Machining Science - Part I
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Lecture – 06

Hello and welcome to the 6th session of the Manufacturing Science, Machining Science course discussion.

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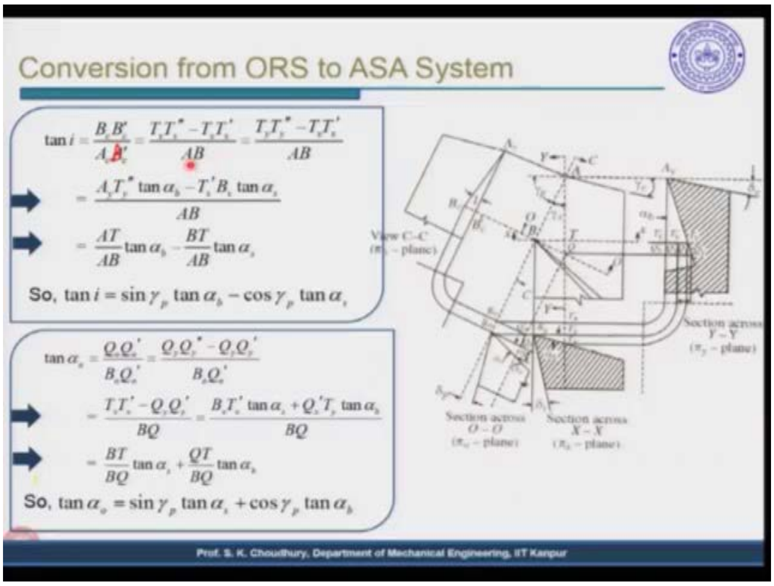

Now, let me remind you that what we said in our earlier class is that if we have a tool given in one of the systems, either in ASA or in ORS or in NRS, we have to convert that system of the tool angles in another system if we are using that tool there. Meaning, that ASA system cannot be directly used in the ORS system if you do not convert those angles because that is required for the regrinding of the tool.

Then we said that the conversion from one system to another system is not so difficult. And we have shown this. If you look at this system, what we have shown here is the base plane, and then we have made here all the views and the sectional views of ASA system and the ORS system, and then they are co related through simple geometry which has been shown here.

You can convert from the ORS system to the ASA system in the way it is shown here.

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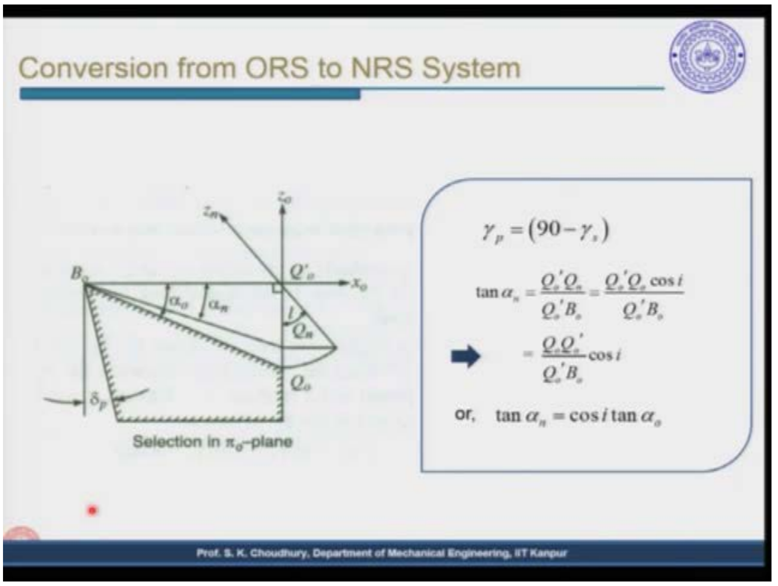

Similarly, what we said is that the ORS system also can be converted to NRS system by projecting the axes from the ORS system to NRS system. Here it is shown that this is the system of axes Z_0 - X_0. This has been projected to the normal rake system when it is inclined with an angle of i with respect to the Z_0 axis or the orthogonal rake system axis.

Then if the tool is projected in the Z_n and the X_n axis, in that case it can actually be said to be the tool which is this B_0Q_n, and this is the tool as in case of the normal rake system.

So, this angle between the newly formed rake face which is in the normal rake system and the X, this can be considered as the normal rake system. So, we have converted the α_0 to α_n that is, orthogonal rake to normal rake system. And again through the geometry as it is shown here, you can easily convert the normal rake system to the ORS system.

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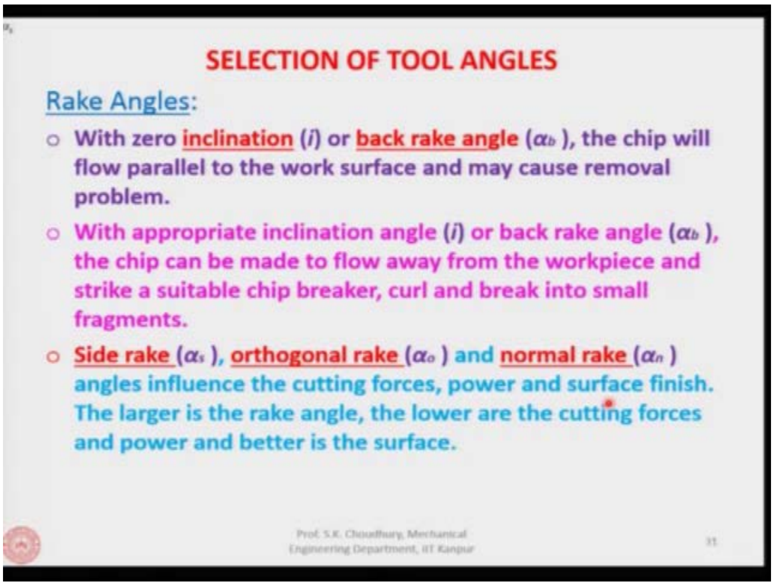

Next what we will be discussing in this session is the selection of tool angles, meaning that how we can select the tool angles properly. Let us take any of these systems, let us say ORS system. In ORS system, we have the rake angle, how to select the rake angle for a certain set of tool and the workpiece materials, and certain set of tool parameters. These are the factors which depend or which dictate us how to select the rake angles.

With zero inclination angle or the back rake angle, the chip will be flowing parallel to the work surface and may cause removal problem. If you do not have any inclination angle or the back rake angle, it will not be possible to remove the chip, because it will flow parallel to the workpiece surface and it can actually entangle with the workpiece.

With appropriate inclination angle or the back rake angle, the chip can be made to flow away from the workpiece, and it can then flow along the rake face of the tool and on the rake face you can have some chip breaker, and the chip while flowing will hit the chip breakers and the chips will be broken. So, the chip removal problem will be solved if we have certain values of the inclination angle or the back rake angle.

If they are zero, in that case the chips will be flowing parallel to the workpiece surface and it will not be possible to remove the chips; that is a big problem in the machining to dispose of the chips. Because otherwise it will entangle with the tool and the workpiece, it will scratch the already machined workpiece surface, and it will spoil the surface finish of the workpiece.

Similarly, side rake, orthogonal rake and the normal rake angles, these are the three rake angles in three different systems; side rake angle is in ASA, orthogonal rake angle is in ORS and normal rake angle is in the NRS system. These angles influence the cutting forces, power and the surface finish. These are very important angles, whereas the back rake angle will not affect the surface finish or the power and the cutting force.

Larger is the rake angle, lower are the cutting forces and power and better is the surface, this is in general. What it means is that if the side rake or orthogonal rake or the normal rake angle is large in value in that case the cutting force will decrease. I will give you the reason and the physics behind it.

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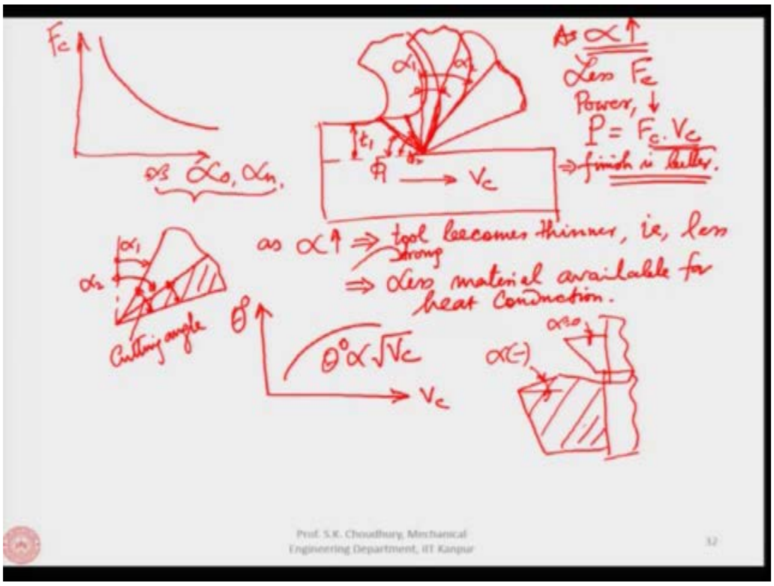

Let us say we have cutting force along the Y axis and the α along the X axis. This α means that either it is an orthogonal rake or it is a normal rake or it is a side rake angle.

So, for less values of these rake angles, the force will be higher; and vice-versa, for higher values of this angles force will be less. Now, why it is so, what is the physics behind it? Let us take an example of the turning. Let us say here we are having the process.

This is the workpiece. This is the tool with certain rake angle. Let us say here the rake angle is α_1; So, as you know that this is the shear plane, and this is the depth of cut or in orthogonal cutting also it is the t_1 which is uncut thickness.

Now, for this we now increase the value of α. So, this α_1 is now increased to α_2.

Then what happens with the flow of the chip is that the chip will be flowing like this, and the shear plane will be something like this. If the shear plane was here for the α_1, for α_2 the shear plane will be like that. So, this is the angle between the shear plane and the cutting velocity vector which is called the shear plane angle, this is let us say ϕ_1 and this is ϕ_2.

So, overall, the shear plane is decreasing in length. Therefore, the force and the power consumption will be less, and the surface finish will be better.

The power is given by $F_c V_c$. So, if the F_c is less, the power will be less and the finish will be better.

So, this is what happens when the α increases. As α increases force will be less, power will be less and the finish will be better. And this is the physics behind it that as the α is increasing, then the shear plane is decreasing, and less force will be required to remove that material with the less shear plane length, and the force requirement will be less as well as the power will be less. Power is given by the product of F_c and the cutting velocity vector which is the V_c.

For larger rake angles, however, less power is consumed which is better from the machining point of view. So, let us increase the rake angle. Let us say this is a tool which has a rake angle of α_1.

Now we are increasing that rake angle and making that rake angle as α_2. So, as a result what is happening is that the tool is becoming thinner. Tool is becoming thinner means the tool strength is going down. So, as α is increasing, the tool becomes thinner, and the thinner means less strength.

Another reason is that as the tool rake angle increases, the material available for heat conduction will be less. This is important because otherwise the heat will be accumulated in the tool.

We have also discussed that as the cutting velocity increases, the temperature increases as $\sqrt{V_c}$. Therefore, as the temperature is increasing, that means, the same has to be conducted, this has to be taken away.

Of course, majority of the heat is taken away by the chip, but still the chip is in constant touch with the tool. So, some of the heat will be conducted to the tool. And if that heat is not taken away, then the tool will have the thermal deformation and the geometry will be lost. So, this is important that there should be more material available in the tool for heat conduction.

So, we cannot infinitely increase the rake angle of the tool, because if we increase the rake angle of the tool, of course, we will get the benefit of having the less power and the less force, but we are having less material available for heat conduction, then the tool will be thermally deformed. And there will be less strength of the tool because tool is getting thinner.

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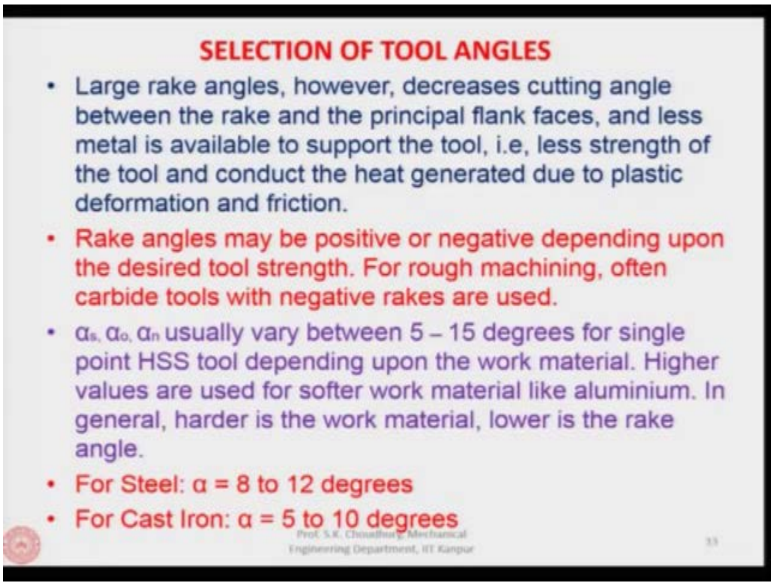

So, these are the points which are described here in this slide. Large rake angles, however, decrease cutting angle between the rake and the principal flank. Cutting angle is the angle between the rake and the flank faces of the tool. So, if the rake angle increases, then this cutting angle is bound to decrease.

More cutting angle is required to support the tool means, to make the tool stronger. As the rake angle is increased, less metal is available, so the tool in that case becomes thinner and the strength of the tool becomes less, and the heat generated due to plastic deformation and the friction will not be conducted or taken out satisfactorily.

So, the heat generated in the machining process is mostly because of the plastic deformation which happens in the shear zone or the shear plane and because of the friction between the chip and the rake face, but mostly it is because of the plastic deformation.

So, this heat generated due to plastic deformation and friction, has to be conducted and if less material is available when the rake angle is increased, in that case the tool will be thermally deformed, because more heat will be accumulated in the tool.

Next point is that the rake angles may be positive or negative depending upon the desired tool strength. For rough machining, often carbide tools with negative rakes are used. We have discussed that the tool may have a shape where we have the zero rake angle or we may have a negative rake angle.

And this is the negative rake angle. In the case of negative rake angle, as you can see the tool is fatter, that means, tool strength will be more and more material will be available here for the heat conduction. So, whenever you have a high speed machining for example, there the temperature produced will be more, and the force generated will be more. So, the tool strength has to be higher.

In that case, such tools with negative rake angle are normally used. Rake angles may be positive or negative depending upon the desired tool strength meaning that if we have to have the tool strength higher, we have to have the negative rake angle. For rough machining often carbide tools with negative rakes are used because in the rough machining more heat will be produced and more force will be exerted.

So, we need to have more material for the heat conduction, and we have to have the higher strength of the tool because the forces will be higher to withstand the higher forces the strength of the tool has to be higher. Side rake angle, orthogonal rake angle and the normal rake angle usually vary between 5 to 15 degrees for single point high speed steel tool depending upon the work material.

Now, 5 to 15^0 is a wide range, of course. The common practice is that if we have high speed machining or you need to have a rough machining, in that case you have to have less value of the rake angles, because the less value of the rake angles will give you the fatter tool and more material will be available for the heat conduction.

So, this is how judicially you have to find out exactly which value that you will be taking depending on what is available, what is the combination of the work piece and the tool, what is the material of the tool and so on. Higher values are used for softer work material like aluminum, because for higher values of rake angle, the force will be less, power consumption will be less, and therefore, you do not need to have the high strength of the tool.

So, large values can be used. In general harder is the work material, lower is the rake angle, I have already explained it to you why because you need to have more strength for the hard work material. So, for steel for example, the recommendations are that these rake angles, that is, the side rake angle, orthogonal rake angle and the normal rake angle should be between 8 and 12 degrees normally.

The selection of a particular value in this range between 8 to 12 depends on whether the material work material is harder, or whether the machining is at high speed. If the workpiece material is soft, in that case you can have the larger values of this in the range of you know 10, 12 and so on.

For cast iron, this is the hard material and supposed to be brittle. So, the α is between 5 to 10 degrees, this is the normal recommendation. But again you have to judiciously find out which value exactly should be used depending on the condition of the machining and depending on the combination of the tool and the workpiece material.

Let us discuss about the flank angles. Now, as we said, the flank angle is between the flank face and the already machined workpiece. We discussed that the flank angle is required to save the flank face from being rubbed over the machined surface, so that it does not rub against the machine surface to spoil it further.

So, the value of the flank angle can be as much as possible, because flank angle does not have much effect on the cutting force or the power consumption. Now, again if you are increasing the flank angle, the cutting angle that I have shown it to you earlier will be less.

With a particular rake angle, if you are increasing the flank angle, the cutting angle between the two faces - the rake face and the flank face, decreases. Cutting angle decreasing means the less material again will be available for the heat conduction and the tool strength will be less.

So, although increasing the flank angle will help you in avoiding the rubbing between the flank face and the already machined surface, but it will again lessen the strength of the cutting tool and less material will be available for heat conduction, because the cutting angle will be less. So, an optimum value can be found out, so that the machining can be optimally performed.

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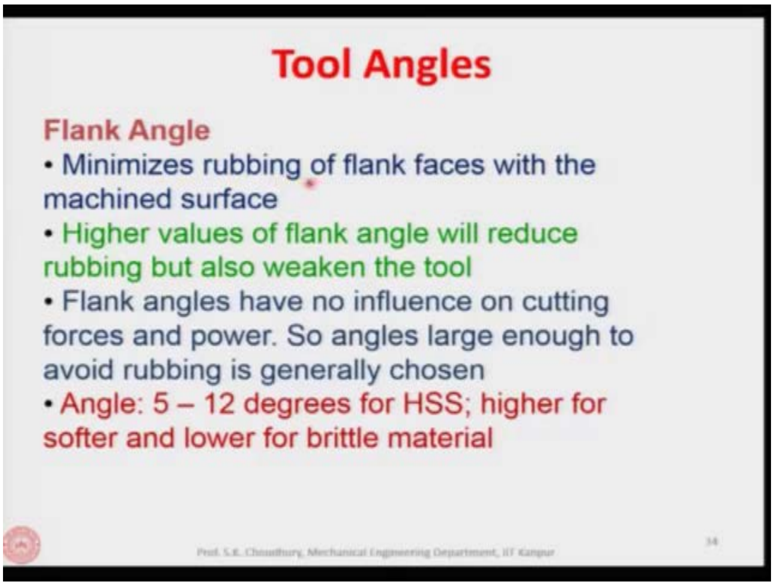

Flank angle minimizes rubbing of flank faces with the machined surface as I explained it to you. Higher values of flank angle will reduce the rubbing, but also weaken the tool. Flank angles have no influence or almost no influence on cutting forces and power. So, angles large enough to avoid rubbing is generally chosen.

Now, the range of angle that is the normally recommended is between 5 and 12^0 for high speed steel and within that, higher values for the softer workpiece material and lower values for the brittle workpiece material. You understand the reason, it is the same as we have already told in case of the rake angles. So, this is the same that the tool width is getting thinner, tool material available is less for the heat conduction.

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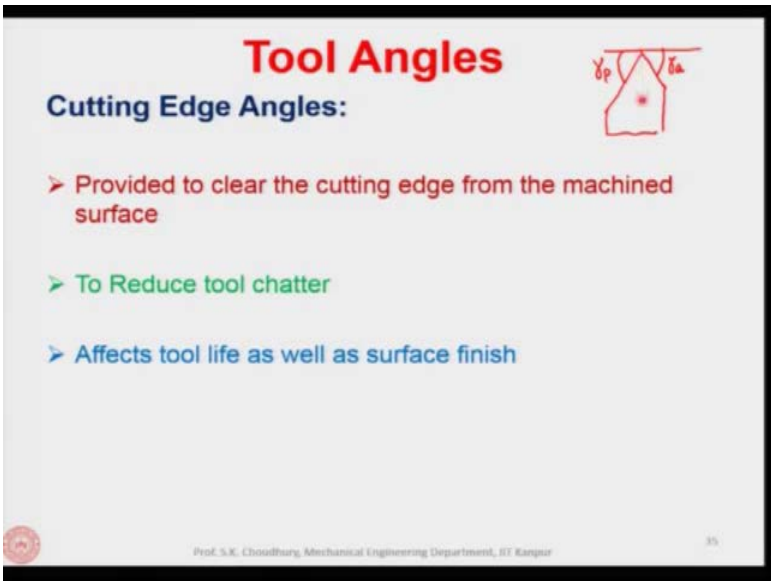

Now, the cutting edge angles, I will remind you that the cutting edge angles are those angles which are made between the cutting edges. So, this is the principal cutting edge; this is the auxiliary cutting edge. And the cutting edge angles are, this is the principal cutting edge angle and the auxiliary cutting edge angle. Now, these angles are given to clear the cutting edge from the machined surface.

Here we have the machined surface where the flank face is rubbing against the machined surface. So, these edges have to be cleared, so that they are do not rub against the machined surface.

This is also to reduce the tool chatter; otherwise, what will happen is that if one of these angles is more, then the radial forces which try to retract the tool from the workpiece, will be higher, and the tool will start chattering - chatter is the self-excited vibration.

So, to reduce the chatter, which is the self-excited vibration, we have to control the cutting edge angles. These angles affect the tool life as well as the surface finish; the reason is the same as given for the flank angles and the rake angles.

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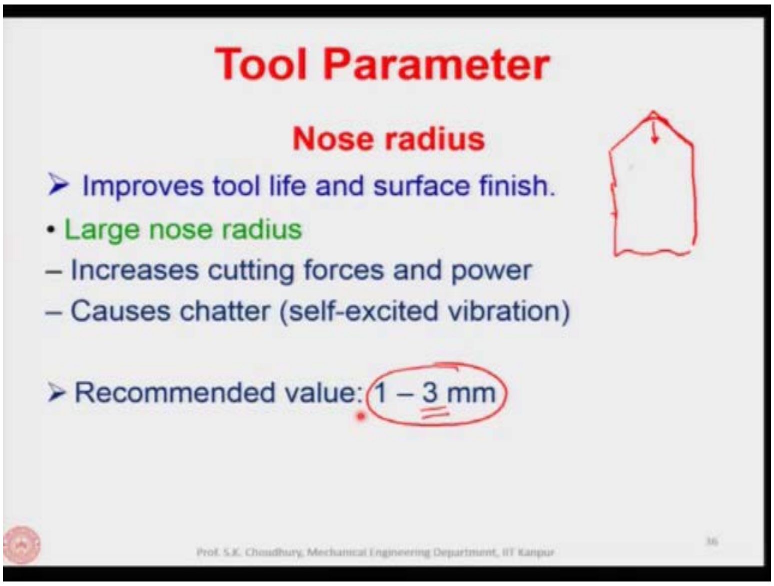

Now, the nose radius; if we have a very sharp tool, as you understand that immediately aa the cutting process starts, this sharp tool will come in contact with the work piece. So, this will be either rounded off or it can be broken. It can be broken because sharp tool will always have a very high stress concentration.

So, because of that as the tool is getting in contact with the workpiece, this will be crumbled or it can be broken, so, normally the tool nose radius is given, certain nose radius is given, so that this does not happen. This is recommended to be between 1 and 3 millimete. If it is less than that, then the stress concentration will be higher, and the tool wear will be high, tool may be broken, tool may be crumbled, it may be thermally deformed and so on.

If this value of *r* is higher than 3 millimeter, in that case again the chatter formation or the self excited vibration will take place, that is, those components which will start detracting the tool from the workpiece, will grow.

So, this nose radius improves the tool life and the surface finish, If the tool tip is very sharp, or let us say, less value of the tool nose radius, then the feed marks will be remaining on the workpiece. We will discuss this in details in a chapter called surface finish, then I will explain it to you that how the surface finish varies if the tool is sharp and in case the tool has a nose radius, then it will be clear to you that why the surface finish is improved if a tool nose radius is given.

So, basically it is because when the tool is sharp these feed marks will be there, more prominent feed marks will be there, and if the tool nose radius is given the feed marks, they will be overlapping on each other and overall the surface roughness will be less, so the surface finish will be better. Large nose radius increases cutting forces and power. I explained it to you because it will be rubbing and also it will have the chatter – self-excited vibration. So, the recommended values are between 1 and 3 millimeter as I said.

These are the factors, that means, the three sets of angles - once again, the rake angle, flank angle, and the cutting edge angles these three sets of angles are very important to regulate and we should be judiciously selecting their values, so that the surface finish could be better, so that less power can be consumed, I mean in the process less force is applied. So, overall our aim is to get the final product with the right shape, size, finish and accuracy.

So, this shape, size, finish and accuracy, will broadly depend on the right selection of these parameters that is the particularly the rake angle of course, the flank angle and the cutting edge angles and the tool nose radius.

So, I will, once again remind you and repeat that here the rake angles are more important, that is the side rake, orthogonal rake and the normal rake because on these angles the power consumption and the force will depend. And as I explained it to you that force will be reduced as the rake angle is increased, but we cannot increase the rake angle infinitely because as the rake angle is increasing, then the tool is becoming weaker and the less material is available for the heat conduction from the tool.

So, then the thermal deformation of the tool will happen, and it will not be able to withstand the high force, that means, if the tool is thin or weak in that case the with the high cutting force the tool will be deformed or the tool can be broken. So, there has to be a value which is a compromise, it cannot be very high, it cannot be very less. For example, if it is very less, in that case the force will be very high.

So, again the tool will be affected. So, these are the factors which have to be taken into consideration while selecting the values of the angles, rake angles, flank angles, cutting edge angles. Of course, flank angles, it is not much of a problem as in rake angle because flank angles do not have much effect on the cutting forces and power, but it will again rub the workpiece, the machined surface.

Again you cannot increase the value of this angle infinitely, because the cutting angle will be in that case less. So, you have to judiciously find out what is the angle suitable for that particular operation. Rest of the things, I will discuss in the next class.

Thank you.