Production Technology: Theory and Practice
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Lecture - 10
Practical Machining Operations

Hello and welcome back to the discussion session of production technology: theory and practice.

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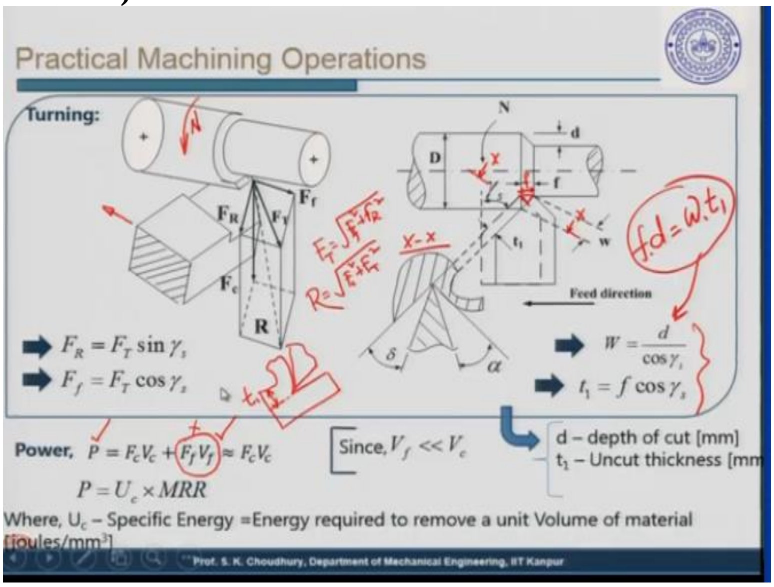

Let me remind you that we were discussing in the last discussion session the practical machining processes, practical machining operations and we discussed initially how the forces in turning are distributed. As you can see in this slide this is the workpiece and the forces are in the parallelopiped. Here is the pictorial view of the turning process; this is the feed which I said as the linear movement of the tool in mm per revolution of the workpiece.

So, the feed unit is given as *mm/rev*. The geometric parameters are the width of cut shown here, depth of cut shown here, then the feed and that t_1 which the uncut thickness t_1, you can also get it from this diagram. I will give you this diagram additionally here is the same diagram as in here and this is the t_1.

For orthogonal cutting, this is equal to the d, the depth of cut because the width and the feed will be the same in that case. Because in orthogonal cutting, the uncut thickness t_1 and the depth of cut *d* are the same but not for all cuts, not for all processes. Physical parameters are related like this that the width of cut is $w = \frac{d}{\cos\gamma_s}$.

γ_s is the side cutting edge angle and the t_1 is related to the feed as $t_1 = f\cos\gamma_s$. In the force relationships we said that this is the F_t which is the thrust force, thrust force remains on the horizontal plane and this is the summing of the F_f and the F_R vector sum. The cutting force F_c is directed vertically. The resultant force will be $R = \sqrt{F_c^{\ 2} + F_T^{\ 2}}$.

And radial force F_R and the feed force F_f components can be found out through the F_T this will be $F_R = F_T \sin\gamma_s$ and $F_f = F_T \cos\gamma_s$. And then I said that if you take the cross-section X-X it will be this diagram in fact this diagram and this diagram is the same you understand that. Here in the sectional view we can show the rake angle and the flank angle like in this diagram and this is the t_1 which is the uncut thickness.

Then we said that the power is product of F_cV_c approximately because the feed velocity V_f is much less than the cutting velocity V_c but otherwise, in the normal way, it is the product of F_cV_c and the F_fV_f. In case the V_f is high, let us say comparable with the V_c, the product of F_fV_f has to be considered but that does not happen in case of turning where V_f is much less than the V_c. So, we ignore it and we say that the P always is F c into V c, because we are ignoring the F_fV_f component.

Power can also be given as the specific energy into the material removal rate and the specific energy by definition is the energy that is spent to remove the unit volume of material it is *Joules/mm*^{3}.

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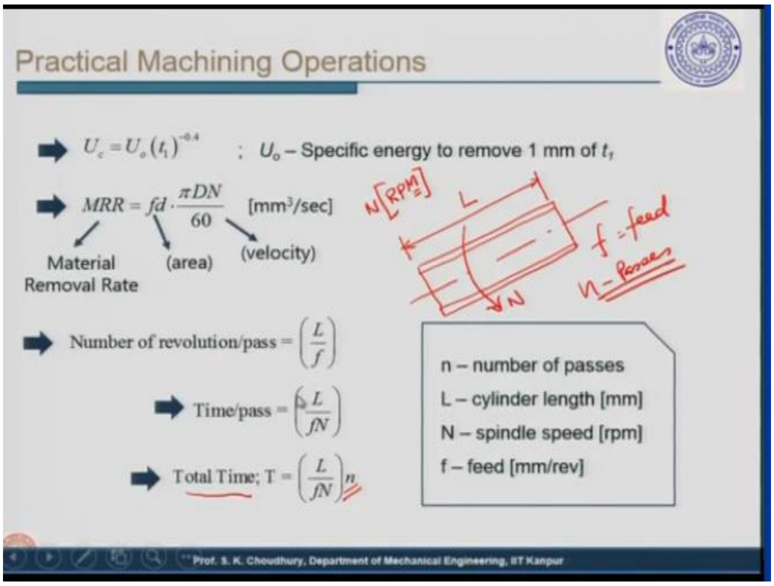

Tthis is given as $U_c = U_0 \left(t_1\right)^{-0.4}$. This is an empirical formula empirical formula means that this is obtained experimentally. You cannot derive this formula because it is obtained experimentally; t_1 is uncut thickness and this is the coefficient (-0.4) obtained experimentally as an exponent. Now U_0 which we said as the specific energy coefficient, by definition it is the specific energy to remove 1 *mm* of t_1.

This is the definition because if you put $t_1 = 1mm$ in that case U_c becomes equal to U_0. Material removal rate is area into velocity and this is given in mm^3/sec. We have taken the velocity divided by 60 that is $\frac{\pi DN}{60}$ and fd is the area in case of turning. So, in case of turning that fd is the area of cut and that multiplied by the $\frac{\pi DN}{60}$ as the cutting velocity gives the material removal rate, MRR.

if we have a job like this which we are turning, the number of revolutions per pass is L/f. If we divide it by *N*, which is the number of revolution then the total time taken can be determined if we know the number of passes. Let us assume that the number of passes is 1 pass, since the depth of cut is very small. So, in one pass we are making it the final cut. In that case the total time will be equal to the same as the L / fN which is the time per pass because the number of passes is 1.

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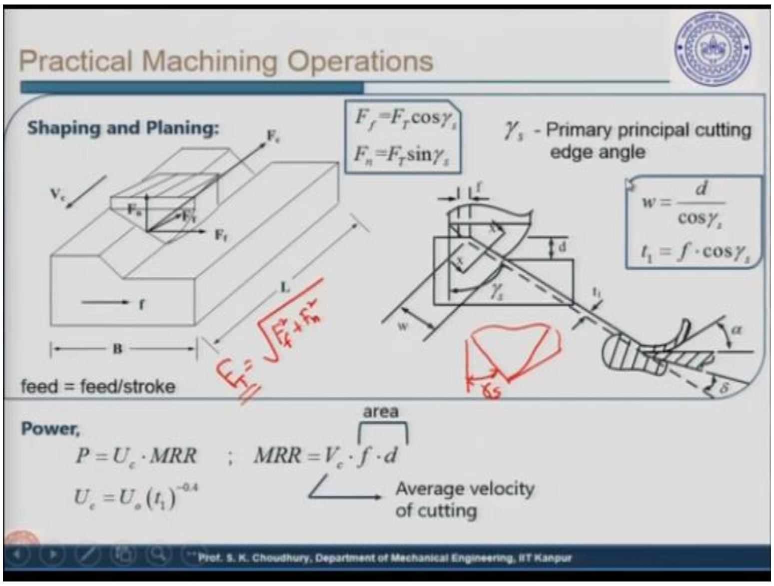

During the discussion on shaping and planing we said that the forces are different and we have shown the forces, F_n is perpendicular to the finished workpiece. F_f is along the feed direction and their sum is the F_T which is the thrust force which is given by $\sqrt{F_f^{\,2} + F_n^{\,2}} = F_T$. By the way this F_T is perpendicular to the transient surface, this is the transient surface.

Transient surface means as the flat is being made gradually the transient surface vanishes, because it should move; the transient surface will be shifted to other place here. And at the end that transient surface vanishes and the entire surface will be the flat surface. So, it is called the transient surface. So, F_T is perpendicular to the transient surface. F_f is given by $F_f = F_T \cos\gamma_s$ γ_s as I said it is here different from the turning.

In turning it was the side cutting edge angle here this is the angle, this is the tool in case of shaping and this angle is called the primary principal cutting edge angle because the principal cutting edge is here this is the principal cutting edge. So, this angle is called the primary principal cutting edge angle. geometrically if you see this is the same as in case of turning, that means the width of cut is here.

This is the distance which is the width of cut. This is equal to $w = \frac{d}{\cos\gamma_s}$. And t_1 we get by the same way as shown in case of turning. If we take a cross section X-X here and this is the X-X as we have taken in case of turning. Here also you can see the tool, the chip flowing along the rake face of the tool and this is the workpiece. This is given in the sectional view because it is the X-X cross sectional view here.

In case of shaping and planning, power is also determined by the specific energy into the material removal rate, $P = U_c \times MRR$ and specific energy is given by $U_c = U_0 \left(t_1\right)^{-0.4}$ and material removable rate is again given by the velocity and the area here is the same as in case of turning, i.e. fd . And the average velocity of cutting will be V_c .Here the average velocity of cutting is taken.

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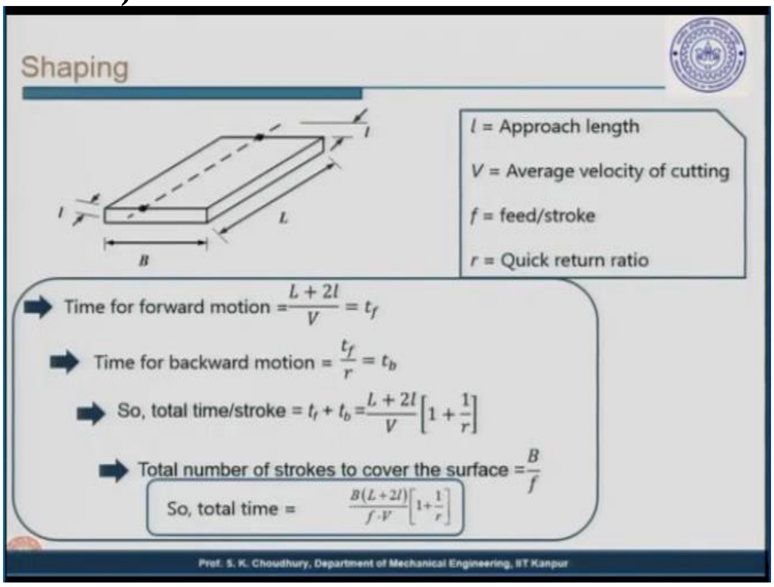

In case of shaping, if we have to calculate the total time taken to machine a part, this is a little different than the turning because here we have to take care of the strokes and few strokes will make the complete machining of the let us say breadth *B*. Let us say in this case the tool is located somewhere in the initial position and when it is coming from the initial position to the contact with the workpiece, it comes at a higher speed, because it is moving in the air.

And then it moves at a certain speed which is the cutting speed then it goes out of contact with the workpiece again with a larger speed, the speed which is faster. This length is called the approach length when the tool is approaching. And then it will cut at a lower speed and then again moves within the approach length at a faster speed, this is the difference here between the shaping and the turning. Let us say this plate is the workpiece that we have to shape, make the flat, this is the length *L* along which the tool will reciprocate.

This is the approach length, *l* and *V* is the average velocity of cutting. *f* is the feed per stroke and *r* is the quick return ratio, quick return ratio is when it is coming back it is not removing material. So, it will come back at a faster speed.

Suppose the tool is coming from this side, it will come faster then it will go here and then it will move at a lower speed then it will go faster, then it will come back at a faster speed. We are assuming that at the entry and at the exit of the tool, the approach length is the same. So, the total time taken in each stroke will include the time taken to travel the full length of the workpiece while removing the material plus the time taken to travel the approach length twice.

This will be $(L+2l)$. Time for the forward motion can be determined by, $t_f = \frac{(L+2l)}{V}$ where V is the average velocity of cutting. the speed of travel for backward motion will be faster and how fast it will travel that depends on the quick return ratio. So, the time for backward movement will be t_f divided by the quick return ratio, *r*.

Let us designate the time for backward movement by t_b . So, the total time per stroke will be $\frac{(L+2l)}{V}\left[1+\frac{1}{r}\right]$. to find out the total number of strokes, that is, how many times the tool has to come forward to remove material and go back that depends on the width of the workpiece, *B*. So, the number of strokes to cover the entire surface will be $\left(\frac{B}{f}\right)$.

Because it is directly proportional to the *B* and it will be the width, *B* divided by whatever feed *f* we are giving. is the total taken to cover the entire surface and to make the entire flat will be $\frac{B(L+2l)}{fV}\left[1+\frac{1}{r}\right]$.

Here this is the difference between the shaping and the turning that here we have to consider an approach length, and another factor is the quick return ratio. Because in case of shaping as well as in case of planning, the tool reciprocates or the workpiece reciprocates and while reciprocating the forward motion will be at a lower speed because it removes material and the backward movement will be at a higher speed.

Because at the backward motion, the tool does not remove material in case of shaping and material is not removed in case of planing. The quick return mechanism that is used for shaping and the planing they are different. In case of shaping, there is a whitworth quick return mechanism which is very popular and you must have seen that in the physics books or in the mechanism book and in case of planing, you cannot use the quick return mechanism.

Because otherwise the bull gear that is basically the mechanism, would have been very very big in diameter and the whole mechanism and the machine would have been very big. In case of planing it is the loose pulley, a tight pulley and the cross belt mechanism that is used as a quick return mechanism. Planing machines are not very popular they are rarely used because in the planing machine, you make very big parts.

If you go to port areas where the big parts for the ship are machined or repaired in the workshop, you will find planing machines are very popularly used because the parts which are to be made in a flat surface or the grooves or the dovetails for example, they are very big surfaces. For those purposes the planing machines are used. There you will see the quick return mechanism is different than the one that is used in the shaping machine that is another difference between the shaping and the planing machine. We will demonstrate the working of shaping machine during the lab sessions.

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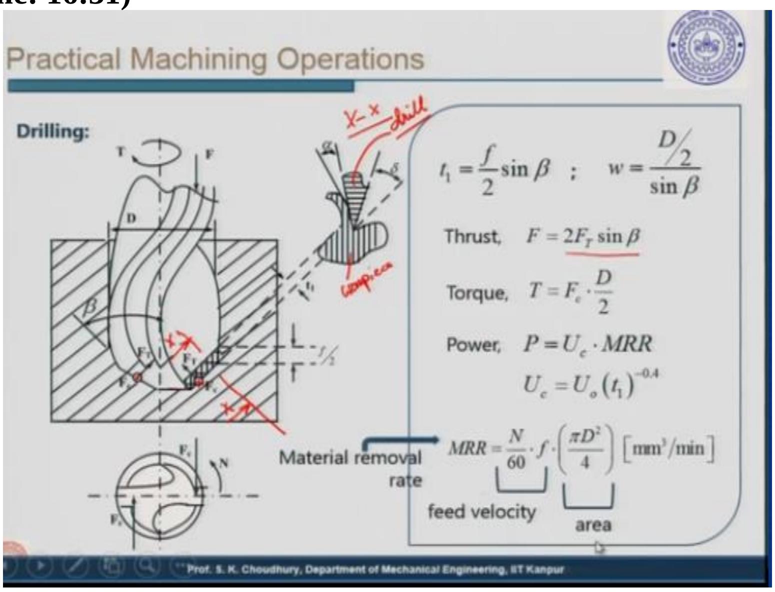

Next is the in the practical machining operations t is the drilling. The tool which is used for drilling a hole, of course, you understand that the drilling process is used for making the hole, the hole maybe the blind hole or it may be a through hole and the tool is the drill. Here you can see the schematic of the drill. In drilling one difference is that here there are 2 teeth. this is the difference between the single point cutting tool in turning where the cutting tool has a single point.

And here there are 2 points - one is here, these are the lips cutting lips. They are popularly known as the cutting lips this is one lip this is another lip. In this view these are the cutting lips, this one and this one. Here the difference is that when you are considering the feed, we said that this is the movement of the tool by one rotation of the workpiece in case of turning. Here since both the rotation and the thrust, that is the penetration of the drill to the workpiece, both are given to the drill.

So, for one revolution of the drill how much the drill has penetrated the workpiece is given by the feed. If you see this in this schematic diagram feed is given to each of these. The total feed is distributed to these 2 teeth, 2 cutting lips and this is the distance moved by the drill in one revolution of the drill which is the distance given as $f / 2$, because the half of it is given to one lip and another half of it is given to the other lip.

And in turning, it is different because it is a single point cutting tool having only one cutting edge, but in case of drilling, there are 2 cutting edges. Here, like in case of turning, if you take a section here, let us say this is X - X and then the view X – X will look like as shown in the slide. This is a sectional view and here is the workpiece, this is the drill. Here you can see only one tooth, another one is here.

In one cross-section only one tool is given, so this you can see that this is very similar to the turning but here only one tooth is given, one cutting lip is shown another cutting lip is on this side. In one section you cannot show both of them. This is the picture with the workpiece and the tool. In this case tool is the drill it is the same as in case of the turning and this is the rake face because the chip will always flow along the rake face of the tool.

And this is the flank face which will be in contact or rubbing against the already machined surface. So, all these concepts will be the same as in case of the turning. However, the forces acting are very different. The torque is imparted for the rotation of the drill and the thrust is given for the drill penetration and that is equivalent to the feed. Without the F the tool could not have been fed to the workpiece. So, this thrust force which is imparted to the drill is the feed given to the drill.

The forces acting are like this. This is the cutting force component F_c which is perpendicular to the cutting edges. The thrust component is perpendicular to this it goes towards the axis of the drill as shown in the slide with 2 arrows.

The F_T will form the thrust force, F_T is the thrust force and the total thrust force that will be acting on the drill will be $F = 2F_T \sin\beta$, β is this angle. From this triangle you can find out this geometrically that $F = 2F_T \sin\beta$. F_T is the component of the thrust force like that and this is the total thrust. Thrust is the force which is applied to the drill, so that the drill while rotating can penetrate the workpiece so that the material can be removed.

Whereas, the total torque will be given by the F_c If you see from the diagram given in the slide, the torque is given in this direction and the N, RPM is in the opposite direction. F_c will be working because this will be resisting the rotation. That torque will be given by $F_c \frac{D}{2}$. It is an approximation that this will be the D / 2.

The power is given in the same way as in case of turning or shaping and the planing. It is given by the specific energy multiplied by the material removal rate, $P = U_c \times MRR$, specific energy is given as $U_c = U_0 \left(t_1\right)^{-0.4}$.

Material removal rate is given by the feed velocity which is N multiplied by f, and area. Cylindrical hole area is $\frac{\pi D^2}{4}$. D is the diameter of the hole or the diameter of the drill. Here I would like to tell you that the drilling process is the process by which you are drilling a hole in a workpiece from the scratch.

The drilling machine will always have a lot of vibration during the drilling process because of the high torque applied for drilling the hole by removing the excess material. For that reason, the hole diameter that you are getting will be little more than the diameter of the drill because it vibrates. So, to make the corrections in the diameter or in the dimensions and to increase the surface finish, we normally do the reaming after the drilling.

This reaming process we will show you in the lab and the instrument that we use for that purpose are the reamers and those reamers are used after the drill is used for drilling the hole to increase basically the surface finish. Coming back to our initial discussion, we have the material removal rate MRR as the feed velocity multiplied by the area and that material removal rate is given in mm^3/min.

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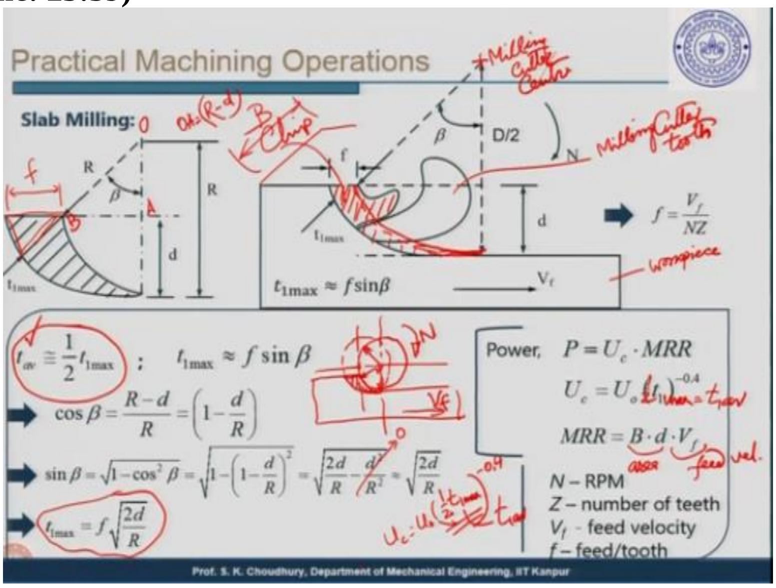

Now, let us discuss the milling process. We will take the example of the slab milling. In slab milling, this is the schematic of this slab milling where this is the workpiece, and this is the milling cutter for which one tooth has been shown. The milling cutter will be like this with all the teeth and this is the diameter, this is the center of the milling cutter. Milling cutter is rotating like this. It will have other teeth all over the periphery of the milling cutter.

But here schematically only one tooth has been shown, this is the chip which is being formed . This is the milling cutter center, around which it is rotating while other parameters are that this is the RPM at which the milling cutter rotates. This is the workpiece which is given the feed velocity V_f ,N is the milling cutter RPM.

Material is removed through the interaction between the milling cutter RPM and the feed velocity given to workpiece. This much material removed is the depth of cut, this is the d

which is the depth of cut. In one revolution of the milling cutter the workpiece has moved a distance which is called the feed, like in case of the turning. So, this is the feed, this is the movement of the workpiece in one revolution of the milling cutter.

That means the milling cutter's initial position was like this, then it has moved to another position. This is the chip which is being removed. Milling cutter is rotating like this and the workpiece is moving like this as shown in the slide.

When the feed V_f is given to the workpiece, and this is the RPM, N given to the milling cutter,. in that case, the chip that will be formed is shown here.

Suppose the milling cutter is moving from here to this position. In that case, the chip will be like this. D / 2 this is the radius of the milling cutter D being the diameter of the milling cutter. So, as you understand that from here to here, this is also D / 2, that is the radius of the milling cutter because as I said that this is one position of the milling cutter. In that case, this is the radius D / 2 and this also D / 2 because this is moving.

This is the milling cutter radius R and this is also the radius, do not get confused, this is not to scale. This R looks bigger than this R but these 2 are the same. From here you can understand that this is the R and this is also the R. From this point to this point when the chip is formed, this is called the maximum uncut thickness as shown in the slide.

Here if you see that in case of milling, in comparison to turning, it is different because the chip thickness becomes from 0 to the maximum. Therefore, normally in case of milling, it is the average value which is taken because initially when it is in touch with the workpiece it is the 0, but it is increasing gradually up to t_{1max} .

So, normally it is given as the $t_{1\ average}$ which is taken roughly as half of the t_{1max} in case of grinding. t_{1max} you can find out from this triangle if we approximate this sector as a straight line and if this angle is considered to be β.

From this triangle, the value of t_{1max} will be $t_{1\max} = f \sin \beta$. This will be an approximate value because we have assumed this sector to be a straight line.

From this triangle, *OAB*, $\cos\beta = \left(\dfrac{R-d}{R}\right)$. Here, *OA* is *(R – d)*. Now, $\sin\beta = \sqrt{1-\cos^2\beta}$ and $\cos\beta = \left(\dfrac{R-d}{R}\right)$. From here if we ignore the value of $\dfrac{d^2}{R^2}$,. we will get, $t_{1\max} = f\sqrt{\dfrac{2d}{R}}$.

This is how we can find out the value of t_{1max} and this is important because t_{1max} is an important factor, since it is used to estimate the power. To find out the power, we have to find out what is the specific energy and for specific energy it is the t_{1max} which is important.

For estimation of specific energy, t_1 in this case has to be $\dfrac{1}{2}t_{1\max}$. So, in case of milling the specific energy becomes, $U_c = U_0\left(t_{1av}\right)^{-0.4} = U_0\left(\dfrac{1}{2}t_{1\max}\right)^{-0.4}$.

Power is the specific energy into material removal rate. Material removal rate is velocity into area of cut which is Bd . *B* is the width, and V_f is the feed velocity which is given to the workpiece.

So, the material removal rate will be area into velocity and the velocity has to be then V_f ; this is the area and this is the feed velocity. *N* is taken in RPM and *Z* is the number of teeth, V_f is the feed velocity, *f* is the feed per tooth. In case of milling, the feed is given as feed per tooth.

Therefore, depending on the number of teeth you will have the feed and the feed is given as $f = \dfrac{V_f}{NZ}$. In case of turning if you remember we had the feed given as the millimetre per revolution because it was the linear movement of the tool.

But here in case of milling it is the movement of the workpiece and the milling cutter is rotating but milling cutter has a lot of teeth. So it has to be feed per tooth that we have to consider.

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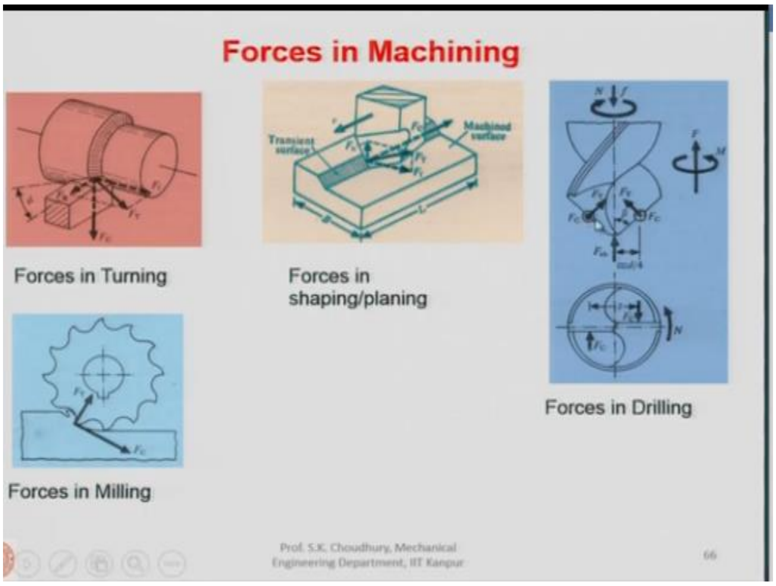

Let us see how forces in machining act. I have already shown you the forces acting during the turning process. In shaping and planing, it is like this, in milling it is the total tangential force and in drilling the thrust and torque are given by F_c and the thrust is given by the F_t. Now we will discuss how these forces can be measured.

Look at this chart, this is for turning, this is for shaping and planing, this is for milling and this is for drilling. You can see that all these forces are very different meaning that if you have to measure the forces, you have to make the arrangement for the measurement, for the device which should be different; one device which will be able to measure the turning forces that device may not be able to measure the drilling forces for example, because here it is very different.

And that device would not be able to also measure the forces in the milling. Therefore, it is very important to discuss how the forces are measured and as I said earlier also that there is an instrument which is called the dynamometer that is used to measure the cutting forces in metal cutting machines.

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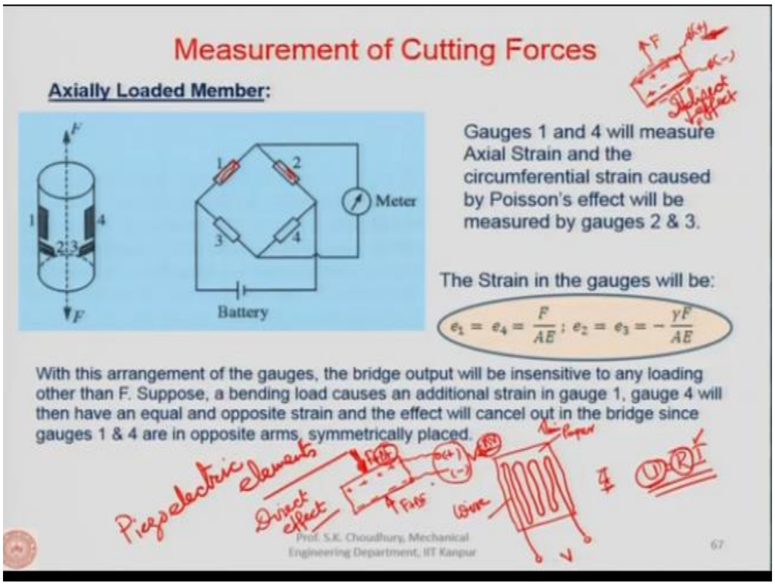

Let us see how the forces are measured for the axially loaded member. The member is like this as shown in the slide. This is a cylindrical job and it is loaded axially. The force is applied from both ends; it is being pulled. This is a cylindrical job and from both sides it is being pulled by some kind of a device. Here we have the sensors which are called the gauges, a gauge which will measure the forces.

For the measurement of cutting forces, for a very long time we are using the strain gauges that many of you might have seen. Strain gauges are very simple as you see here, normally there is a very thin paper. And on that paper there is very thin wire which is in the spiral shape like this. this wire in the spiral shape is glued on the paper.

If we pass some voltage through them then the current that depends on the $U = RI$ according to the ohm's law, the voltage will be depending on the resistance and this is the current. So, this will depend on the resistance of this wire. Now, if the resistance is changed then depending on the current, which is constant, the voltage will be different here. The thin paper with the wire is glued on the surface of this axially loaded member.

One will be in this way, along the axis of the member and another will be perpendicular to the axis of the axially loaded member. Each one of them is a strain gauge. The principle is the same that is on the thin paper there is a spiral wire which is glued on this member. When this member axially loaded member will be deformed, the wire which is now rigidly glued on this will be deformed and the resistance will be changed. When the voltage is passed, it is changed.

Then the voltage is changed depending on the change in the resistance and change in the resistance of the wire is proportional to the change in the shape of this because of the deformation of the axially loaded member. The loaded member is given an axial load for the deformation. It will show through the change in the voltage which will be proportional to the change in that axial load.

These are the sensors, these are called the strain gauges, these strain gauges are here. This is one point of the wire.It is like a spiral and connected at another point and so on this point and then we have this connection here as shown in the slide..

This makes a wheatstone bridge which you must have seen in your school labs. Within these points of the bridge a galvanometer is connected and within these points there is a battery through which the voltage is passed. Gauges 1 and 4 will measure the axial strain and the circumferential strain caused by Poison's effect will be measured by gauges 2 and 3.

All are strain gauges. 1 and 4 will measure axial load. Axial strain would not be measured by gauges 2 and 3. These gauges will give you some value which will be the circumferential strain which is due to the Poison's effect. The strain in the gauges will be now e 1, e 4; gauges 1 and 4 are for the measurement of axial load *F*.

Strain in 1 and 4 will be given by $\frac{F}{AE}$ where F is the axial load, A is the area, and E is the modulus of elasticity. Strain in gauges 2 and 3 will be given by e 2 and e 3. These are the gauges which will measure the circumferential stress. Circumferential stress will be poison's ratio into the axial strain value with a negative sign. With this arrangement of the gauges, the bridge output will be insensitive to any loading, like bending load etc., other than the axial load, F.

When there is a bending load that causes an additional strain in gauge 1, the gauge 4 in that case, since they are dimensionally opposite, will have an equal and opposite strain because of the bending force. As a result, they will nullify the effect of the bending force. Symmetrically placed 1 and 4 gauges will have equal and opposite signal. Once again, suppose the bending load causes an additional strain here.

Then gauge 4 will have an equal and opposite strain and effect will cancel out. Therefore, whatever gauges 1 and 4 are showing will be only because of the axial force acting since they are diametrically opposite and that is why they are put opposite to each other. Similarly, 2 and 3 they will show you only the circumferential strain and these are the values as shown in the slide.

So, the strain that you will measure by this meter is proportional to F. If you are measuring the strain, this will indirectly give you the value of the force that is acting here. These strain gauges are quite, so to say old fashioned in the sense that these days the strain gauges are rarely used because they have been found to be not very reliable.

Since these are very thin this is a spiral wire it is very, very thin, because they have to be very sensitive, why it is thin because you know any small deformation should be sensed by this kind of change in the resistance. But if anywhere it is torn, you would not be able to find out because this is glued to the paper and the entire paper is glued to the member. It is very difficult to find out if anywhere anything is damaged in the wire of the strain gauge.

Second factor is that these strain gauges do not work in the high temperature condition for example, higher temperature condition environment. In that case because of the temperature fluctuation or the high temperature, they will be thermally deformed. And that change in the resistance you cannot then find out whether it is due to the deformation, due to the force which you are measuring or due to the change in the environment or change in the temperature or due to the high temperature.

Therefore, these days Piezo elements are used more popularly for measuring cutting forces. These are called the Piezoelectric elements. The piezoelectric elements have a unique property as follows. Let us say this is the piezoelectric element. If we apply force here, this force will produce the EMF. If you connect with the wire here this will have the plus and this will have the minus. If you measure the voltage here, this voltage will be proportional to the applied force.

Another effect of this piezoelectric element is opposite indirect effect that if you apply the voltage at the input, then the element will be expanded. Let us say I will put it here if this is the piezo element, so since it is the (+) it is (-) here and if you put the plus and minus in these nodes, this will be expanded. I am exaggerating that. And if you remove that voltage, it will come back to the initial position.

The first one is the direct piezo effect and this is the indirect piezo effect. Both these effects are being used in mechanical engineering these days for making the transducers since they have very high quality and very high sensitivity. When you are measuring the forces, here the force you apply and find out what will be the voltage at the output. Same thing as in here and as in the case of the gauges where you are measuring the strain.

Depending on the voltage that you are getting at the output, you can find out that what is the F, if you are changing that by say ΔF, that is the force is changed to $(F+\Delta F)$, in that case V will be changed to $(V+\Delta V)$ .So, this ΔV will measure what is the change in the force that you are having, i.e. ΔF. This change in the voltage or the voltage itself because of the application of the force you can correlate and say that this is the magnitude of the force equivalent to this voltage that you are measuring at the output.

This is as far as the direct effect of the piezo element is concerned. The indirect effect similarly, here as you can see that it is the opposite; that once you are applying the voltage here this will be expanded. This will be expanded means this can create force. For example, if we put it enclosed inside a cylinder and if we seal both these surfaces and in that case if you keep one face free and the other face immovable, in that case this free surface will have the tendency to go up or move forward.

If you attach something like a tool, the tool will go up this way. The indirect piezo effect that the element will expand and come back to the initial position when voltage is applied, this effect is used in the case of making a piezoelectric vibrator, in case of ultrasonic machining, in ultrasonic machining or ultrasonic welding we know that we have to use a very high frequency vibration due to which it is called the ultrasonic machining.

Ultrasonic machining is with the help of a very high frequency vibration and that high frequency cannot be produced with the help of the electromagnet. By high frequency we mean this frequency is about 20, 25 kilo hertz. So, 20, 25000 times per second is the vibration. This high frequency vibration can be created by means of using this indirect effect of the piezo elements. When the current is passed and the whole thing is expanding. The frequency of the current can also be changed.

In that case at that frequency, it will be expanded and come back that itself will be the vibration. Depending on the input frequency of the current you can have the output frequency and you know that normal frequencies 50 hertz per second or 50 hertz. In our electric circuits we have the 50 hertz cycle that is the frequency and that frequency can be changed you put the high frequency current and then you supply that at the input of this piezo elements or piezo vibrator it will vibrate at a very high frequency.

And in many other cases such kinds of piezo elements are used for making the vibrators because earlier most of the vibrators were used to be the electromagnetic vibrators and the electromagnetic vibrators cannot give such a high frequency vibration. Now this effect that is the direct effect it is in fact more popularly used in case of mechanical engineering as transducer. Another use of this kind of effect that is the direct effect is on the doors.

Those piezo elements are also used as paste which is piezoelectric element, for the security purpose. If it is a glass door and it is broken, in that case the force that is being applied will create some kind of a signal, some kind of an output that output could be exaggerated, i.e. amplified and that will activate an alarm.

If you see the glass doors in the big shops, they will have such kind of elements which are piezoelectric elements where this kind of effect is used, that is, if the force is applied, then the output will be some sort of voltage. This voltage will be very small in the magnitude and this can be amplified. Once again, that means if we see this slide, then this is for the axially loaded member and axially loaded member with the help of this whitstone bridge we can find out what is the strain and what is the circumferential strain.

So, this is the axial strain measured by gauges 1 and 4 and the circumferential strain will be measured by the gauges 2 and 3. The rest of the measurement techniques for other processes we will discuss in the next session of our discussion. Thank you for your attention.