Metal Cutting and Machine Tools
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Lecture-18
Gear Cutting CNC and Non Traditional Machining

Welcome viewers to the 18th lecture of the course metal cutting and machine tools. In this lecture we will try to cover gear cutting, computer numerical control and non-traditional machining methods. Though I have a feeling that the last part of our discussion might be spilling over because this extent of the first 2 by themselves it will be quite time taking. So, let us move on, right away to gear cutting methods.

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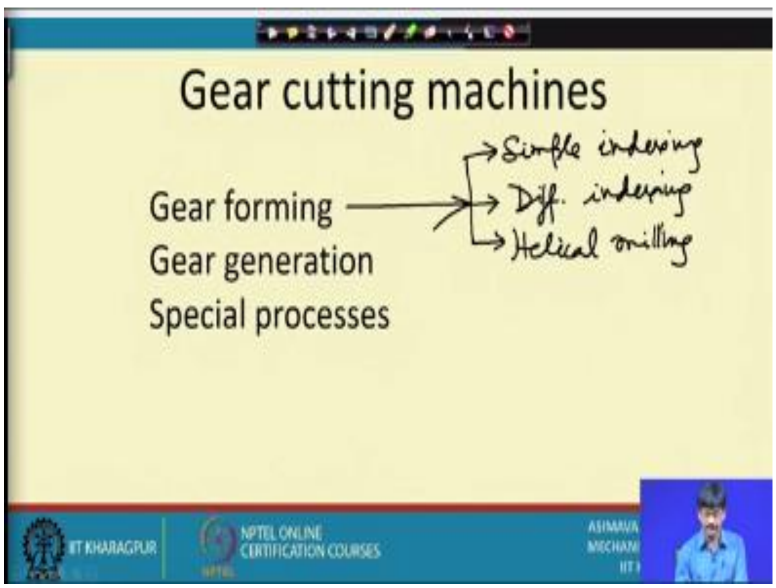

You will notice that we have already discussed something about gear cutting in case of milling machines. In milling machines we have discussed forming methods, that means where the shape of the cutter is conjugate or opposite of the job shape and that is what we have done in milling. So, I will just pen down, jog down those notes, here we have discussed about simple indexing which comes in handy during milling, simple indexing.

We have discussed about differential indexing all very relevant to gear cutting and we have also discussed something about helical milling, so which will allow us to cut helical teeth. We have not carried out any calculations on helical teeth, I will quickly within 5 minutes or so I will try to discuss what are the calculations involved in helical milling? So, if you remember in helical milling we had a figure in which we extensively discussed that the rotational motion of the lead screw has to be related to the rotational motion of the workpiece, why?

Because if we are cutting a helix, then the rotational motion involved in making the helix and the straight line motion in climbing along the helix, they need to be related. So, if they need to be related what was the rotational motion coming from? The rotational motion was coming from the rotation of the job and this was the figure like.

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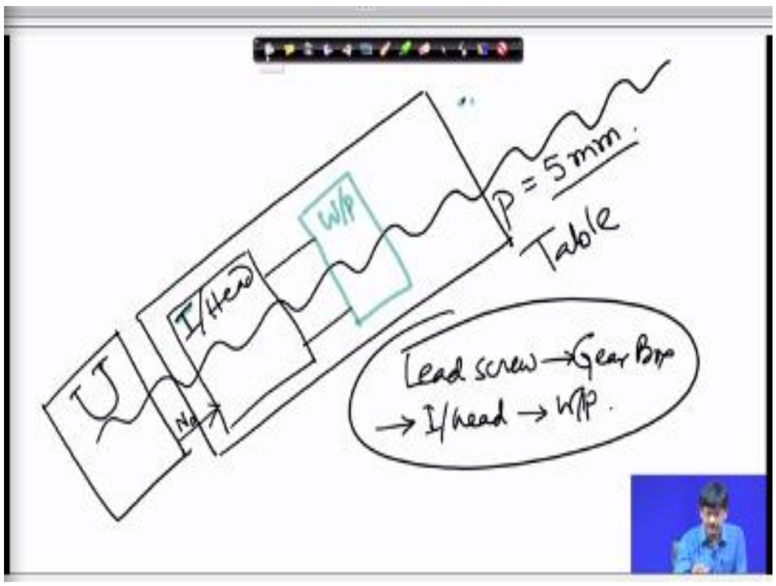

I will draw the simplest possible description, this was the lead screw, it was at an angle. So, if we had the lead screw it must have been traveling on a nut which had a pitch, so let us say this pitch is equal to say P or say 5 millimeters. So, if the lead screw has a pitch of 5 millimeters per rotation it will make the table travel, so this is the table, the table will be traveling per rotation by distance of 5 millimeters.

And what did we do after that? We connected gearbox here, so let that gearbox ratio be U that is fine. So, if U is the gearbox ratio it was ultimately giving its output, let us call it N_o output to the indexing head. And in the indexing head it undergoes a change in rotation and ultimately it is giving that rotation to the workpiece. So, this one holds the workpiece, let me put a different colour, this is the workpiece.

So, screw rotates, table moves, gear ratio changes this RPM and gives it to the indexing head, this is indexing head, I/head. So, we will write this down, so that we do not forget, so it is lead screw to the gearbox to the indexing head and then on to the workpiece. How much straight line motion should take place? How much should be the linear motion by the time that the workpiece rotates once? That we need to find out and we can apply it in this particular relation and that will give us a helical cut. So, let us quickly have a look.

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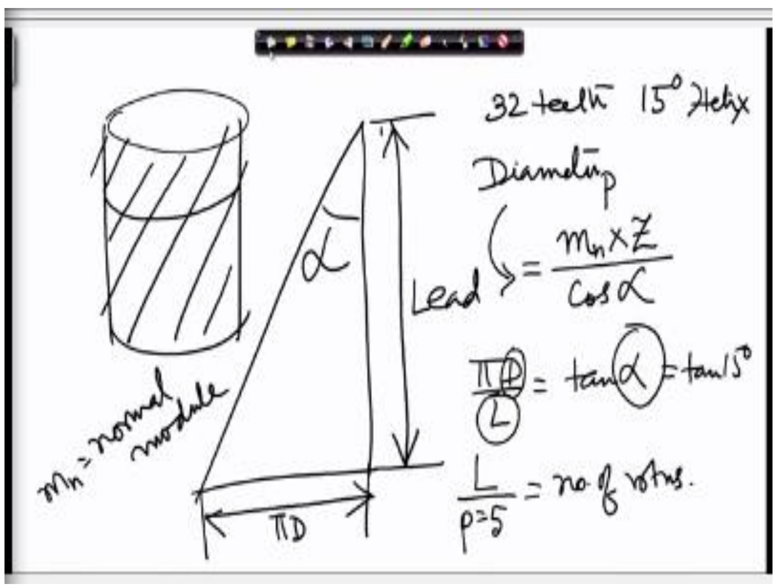

First of all, if this be the gear, these are the helices as many teeth as you have so many helices, so it is a multi start threaded element but we take only a slice of that and this is our gear. So, if we unwrap this helix, if we unwrap a single helix it would look like this, this is it, where if we are unwrapping it this must be πD, so this is πD and this is given a name lead. You must have noticed that we were saying the multiple start threads if we move like this distance between similar successive points will be equal to lead.

And this is α and this is given to us if it is not given it can be calculated from the other values. So, how much is this value and how much does the table have to travel? The table has to travel this much and during that time the workpiece has to rotate once during the time that the tool moves by this much. So, suppose the lead is given to us, if it is not given to us something else must be given to us.

Say you will be given something like 32 teeth, then maybe 15º helix angle, all these things. So, first of all we will be calculating the diameter, pitch diameter of the gear. What will be this equal to? It will be equal to module which will be given, normal module. So, normal module, so let me write down, m_n is normal module, normal module * number of teeth / cos α. Because in order to accommodate teeth at this angle the pitch diameter of the helix angle is slightly larger than the corresponding spur gear.

So, diameter of this helical gear is this much and if you want to find out the lead pitch diameter you can use this expression that this one multiplied by πD/L = tan α. So, we know α, so we can put here and this one it becomes known to us, tan 15º and D has been calculated just now and therefore you can easily find out L. Once you find out L you can divide this by pitch = 5 millimeters to find out the number of rotations of the lead screw.

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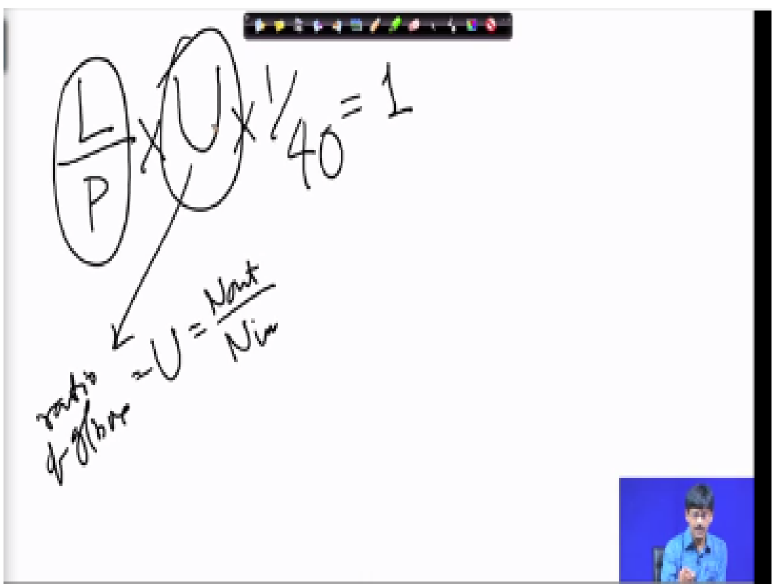

Once you get this value, once you get L/P these many rotations enter the gearbox, at the gearbox ratio is not known, that is what we need to find out. Ratio of gearbox equal to say U a variable equal to actually N_{output}/N_{input}, this is the input. So, this multiplied by this will give you N_{output}.

This one multiplied by the indexing head ratio, so it reduces the RPM by a factor of 40, this must be equal to 1.

And from here we will be able to find out this value. So, this calculation will tell us what should be the gear ratio for cutting a definite helix angle on the milling machine. So, with this we come to the next part of our discussion, gear generation. Gear generation is much more sophisticated than gear milling; we have already discussed it while discussing gear milling. So, we will now directly go on to some methods of gear generation.

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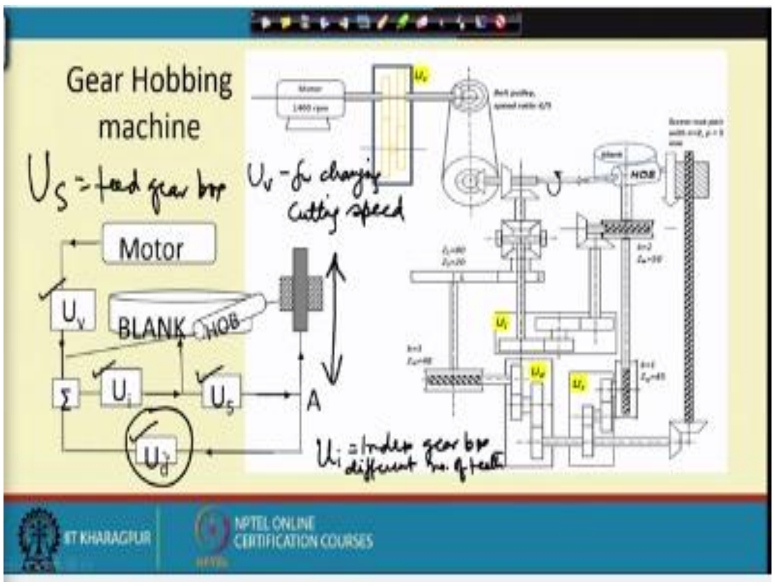

Gear hobbing, what is gear hobbing? Gear hobbing means that just like a worm and worm gear they are meshing, let me just give you the idea in simple words.

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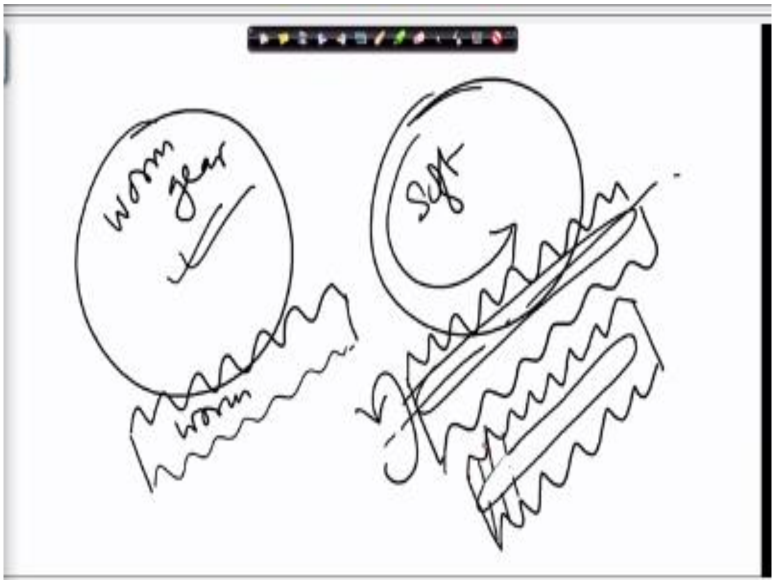

Just like a worm and worm gate is meshing this way if you look at it from the top this is the worm and this is the worm gear and this is the worm. What if I did not have the worm gear fully made but it was simply a cylinder? And the worm is perfectly made of solid and hard and strong material and this is soft. And I made them go through the motions as if they are fully operational worm and worm gear.

The worm will essentially remove those portions of the soft material which do not belong to the worm gear. So, I provide them with motion as if they are worm and worm gear, but this is just a solid cylinder but of soft material. So, the worm will selectively push out all those materials which do not belong to it, but if it is hard it can do? It cannot do it.

So, in that case what we do is? From such a worm we remove material, so that in longitudinal gashes, so that it develops cutting edges. So, you have a threaded element, ordinarily it has smoothly running helical threads like these but we remove that here, we remove material here, so that it develops cutting edges here. This is a cutting edge it develops I have lost the figure.

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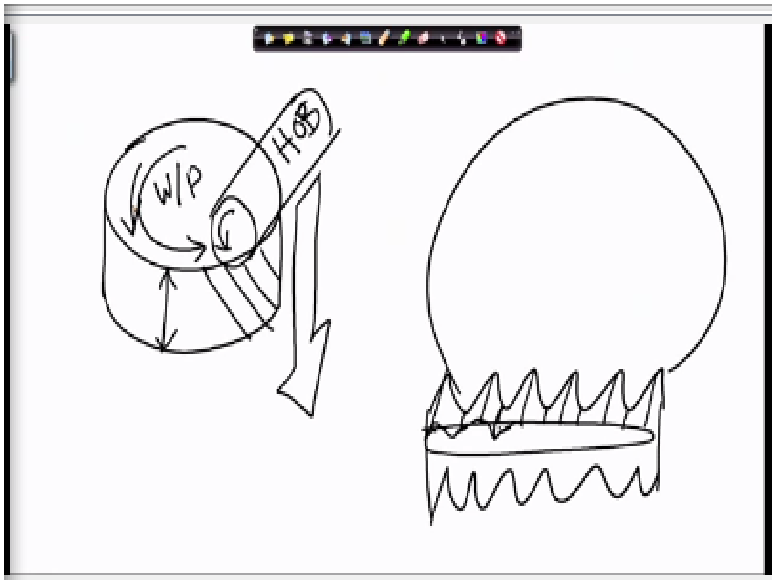

I remove material from this thread, so that these threads are discontinuous now they end up here and therefore it develops cutting edges here, sort of, these are sharp. So, as it is sharp now it can engage with a hard cylindrical body and remove those materials which do not belong to it and cut it away. But for this we need to give it certain types of motion, what are these motions? First of all if I have the cylindrical body, I need to rotate it, so this is the workpiece now, it has to be made into a gear.

This is the worm which we were talking of being used as a cutter and it is given a name called hob. The hob is a worm with cutting edges, so that also needs to be rotated. So, let us see, we rotate this and in order to cut from the top to the bottom in order to cover this whole width this needs to be moved downwards. So, these are the 3 main motions that we need to give in gear hobbing, what else?

In addition if you want to cut helical threads we need to disturb this speed ratio that they would have if they are worm and worm gears, we disturb this ratio, so that the worm instead of cutting straight down starts the cut gets staggered to one side. So, for that we add or subtract an extra rotation to the workpiece. So, this is what hobbing is all about. What is the characteristic feature of hobbing?

Hobbing can cut very accurate gears provided you are using a say single thread hob, if you have multi start hob instead of single start hob might be accuracy problems, that is geometric accuracy might suffer. So, here we have shown some figure of the hobbing machine which at the outside will be difficult to understand but we can get the basic idea from this schematic figure. If you look at this schematic figure what is to be noticed is that from the motor we derive power first of all the hob has to rotate, the blank has to rotate and the hob has to go down.

And we are placing some gear boxes to make the machine very versatile, you can notice there are 4 gearboxes, what is this one for? The speed gearbox or U_v is to have higher rotational speed of the hob, higher cutting speed. If you want higher cutting speed you can increase the value of U_v, if you want different numbers of teeth to be cut you can change this one. So, we can quickly write U_v for changing cutting speed.

For example, U_v is here in the detailed figure U_v is here, what is U_i? U_i is the index gearbox for changing number of teeth. If you want to cut a different number of teeth you use this one**.** What is U_s? For controlling this up down motion feed, feed gear box it is called, U_s is feed gear box. Last of all this is for changing the helix, if you want to cut different helices then only we will use this otherwise it is disconnected. So, I would like to show you some calculations let us see whether we can do it very fast.

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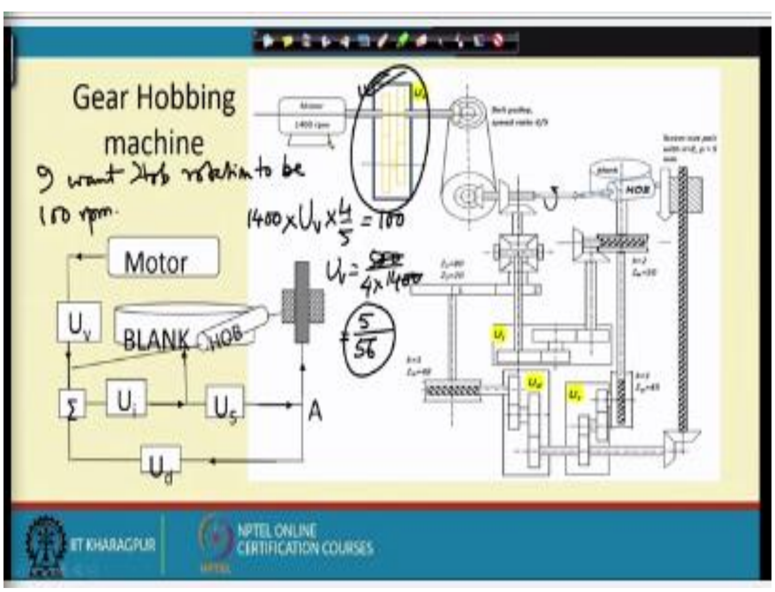

Yes, for example suppose I am interested to get this U_v designed what should be the value of U_v? Now where is the hob rotating? The hob is rotating here, so let me give you some values. I want hob rotation, hob rotation will define the speed that it develops in its periphery, hob rotation to be 100 RPM, how can I get that? So, I start from the motor that is what should be U_v, so that I get 100 RPM on the hob.

So, we can make a calculation this way very fast. I start from the motor 1400, I multiply it by U_v, I do not know the value, so U_v multiply it by it comes out and there is a 1 is to 1 bevel gear then belt pulley speed ratio is given to be 4/5, then again 1 is to 1, 1 is to 1 etcetera, all these things hob that is it, 100. So, U_v will come out to be 500 divided by 4 * 1400, let us cut this out and we get U_v = 5 divided by what is this? 4 * 14, so that means 56. This should be the ratio of U_v, 5/56.

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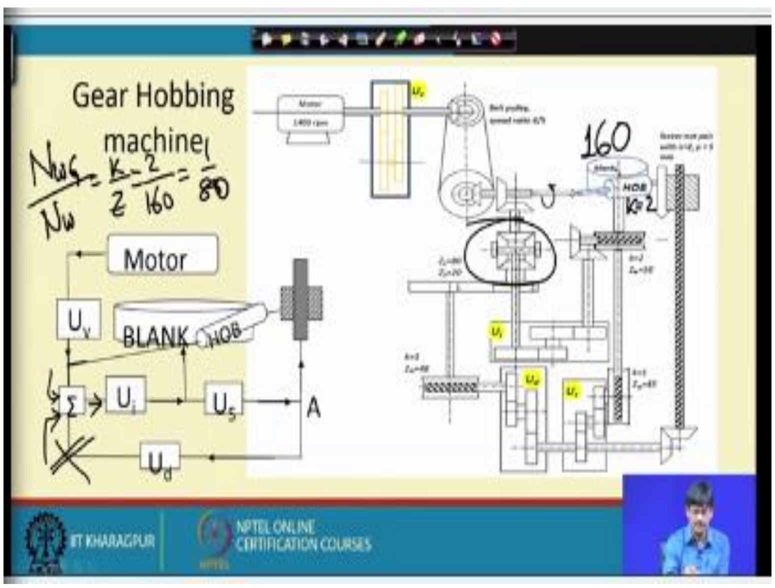

Let us see in what way this figure is connected to this one? This is a schematic and this is a detailed one, do they tally? For example, from the motor it said U_v and then you come to the hob. So, from the motor U_v and then through all these things you come to the hob, so this matches. Let us take another connection like can we find out how U_i is placed here? So, U_i is placed between blank and the motor, so from the motor first we will go to U_v and then there should be a bifurcation no bifurcation**,** here there is a bifurcation.

So, this one had gone to the hob and now we are coming in the other path, this is our other path, so what is this σ? σ is this member; it is called a differential. The differential has the advantage that it can add up 2 inputs and produce 1 output. Now why is it put here? It is put here with this idea if you want to cut spur gears simply have this input and it produces a fixed output. In during that time if you are cutting straight spur gear do not connect this up.

If you wanting to cut a helical gear then that extra rotation which we were talking about it is provided from this side, so that you have 2 inputs now and a single output. So, since a differential can do that very nicely, so we have put a differential here. So, differential essentially adds up the input for spur gear cutting and the input for helical gear cutting and produces a common output.

So, at this moment we are not talking about any differential but we are talking about a particular number of teeth to be produced and how to design U_i with that. Generally, when the differential is not connected in any way to the other line we can take its ratio to be half, this can be proved. So, for the time being without proof please accept that this is going to offer half as a ratio in the kinematic chain therefore we can establish it this way that let us if we have to calculate what U_i should be let us say how many number of teeth we want to cut?

So, let us say we want to cut 160 teeth, what is the speed what is the characteristic of the hob? Say k = 2, that is it is 2 start. Then what should be the speed ratio of the hob and blank if they are treated as worm and worm gear? Generally, if you remember we have already derived that worm gear speed by worm speed is equal to k by z and that means this is 2 by 160 which is equal to 1 by 80. And therefore this speed ratio should be maintained if we sort of control the speed ratio to be 1 by 80 then we will end up cutting 160 teeth that is the idea of gear hobbing.

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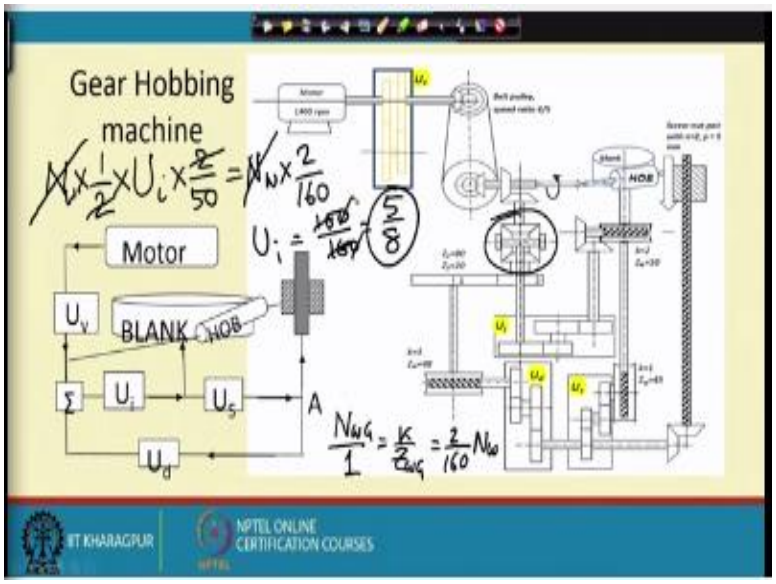

So, let us see how this can be done, let us travel from the hob end up in the blank and set this RPM to be 160 and from that solve the value of U_i. So, what we do is we start from the hob, say hob is rotating at N RPM, that is fine hob rotates N RPM and therefore we go to this way 1 is to 1 we come across this one and we have already agreed that this is half, so this is half.

So, basically we are traveling this way, we are coming here, going this way and ending up in the blank. So, multiplied by half and after that we directly move on to U_i, so multiply U_i this is not known this only will be calculated, multiplied by out we go up and this is having k = 2 and z = 50, this particular worm and worm gear mechanism just preceding the workpiece, so this is 2/50.

This must be equal to how much? This must be equal to if the table rotates N times how much should the job rotate? We know that N worm gear is equal to is related to the worm this way Z_{WG}, so this is 2 by 160. So, we can remove N_w and keep it here, so N_w N_{worm} that is, so we simply put this value here, N worm multiplied by 2/160. And therefore U_i can be solved, N worm cancels out and therefore we have 2 and 2 cancelling out.

And therefore U_i = 100/160, so this one cancels out this is 8, 5/ 8 U_i = 5 by 8. So, since time is short we have to cover other things also I will leave this here and give you a text question with the solved answers and upload it, so that you can follow. So, we will directly move on to another subject now. So, this way all the gear boxes can be designed, what their values should be?

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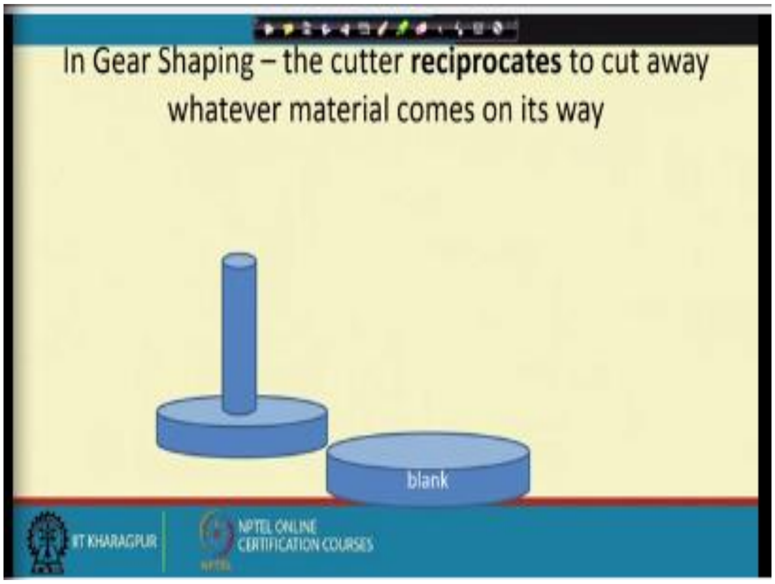

So, now we come to the idea of gear shaping. Gear shaping can be explained in just one sentence, while 2 gears are rotating, if these 2 are rotating together if one is a solid and the other is made to reciprocate, this one will remove all the material it meets on it is way and what will result is the actual gear. So, there is a solid material and this one is a perfectly made gear, they are made to rotate together that is you are giving them individually rotations.

So, that they are rotating against each other, this one reciprocates and it removes all the material while they are rotating together that is it, this is gear shaping. Gear shaping is very accurate but it is slower than gear hobbing, if you want gear to be very accurate and if you want it to come out very fast then you should go for gear hobbing. Gear shaping is slower but it does not have that problem of number of starts etcetera it is very accurate.

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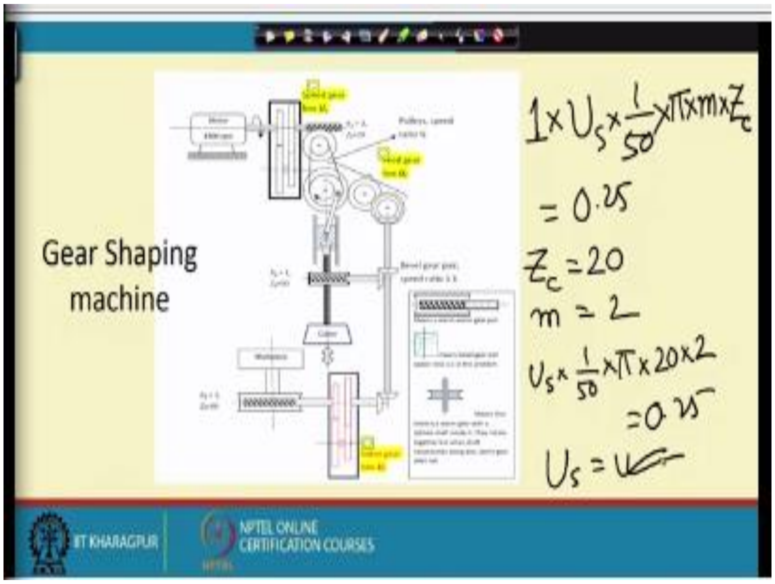

Next, gear shaping has a structure of this type. Let us try to draw the schematic drawing since it is not provided here. So, if we notice this is the motor, this is the way you can read it, this is my motor. Now what are my outputs? First of all, as we discussed the cutter is rotate moving up and down. So, I write cutter, the cutter is slightly trapezoidal, so that it has cutting edges and at the front but otherwise it is just another gear.

So, up and down and in order to control this up and down movement that means to get different speeds we put here a gearbox. So, U_v the speed gearbox it controls the speed. So, from the motor we will connect to the speed gearbox and that connects to the reciprocation, so that is it, it reciprocates. But the cutter and the workpiece they are also supposed to roll, so you have to provide rotation for the workpiece.

So, the workpiece is here I mean cutter and the workpiece, so this has to rotate as well. And in order to control this rotation we provide yet another gearbox and this is called U_s. We draw the power from here you might say why do you suddenly draw it? There is a definite reason which I will be explaining. So, we give it to this one for rotation, so the workpiece also must be rotating.

So, for the workpiece we draw the power from here and rotate it, while rotating we place another gearbox and this one is called index gearbox, it controls a number of teeth. So, let us quickly have a look, is this really coming out this way workpiece? Cutter gets 2 motions up and down and rotation, workpiece gets one rotation, one motion that is the rotation. So, that is interesting, so let us see does it match with this one?

Speed gearbox, speed gearbox is here, so from the motor of speed gearbox, yes it matches. And after that there are some mechanisms and this one is rotating and these just like those steam engines it has been a crank connecting rod mechanism and it moves up and down, that is good, so it moves up and down. Here is a bifurcation; the power is taken out here after the speed gearbox, so after the speed gearbox the power is taken out.

And it travels and this itself is called the feed gear box, this one. It passes through the feed gear box and it goes to the cutter once again but now to rotate it. With this one you have bevel gears and worm and worm gear and now this one while it is moving up and down it also rotates, how does it do it? With a spline shaft, I will be uploading a figure of the spline shaft, so that you can understand, also a figure of the gear shaper and operation.

So, after this there is a bifurcation also and this is the bifurcation and it comes here and goes into U_i and ends up in the workpiece. Now suppose I set some problems for you, what should be the speed gearbox so that the cutter has 98 strokes per minute, so I will start from the motor once again and I will write 1400 multiplied by U_v multiplied by there is a worm and worm gear there, so k/z, 2/20 multiplied by pulley speed ratio 3/4.

This one itself one rotation here, one reciprocation here this itself should be the number of strokes per minute, 98 strokes per minute and from here U_v can be solved. I leave this to you, most probably this will come out to be 14/15, please calculate it yourselves. Suppose I also set that the rotation of the cutter per stroke of the cutter, the rotation of the cutter which will define you how fast they are rolling.

If they rotate too fast, then the surface roughness will suffer. So, the rotation of the cutter suppose I set it to be say 0.25 millimeters per stroke of the cutter just like feed motion on the lathe per revolution of the job, so here per stroke of the cutter. If I set this how are we going to solve it? So, let us start from one stroke of the cutter, so when it executes one stroke then basically then this rotates once, so we start from here.

Big pulley rotates once, so feed gear box is getting an input RPM of 1, I mean rotation of 1 not RPM. So, U_s 1 is to 1, 1 is to 1 then it enters k/z = 1 by 50, this one is the number of rotations of the cutter. Per rotation of the cutter the cutter executes a circumferential motion of 1 circumference πD. So, x rotations will have x*πD amount of circumferential movement. So, this is the number of rotations of the cutter multiplied by πD, π*D = module into number of teeth.

So, we write module into number of teeth on the cutter = 0.25 this is the amount of millimeter movement of the circumference of the cutter per stroke feed motion. So, suppose I give you z_c = 20 and m = 2, so you will have U_s * 1/50 * π * 20 * 2 = 0.25, from here U_s can be calculated. So, I will frame formal questions on gear hobbing and gear shaping and provide it to you, so that you can have a good idea how these machines work. So, that is the end of the 18th lecture, thank you very much.