Production Technology: Theory and Practice
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Lecture – 06
Cutting Tools and Types of Machining

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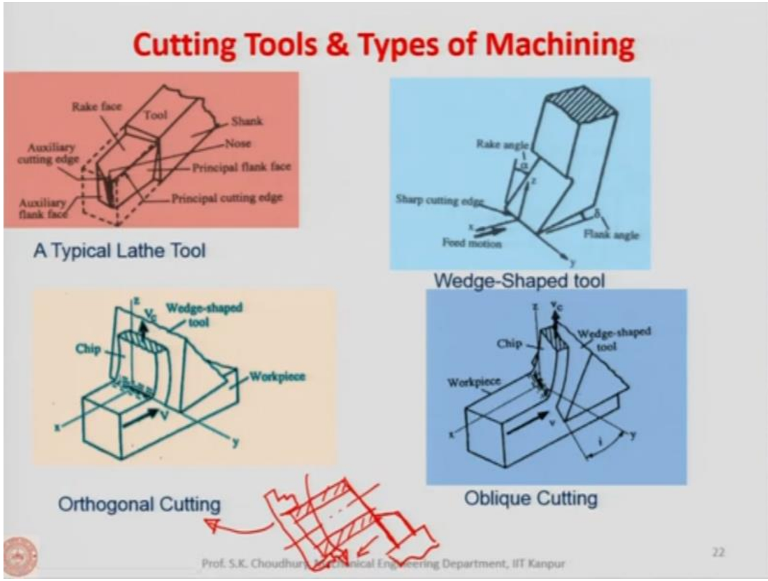

Hello and welcome back to our discussion series of this course. I remind you that last time what we discussed in the cutting tools and types of machining that what is oblique cutting, what is orthogonal cutting and I told you that normally in practice oblique cutting is used because in oblique cutting the tool grabs the workpiece material gradually and therefore, the tool strength available will be more than in case of the orthogonal cutting.

orthogonal cutting is a 2dimensional cutting where the chip flows exactly perpendicular to the cutting edge, because in case of orthogonal cutting the tool edge is perpendicular to the cutting velocity vector and in case of oblique cutting this is not the case. That means, the tool edge is inclined with respect to the cutting velocity vector. Therefore, the chief flows along the x, y, z axes, along all the axes.

As a result, the cutting forces in case of orthogonal cutting are confined to one plane, xz plane. Whereas, in case of oblique cutting the cutting forces will remain in xyz plane because the cutting edge is inclined with respect to the cutting velocity vector. That is the basic difference between the oblique cutting and the orthogonal cutting. Once again, mostly it is the oblique cutting that is used in practice.

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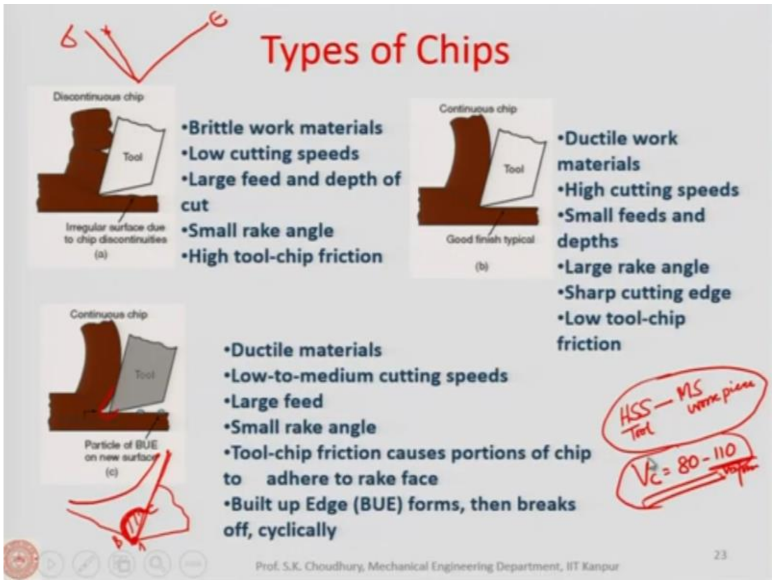

Next, we discuss the type of chips. I told you that there are continuous chips, there are discontinuous chips and there are continuous chips with built-up edge formation. I told you about the mechanism of the built-up edge formation that why built-up edge is formed. Once again, because of the high strain rate of deformation, because of the very high pressure and temperature, a thin layer is removed from the chip, which is in contact with the rake face of the tool.

As a result of that high pressure and the temperature, a thin layer will also be removed from the rake face of the tool. Those two surfaces become fresh surfaces and they will have the afinity to get welded. So, they get welded and the welded junction is formed between the nascent surface of the chip and the nascent surface of the rake face. This welded junction will resist the flow of the chip along the rake face and it will start piling up at the rake face.

Particularly around the cutting tool edge. Once it piles up, it will further create resistance to the flow of the chip and the piling up will start growing and as it grows beyond a certain level, so it becomes unstable and then it breaks. But if the condition of high pressure and high temperature remains the same in that case the piling will continue and the built-up edge will again start growing and gets piled up.

Then it is broken because it is unstable, and then again piles up and so on. We discussed that this piling up happens because there is certain temperature and pressure so that temperature and pressure occur at a certain cutting condition, particularly for the high speed steel tool and the mild steel as a workpiece combination, the cutting velocity is normally in the range of 80 to 110 *m/min*.

Now, if the velocity becomes more than 110 *m/min*in case of mild steel and the high speed steel, then the temperature will be more than the temperature of re-crystallization of the workpiece material and I told you during the discussion on materials and their properties that during recrystallization, the new grains are formed. In that case, the built-up edge vanishes, because the temperature goes beyond the temperature of recrystallization.

That means the formation of the built-up edge becomes only at a certain range of cutting parameters particularly the cutting speed and when the temperature occurs within a certain level.

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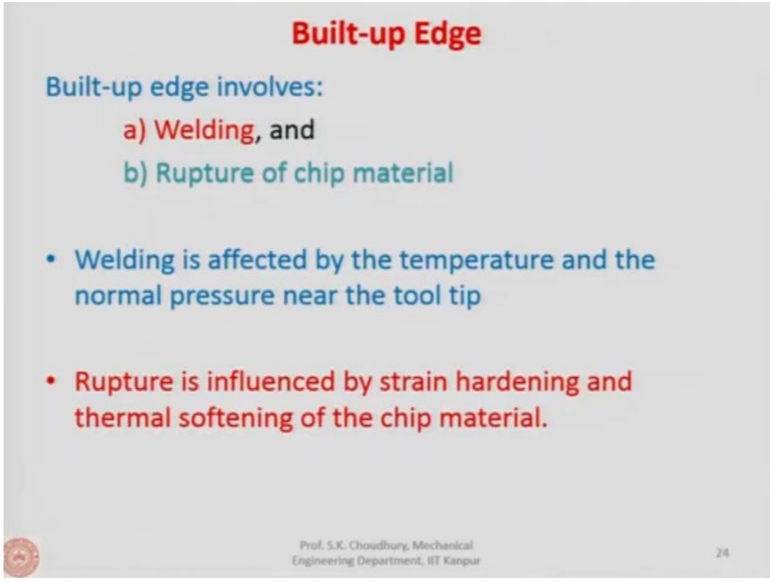

Built-up edge involves therefore, welding and rupture of the chip material. welding because the two nascent surfaces of the chip and rake face get welded and it will be ruptured. Welding is affected by the temperature and the normal pressure near the tool tip which becomes very high and the rupture is influenced by the strain hardening process and the thermal softening of the chip material because at a high temperature it is thermally softened and the temperature occurs as you increase the cutting velocity.

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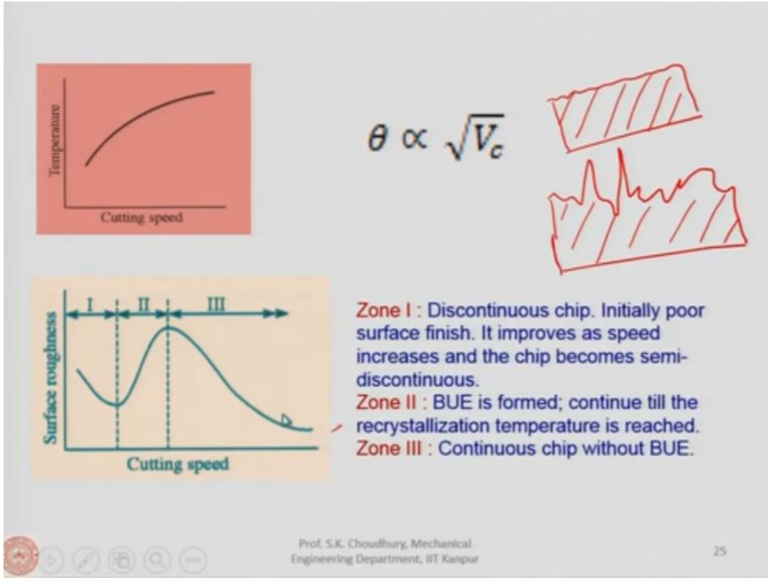

The temperature is proportional to the square root of the cutting velocity. As the cutting velocity increases the temperature also increases but in this fashion; it will be nonlinear, it will not be proportionally increasing but it will be like this because it is $(V_c)^{0.5}$ this is proportional to $(V_c)^{0.5}$. At this temperature, surfaces will be welded since the temperature increases with the increase in cutting speed and there it will be ruptured.

Therefore, the welding is affected by the temperature and the normal pressure near the tool tip which is very high but the rupture is influenced by the strain hardening and the thermal softening of the chip material. Now, let us see what is discontinuous chip? What is continuous chip with the built-up edge formation? As the cutting speed increases, let us say for different condition of machining, the cutting speeds are different.

For different cutting speeds, what will happen with the surface roughness or the surface finish? As you understand that surface roughness defines surface finish; meaning more the surface roughness, rougher is the surface, surface finish is low and vice versa. Surface roughness is the undulations on the surface. By undulation we mean that if we look at the surface, if you suppose exaggerate the surface, it can look like this.

Let us say that this is the metal surface. If you exaggerate this will be the undulation. More the undulation more will be the roughness and less will be the surface finish. But if a surface looks like this that means the undulations are less and the surface finish is better. You can say that this surface finish of the surface is better than this surface, because here the surface roughness is more than in this case.

As the cutting speed increases, the curve which represents the change in the surface roughness goes like this; it has 3 distinct zones, 1 zone where the curve is falling then it starts improving, i.e. surface roughness is going up and then again surface roughness goes down. At the very beginning here the cutting speed is small.

So, with the low cutting speed, discontinuous chips are produced. Discontinuous chips means, I already told you that there will be fluctuation in the forces and there will be feed marks remaining on the surface spoiling the surface. So, the surface finish will be bad. Therefore, the surface roughness is high. Then as the cutting speed increases further, let us say beyond this point, then the chip turns from the discontinuous to continuous chip, because the speed is increasing.

Therefore, the surface finish improves meaning the surface roughness decreases. It comes to this point, then it goes into that zone of the cutting speed where the temperature and pressure will be favorable for the built-up edge formation. I remind you that for mild steel this is 80 to 110 *m/min*. if the material is mild steel, in that case this will be the 80 to 110 *m/min*cutting speed.

Further, since the built-up edge has been formed, the surface finish will be bad because again cutting force fluctuates, then the power fluctuates, as I said this rake angle changes and it is a dynamic change in the rake angle as the as the built-up edge is piled up and then it breaks. Therefore, the surface finish is deteriorated and because the surface roughness goes up, it goes up to a point beyond which the cutting speed, the temperature rises further.

Because the temperature rises proportional to $\sqrt{V_c}$, then from here the temperature will be more than the temperature of recrystallization and the built-up edge vanishes. Therefore, the surface finish improves and because the surface roughness goes down because the built up edge is no more and cutting process is smooth. These are the 3 distinct zones that are demonstrated during the cutting process for different cutting velocities.

At lower cutting speed it is discontinuous chips, at medium cutting speed built-up edge can be formed and at higher cutting speed the surface finish is better. Surface finish overall will be always better at a higher cutting speed than at the lower cutting speed. At this moment what we are telling is that the reason is that the built-up edge does not appear. There are other reasons as well, that we will discuss later.

You can read the staements written in the slide. Here the zone 1 is the discontinuous chip. Initially poor surface finish is generated. It improves as the speed increases and the chip becomes semi-discontinuous here. In zone 2, I already told you that built-up edge is formed which continues till the recrystallization temperature is reached and then the continuous chip without the BUE is formed because BUE vanishes, since the temperature goes beyond the temperature of recrystallization.

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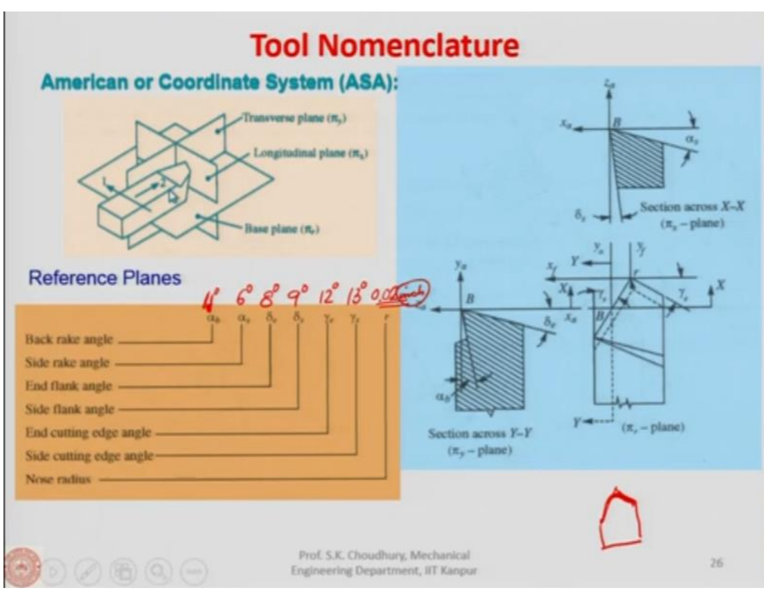

Next we will discuss the tool nomenclature which is that how the tool angles and geometrical parameters of the tool, particularly the angles and the tool nose radius, are defined. In different countries this nomenclature or the definition of the angles is different. Depending on that we have distinguished, particularly I will discuss 3 systems quickly and one of them is used in India also but all others used in other countries.

But we have to discuss because we have to understand it since we are using tools in that nomenclature, in that system, where the nomenclature is given in that system. We have to use those tools in our system. So, we have to adjust the angles accordingly for grinding of tool angles and setting the tool on the machine. How to adjust, what are those adjustments that we will discuss now. The first nomenclature is in the coordinate system, this is expressed in the coordinate system where xyz coordinates are used.

Let us say this is the plane which is the base plan. This is the plane where the tool is rested like this. With respect to the base plane, there are 2 perpendicular planes, one is the transverse plane, this is along the transverse feed. I will remind you that the transverse feed is the feed when the tool moves perpendicular to the axis of the workpiece when facing operation is done. That is the transverse plane along the transverse feed.

Another plane is perpendicular to both the base plane and the transverse plane, called the longitudinal plane. Here it is given as $\pi - X$. this $\pi - X$ is the longitudinal plane along the longitudinal feed; longitudinal feed is the normal feed direction. This is the direction along the axis of the workpiece. These are the 3 mutually perpendicular planes in which the tool angles are defined. Looking at the diagram, this is the tool in the base plan, that is the π r plane, and that is the base plane.

At this point B, we will take 2 sections, 1 section is X-X this is along the longitudinal feed direction; and another section is the Y-Y ; this is along the transverse plane Y-Y. We will place this view here that is X-X we will place it in here and Y-Y cross section we will place here. If we take the cross section at this point and look at the tool, the tool will be visible in this way where this is the rake face, this is the flank face.

Mind one thing - here in this base plane rake face and the flank face will not be visible. So, in this case you take the plane, and take the cross section like this and then you place it like this and see this or you take this cross section like this at V point and then you place it here. Then only the rake face and the flank face will be visible. Similarly for the Y-Y if you section it like this and reveal t what is visible, like this.

In this plane, rake face here and the flank face will be visible. Otherwise, in this base plan neither rake face not the flank face will be visible. Now three planes are here. Here the angles given are the back rake here, this is one of the rake angles. Now mind it there will be two rake angles because there are two inclinations along the rake face. Two inclinations because one is along the tool rake face where chip flows.

And another inclination where the resistance to flow of the chip will be minimum or the rake angle is more. Therefore, there are more than one rake angle. Here this is another inclination of the rake face and this is given by the side rake angle. Both the rake angles define the inclination of the rake face with respect to a line perpendicular to the cutting velocity vector. For example, in case of the back rake angle, this is the angle between the rake face here and a line, this is the line which is perpendicular to the cutting velocity vector.

Similarly, here this is the line X_a, this is perpendicular to the cutting velocity vector and this is the angle between that line and the rake face of the tool. So, these are the two rake faces, similarly, there will be two flank faces, since there are two rake faces there have to be two flank faces as well. One flank angle is the end flank angle, δ_e and another is the side flank angle. This is the δ_s. These are the two sets of angles, two rake angles and two flank angles in the coordinate system.

Coordinate system is also called the American system because it is used in the United States. Other 2 angles are the cutting edge angles, these are the 2 cutting edges, this is the principal cutting edge and this is the auxiliary cutting edge. The principal cutting edge makes an angle with the y-axis which is called the side cutting edge angle. And when the angle is with respect to x-axis, this is the end cutting edge angle with the auxiliary cutting edge.

Once again, principal cutting edge on y-axis makes the angle of side cutting edge angle and the auxiliary cutting edge on x-axis makes an angle of end cutting edge angle. This is another set of angles which is cutting edge angles. 3 sets of angles, 3 sets of rake, flank and the cutting edge angles. So, there are 6 angles altogether. And another important parameter is the nose radius. This is the *r*.

Normally the tool is not very sharp, because when the tool is sharp, in this case, there will be a lot of stress concentration, and the tool may be broken and it can chip in. That is the chipping of the tool. It can break as soon as it comes in contact with the workpiece. Therefore, normally there is a nose radius given to the tool tip.

We will see later that it has another advantage also. When we have nose radius, the surface finish improves. I will tell you the physics behind it, why the surface finish improves, when we discuss the surface finish chapter. Overall, there is a nose radius given and the value of the nose radius can be different and that nose radius is also mentioned in this nomenclature as one of the parameters, so 6 angles and the nose radius.

These are the 7 parameters which are mentioned in a certain sequence. In the coordinate system, that sequence is that the first angle will be the back rake angle then the side rake angle then the end flank angle, side flank angle, the end cutting edge angle and the side cutting edge angle after that this is a nose radius. Please note that the flank angle and the clearance angle is the same.

In some books you will find that it is given as a flank angle, in some books it can be given as a clearance angle, these are the same. On the tool, when you are purchasing a tool, this will not be written that which one is the back rake which one is the side rake and so on. The tool may have this kind of a nomenclature 4^0 - 6^0 - 8^0-9^0-12^0-13^0 - 0.02 inch, this is inch because it is American systems.

Nose radius is given in inch, but inch will not be written after 0.02. You have to read, you will not be said that this will be back rake angle, you have to read that the first angle is the back rake angle. So, the back rake angle for this tool in this nomenclature will be 4^0, side rake angle will be 6^0 and flank angle will be 8^0, side flank angle will be 9^0 .,.

End cutting edge angle is 12^0, side cutting is 13^0 and the nose radius is 0.02 inch. This is about the coordinate system. This system is the easiest one because it is in the x, y, z system of axes as shown in the slide.

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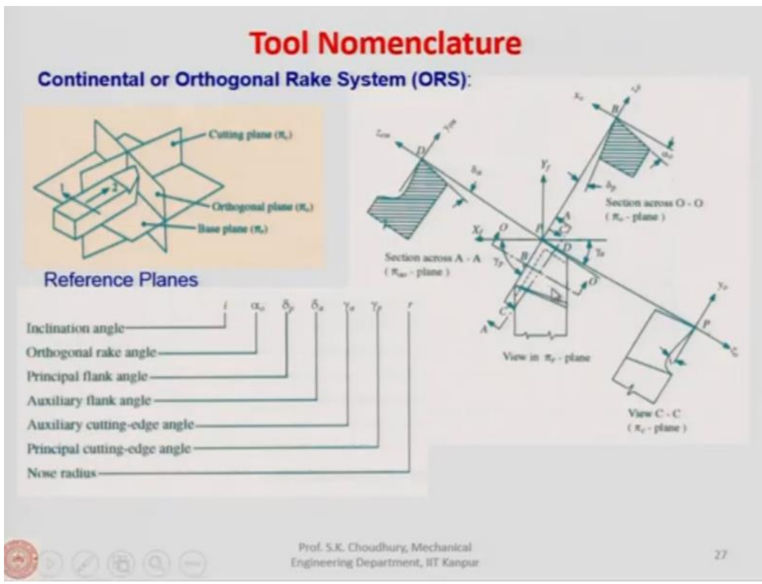

Let us discuss another system which is called the Continental or orthogonal rake system. This is the ORS or orthogonal rake system. In the orthogonal rake system, the reference planes are the following, that it is the same base plane like in case we have taken for the coordinate system where the tool is located, tool is lying there. Now with respect to that we will take the other angles in other planes.

With respect to the base plane, we have two more planes which are different than in case of the coordinate system. One plane is the cutting plane. This cutting plane is the π_c; cutting plane is the plane which will contain the cutting edge, cutting edge is lying on the cutting plane that is the cutting plane containing the cutting edge.

Now perpendicular to that is an orthogonal plane; orthogonal plane is perpendicular to this. Therefore, if we have the tool view in the base plane like this, at this point B we will take such kind of sections, one section will which will be CC. This will be a view because it is not a sectional view which is not cutting across but it is just lying on that C, we said that the cutting plane will contain the cutting edge, this is the principal cutting edge.

This is the auxiliary cutting edge. I mentioned that these are the cutting edge angles; this is the principal cutting edge, and this is the auxiliary cutting edge. Now, with respect to this O-O, first let us say C-C is the plane which will contain the cutting edge. So, we will take a view because it is not the section. The view will not be hatched as you understand.

This is the principal cutting edge, this is the plane which is containing the principal cutting edge, then when it is shown here, we will see the rake angle and the flank angle or the rake face and the flank face like in case of the coordinate system. When we see the view, that is why it is written view C-C, this is the rake face, inclination of the rake face, and this is the flank face.

This is the tool which is shown if we take that view C-C, means that if we look at the tool from here, perpendicular, to this from the top, perpendicular to the principal cutting edge, you can see this view. In this view, this is the inclination of the rake face and with respect to Y_0, this will be the angle which is called the tool inclination angle which is I . This tool inclination angle is also called the angle of obliquity.

That we will discuss a little later. I will explain it to you another section we will take as O-O which is perpendicular to C-C. This is the orthogonal plane, O-O is perpendicular to the π_c, that is the cutting plane. Along this O-O, if we see this view, this will be the inclination of the rake face and this will be the inclination of the flank face. Once again, it will be principal cutting edge we are sectioning it like that.

So, we are taking the sectional view along the O-O which is perpendicular to this principal cutting edge and we are looking at it. Here it will be the flank face and the rake face that will be revealed. Another plane we will take again here in this; we will hatch it because this is the sectional view whereas, in C-C this was a view and this view as I said this is like if you see the tool from here, perpendicular to this.

We will take another section which will be perpendicular to the auxiliary cutting edge. But perpendicular to the auxiliary cutting edge will be A-A and similar to this, we will have a view like this and in this view, if you see this in the auxiliary cutting edge, this is the inclination of the rake face. I would like to point out one thing that this inclination of the rake face and the inclination of the rake face here or the inclination of the rake face here, they are different.

Because I said there will be multiple or more than one inclinations on the rake face. Therefore, we are calling these rake angles which define the inclination of the rake face. They are called differently, I will tell you what are those. We have again three sets of angles, that is the one set of rake angle, one set of flank angles, and one set of cutting edge angles.

This is the principal cutting edge, this is the auxiliary cutting edge this is the same in ASA. Another set of angles is called a cutting edge angles and this is tool nose radius. Now all these angles are given in a particular sequence like in case of the ASA or the coordinate system and this sequence is the following. First it is mentioned what is the inclination angle.

Inclination angle is here this is the i, next to that it is the orthogonal rake it is called because this is the orthogonal plane, orthogonal plane is perpendicular to this cutting edge therefore, these two angles i and α_0 will sufficient to describe the inclination of the rake face. You can also say that there is another rake angle which we do not show in this nomenclature.

This is because i and α_0, inclination angle and orthogonal rake angle together sufficient clearly describe the inclination of the rake face. Similarly, inclination of the flank face will be defined by the principal flank angle. You can see from here, principal flank angle because this is the principal cutting edge. So, on this edge this plane is revealed and the plane is the orthogonal plane.

So, both this orthogonal rake angle and the principal flank angle are in the orthogonal plane and next is the auxiliary flank angle which is defined in the plane perpendicular to the auxiliary cutting edge. Auxiliary cutting edge is here, PD and perpendicular to that is the AA. So, this is the auxiliary flank angle. These two angles, namely principal flank angle and auxiliary flank angle, define the inclination of the flank face.

And then we have the principal cutting edge angle with respect to the principal cutting edge and the X-axis. Please note that in ASA it was not principal cutting edge, it was the γ_s, the side cutting edge angle and the side cutting edge angle was determined with respect to *Y*- axis, principal cutting edge and Y- axis and here it is with the X- axis. It will be 90 minus that angle, 90 minus γ_p is the γ_s. Another angle is with respect to the auxiliary cutting edge and the X- axis this is called the auxiliary cutting edge angle.

So, these are the 6 angles like in case of the ASA, one set of rake angles, one set of flank angles and one set of cutting edge angles, plus the tool nose radius, and since it is in the orthogonal rake system or it is also called the continental system, this is given in the unit of millimeter, whereas in case of coordinate system since it is an American system, there it is given in inch.

This is the sequence; once again - inclination angle, orthogonal rake angle, principle flank angle, auxiliary flank angle, auxiliary cutting edge angle, principle cutting edge angle and the nose radius. In this sequence the values will be given here. You have to read that the first value stands for the inclination angle; second value stands for the orthogonal rectangle and so on. By the way, this orthogonal rake system is the system which we adopt in India also.

And some of the European countries including Russia, Germany, probably France. In both of these systems, that is the ASA and the ORS, angles which defined the inclination of the rake face, inclination of the flank face or the inclination of the cutting edges do not coincide with the angles when the tool is in the working condition or when the tool has to be reground.

What does it mean is that the tool has to be reground when the geometry of the tool is lost, like it is worn out. So, the rake angle has to be established again because it is spoiled, it has been rubbed off. The wearing action has taken place or the rake face or the flank face has been worn out. The tool, when reground, has to be placed on the grinding machine according to the angle at which the tool will be working.Those working angles do not coincide with these angles which define the inclination of the rake, flank and cutting edge angles.

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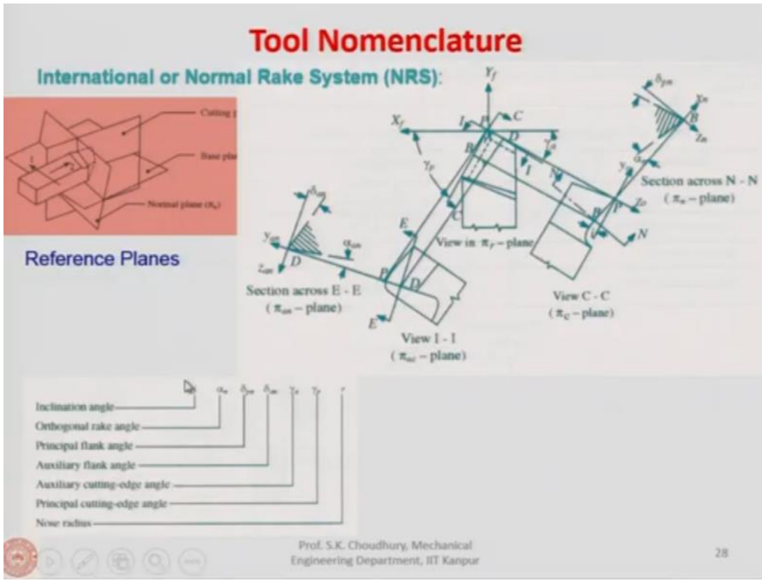

Here is another system which is called the International or Normal rake system. This is called the international system because many countries are now trying to adopt this system where all the countries will have the nomenclature according to this system. In that case it could be easier for all the countries to buy tools from each other and do not have to bother about the working angles.

Because on those working angles only the NRS will define the inclination of the rake face, inclination of the flank face or the inclination of the cutting edges. Let us see what are the planes that the NRS or the normal rake system uses. Here we have the base plane which is the same as in case of the ASA or the ORS; then we have the cutting plane which is the same as in the case of the ORS. Cutting plane will contain the principal cutting edge.

Only difference here is that another plane is taken which is different from the orthogonal plane here it is called a normal plane and the normal plane is perpendicular to the cutting edge. This cutting edge is visible when we are taking the views here on these cutting edges; you take a normal, then you will get the normal plane, whereas in the orthogonal plane it is not the case because orthogonal plane was perpendicular to the base plane.

All those three planes are mutually perpendicular planes. So, the normal plane is different than the orthogonal plane that we have taken in the ORS. In this case C-C this is the view, this is containing the cutting edge and the view will be the same as in case of the ORS. We have taken this view along the C-C, the same here then we will take another view and this will be I- I along the auxiliary cutting edge and here the view will be like this.

This is the rake face, this is the flank face. So, what we are having is a cutting edge. which The rake face will contain the cutting edge, the cutting edge will be at the end of the rake face. If we take perpendicular to this cutting edge in N-N, perpendicular to this cutting edge which is E-E.

Then we will see these two views. In these two views, this is the rake face, which will be revealed here and this is another rake face here this is revealed here. Rake face is not visible, it is inclined, either it is inclined like this or it is inclined more or it is inclined like this it is not visible, but the face the cutting edge is visible.

If you look perpendicular to that then only this inclination will be visible. This inclination we are saying as the inclination which is of the rake face in here and in here so they are different inclinations. Therefore, the angle which is between the rake face and the line perpendicular to the cutting velocity vector - it is here and this line in this case and this line in the case of the N-N these two angles, one angle is called the normal rake angle and another is called the auxiliary normal rake angle.

Because this plane or this view is along the auxiliary cutting edge and this is normal. Therefore, normal to the cutting edge and hence, this plane is called the auxiliary normal plane and this is called the normal plane because this is the cutting plane and perpendicular to the cutting plane will be the normal plane here.

In this sequence the angles are defined, that is, inclination angle first like in case of the ORS then the normal orthogonal rake angle, principle normal flank angle, this will be normal rake angle this angle is that normal rake angle you can correct it this is the principal normal flank angle, this is auxiliary normal flank angle, this is auxiliary cutting edge angle, this is principal cutting edge angle and this is the nose radius which is also given in millimeter because it is in the international system.

Exactly in this sequence the angles are defined and you have to read according to this sequence, if the first angle is given as let us say 1^0 or 0^0 ,you cannot say that this angle is anything else but inclination angle and you have to read it in this sequence. Suppose we purchase a tool in the coordinate system and we have to use it in the orthogonal rake system. Since the orthogonal rake system nomenclature is different than this coordinate system or the American system or ASA system, we have to convert these angles to our system.

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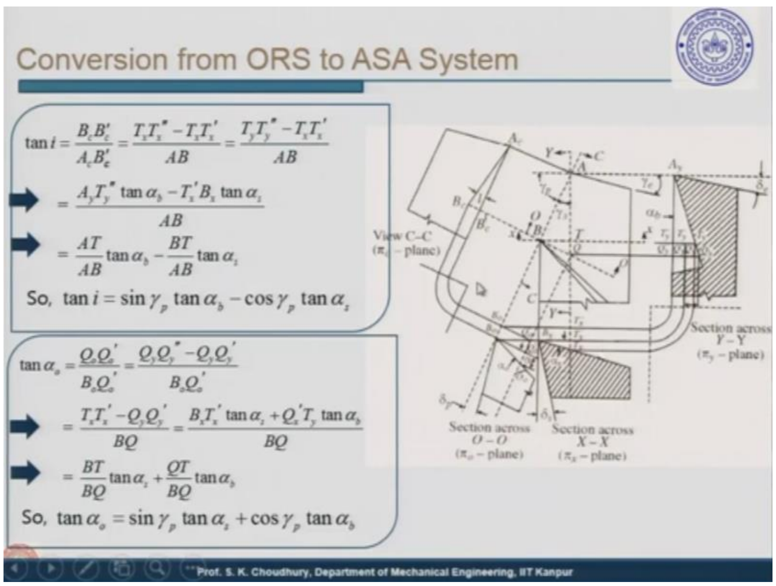

This conversion is not very difficult. Here is the base plane, on the base plane the view is put here, from here it will take a C-C like in the case of the ORS system, and the view is like this, then we will take X and Y like in the coordinate system X-X we will put it in here and Y-Y we will put it in here. C-C we are putting it in the opposite side, this is the view along the cutting plane C-C this view along the cutting plane we are putting in here, this is the Y-Y section we are putting in here.

This is the X-X we are putting in here and then there is another one which is perpendicular to this that is O-O we are putting it in here. Now, as you can see that in these four views that we have shown or rather five views, this is one view that is in the base plane, we have combined the views of the coordinate system this is X and Y, X-X, Y-Y and the orthogonal rake system, that is C-C and here is orthogonal that is O-O So now if we can project these points to the other views, then we can correlate , the angles using simple geometry.

Let us take an example. Let us say tan of this angle is this divided by this will be $A_c B_c'$. $A_c B_c'$ can be projected to this we base this thing as AB and $B_c B_c'$ can be projected to other views like this, take a perpendicular here, put those points here. Then you take a turn and perpendicular to this, project it in here and then go perpendicular to the surface going here and wherever it intersects it will be on this view.

From this view similarly, you put a mutually perpendicular planes and project these points and you can go to this view. If you carefully see this diagram, this conversion is plain geometry and this can be found out from the reference books from any textbooks, metal cutting textbooks including some of the textbooks that have been referred for this particular course.

Now $B_c B_c'$ therefore, can be said to be equal to $T_X T_X''$ and this value is projected as the $B_c B_c'$ here. The same $T_X T_X''$ can be projected here as $T_Y T_Y''$ like this and this here. Similarly, if you do that in this case finally, what you can find out is that this equation relates $\tan i$ to the $\sin\gamma_p \tan\alpha_b$. $\tan i$ is in the ORS system, $\sin\gamma_p$ is in the ORS system.

That is the principal cutting edge angle, we can see that it is in here γ_p and i angle is here this is the tool inclination angle. So, this is multiplied by $\tan\alpha_b$, α_b is the back rake angle, which is in the ASA system and minus $\cos\gamma_p$ and the $\tan\alpha_s$ again this α_s is the side rake angle in ORS system. This is also in coordinate system. So, you can see that this equation relates the ORS system with the ASA system.

Therefore, if we have a tool in the ORS system or in ASA system and you have to convert to other system like ASA, you can always do that using this simple equation which is obtained through simple geometry. Similarly, $\tan\alpha_o$, α_o is the orthogonal rake angle; this can be found out from geometry as $Q_o Q_o'$. divided by this and $B_0 Q_o'$ can be projected to BQ as shown here.

This is in the base plane and so on. Like I have shown it here finally, you can find out that $\tan\alpha_0 = \sin\gamma_p \tan\alpha_s + \cos\gamma_p \tan\alpha_b$. Here also the orthogonal system is related to the ASA system. So, either you have the ASA tool or ORS tool, it can be converted to any other systems . This is the conversion from the ORS to ASA because in one tool we have taken views of ORS and ASA, that is the coordinate system and this is the orthogonal rake system.

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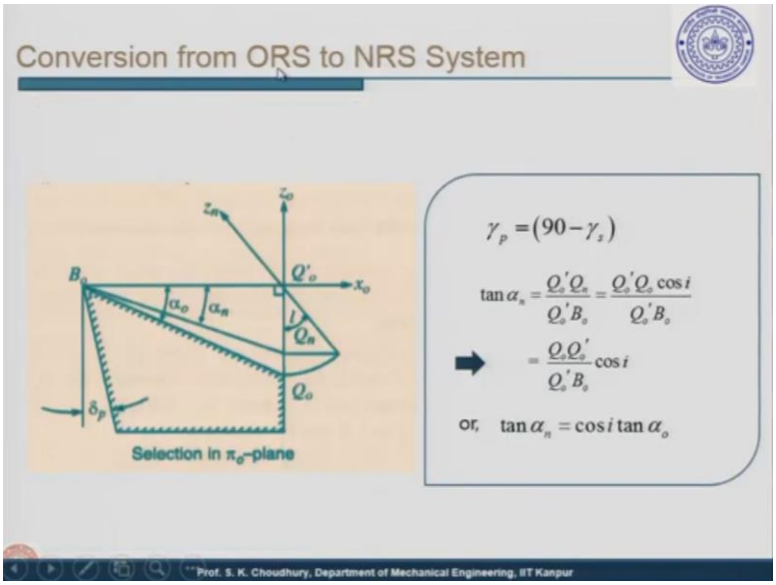

Similarly, we can convert the ORS system to NRS system, that is orthogonal rake system to the normal rake system. For that there is an interesting procedure that can be followed because mostly it is the rake angle which is important. Let us say that we will convert the rake angle. Since it is ORS from NRS, so we will take a section along the orthogonal plane.

Along the orthogonal plane let us say this is the hatched one. Therefore, the B_0 Q_0 makes an angle with the line B_0 X_0 perpendicular to the cutting velocity vector, which will be orthogonal rake system because this is the rake angle, this is the rake plane and hence this will be the orthogonal rake angle. Therefore, this angle will be the principal flank angle because this is the angle in the ORS system.

Then what we can do is that this is the axis X_0Z_0, this is the axis in which we are showing the orthogonal rake system, the view in the orthogonal rake system that means, this is as if the sectional view along the orthogonal plane with respect to X_0Z_0 particularly the Z_0 axis we will incline with an angle of i . When you do that, then if we can project the system on this it will be the normal rake system.

Because this with an angle of i with respect to the orthogonal rake system will be the normal rake system. And then these points we can project on the Z_n axis like that, and then we are coming back to the Z_0 axis here then this point if we connect with the edge of the tool, then the tool now that is given can be assumed safely as the sectional view in the normal rake system.

Therefore, this inclination or this face will be the rake face in the normal rake system and the angle between the inclination of the rake face here and the line perpendicular to the cutting velocity vector will be normal rake angle. Once again, how we can convert this tool to a tool which is in the normal rake system. We are projecting this on the axis which is inclined to the Z_0 in the orthogonal rake by an angle of i which is the inclination angle.

Then if this point is converted or projected to the orthogonal rake axis that is the Z_0 and then if we connect orthogonal rake point here with this point, then this tool will be considered to be the tool in the normal rake system and this angle will be then the normal rake angle because this face will be the rake face in the normal rake system. So, if we can do that, in this case you can find out these relationships by simple geometry.

Now $\tan\alpha_n = \dfrac{Q_0'Q_n}{Q_0'B_0}$ then these are simple geometry and from here you can find out that this is $\cos i$ and this one is the $\tan\alpha_0$ in the orthogonal rake system. Therefore, all together $\tan\alpha_n$ which is in the normal rake system this is equal to the $\cos i$ which is also in the normal rake system as well as it is in the ORS system.

And the $\tan \alpha_0$. So, this equation relates the orthogonal rake system with the normal rake system. This looks a little complicated but this is actually simple. In one view we have shown the projection or the sectional views and the projected views of both the systems ORS and the ASA. And then we are projecting points, edges from one view to the other views and geometrically relating them. Finally we are finding out the equation which will relate the two systems, angles of to both systems.

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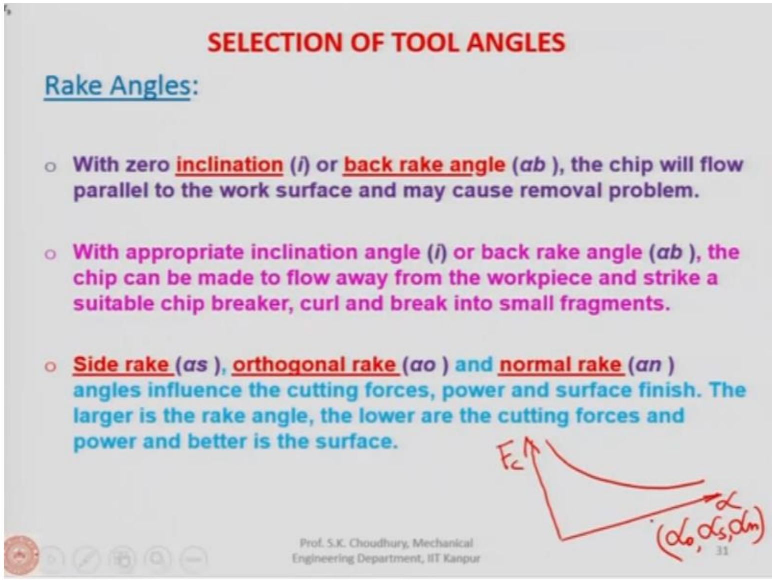

Very important point is how to select the tool angles. Meaning that we have now described the sets of any of these systems, be it in ASA system or ORS system or NRS system, we have basically the two rake angles, two flank angles and two side cutting edge angles. How to select what is that value of the angle that you will be selecting - this is very important and let us discuss on which factors the selection depends.

With 0 inclination or back rake angle that is *i* or the α_b 0^0, the chip will flow parallel to the work surface and may cause removal problem. In that case it can further entangle with the workpiece and the tool. It can cloud the machining zone. Suppose you are using any transducer, any sensor that is non-contact, using that sensor you are taking the signal with respect to the workpiece or with respect to the tool.

In that case that distance between the tool and the workpiece, if this place is clogged with the chip and the chip is not removed, that will give you wrong signal but overall more dangerous is even without any sensor, it can entangle and entangling is always a problem I told you, when we discussed the continuous chip formation that continuous chip formation is not desirable because it will scratch the workpiece and the tool.

And spoil the tool geometry and the already machined surface. Therefore, with the 0 inclination angle of the back rake angle, the chip flows parallel to the workpiece surface and it will be difficult to remove. So, we have to have some value of inclination angle or the back rake angle, then the chip can be made to flow away from the workpiece and strike a suitable chip breaker.

If you remember, I told you about the chip breaker which is basically a protrusion on the rake face or a crater on the rake face where the chip can be broken so that the chip does not flow continuously. We can have some value of the inclination angle or some value of the α_b. Right now we are talking qualitatively not quantitatively. How much value is required that we will discuss later. We are saying that there should be some value of the angle.

Because an inclination angle is 0^0 means it will have problem with the chip flow. The chip in that case should be made to flow away from the workpiece and strike a suitable chip breaker, curl and break into small fragments. That is when you need to have some value of the inclination angle and some value of the α_b. Now side rake, orthogonal rake and the normal rake angle, these angles influence the cutting forces power and the surface finish.

The larger is the rake angle, the lower at the cutting forces and power and better is the surface. Overall, what we say is that suppose if we say that along the X-axis we have the α. this α as we said is α 0 or side rake or normal rake like any one of them and if we say that this is the force cutting force along the Y-axis, then the curve will go like this, meaning that as the α value decreases, the force goes up and vice versa that is the force goes down with the increase in the value of α. So, why this happens? This I am going to discuss and explain it to you in my next discussion session. Thank you very much for your attention.