Spur and Helical Gear Cutting
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Lecture – 33
Gear Shaping - III

Welcome viewers to the 13th lecture of our series of Spur and Helical Gear Cutting. So, today, we are well poised to start some discussions on gear shaping machines.

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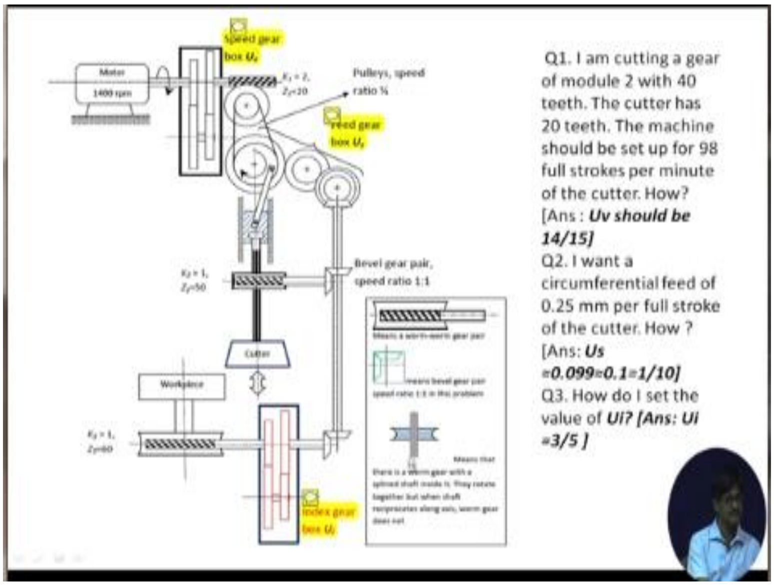

So, we will discuss about gear shaping machines and take up a numerical problem and I will also post some supplementary material in which you can see actually a gear shaping machine in action and we will also solve some multiple choice questions. So, let us start with this drawing. Though after first sight, this might be looking quite formidable. Actually, the thing is quite simple.

For example, in all such drawings involving a large number of machine elements. Let us, first pinpoint or identify the prime mover. This is the prime mover. The motor is rotating at say 1400 RPM and after that, we have some regular machine parts. For example, let us see from here, we have a gearbox here and from our prior knowledge, we can see that this must be the speed gearbox.

So, here, it is written speed gearbox U_v. So, inside there are some gears. You might say what are the numbers of teeth of these gears, I will say, it will vary from case to case. If, you are applying a particular condition that I want this particular cutting speed or this particular number of strokes per minute that will decide this particular gearbox setting.

So, at this moment, it is having no particular numbers of teeth assigned to these respective gears. After that, at the output side of the gearbox U_v, I have this particular machine element connected with a disc shaped body. What is this? This one looks like a threaded element. And this value of $K_1 = 2$ and $Z_1 = 20$, this gives you the hint that it must be a worm and worm gear pair.

So, we have a worm and worm gear pair, just beyond the speed gearbox. That is fine. What does this worm and worm gear pair do? It is having number of starts equal to 2 and number of teeth on the worm gear equal to 20. Which is the worm gear? This is the worm gear. So, it will undergo rotation. Coaxial with the worm gear, we have sort of a pulley attached.

This one is a pulley and it has the same rotations per minute as that the worm gear. With this pulley, we have a belt and this belt is going all around a larger pulley at this particular position. So, we will effectively have rotation of this larger pulley due to this belt connection with this smaller pulley. Once this pulley is rotating, there is a connecting rod connected with a reciprocating block, this one.

This slider slides in these guide ways to and fro and as you can well understand, this rotation causes reciprocation of this block. Once this is reciprocating, this shaft with an end collar embedded inside this block will have to move up and down. So, this one also moves up and down and it is a spline shaft. What is a spline shaft? A spline shaft is that which has just like gears it has teeth cut on it.

In its cross section, you will find just like gears, you will have some teeth. What is the purpose? The purpose of the spline shaft is that while it is moving up and down, it can also suffer rotation by a member connected with it, teeth on teeth. We will see an example both as a drawing and also as an active working member in a video recording of the process. So, we have come down up to this point, pulley, connecting rod.

So, this pulley this arm is acting as a crank. So, crank, connecting rod, sliding block and then spline shaft. At this moment, the spline shaft has not been given any rotation. It is simply reciprocating. This reciprocation, at the end of the reciprocation, we have the cutter. The cutter is represented by a trapezium, but up till now, you have noticed that we have referred to the cutter as just another gear, a perfectly made gear.

Then why does it have this trapezoidal shape? At least, if it had been circular in shape. That is if it had been represented by a perfect cylinder, it should have come out as a rectangle, just like the work piece with an axis line, but we actually give some relief angle or clearance angle towards the back of the cutter. So, that while it is machining, its surface does not interfere with the finished surface formed on the work piece.

As it goes down, it removes material by this side, the rake surface, and the clearance surface is relieved away. The flank of the cutting teeth is relieved away from the finished surface. So, that there is no unnecessary rubbing. So, we are now convinced that the cutter is capable of moving up and down. Due to all these belts, pulleys, gearings, bearings, all these things ultimately make the cutter move up and down.

What are the other connections? Let us have a quick look at that. Co-axial with the larger pulley if you look at the top, we are having a gear. This gear is connected with a number of gears and it makes up a gearbox. Though not exactly shown in a proper box, this serves as the feed gearbox. So, we basically have a bifurcation here. So, just after the speed gearbox, there is a bifurcation.

One side goes for reciprocating the cutter, up down and the other side goes and ultimately this one connects up with a bevel gear. There is a bevel gear pair which makes ultimately this shaft rotate, this vertical shaft, long vertical shaft. What is it doing? It is having another bifurcation, power flows out here and the power flows out here in the form of rotations. And let us take this one.

So, through this particular bevel gear pair, we are having rotation of this shaft and now, you are well conversant with this shape. This must be another worm and a worm gear. What is this worm gear doing? Exactly as we previously came across, it is making the spline shaft to rotate.

But when the cutter shaft is moving up and down, how come this is remaining in position and not moving up and down with it? That is it.

Because, the spline shaft can move through bodies without sharing its straight-line motion. But when the spline shaft is rotating, it has to share its rotational motion with another member which is connected to the spline shaft through teeth. So, rotation is shared between this worm gear, this one designated as $Z_2 = 50$ that means it has 50 teeth and the number of stars on this form is equal to 1, and therefore they rotate together.

Rather, the worm gear makes the cutter shaft rotate. Now, why does not the cutter shaft come out of an assembly here? Because it is still inside a rotational space. So, it is within a hollow surface of revolution, so there is no problem. It remains in position moves up and down and also rotates inside this embedded space.

So, now, we have rotation of the cutter added to its reciprocation. So, as previously planned, the cutter is now reciprocating as well as rotating. This rotation is brought further down and we have the index gearbox. So, up till now we have come across the speed gearbox, we have come across a feed gearbox and we have the index gearbox here. The index gearbox has its output given to yet another worm and worm gear pair, where number of starts is 1 and a number of teeth equal to 60.

So, where do we arrive? We arrive at the work piece. If you remember the work piece has rotation as well as a radial infeed towards the cutter, we have not studied the radial infeed as an added line of mechanisms bringing the ultimate motion to the work piece towards the cutter, but we will definitely study this thing.

At least while watching a video on the machine, we will definitely come across this radial infeed. So, this rotation ultimately rotates the work piece because if you remember, in the gear shaping and the gear hobbling machines which work on generation, we have to make the cutter and the work piece rotate individually by giving power to them. It is not that one of them drives the other. Because of the simple reason that the work piece to start with does not have any teeth on it.

So, the cutter and the work piece both have to be made to rotate as if they are rolling against each other as fully made gears. So, that is what we have done. We have made the cutter rotate, we are making the work piece rotate here and we will maintain the RPM ratio, as if the work piece is already having the required number of teeth. The cutter has a fixed number of teeth, this particular cutter if you do not change it.

So, now, we are convinced that the single motor source through these 3 gearboxes and some other mechanisms, which we have discussed now, it is able to successfully reciprocate the cutter, rotate the cutter as well as rotate the work piece. And now, it is a good time to solve a problem and see what sort of restrictions and other things define ultimately, the gearbox ratios.

Question: I am cutting a gear of module = 2 with 40 teeth and I have forgotten to mention is that the gear to be cut is a straight spur gear, not a helical gear. So, a straight spur gear is being cut with module = 2 and 40 teeth. So, the cutter has 20 teeth. The machine should be set up for 98 full strokes per minute. What does that mean?

It means that they will be 98 up and down movements of the cutter per minute. Now, how do we do this? I have already provided you with an answer. So, that you can try it out yourselves before we discuss the solution and see whether you have a correct answer. So, the correct answer is U_v should be $\frac{14}{15}$. Next question is; I want a circumferential feed of 0.25 millimetres per full stroke of the cutter. How do I achieve this?

The answer is that the feed gearbox U_s should be set to a value of roughly $\frac{1}{10}$. So, if you set a value of $\frac{1}{10}$ to the feed gearbox, you will be achieving circumferential feed of 0.25 millimetres per full stroke of the cutter. Now, you might ask a question here that if I have 0.25 millimetres of circumferential feed on the work piece, will it be the same thing?

The answer is yes. Because when the cutter and the work piece, they are rolling against each other without slip, they are supposed to have the same amount of circumferential movement. They share equal circumferential movement. Therefore, we can either say the circumcision feed on the cutter of 0.25 millimetres or circumferential feed on the work piece of 0.25 millimetres per full stroke. Last of all, how do I set the value of U_i?

The answer is; U_i is defined by the number of teeth which is being cut and the cutter number of teeth. So, from that the solution is U_i for this particular case will come out to be $\frac{3}{5}$. So, if you are interested, solve the problem yourselves and compare the answers with these answers which are provided.

And if you have any issues, then we can share the solution and you can quickly look up what might have gone wrong or maybe you are right and this discussion has some issues. So, let us quickly go through and here we are having some symbols which I have discussed in case you have some doubts about some of the mechanisms. This is a worm and worm gear; this is the worm; this is the worm gear.

There are other ways in which we have depicted it. This is a pair of bevel gears and this one is a worm gear with splines inside which is fitting to this spline shaft so, worm gear on a spline shaft.

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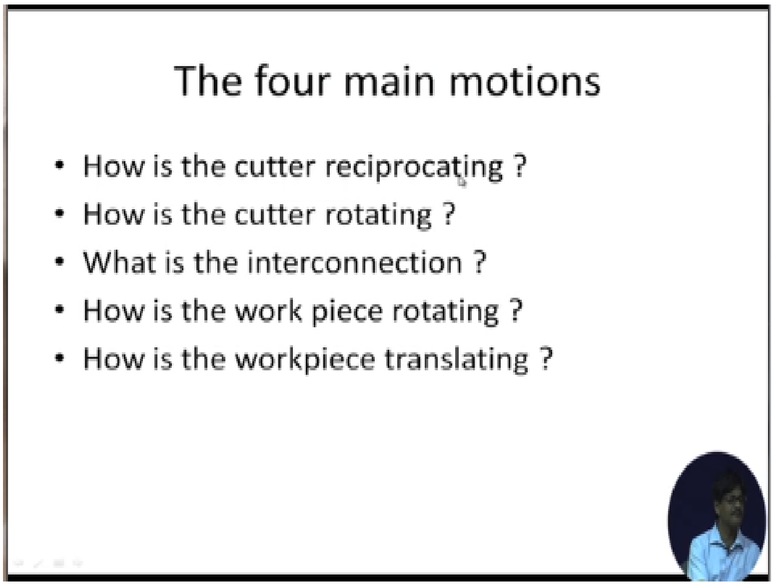

So, the 4 main motions: how is the cutter reciprocating? Already discussed. How is the cutter rotating? Already discussed. What is the interconnection the spline shaft part? Already discussed. How is the work piece rotating? We have already discussed this. How is the work piece translating which means the radial in feed? This, we have discussed theoretically but with respect to a numerical problem, we will definitely take this up.

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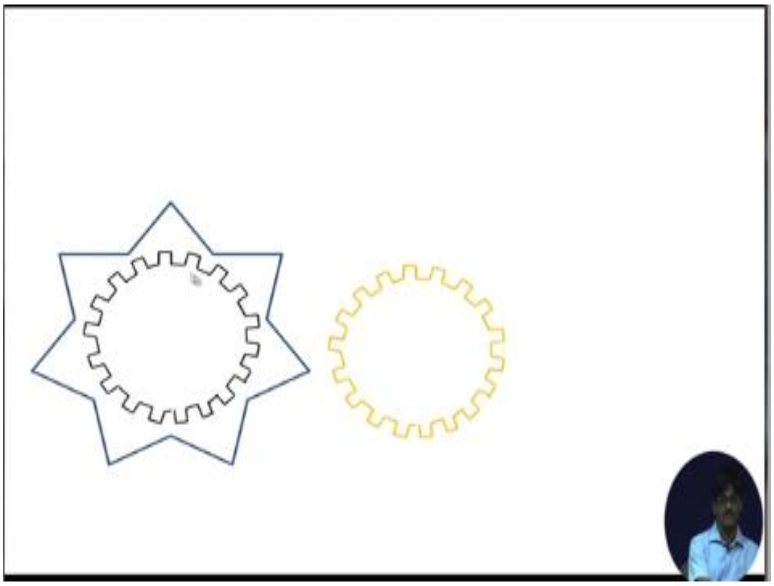

This is an example how the spline shaft works. Suppose, you are seeing from the end one spline shaft here. Spline shaft is rotating and this is a hypothetical virtual member which is a machine element with a hollow interior with fitting splined teeth. So, these teeth match exactly with these external teeth. So, these are internally cut teeth in this hollow member. These are external teeth.

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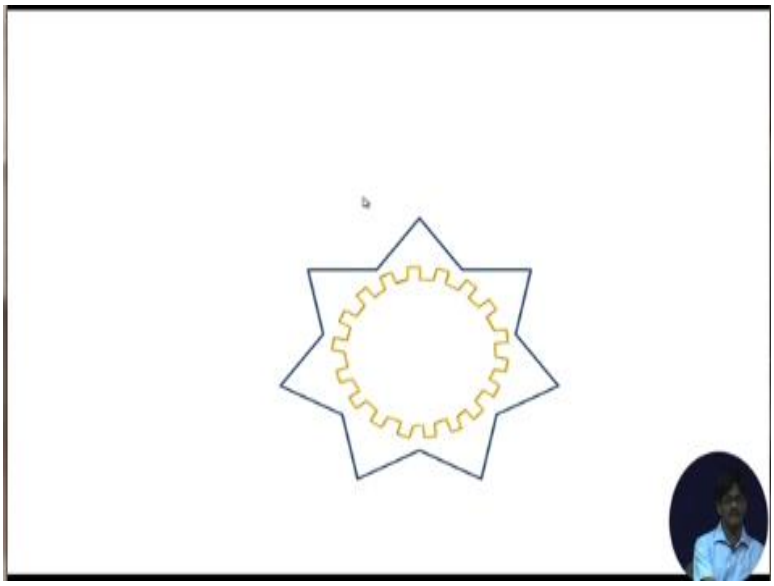

So, that if they are assembled, they will have the same rotations are made this way. Inside the spline shaft and outside, this member and as we discussed, they have translational independence. While this member might be translating, the spline shaft might not.

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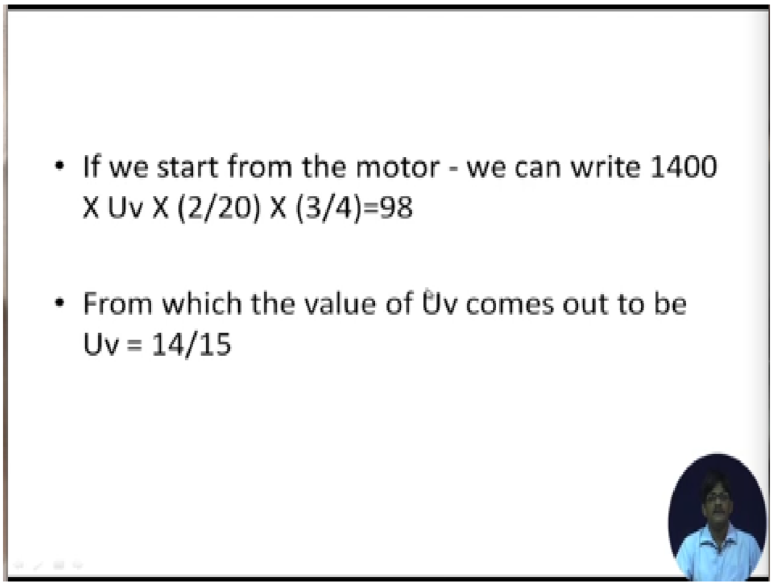

Now, the solutions. Keeping this one let us try on pen and paper the solution for U_v.

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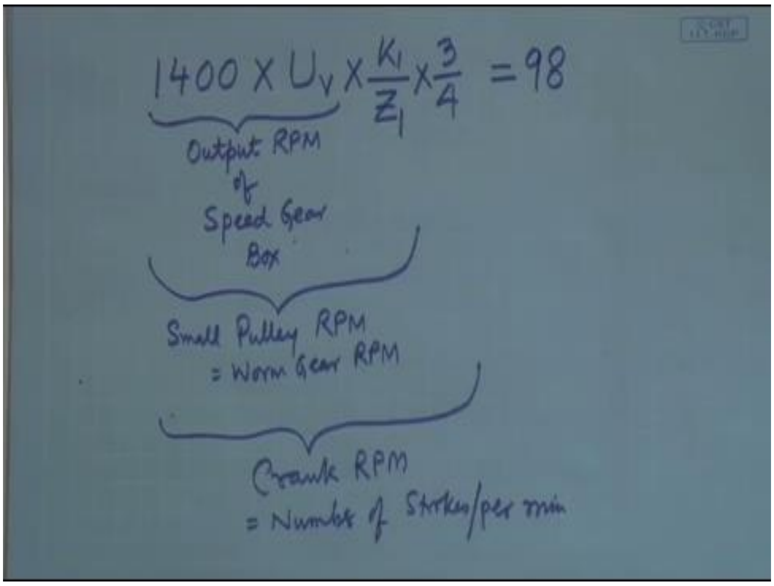

Starting from the motor, we have 1400 RPM. Actually, it should have been 1440 but anyway it does not matter for the sake of calculations to understand the principles. It is as good as 1440. So, we start with 1400 RPM and then comes the speed gearbox.

Since, $U_v = \frac{\text{Output RPM}}{\text{Input RPM}}$

$U_v \times 1400 =$ Output RPM of speed gearbox

So, if this is the output RPM, it must be shared with this particular worm. So, the worm has this RPM and therefore, just multiply the speed ratio of the worm and worm gear which is equal to $\frac{K_1}{Z_1}$.

$$1400 \times U_v \times \frac{K_1}{Z_1}$$

So, we come to the output side of the worm and worm gear, which means the worm gear RPM. The worm gear RPM is shared with the pulley.

So, if the pulley speed ratio is given.

$$Small\text{ pulley RPM} = 1400 \times U_v \times \frac{K_1}{Z_1} = \text{worm gear RPM}$$

So, once we pass through belt pulley, therefore, if you notice in the figure, it is written pulley speed ratio $\frac{3}{4}$ and everywhere, we will assume that the speed ratio is given as output by input so, that we can simply multiply this.

$$1400 \times U_v \times \frac{K_1}{Z_1} \times \frac{3}{4}$$

So, now, we come to the crank. The crank RPM is this. So, we write crank RPM and this essentially is equal to the number of strokes per minute. So, we have found out the number of strokes per minute and we equate this to the number of strokes which is required and it is said 98 should be the number of strokes per minute that is it.

$$1400 \times U_v \times \frac{K_1}{Z_1} \times \frac{3}{4} = 98$$

Now, we can solve for U_v. but $\frac{K_1}{Z_1}$ is in variable form. So, we have to replace this by this value.

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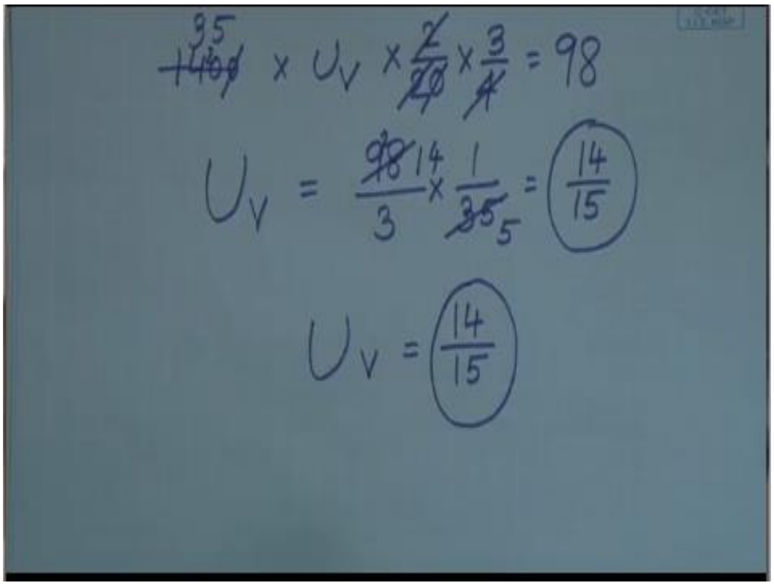

So:

$$1400 \times U_v \times \frac{2}{20} \times \frac{3}{4} = 98$$

Once we have this. Let us solve for U_v. U_v comes out to be. So, we have:

$$U_v = \frac{98}{3} \times \frac{1}{35} = \frac{14}{15}$$

So, answer is $U_v = \frac{14}{15}$. So, let us take the next case. I think we are now on the second problem. I want a circumferential feed of 0.25 millimetres per full stroke of the cutter. Now, in this case if you look at the figure, we are starting from the cutter.

So, for 1 stroke, we will start moving from the cutter, move backwards, come to the main line, then move forwards and go to the rotation of the cutter and equate the circle circumferential movement to 0.25 millimetres. So, let us do that. So, let us start from cutter reciprocation. Cutter reciprocates once fully, up down. Therefore, the large pulley rotates once fully during this time.

So, this one rotates once and therefore, we can say, the input to the feed gearbox is only one rotation. So, once we give 1 rotation to the feed gearbox, its outputs U_s number of rotations. And this passes through this one, passes through this worm and worm one gear and ultimately rotates this particular gear. Let us find it out.

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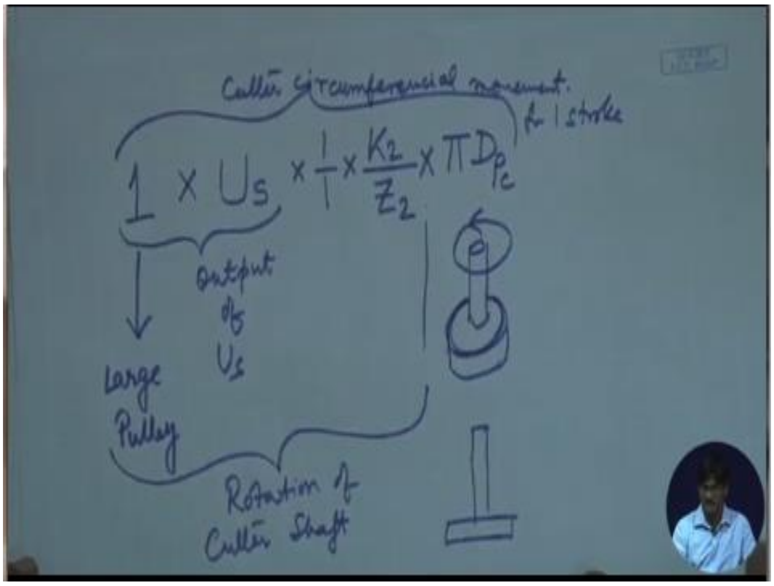

First of all, one reciprocation of the cutter = 1 rotation of the large pulley. We are talking about rotations. This is input to the gearbox U_s feed gearbox. So, the output of the feed gearbox must be equal to $1 \times U_s$. This is always expressed as $\frac{\text{Output}}{\text{Input}}$. So, multiplied by input, only output remains.

$$1 \times U_s = \text{Output of } U_s$$

So, after U_s, we pass through the bevel gear. So, we multiply $\frac{1}{1}$.

$$1 \times U_s \times \frac{1}{1}$$

There is no need of doing that. Anyway, to keep track of the mechanisms which we go through another 1:1 will be there and after that, we passed through the worm and worm gear. In what way, $\frac{K_2}{Z_2}$ and therefore we are now on the cutter shaft in the form of rotations. So, we can write rotation of cutter shaft.

$$1 \times U_s \times \frac{1}{1} \times \frac{K_2}{Z_2} = \text{Rotation of cutter shaft}$$

However, cutter shaft rotation is not specified in any manner, but cutter circumferential movement is specified. So, let us find out for these many rotations how much is the cutter circumferential movement? What is the cutter circumferential movement for one rotation of the cutter? Definitely, πD that means one full circumference that is if the cutter is here or other, let us draw it in an isometric form.

If the cutter is here, if this rotates once completely, how much is the circumferential movement of the cutter? Definitely equal to 1 circumference. Therefore, if you x number of rotations of the cutter, this we know, rotation of cutter shaft. So, the amount of circumferential movement on the pitch circle must be simply equal to this thing into πD . For one rotation, πD amount of circumferential movement, for X rotation, X × πD.

$$1 \times U_s \times \frac{1}{1} \times \frac{K_2}{Z_2} \times \pi D_{p_c}$$

Where D_{p_c} is the cutter pitch diameter. Now, this can be simplified. So, we write that:

$$1 \times U_s \times \frac{1}{1} \times \frac{K_2}{Z_2} \times \pi D_{p_c} = \text{cutter circumferential movement for 1 stroke}$$

So, let us now, just sum it up and find out how much this.

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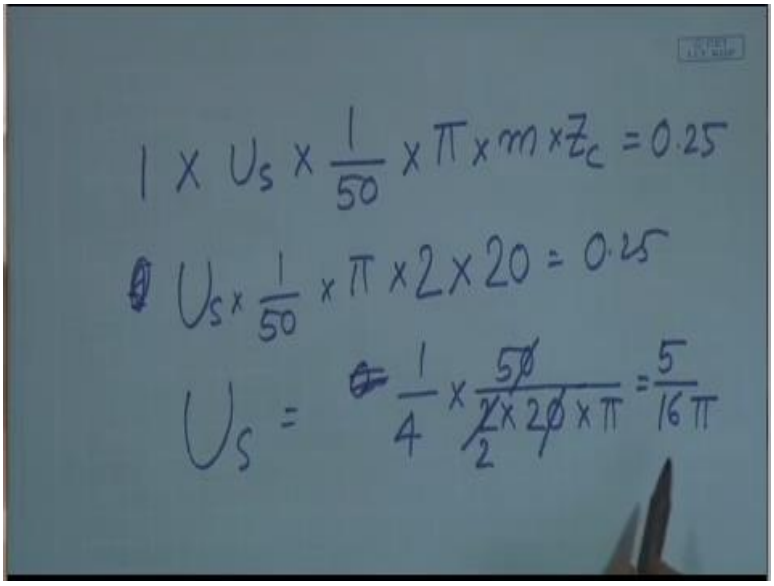

$$1 \times U_s \times \frac{K_2}{Z_2} \times \pi D_{p_c} = 1 \times U_s \times \frac{1}{50} \times \pi \times m \times Z_c = 0.25$$

Z_c = number of teeth on cutter

This circumferential movement must be equal 0.25 millimetres and for that, we will solve for U_s.

By the way, let me just put in this value. So, that we have the final form:

$$U_s \times \frac{1}{50} \times \pi \times 2 \times 20 = 0.25$$

$$U_s = \frac{1}{4} \times \frac{50}{2 \times 20 \times \pi} = \frac{5}{16\pi}$$

I will just compare this with the calculation which we have already done.

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And see whether we have got something correctly. I think we have solved it and got a particular value. You can quickly calculate it, whether it comes out to be $\frac{1}{10}$ roughly that is 0.099 recurring. So, it is being made to equal 0.1. So, if you put in this particular feed gearbox value, you will get circumferential feed of 0.25 millimetres.

So, with this, we come to the end of this lecture. We will take up the rest part of the problem in the subsequent lecture. Thank you very much