Machining Science - Part I
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Lecture – 20

Hello and welcome to the 20th session of the discussion on the Machining Science course and this is the last session.

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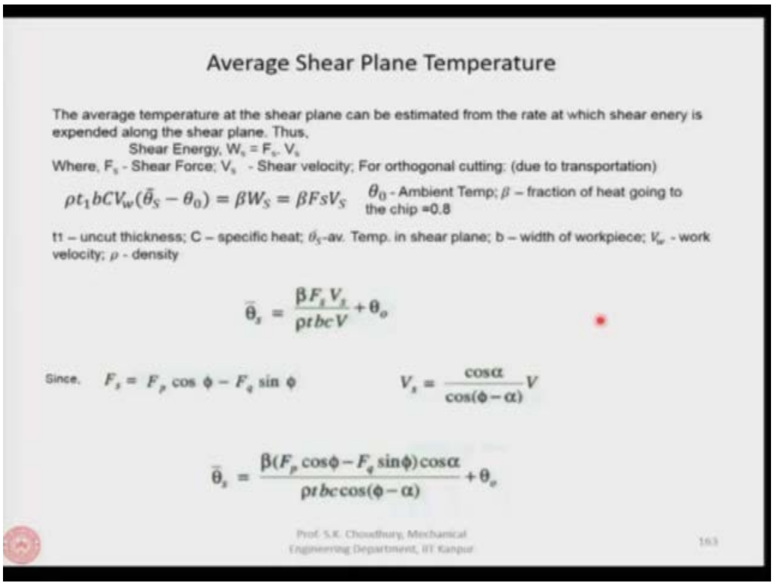

Let me remind you that in our previous session we were discussing the thermal aspects of machining and we said that because of the plastic deformation, the majority of the heat is produced. Another source of heat generation is the friction between the chip and the tool along the rake face of the tool. Finally, a bit of heat is generated because of the friction between the flank face and already machined surface. Now out of the total 100 percent of heat which is generated, majority of the heat which is about 80 percent goes with the chip.

Next about 15 to 20 percent of it goes with the tool and the rest up to 5 percent remaining in the work piece. I also discussed that temperature in the cutting zone can be measured using the thermocouples. But, when we measure the temperature in the machining zone, it will be the temperature of the machining zone and not the temperature in the shear plane or the temperature in the tooth chip, tool chip contact length or tool chip contact area. But, it is very important to find out what is the average temperature in the shear plane or the average temperature in the chip tool contact length.

There is a thermal model through which we can find out the average shear plane temperature. If you see the above slide, I will repeat once again that it can be measured from the rate at which the shear energy is expended along the shear plane. W_S is the shear energy which is equal to $F_s V_s$. For orthogonal cutting due to transportation of heat, we have an equation from the thermal engineering and as 80 percent of heat is going to the chip therefore the coefficient is 0.8. From the equation, $\rho t_1 bCV_w(\bar{\theta}_s - \theta_o) = \beta W_s = \beta F_s V_s$, we can find out the value of the average shear plane temperature which is equal to $\dfrac{\beta F_s V_s}{\rho t_1 bcV}$. And, then we put the value of the F_S from the Merchant's as $F_s = F_P \cos\phi - F_q \cos\phi$. And, the V_S which is the shear velocity which we have also derived from the sin rule as $V_S = \dfrac{\cos\alpha}{\cos(\phi - \alpha)} V$.

So, the expression for the average shear plane temperature is

$\bar{\theta}_s = \dfrac{\beta(F_P \cos\phi - F_q \cos\phi)\cos\alpha}{\rho tbc\cos(\phi - \alpha)} + \theta_o$. This is the analytical way of finding out the average shear plane temperature.

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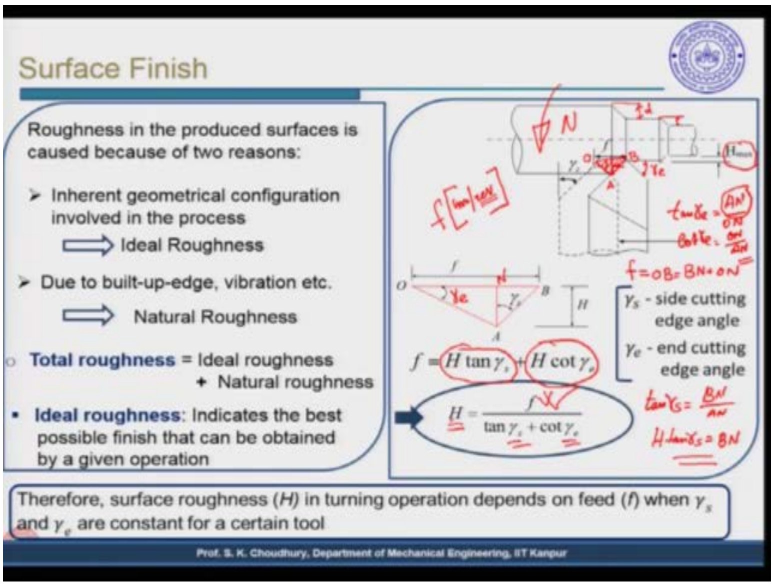

Next we will discuss the final topic which is the surface finish. This is one of the most important factors because if the surface finish is not produced according to our requirement the machining process is not satisfactory. And, earlier we have seen that we can control several parameters for getting a better surface finish. The surface roughness is opposite to the surface finish meaning that when the surface roughness is very high the finish is very bad and the surface roughness is indicated by the undulations on the surface after machining.

Let us see why the surface roughness is produced on the machined surface. Particularly the surface roughness in the produced surfaces is caused because of two reasons; one which is based on the inherent geometrical configuration involved in the process. What are those inherent geometrical configurations? That means, we have a certain process, we have a certain machine tool of certain accuracy, we have certain combination of work piece and tool material and some other things. These are the inherent geometrical configuration; that means, we cannot have much control on that. Therefore, it is called the ideal roughness.

So, the roughness produced because of the inherent geometrical configuration in the process will be known as the ideal roughness. And, the second reason is due to built up edge formation and due to vibration etcetera. On these parameters we have the control as we can reduce the built up edge formation, we can reduce the vibration and production of the surface roughness by these factors is called the natural roughness. The total roughness will be sum of the ideal roughness and the natural roughness.

Ideal roughness indicates the best possible finish that can be obtained by a given operation. What does it mean that you cannot get better than ideal roughness, in the sense that we cannot have any control over that. So, this is the best possible finish that can be obtained. Now let us take an example of a turning process and say that turning process is performed by a single point cutting tool which is sharp.

This tool is given a feed along the work axis and the work piece is rotated at a particular frequency. Let us say the rotation of the work piece is N and for each rotation of the work piece the tool is moved. Now, let us say in one revolution of the work piece the tool has moved by a distance f which is known as the feed. Feed is given in millimeter per revolution unit.

So, f is the millimeter of the movement of the tool along the feed direction per revolution of the work piece. N is given as the RPM or revolution per minute and d be the depth of cut. H_{max} is undulation that is being formed on the work piece which is the surface roughness.

γ_s will be the side cutting edge angle and γ_e will be the end cutting edge angle. Now, if we take ΔAOB and exaggerate it. γ_s is the angle between AB and a line drawn normal to the OB from the point A, which is AN. γ_e is the angle between OA and OB.

AN is the value of the surface roughness and OB is the feed value and the angles are side cutting edge angle and the end cutting edge angle.

$OB = ON + BN$. $\tan\gamma_s = \frac{BN}{AN}$ and AN=H. or $H.\tan\gamma_s = BN$. Similarly, $\tan\gamma_e = \frac{AN}{ON}$.

So, $\cot\gamma_e = \frac{ON}{AN}$ or $AN.\cot\gamma_e = ON$ or $H.\cot\gamma_e = ON$.

As, $f = ON + BN$. Using above equations and taking H common, we have,

$$H = \frac{f}{\tan\gamma_s + \cot\gamma_e}$$

Now, this is important because here we know that if we are having the turning process with a sharp tool then this is how we can control the surface roughness because we know that the surface roughness basically depend on the feed. We have a particular tool that we have selected where we have the γ_s and γ_e which are fixed. Now, let us see that if we have the nose radius then how this process is getting affected.

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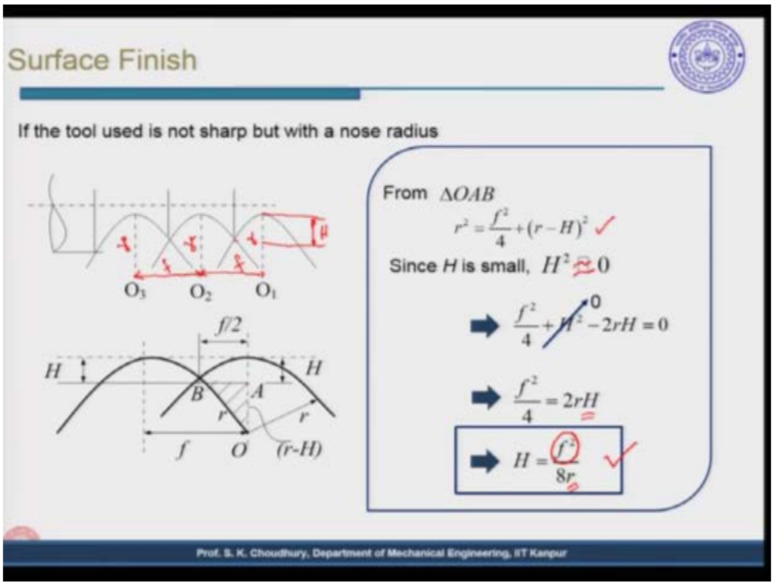

Let us say if the tool used is not sharp now, but suppose it has a small nose radius let us say the value of the nose radius is *r*. Everywhere it is *r*. Now as the tool is being fed along the work axis, it has been fed from O_1 to O_2 in one revolution of the work piece. The same value is coming in the next revolution of the work piece. $O_1O_2 = O_2O_3 = f$ and *H* that will be the undulation on the surface will be from the peak to valley.

Consider ΔOAB shown in the above figure, then $OB = r$, $AB = \frac{f}{2}$ and $OA = r - H$.

Substituting above values in $OB^2 = AB^2 + OA^2$. After solving and ignoring H^2 which is very small, we have

$$H = \frac{f^2}{8r}$$

On comparing this case with the case of sharp tool, it can be seen that surface finish is better when we use a tool having nose radius. When tool with nose radius is used, *H* is mostly dependent on the f^2 and it is inversely proportional to *r*.

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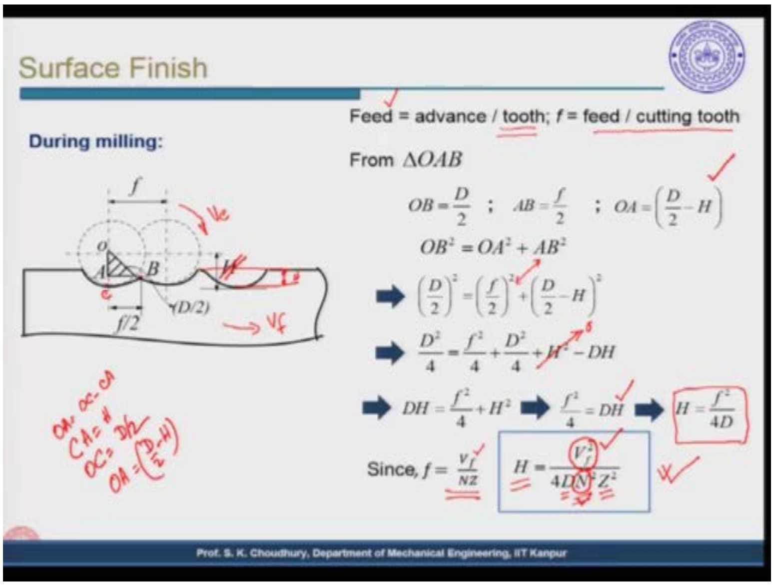

Next let us say that during milling what happens. Now earlier I said that in case of milling the feed is taken as the feed per tooth; that means, in milling cutter there are more than one tooth may be 6, 8, 12. And the movement of the tool corresponding to one tooth is given by the feed which is called the feed per tooth. So, *f* is equal to feed per cutting tooth.

So, feed is the advancement per tooth. Now, in case of single point cutting tool feed is the movement of the cutting tool that is because there is only single point. Here each tooth is considered to be a single point tool in case of milling cutter. So, advancement per tooth of the milling cutter is considered to be the feed in milling. In the above figure, two positions of the milling cutter are shown. Let us say V_f be feed velocity and V_c is the velocity given to the milling cutter. Distance between the two centers is advancement per tooth and therefore, this is considered to be the feed, *f*. Now, join the centre of the milling cutter to the intersection.

Therefore, in ΔOAB, $AB = f/2$, $OA = OC - CA$, Peak to valley distance, $H = CA$, $OC = D/2$

Therefore, $OA = \dfrac{D}{2} - H$.

From ΔOAB, $OB^2 = OA^2 + AB^2$. Putting the above values,

$$\left(\frac{D}{2}\right)^2 = \left(\frac{f}{2}\right)^2 + \left(\frac{D}{2} - H\right)^2$$

After solving and ignoring H^2 which is very small, we get,

$$H = \frac{f^2}{4D}$$

Since, $f = \frac{V_f}{NZ}$; $H = \frac{{V_f}^2}{4DN^2Z^2}$ where, Z be the number of teeth.

Now, if we look into this equation carefully you can actually say that we have few parameters here which can be manipulated to get the minimum roughness. And amongst this basically that is the V_f and the N because D is the diameter of the milling cutter which is fixed you have selected a particular milling cutter and that milling cutter will have particular number of teeth. Therefore, you can decrease the value of the V_f or you can increase the value of the N, to decrease the H. But now if we change the value of the V_f, the MRR will be affected or the production rate will be affected because MRR is the area into velocity.

So, in that case V_f should not be changed because we do not want the power or the production capacity to be changed. Therefore, the only parameter which is left is the RPM of the milling cutter and by changing the RPM of the milling cutter you can actually change the surface roughness or the surface finish during the milling process. This is the basic idea behind this to discuss that what are the parameters on which we can have the control to manipulate or to improve the surface finish of the surface during the milling process.

So, analytically we can say that these are the two parameters, but V_f cannot be changed because by changing the V_f once again I am repeating the production rate will be changed and we can change only the N which is the RPM of the milling cutter.

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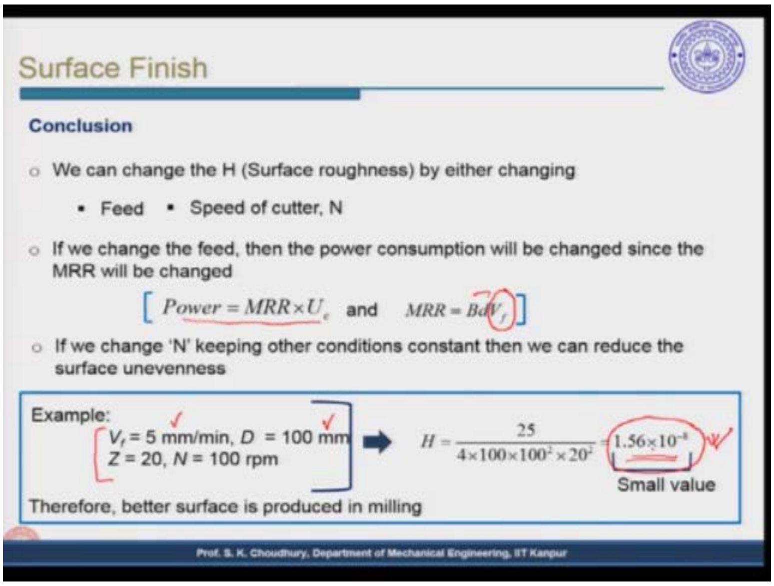

Now, let us see what happens in case of grinding. Before we do that let us conclude that we can change the H as I said by either changing feed or speed you can change the H. By changing V_f, power will be changed which includes MRR in which V_f is involved. Now there is an small numerical example you can see that the V_f is given, diameter is given, Z is given as number of teeth, RPM is given and from the equation find out the value of the H.

So, if you compare from the example given that with the similar parametric value of the turning or milling you can see that in turning the surface roughness will be more; because you can see H is 1.56 into 10^{-8}. These are the very practical values and for these values you will have a very small value of the surface roughness. So, this is in millimeter because here we are taking all this in millimeter.

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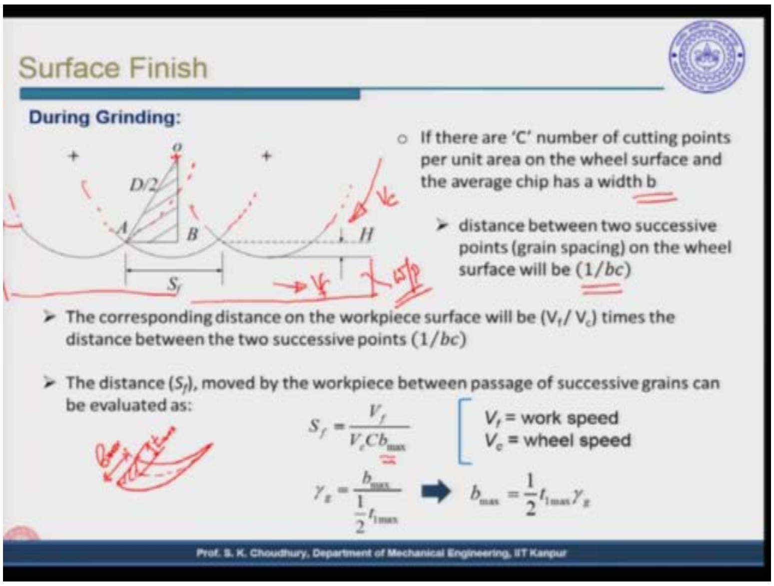

Let us see what happens in case of grinding. In the schematic diagram of the path that the grinding wheel is going through as the feed V_f is given. Let us say we have the two positions of the grinding wheel. The centers of the grinding wheel are also shown. Feed velocity V_f is given to the workpiece. Because of the feed velocity and the cutting velocity which is imparted on the grinding wheel there will be a movement which is equivalent to in case of milling for example, is the feed per tooth or in case of turning it is the feed. So, here let us see what happens if there are C number of cutting points per unit area on the wheel surface and the average chip has width b then the distance between two successive points or the grain spacing, on the wheel surface will be $1/bC$.

The grinding chip has the maximum width b_{max} and the t_{1max}. So, we are saying that if the chip has the width let us say b and C is the number of cutting points per unit area on the wheel this is otherwise called the grain concentration which is C.

Now, then the distance between the two successive points on the wheel surface will be $1/bC$. The distance $1/bC$ is on the grinding wheel. The same distance when it is translated on the work piece will be equal to $\frac{V_f}{V_c bC}$. This distance we will call as the S_f on the work piece that is the distance moved through the successive grains on the work piece. So, the S_f can be given therefore, as $\frac{V_f}{V_c bC}$. Of course, the V_f is the work speed γ_g is the grinding wheel ratio.

Therefore, $S_f = \frac{2V_f}{V_c C t_{1\max} \gamma_g}$

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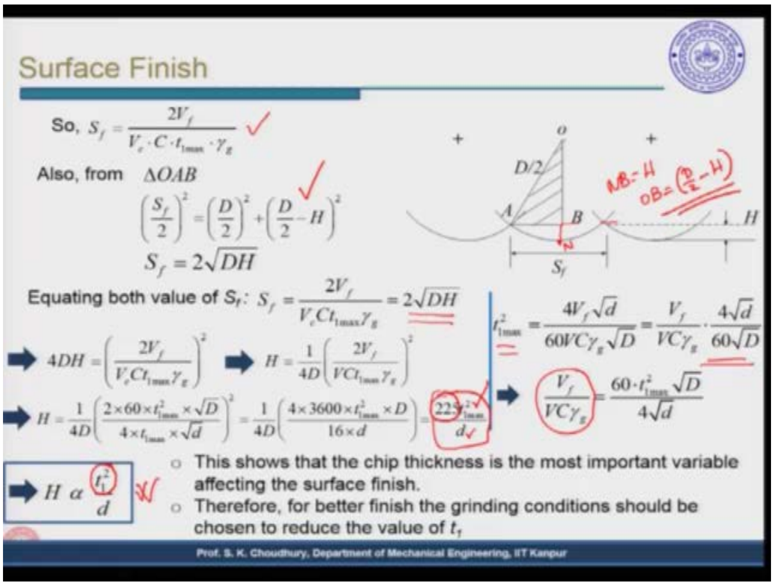

From, ΔOAB; $OA^2 = AB^2 + OB^2$ where, $AB = S_f / 2$, $OB = ON - NB = \frac{D}{2} - H$, From these values we have,

$S_f = 2\sqrt{DH}$; D is the grinding wheel diameter.

Equating the two expressions of S_f as $S_f = \frac{2V_f}{V_c C t_{1\max} \gamma_g} = 2\sqrt{DH}$

Using, $\frac{V_f}{VC\gamma_s} = \frac{60.t_{1\max}^2 .\sqrt{D}}{4\sqrt{d}}$ and solving we get,

$$S_f = \frac{225 t_{1\max}^2}{d}$$

And then we can say that $S_f \propto \frac{t_{1max}^2}{d}$.

This is important to know because then we can find out that if we have to improve the surface finish in the grinding process we actually have to manipulate the t_1 which is the uncut thickness. That is the importance of finding out the t_{1max} . You remember how scrupulously we found out the t_{1max} . This is also an another important point that we can manipulate the t_1 which is the uncut thickness. In case of grinding it is the t_{1av} which is half of t_{1max} and that actually can be regulated to improve the surface finish of the grinding process.

Overall this is what I wanted to tell you during the 20 sessions of our discussion on the course on machining science. I hope you have enjoyed; if you have any question then we can discuss it in the forum.

Thank you for your attention.