, so that is not a problem assume that the nut is forcing the screw and it is just moving like this. So, suppose contact is like this ok, but then suppose suddenly you reverse the direction in that you have to move this much distance that is called lost motion. So, that means whenever there will be reversal then that type of problem will be there so that is called backlash phenomena.

So, for backlash elimination sometimes people use a double nut compensation type of thing that means, suppose you have this type of screw and so, many teeths are there I am not showing them all. But suppose there is I put one nut in which the teeth are aligned in the this direction gap is still there, but suppose it is it is it is like this it is like this and I provide here another suppose nut there are so many means nut threads.

But I am just showing one, but in this I align in this direction I can align in between two nuts I can put special. So, that this portion keeps pressing in this direction and other portion keeps pressing in the different direction. So, then even if there is a reversal of direction you can see there is no lost motion because this nut is already in contact with the screw, so we say one nut is compensating for the other and it is called double nut compensation.

So, in most of the machines there is no proper backlash elimination arrangements that is why generally up milling is preferred there. And show that this can be this phenomena it not there and down milling is not preferred because in up milling that this will always have it will always keep pressing in one particular direction, because these motions are in opposite direction. So, proper pressing is there in the down milling that type of pressing is not there ok.

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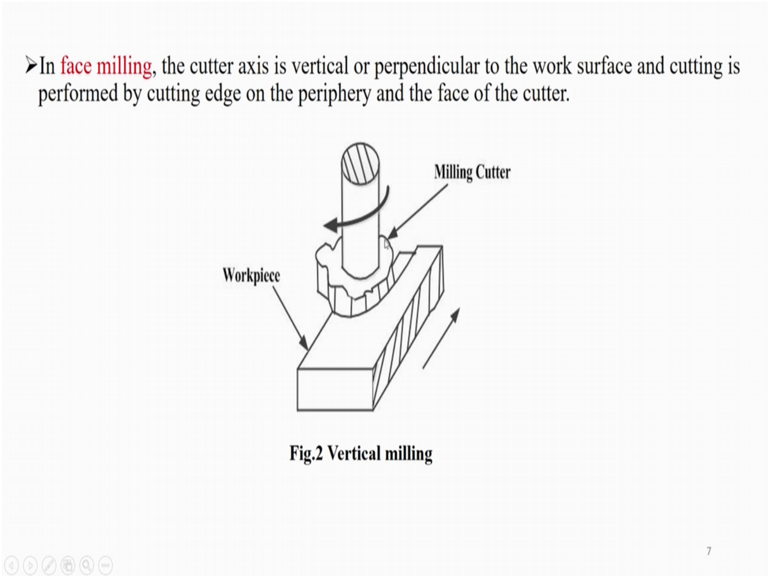

Fig.2 Vertical milling

So, these are reason now in face milling the cutter axis is vertical or perpendicular to the work surface and cutting is performed by cutting edge on the periphery and the face of the cutter. So, that is the face of the cutter also cuts periphery also cuts and we are doing here the vertical milling that type of thing has been shown here.

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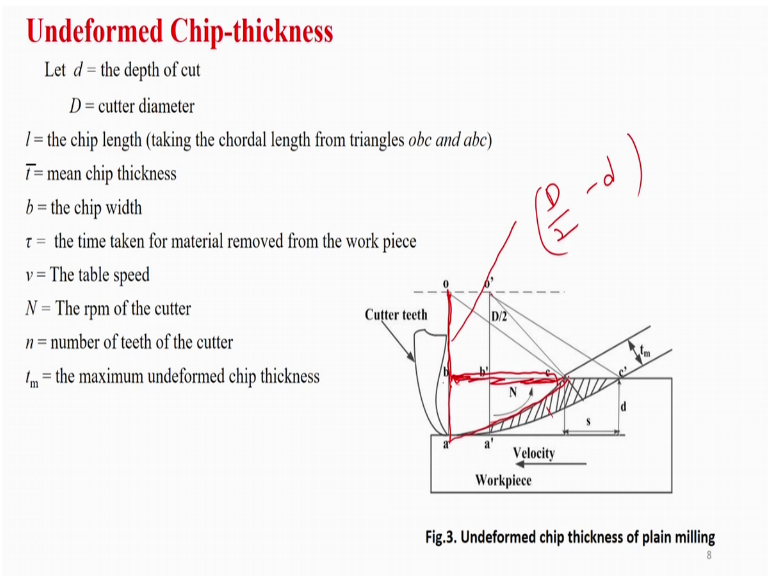

Fig.3. Undeformed chip thickness of plain milling

Now, let us discuss in the case of plain milling in let us say it is a horizontal milling I want to see how the chip thickness varies. So, here I am showing that type of situation that this is a cutter and let us say this is a table with a velocity work piece velocity like this and this is moving in this direction. So, naturally this is the case for up milling ok, because the cutter is rotating like this and the job is coming like this, but let us assume that centre of the cutter is here and this is actually coming here related to work piece let us say work piece is stationary, so it will naturally come here

So, initially it was at o and it was like this and after that it has become like this here. So, it is it is rotating now just see that here if you just take a if it is rotating in this position it at O with as a centre it would have covered this type of a(Refer Time: 19:33) of radius D by 2 D is the cutter diameter. And small d is the depth of cut, but, but by that time it has moved at O prime and suppose it rotates here. So, it will give like this type of thing it will give that means, this is the centre ok.

So, naturally if we assume that it was a position O and then we have kept it suddenly at o prime then in that case this will be the path. So, in a way I am saying that this much is the basically depth of that thickness basically this is the thickness chip thickness because this portion of material will be removed because initially itself at this location it is made like this, but then suddenly I will be moving and I will be putting this teeth here ok. So that means, because by the time that tooth this was the tooth and in this suppose we assume that this is this tends O prime is the basically feed per teeth ok. So that means, per tooth feed is this and you have got this type of material.

So, this D is the cutter diameter, so D by 2 is the radius l is the chip length that means, we take the chordal length from triangles o b c and a b c. So, o b c this one and a b and a b c a b c is this so that means, this is a so this will be the chip length actually this a c ok. So, now, your t is the a t bar is the mean chip thickness average chip thickness b is the chip width, chip width is actually not shown here perpendicular to the paper.

And tau is the time taken for material removed from the work piece, v is the table speed, N is the r p m of the cutter small n is the number of teeth of the cutter and t m is the maximum undeformed chip thickness that is t m which is visible here that t m is this one because it is going and when it has moved like this. So, next chunk is removed in this way and it is t m so t m is this much.

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- The chip length (from triangle OBC and ABC) can be given as:

$$l^2 = \left[\left(\frac{D}{2}\right)^2 - \left(\frac{D}{2} - d\right)^2\right] + d^2$$

$$l \approx \sqrt{dD} \qquad (1)$$

The volume of an individual chip

$$(Vol)_{chip} = l\bar{t}b = \bar{t}b\sqrt{dD} \qquad (2)$$

- The volume of an undeformed chip can also be obtained by dividing the material removed from the work piece in time (τ) by the number of chips

Thus,

$$(Vol)_{chip} = \frac{vbd\tau}{nN\tau} = \frac{vbd}{nN} \qquad (3)$$

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Now, let us see chip length from triangle OBC and ABC can be given as suppose this is l square that means, suppose we say AC square. So, that is a D by 2 square because it is that diagonal is D by 2 square and this minus this thing suppose I say D by 2 and this distance is actually D by 2 minus d o b is actually o b o b that means, this distance is actually D by 2 minus d. So, if I want to find out this distance that means, b c from here to here that means, this one let me show in a thicker way this one.

So, I have to subtract from D by 2 square by Pythagoras theorem D by 2 square minus D by 2 minus d square that is what is written here D by 2 square minus D by 2 minus d square. So, by Pythagoras theorem this has come b c and this is already written as d. So, this distance so now, this square plus this square b a square will give me this square, so that is why I am writing plus d square.

Now, we simplify this D by 4 square and all those type of things, but assume that d is very small. So, that d square can be neglected now here also let me just see that it becomes D by 4 square and this becomes minus again D by 4 square ok. So, this becomes minus becomes plus D d and plus it becomes d square minus d square and that was minus d square minus d square, but these this square this square cancels, so this cancels. So, ultimately you are left with d D, so l is under root d D why we say under root approximate only because this is really not perfect triangle because this is curved surface, but we are assuming that it is more or less like a straight line. So, l has come under root d by D square root of that square root of d times small d times d so that means, chip length will increase if the temperature cutter diameter increases and also the depth of cut increases.

Now, volume of an individual chip is actually l and average thickness t b so that means, we can say t b under root d by D. Now volume of an undeformed chip can also be obtained by dividing the material removed from the work piece in time tau by the number of chips.

So, volume of a particular chip can also come by this formula we speed of that table b is the width and d is the depth and multiplied by time and this is a this is this is the total material removed in term time tau, but by that time cutter has rotated by suppose in 1 unit time it rotates by capital length. So, in time tau it will rotate by n times tau and there are n teeth's in this one, so total number of teeth's involved will be n N this one. So, per teeth removal of the material is this. Each teeth is removing 1 and I am assuming that each teeth is making one chip. So, that is what we are getting volume of the chip by this formula also so, we can equate this and this we can equate these two together.

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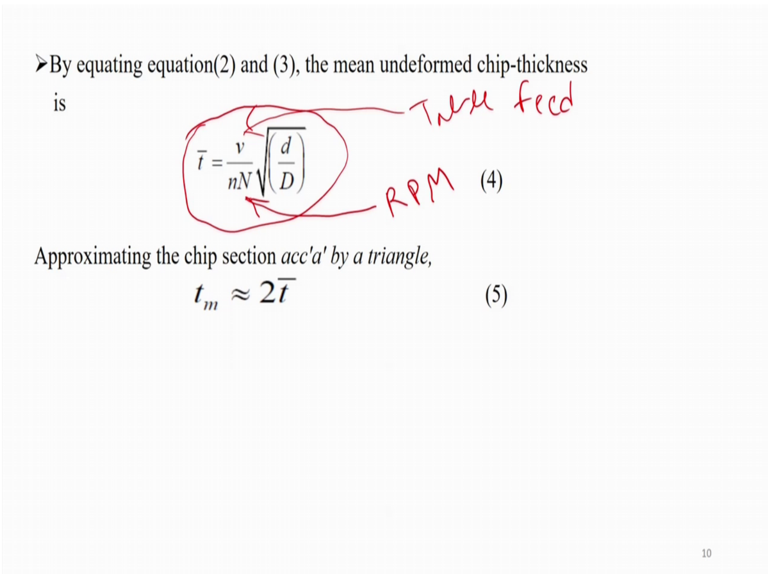

And then by equating 2 and 3, the mean undeformed chip thickness is given by this. So we are getting t is equal to this one. Now, we can also say approximate the chip thickness by a triangle chip section is shown here that can be like a triangle. So, therefore, we can say in the triangle it average is this therefore, approxy t m is equal to approximating 2 t times ok. So, that type of expression has come. This expression is showing that the chip thickness will increase if the depth of cut is increased, but if the cutter diameter increases then the chip thickness will decrease and this is what will be like this.

And it is and of course, chip thickness will be reduced if the number of teeth are more and RPM is more and naturally if the velocity is more table velocity is more than the chip thickness will be this one this is table velocity. That means, table feed and this is naturally that this is table feed and this will be n N means this is RPM, RPM of cutter or revolution per minute, you have huge consistent units of portion that whether it is if it is a millimetre per minute then you can use RPM, otherwise RPS can be used.

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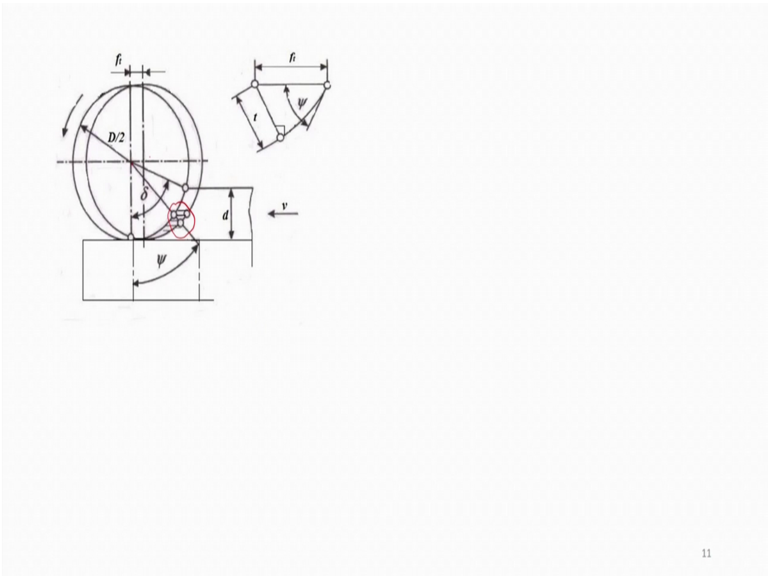

So, another way of looking it like this that suppose this is the up milling process and this was in one position then finally, it is coming like this and this is f t, I am showing that this is this that means, per tooth this is the feed. So, and it has come like this type of things so we show here that if we show like that ft. So, we show that suppose here it is this position this portion I show in a large way and this is the angle psi here and this one is angle psi. So, this angle is also psi and this is t and these are 90 degree assume and this is f t, so from this also we can get some expression ok, so that way we can see that basically we get f t sign phi type of thing.

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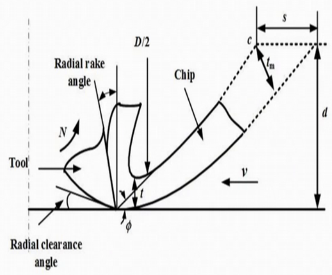

Fig.4 Chip formation in plain milling

For applying the orthogonal cutting theory, the rake angle is the same as the radial rake angle (Fig.4) when the helix angle is zero.

➢The chip-thickness varies from zero to (t_m) may be approximated to uniform value equal to .

Now, here chip formation in the plain milling is like this suppose we want to apply the orthogonal cutting theory we can consider it as a one cutting tool one tooth means one cutting tool, and this is radial angle is this that is rake angle radial rake angle is given here this is radial clearance and this is the chip and this is t m this is s and the chip is going like this. Now, chip thickness varies from 0 to t m and may be approximated to uniformly this one approximated by this one as we have mentioned there.

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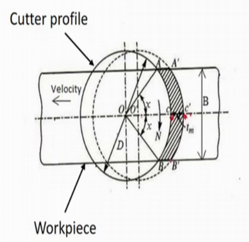

Fig. 5 Undeformed chip-thickness in face milling

Now, undeformed chip thickness in face milling we will go like this in face milling suppose the this is in position O and then it suppose it has come in position O prime that centre. So, that means, that if it has come in this position O prime in that case this one is the material removed, so this is the maximum t m this is maximum t m and this is b b prime and this is what this one.

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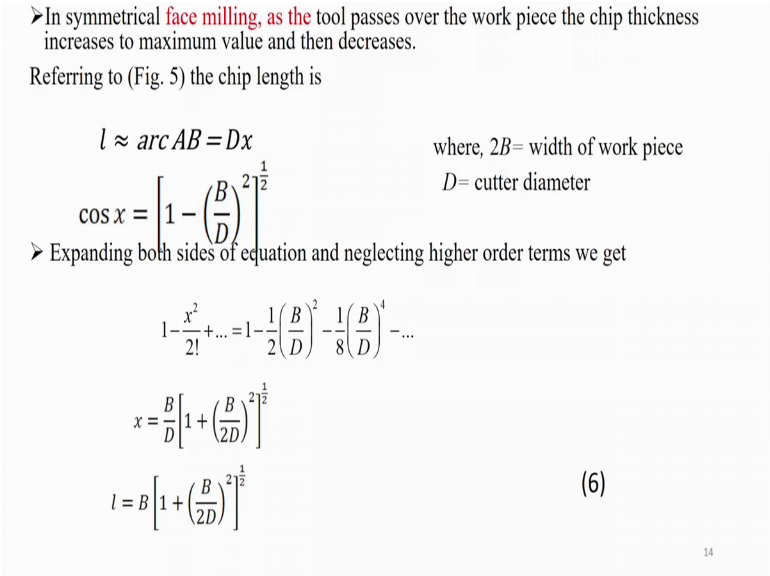

So, in symmetric face milling as the tool passes over the work piece, the chip thickness increases to maximum value and then decreases ok. So, tool is passing over the chip thickness. So now, what happens that here refereeing to this figure, the chip length is l is equal to arc of A B that is the chip length. Now, here chip length is actually D x, D is the diameter and x is the total included angle here and 2 B is the width of the work piece, D is the cutter diameter then cos x can be written as 1 minus B by D square and 1 by 2. So, expanding both side of the equations and neglecting higher order terms, we get 1 minus x square this much. So, ultimately we get expression for x as this much B by D 1 plus B by 2 D square this one and l is equal to B 1 plus B by 2 D square and this is this one.

So that means, this is the length of the chip if that one this one that this has come length of the chip, if the of course, if the diameter is very large then B by 2 D term this term will become almost 0 and in that case you will get 1 plus. So that means, result will be B itself, but if the otherwise result of the chip is slightly more because of the curvature effect; so that means, B by 2. So that means, you have got one expression for that one.

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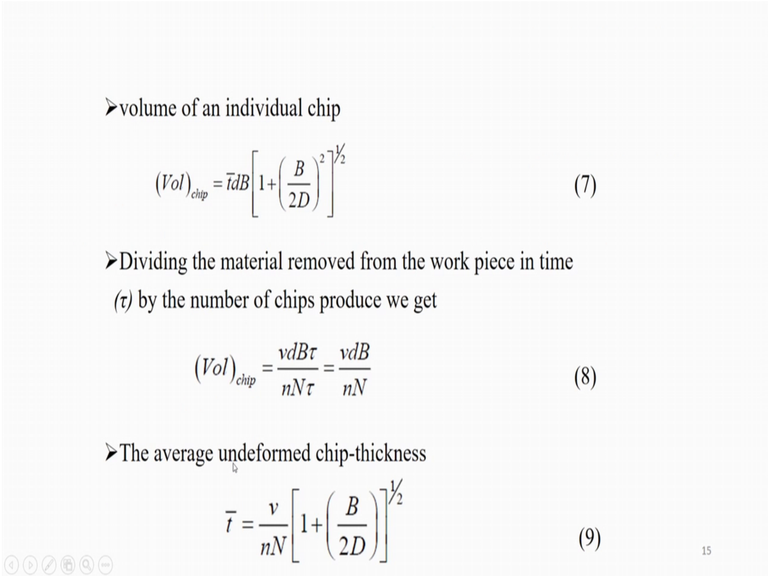

And volume of an individual chip volume of the chip is equal to t D B, so it is that means, length is known. Now I am multiplying length by that basically the average chip thickness and the corresponding that small d is the that means, ok, that means, depth in that direction that means, that axial depth. So, we get t D B 1 plus and dividing the material removal from the work piece in time tau by the number of chips like in the previous case.

We get volume of chip is equal to v d B tau, but in that much time these many tooth's have percolated. So that means, n N tau and that is why it become v d B divided by n N now the average and deformed chip thickness is given by like this both the volumes will be equated and you will get undeformed chip thickness as t is equal to v divided by n N and 1 plus B by 2 d D this will be square root of that and in this case also we get similar type of expression.

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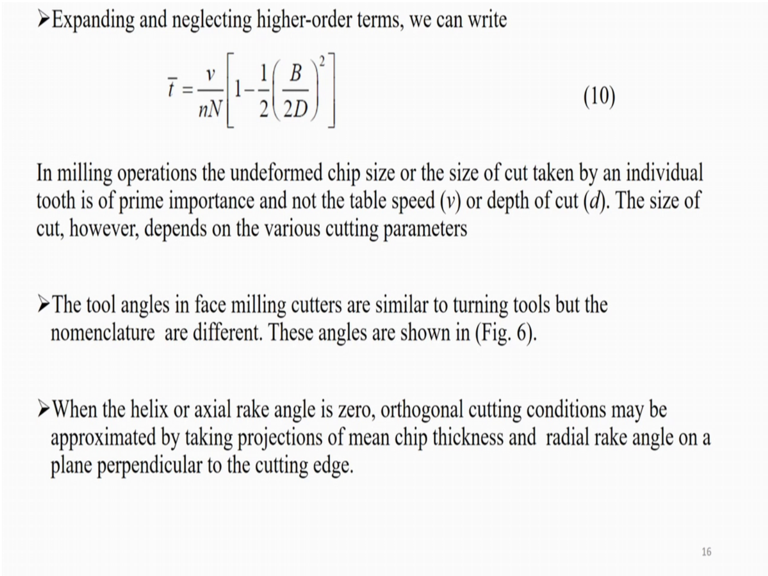

And expanding and neglecting the higher order terms we can write t is equal to v by n N 1 minus 1 by 2 B by 2 D square. So that means, if the width increases then thickness increases decreases because this is minus term here.

So, in milling operations the undeformed chip size or the size of cut taken by an individual tooth is of prime importance and not the table speed v or depth of cut D the size of cut however, depends on the various cutting parameter ok. So, tool angles in face milling cutters are similar to turning tools, but the nomenclature are different these angles are shown in next slide ok. When the helix or helix rake angle is 0 orthogonal conditions can be approximated by taking projections of mean chip thickness and radial rake angle on a plane perpendicular to the cutting edge.

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➢When the side cutting-edge angle is also zero, α is equal to the radial rake angle.

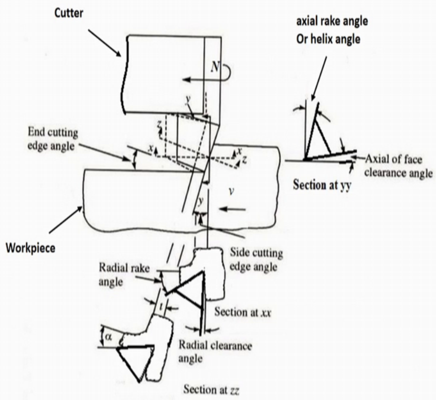

Fig. 6 Chip formation in face milling

So that means, it is when the side cutting edge angle is 0 alpha is equal to the radial rake angle. So, here we are showing the nomenclature, this is the cutter and if we take one section at x x this is coming like this. So, we get a radial rake angle here, we get radial clearance angle here and we are getting that alpha and we are getting axial rake or helix angle, axial rake is basically helix angle and this is the face clearance angle like that, so that way we can make.

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Forces:

➢Plain milling:

Figure 7 shows the forces acting during plain milling. The resultant force can be resolved into three components.

Three components of force shown in Fig. 7(a).

Fp' = Force acting along the tangential direction

Fq' = Force acting along the radial direction

Fr' = Force acting along the axial direction

➢The components along longitudinal, vertical and transverse directions can be taken as F_p, F_q and F_r as shown in Fig. 7(b).

➢When a straight cutter used, the axial or transverse component is zero and a two-dimensional force system is obtained Fig. 7 (c) and (d).

➢In milling due to periodic nature of chip formation, the forces also vary periodically leading to variation in cutting speed and vibrations.

Now, let us discuss about forces.

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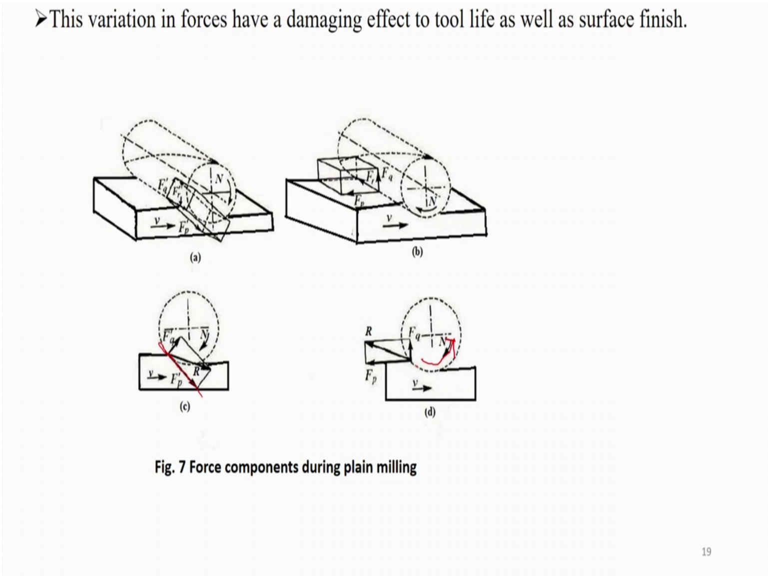

Fig. 7 Force components during plain milling

We are seeing that there are some forces acting ok. So, these are will be denoted like F force acting along the tangential direction, then force acting along the radial direction, then force acting along the axial direction. And these components along longitudinal, vertical and transverse directions can be taken as F p, F q and F r when a straight cutter used the axial or transverse component is 0 and a 2 dimensional force system is obtained, but we can use helical one also, so you have to get another component. So, milling due to periodic nature of chip formation the forces also vary periodically leading to variations in cutting, speed and vibration.

Now, I am showing the forces here you are seeing that this is F p prime then F q prime and this is F r prime in their perpendicular direction and in this simple system that this is F p, F q and F r horizontal and this one with reference to table. And I am showing that one if in a plain milling in the straight cut milling there is this one F p prime F q prime and this is going like that. So, these forces are shown on the this one suppose, suppose this tool is there and this one is this is coming, so actually this cutter is applying a force in this direction on the work piece.

So, work piece is applying a force on the cutter in this direction that means; F p prime similarly the work piece is applying a force F q prime on the cutter in this direction that means, it is trying to lift the cutter and cutter is trying to press it down so F q prime. So, these are the forces on the cutter by the work piece by Newton’s law it will be equal and opposite situation for the work piece. So, that is why you are getting like this and in this case there is a force F p again F q that means, work piece is putting a force F q here and also because this work piece is actually dragging this one yeah.

So, this is F p F q and yeah in the same way it has been shown and this is ok, so this is about this one. So, it if it is in the opposite direction then it should have been like this that means, it should be down milling situation in that case this will be this one ok. So, this will be this direction will be shown in the opposite that direction then ok.

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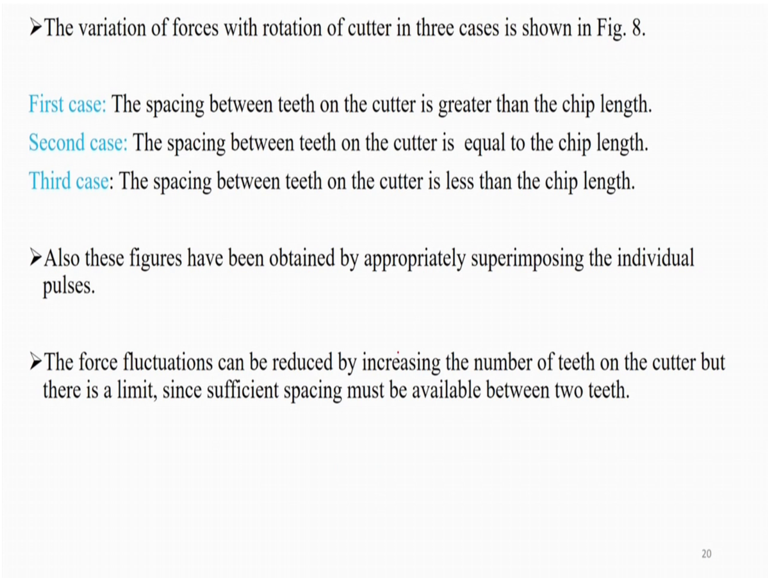

So, this is these are the force components the variation of forces with motion of cutter in three cases are shown.

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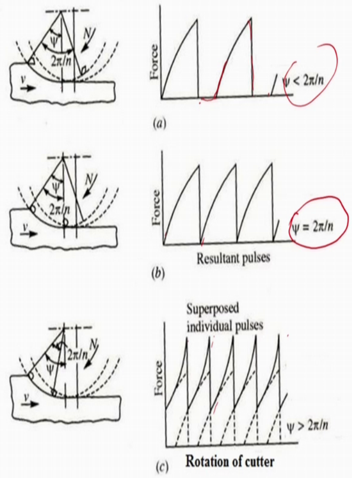

Fig. 8 Force fluctuation in plain milling for zero helix angle

Now, what may happen that suppose is teeth's are spaced very far away. So, spacing is far away that means, to a t is 2 pi by n is this much, but the distance, but this bite angle is only phi so that means, one teeth has gone here, but the other has yet not come. So, in that case you will get this situation that means it is the fluctuation is happening spacing between teeth on the cutter is greater than the chip length.

So that means, force increases gradually as the chip thickness increases from 0 to maximum, but then it decreases suddenly then there is a gap, because no contact is there then it goes and this is the thing. So, this is very jerky situation you get that type of thing. Other situation is that psi is equal to exactly 2 pi by n.

So, force decreases and then suddenly it increases. The third situation is that psi is greater than 2 pi by n, in that case what happens that here? Individual pulses are going like this and force is going up, but suddenly the other teeth also have has made contact, so that thing is also there. So, what happens that their resultant effect will be like this, so it is never becoming 0 and there is a less amount of fluctuation and you get that type of thing. So, this is what we have shown the individual forces have been superimposed.

So, first case the spacing between teeth and the cutter is greater than the chip length and second case the spacing between teeth on the cutter is equal to the chip length and the third case the spacing between teeth on the cutter is less than the chip length. These figures have been obtained by appropriately superimposing the individual pulses force fluctuations can be reduced by increasing the number of teeth on the cutter, but there is a limit since sufficient spacing must be available between 2 teeth's otherwise there will be lot of problems including the chips may also get obstructed between.

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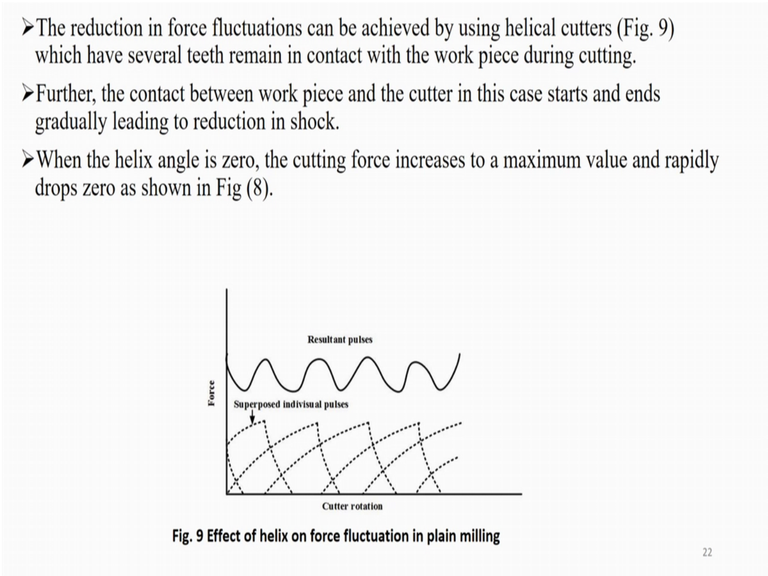

Fig. 9 Effect of helix on force fluctuation in plain milling

So, reduction in force fluctuation can be achieved by using helical cutters which have several teeth remain in contact with the work piece during cutting because there is helical.

So, in the width direction one portion is cutting, but the other is not cutting like that. So, it balances further the contact between work piece and the cutter in this case starts and ends gradually leading to reduction in shock. When the helix angle is 0 the cutting force increases to a maximum value and rapidly drops to 0, as we have shown in this figure that means, here like that, but otherwise if we superimpose individual pulses then resultant force may be like this. So, effect of helix is to make is smoothen that forces coming on that one.

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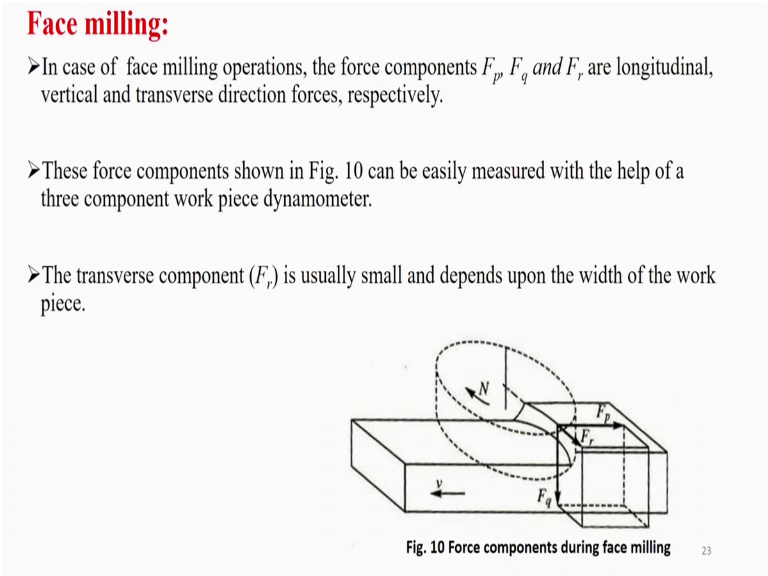

Fig. 10 Force components during face milling

In the face milling operation, the force components F p, F q and F r are longitudinal, vertical and transverse direction forces. These force components can be measured with the help of a three component work piece dynamometer; transverse component F r is usually small and it depends upon the width of the work piece ok.

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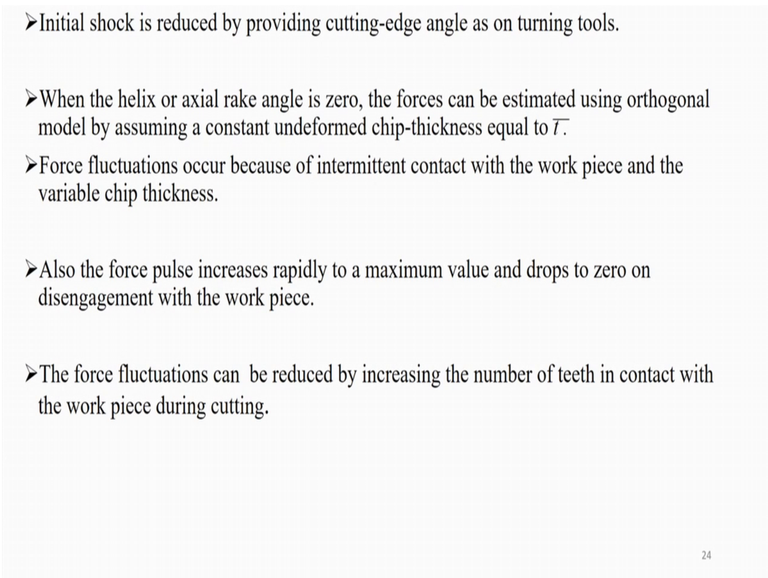

So, this becomes like this. Initial shock is reduced by providing cutting edge angle as on turning tools. When the helix or axial rake angle is 0, the forces can be estimated using orthogonal model. Force fluctuation occur because of intermittent contact with the work piece and the variable chip thickness. Also the force pulses increases rapidly to a maximum value and drops to 0 on disengagement with the work piece. Force fluctuation can be reduced by increasing the number of teeth in contact with the work piece during cutting.

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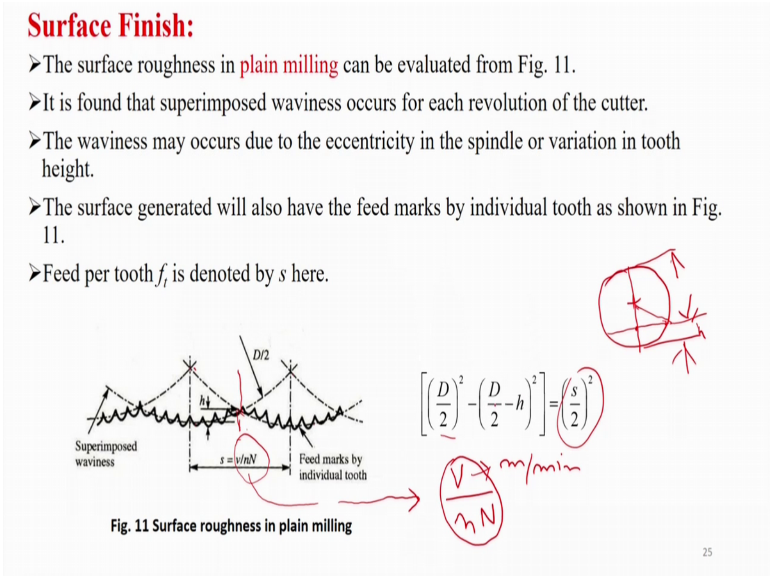

Now, let us discuss something about the surface finish, now surface roughness in plain milling can be evaluated from figure this one here what happens it is found that superimposed waviness occurs for each revolution of the cutter, but suppose this distance is s is equal to v by n N s is the feed per unit tooth that which we wrote f t there. So, it is v divided by n N is the suppose revolution by that much time and then what happens that here that is denoted by s here that what happens this is v is the suppose the distance of the table in meter per minute. If I divide it by n I will be getting meter per this distance moved in one revolution, but if I divide it by n also then I will get distance moved by 1 teeth ok.

So that means, one portion was here and the other is here, so here that is it is showing that suppose you have removed the material like this and then we also moved we move this portion is here then this has moved here. So, here it has removed suppose this much material, so this much portion remains.

So, this h is called basically the height of the peak. So, this can be obtained like that D by 2 square minus D by 2 is this radius minus D by 2 h square s by 2, so suppose s by 2 because this distance is actually s by 2. So, situation is like this is s by 2 s is here and this is h this distance is h this distance is h and this is really D by this is this one. So, it is actually D by 2 minus h ok, so D by 2 and this is h, so if I do Pythagoras theorem this is s by 2 square is equal to D by 2 square this minus D by 2 minus h square.

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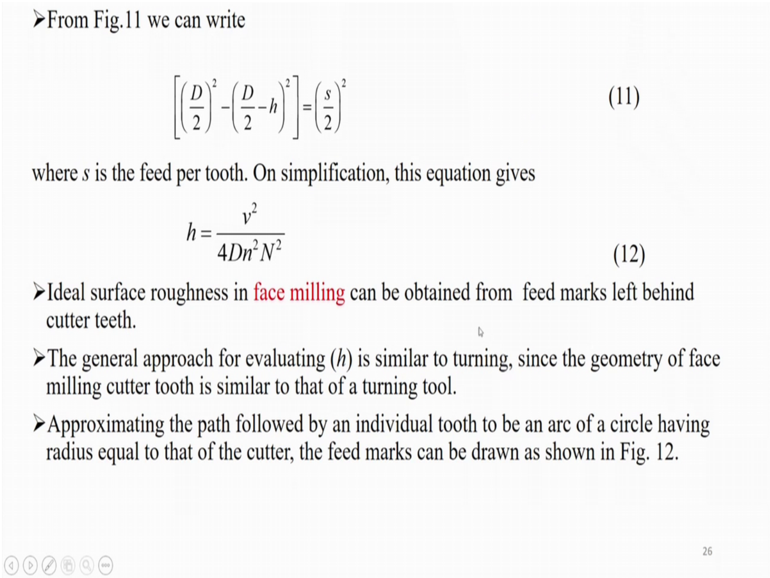

So, if we do simplify it here this becomes from this one it becomes like this and simplification we get we can put the expression for s and we get h is equal to v square by 4 D n square by N square.

So that means, that your roughness height will be proportional to square of v that means, table feed is more then you will be poor surface finish, but if diameter is increased it is better, if more teeth's are there better, if more all PM is there it is better. So, ideal surface roughness in face milling can be obtained from feed marks left behind cutter teeth. General approach for evaluating h is similar to turning, since the geometry of the face milling cutter tooth is similar to that of turning. Approximating the path followed by an individual tooth to be an arc of a circle having radius equal to that of the cutter, the feed mark can be drawn as shown in this figure 12.

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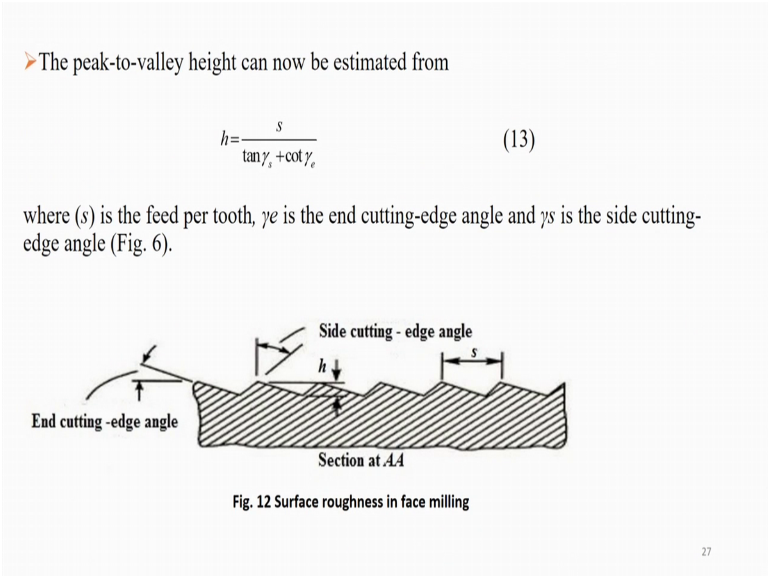

Fig. 12 Surface roughness in face milling

So, here also suppose we have this one sharp edge in plain milling face milling we are cutting like this and here it is h. So, like in turning h is equal to S divided by tan gamma S plus cot gamma e s is the feed per tooth and gamma e is the end cutting edge angle and gamma s is the side cutting edge angle.

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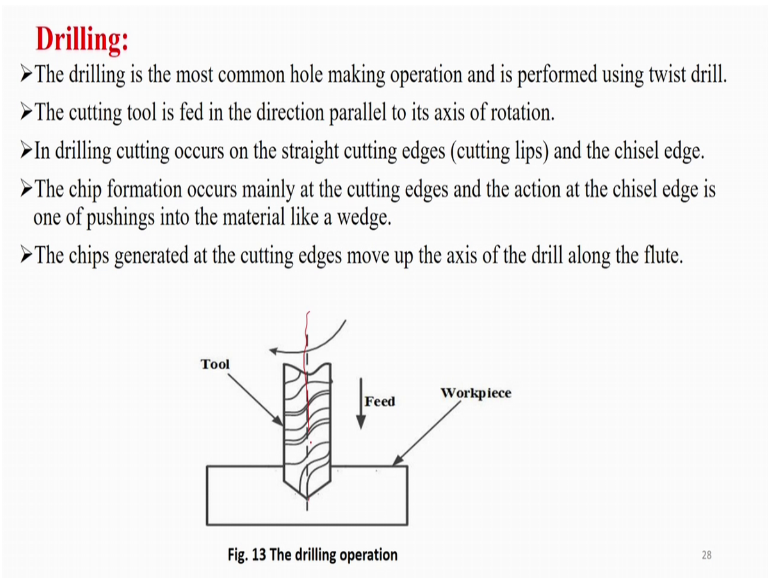

Fig. 13 The drilling operation

And in drilling is the most common hole making operation and is performed using twist drill the cutting tool is fed in the direction parallel to its axis of rotation it is axis of rotation is this. So, the feed is also in this direction in drilling cutting occurs on the straight cutting edges cutting those are called cutting lips and the chisel edge.

Chisel edge here and the cutting edge is straight here the chip formation occurs mainly at the cutting edges, and the action at the chip chisel edge is one of pushing into the material like a wedge. So, chip generated at the cutting edge edges move up the axis of the drill along the flute. So, it is chips actually moved through the flutes in a due to helical that path and it is like that.

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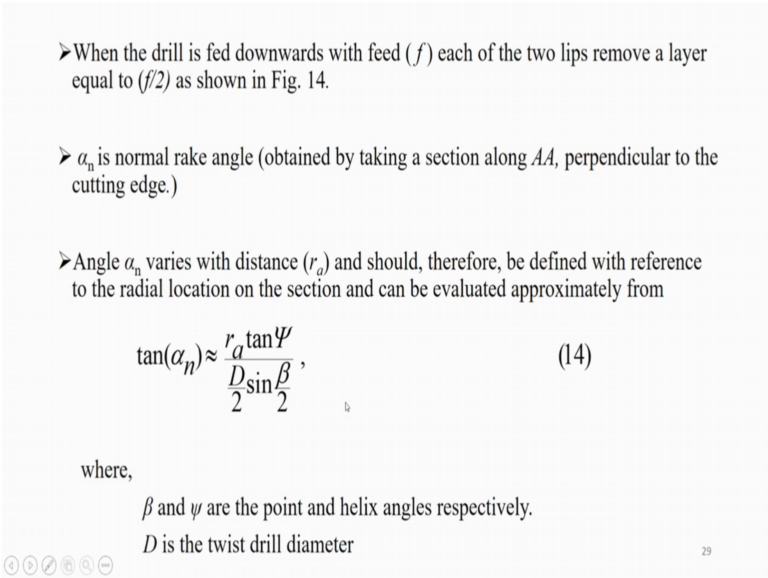

So, drilling when the drill is fed downwards with feed f each of the 2 lips remove a layer equal to f by 2 as shown in figure this one figure 14.

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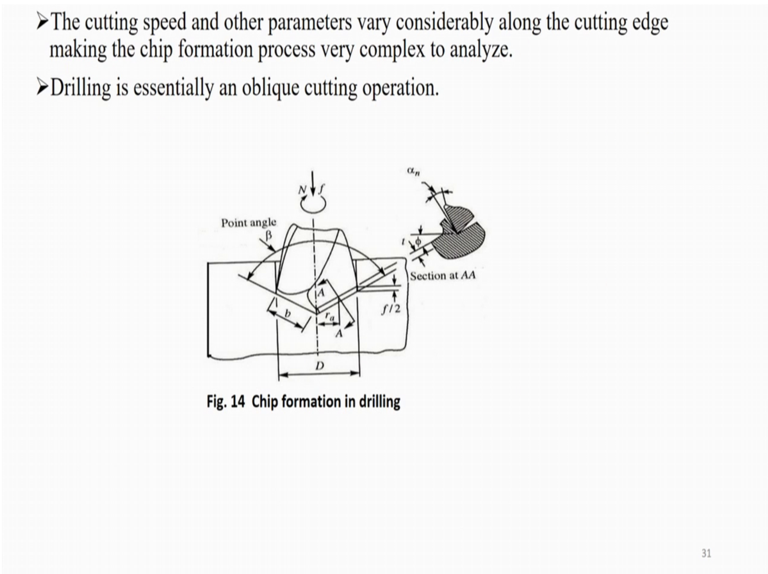

That means there are 2 lips, so each f by 2 f by 2 ok. Now, here alpha n is normal rake angle, so alpha n is shown here that if we take a section. So, we can get here alpha n section a will give you alpha n and alpha angle alpha n values with distance r a and should therefore, be defined with reference to the radial location on the section and can be evaluated approximately from this there is a formula that tan alpha n is equal to r a tan psi D by 2 sin beta by 2. Beta is the point angle and psi is the helix angle d is the twisted diameter beta is actually complete point angle that is shown here.

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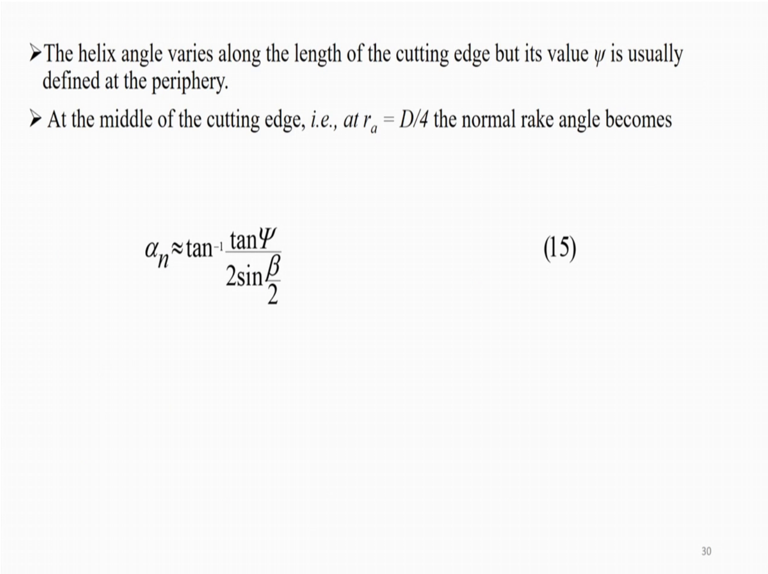

So, this formula is there and this one helix angle varies along the length of the cutting edge, but its value psi is usually defined at the periphery. At the middle of the cutting edge that is at r a is equal to D by 4 the normal rake angle becomes alpha n is equal to tan inverse tan psi divided by 2 sin beta by 2 ok.

So, alpha n expression has come like this cutting speed and other parameters vary considerably along the cutting edge because here the cutting surface is different here the periphery is different. So, making the chip formation process very complex it is essentially an oblique cutting and you are seeing here in this figure that n is there and f is there this is point angle 2 lips are like that cutting. And this is a point angle and this y will be that is psi and then this is alpha n and then this is section at AA has been shown here and this will be psi and this is this angle this thickness chip thickness is shown here like t.

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Undeformed Chip-thickness

- Referring to Fig. 14,

  The undeformed chip-thickness = t

  The chip width = b

  (t) and (b) can be evaluated as

$$t = \frac{f}{2}\sin\frac{\beta}{2} \qquad (16)$$

$$b = \frac{D}{2\sin\frac{\beta}{2}} \qquad (17)$$

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Now, undeformed chip thickness from this figure is called t chip width is b, so this chip width is b. So, t and b can be evaluated as t is equal to f by 2 sin beta by 2 and b is equal to D by 2 sin by beta by 2 similar to turning, so these expressions are here given here. So, you are seeing that t is equal to b by 2 this one. So, feed and b is equal to this much b is actually this width here, so b by 2 b is equal to D by 2 sin beta by 2 so that means, this is the you can say this is the chip width.

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Forces and Power:

The drilling force can be resolved into the components

F_p = The tangential component

F'_q = The force component normal to the cutting edge.

F'_q can be further resolved into two components

1. The radial component = F_r
2. The thrust component = F_q (acting axially)

These forces are shown in Fig. 15.

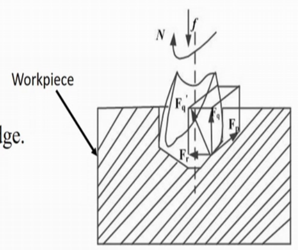

Fig. 15 Force components in drilling

- The total force in the tangential direction during drilling consists of tangential components at the cutting edges and the forces due to flank friction. Chisel edge also contributes to it.
- Thus, for a twist drill with two lips

$$F_P = 2\left[F_p + F_{p1} + F_{p2}\right] \qquad (18)$$

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Now, forces and power the drilling force can be resolved into the components F p is equal to tangential component and F q prime is equal to force component normal to the cutting edge F q prime can be further resolved into two components radial component is F r and thrust component is F q. These components have been shown these forces are shown here total force in the tangential direction during drilling consists of tangential components at the cutting edges and the forces due to flank friction chisel edge also contributes to it thus for a twist drill with 2 lips F p is equal to 2 F p plus F p 1 plus F p 2, so here F p is equal to this 1 ok.

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Here, F_{p1} and F_{p2} are the tangential components of the forces due to friction and extrusion at the chisel edge.

Similarly, the total thrust force F_Q during drilling with a twist drill having two lips given by

$$F_Q = 2\left[F_q + F_{q1} + F_{q2}\right], \qquad (19)$$

where Fq_1 and Fq_2 are the thrust forces due to friction and extrusion.

➢Experiments show that F_{p1} and F_{p2} are much smaller than F_p with more than 85% of the torque coming from cutting action at the lips.

➢The contribution of force due to friction F_{q1} on total thrust is negligibly small, usually less than 3%.

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So, this will be F p 1 is this one twist thus for a twist drill with two loops that is one is due to chisel may be F c F c plus F p 1 plus F p 2. So, here hence F p these are F p 1 and F p 2 are the tangential components of the forces due to friction and extrusion at the chisel edge. Similarly, the total thrust force F q in a drilling with a twist drill having 2 lips is given by 2 F q plus F q 1 plus F q 2 where F q 1 are the thrust force due to friction and extrusion and one is above the cutting. So, F p 1 and F p 2 are much smaller than F p with more than 85 percent of the torque cutting from cutting action at the lips.

So, this if I can use this is capital p this is correct symbol then I can use F p that means, this is cutting component and this is F p 1 and F p 2 that means, friction and extrusion. So, contribution of, so F p is more than 85 percent and this is contribution of force due to friction on total thrust is negligibly small usually less than 3 percent.

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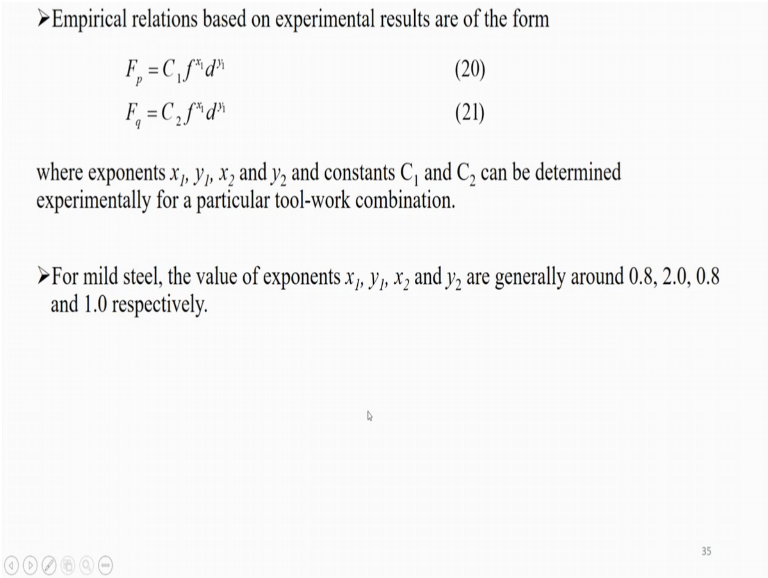

And empirical relations based on experimental results are of the form Fp is equal to C 1 f to the power something and F 2 is the corresponding thrust component we get this one. So, for mild steel the value of exponents are generally around 0.8 and d is means this is 2 ok. So, d D is that is diameter here that is 2 and this is this one is 8.8 and 1.

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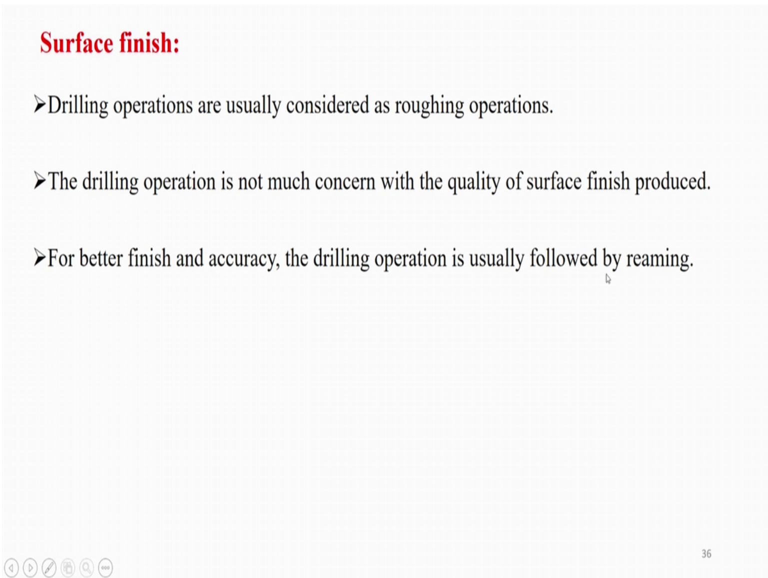

Now, surface finish of drilling operations are usually considered as roughing operation. So, drilling operation is not much concern with the quality of surface finish. For better accuracy, the drilling operation is usually followed by reaming, ok.

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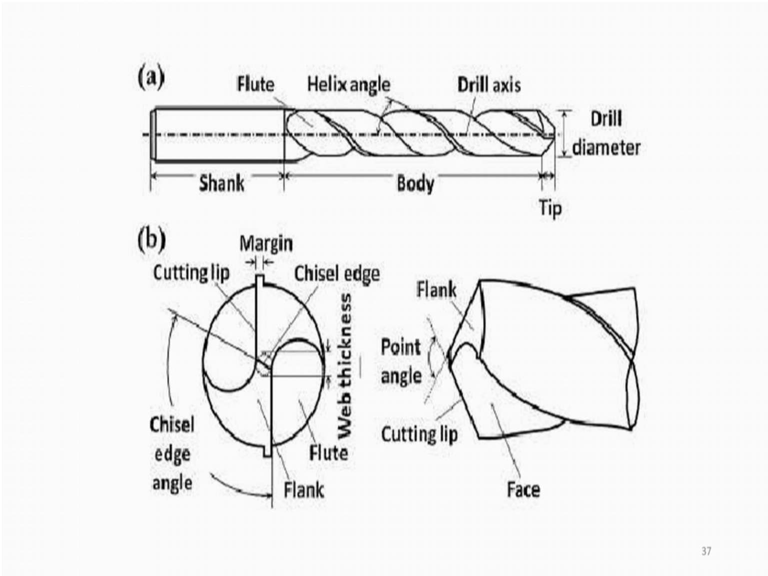

So, this is I am showing that one complete drill that you can just see that actually may be you take a real drill in your college and you can compare this one this portion is called shank which fits in a shank holder then these are the flutes on which chips will moved and this is inclined. So, this is helix angle these flutes are inclined and this is the drill axis then this is drill diameter and this portion is called tip here you are having the cutting lips and if we show that these are one cutting lip here and then this is another cutting lip here this is point. So, this is called point angle and this portion is the flank because cutting edge is there then side surface is the flank and here that this portion that body will be little bit down compare to the cutting lips.

So, this is called some margin this is cutting lip this is going up to this and this is called margin and this is this is called this is chisel. So, this is called chisel edge angle from here to here and this is the flank and this is called here basically the web thickness in this portion here it is a this one and then this is called flute ok. So that means, this is the complete that nomenclature of this one drilling and a drill and this has been shown.

So, we have talked today about milling and drilling operation although the force calculation etcetera is very complicated here, but we have actually discussed bit because these are essentially oblique cutting, but this will certainly give you some idea about the physics of the process. So, we will continue our discussion in the next class.