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 nontraditional machining methods and though I have a feeling that the last part of our discussion might be spilling over because you know this extent of the first 2 by themselves, it will be quite you know quite time taking. So, let us move on right away to gear cutting methods.

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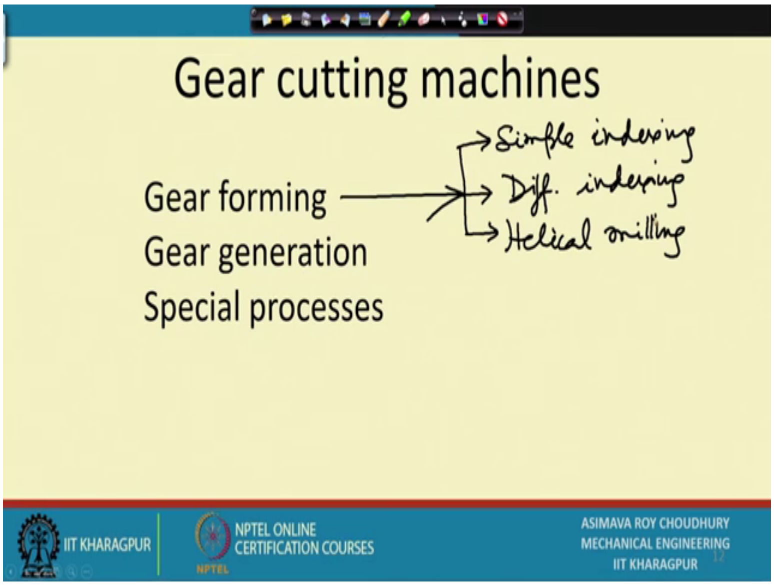

You will notice that we have already discussed something about gear cutting in case of milling machines ok, in milling machines, we have discussed forming methods; that means, where the shape of the cutter is conjugate or opposite of the job shape and that is what will be what we have done in milling. So, I will just pen down jot down those notes here, we have discussed about you know 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 ok, 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 the we extensively discussed that the rotational motion of the lead screw has to be related to the rotational motion of the work piece 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 ok. 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.

So, let us this was the figure like I will draw the simplest possible description this was the lead screw ok; it was at an angle.

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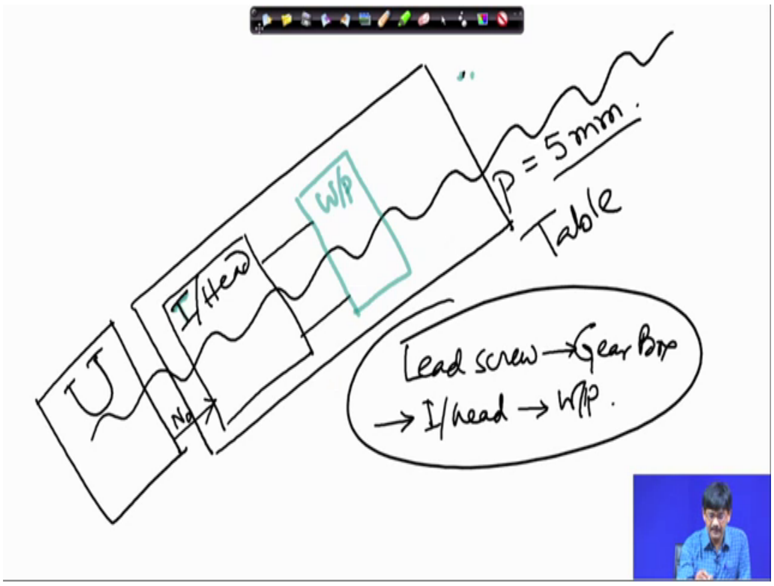

So, if we had the lead screw it must have mean traveling on a nut which had a pitch. So, let us say this pitch is equal to say P or say 5 millimeters. So, if the lead screw has a pitch of 5 millimeters per rotation, it will make the table travel. So, this is the table, the table will be traveling for rotation by a distance of 5 millimeters and what did we do after that? We connected a gearbox here. So, let us that gearbox ratio be U; that is fine. So, if U is the gearbox ratio, it was ultimately giving its output ok, let us call it N o output to the indexing head and in the indexing head it undergoes a change in rotation and it ultimately it is giving that rotation to the work piece. So, this one holds the work piece, let me put a different color, this is the work piece work piece.

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, its lead screw lead screw to the gearbox to the indexing head and then on to the work piece [FL], how much rotation a how much straight line motion should take place linear motion how much should be the linear motion by the time that the work piece 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 ok. So, let us quickly have a look.

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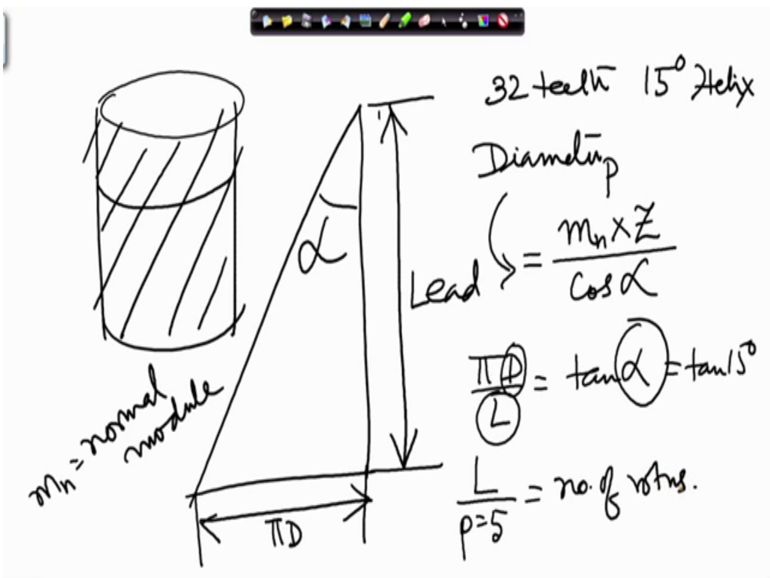

First of all if this be the gear this; these are the helices as many teeth as you have so many helices. So, it is a multi start threaded element, but we take only a slice of that and this is our gear.

So, if we unwrap this helix, we if we unwrap a single helix, it would look like this, this is it where if we are unwrapping it, this must be pi D . So, this is pi D and this is given name lead you must have you 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 alpha and this is given to us, if it is not given, it can be calculated from the other values ok. So, how much is this value and how much does the tool have table have to travel, the table has to travel this much and during that time, the work piece has to rotate once ok, work piece 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 15 degrees helix angle all these things. So, first of all we will be calculating the diameter diameter pitch diameter of the gear what will be this equal to it will be equal to you know module, will be given normal module. So, normal module.

So, let me write down m n is normal module normal module into number of teeth divided by cos alpha because in order to accommodate teeth at this angle, the diameter of the pitch diameter of the helix angle is slightly larger than the corresponding what you call it spur gear. So, pitch diameter of this helical gear is this much and if you want to find out the lead pitch diameter, you can you can use this expression that this one multiplied by pi and L by sorry pi D by L pi D by L is equal to tan alpha.

So, we know alpha. So, we can put here and this one it becomes known to us ten 15 degrees and D has been calculated just now D has been calculated just now and therefore, you can easily find out L, once you find out L, you can you can divide this by pitch equal to 5 millimeters to find out the number of rotations of number of rotations of the lead screw once you get this value.

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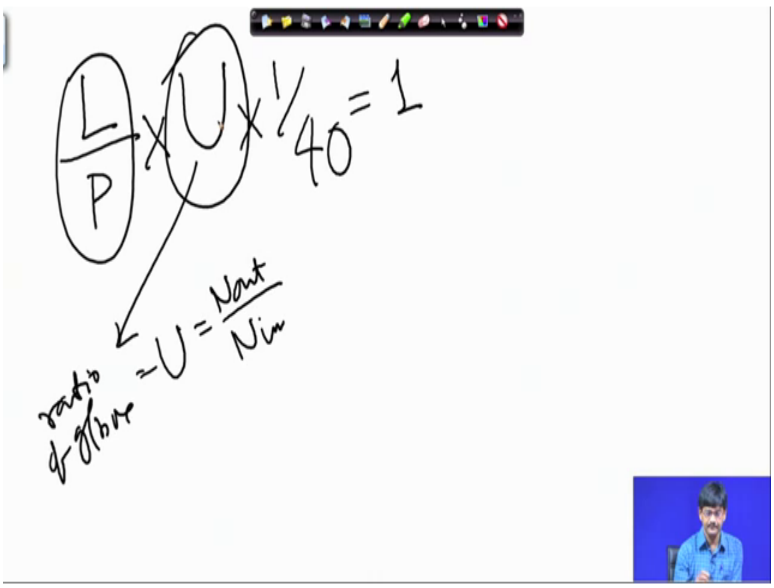

Once you get L divided by P, these many rotations enter the gearbox at the gearbox ratio is not known that is what we have to we need to find out ratio of gearbox equal to you know say U, a variable equal to actually output by n input this is the input. So, this multiplied where this will give you the 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 ok.

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 discuss it while discussing gear milling. So, we will now directly go on to some methods of gear generation.

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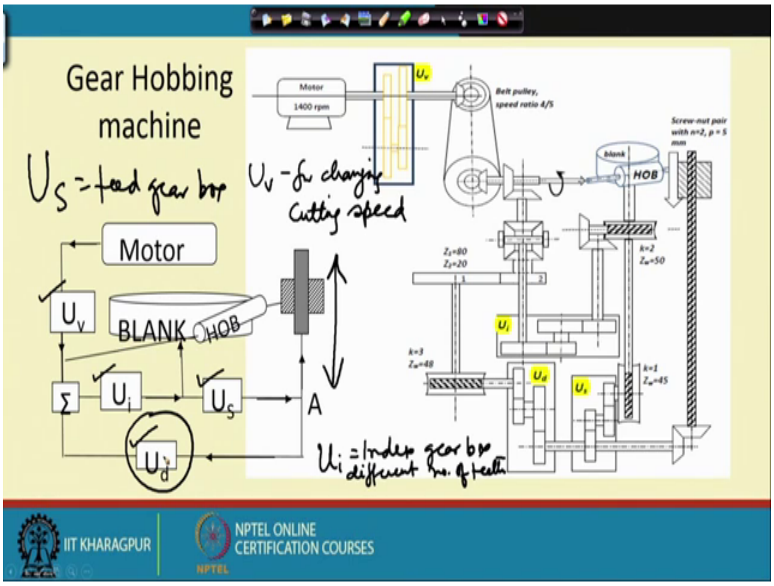

Gear Hobbing; what is gear Hobbing? Gear Hobbing means that just like a worm and worm gear they are machine ok, let me just give you the idea in simple words just like.

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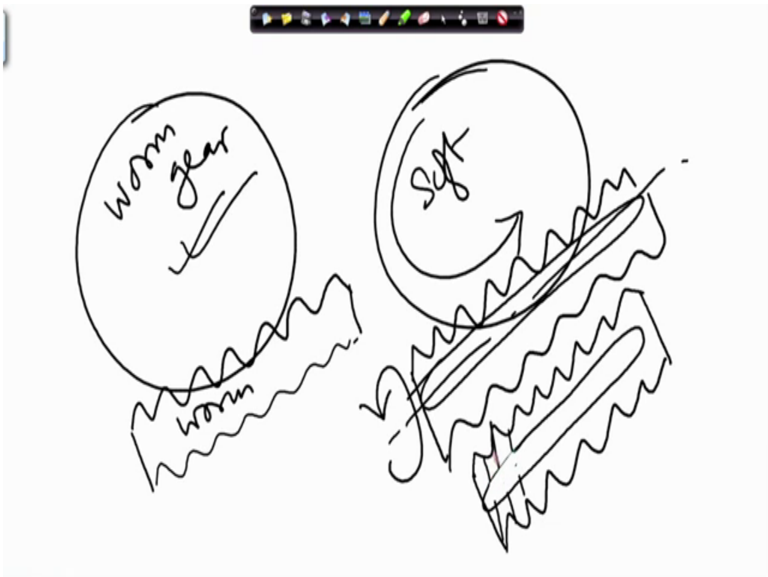

You know a worm and worm gate is machine, this way if you look at it from the top, this is the worm and this is the worm gear and this is the worm; what if I did not have the worm gear fully made, but it was simply a cylinder and the worm is perfectly made of solid strong and hard and strong material and this is soft and I made them go through the motions as if they are fully operational worm and worm gear the form will essentially remove those portions of the soft material which we do which do not belong to the wrong gear ..

So, I provide them with motion as if they are worm and worm here ok, but this is just a solid cylinder, this is just a solid cylinder, but of soft material. So, the worm will selectively you know push out all those materials which worm belong to it, but if it is hard it can do it cannot do it. So, in that case, what we do it do is from such a worm we remove material 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 sorry it develops cutting edges here this is a cutting edge, it develops, sorry, I have lost a figure I remove material from this thread.

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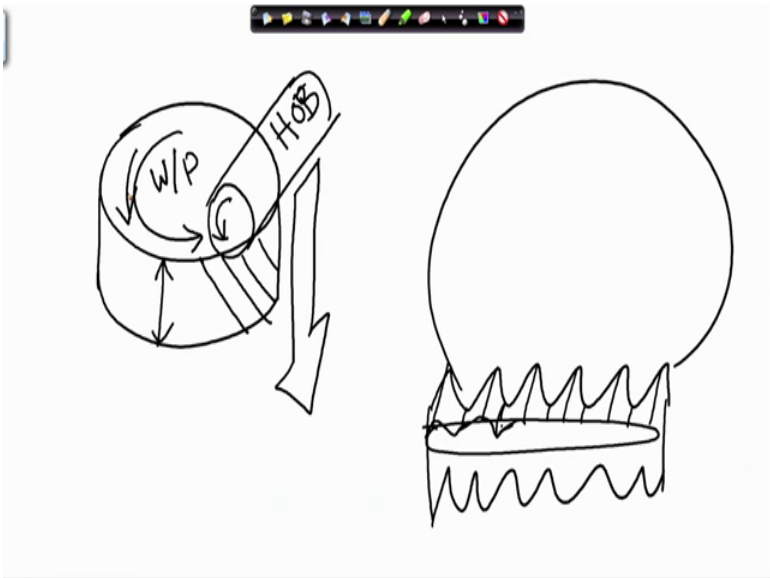

So, that these threads are discontinuous now they end up here and therefore, it develops cutting edges here sort of these are sharp. So, as it is sharp now it can engage with a hard cylindrical body and remove those materials which those do not belong to it and cut it away, but for this we need to give 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 work piece now it has to be made into a gear this is the worm which we were talking of being used as a cutter and its 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 you know disturb this you know 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 work piece ok. So, this is what hob Hobbing is all about , what is the characteristic feature of Hobbing Hobbing can cut very accurate gears provided you know you are using a say single thread hob if you have multi start hob instead of single start hob at a might be accuracy problems that is geometric accuracy might suffer. So, here we have shown some figure of the Hobbing machine which you know 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 in the detailed figure U v is here what is U i? U i is the index gearbox index gearbox for changing number of teeth if you want to cut a different number of teeth you use this one for different number of teeth, 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 helixes then only we will use this otherwise it is disconnected ok. So, I would like to show you some calculations let us see whether we can do it very fast 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.

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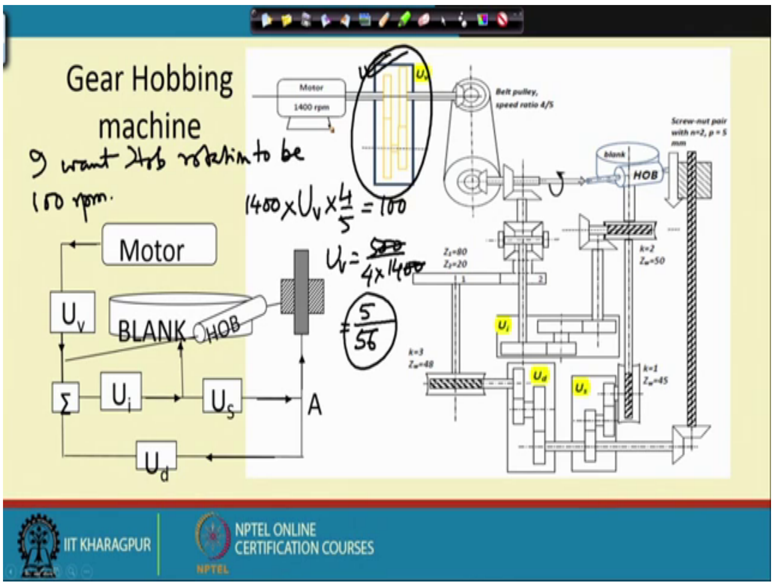

I want I want table hob rotation, you know hob rotation will define the speed that it develops in its periphery of rotation to be 100 rpm, how can I get back .

So, I start from the motor that is what should be U v. So, that I get hundred rpm on the hub. So, we make 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 by 5, 4 by 5, then again 1 is to 1, 1 is to 1, etcetera. So, all these things hob that is it 100, U v will come out to be 500 divided by 4 into 1400, let us cut this out and we get U v is equal to 5 divided by what is this 4 into 14 so; that means, 28; 56, this should be the ratio of U v, this should be the ratio of U v 5 by 56.

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 v is U i is placed here. So, U i is placed between you know blank and the motor. So, from the motor first we will go to U v and then there should be a bifurcation no bifurcation is a 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 sigma? Sigma is this member, it is called a differential. The differential has the advantage that it can add up 2 inputs and produce one output. Now why is it put here its put here with this idea if you want to cut spur gears simply have this input and it produces a fixed output in that connection 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 force per gear cutting and the input for helical gear cutting and produces a common input and a common output ok. So, at this moment we are not talking about any differential, but we have 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 anywhere to the other line we can take its ratio to be half this can be proved ok. 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 how many number of teeth we want to cut.

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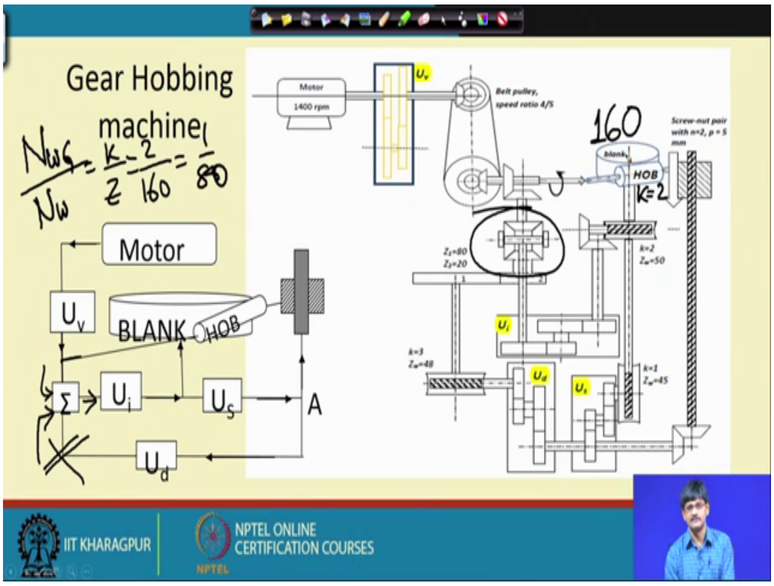

So, let us say, we want to cut 160 teeth , how many what is the; you know speed what is the characteristic of the hob say K is equal to 2 that is it is to start then what should be the speed ratio of the hob and blank, if they are treated as worm and worm gear gently, if you remember, we have already 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, sorry, 1 by 80 and therefore, this speed ratio should be maintained, if feel sort of 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 ok.

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.

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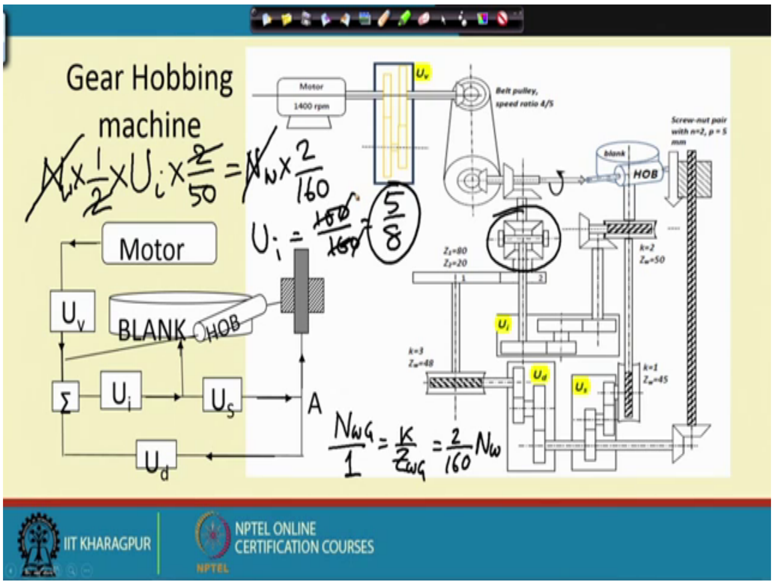

Hob is rotating at N rpm, that is fine, hob rotates N rpm and therefore, we go to this way ok, 1 is to 1, we come across this one and we have already ah, you know agreed that this is half. So, this is half. So, we basically we are traveling this way we are coming here going this way and ending up in the black. So, multiplied by half and after that we directly move on to U i 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 equal to 2 and Z Z equal to 50, this particular worm and worm gear mechanism just preceding the work piece.

So, this is 2 by 50 , this must be equal to how much this must be equal to if the hob rotates N times how much should the job rotate we know that N worm here is equal to is related to the worm this way sorry Z W G. So, this is to 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 by 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 is equal to hundred by 160. So, this one cancels out this is 8 no sorry 5, 5 by 8 U i is equal to 5 by 8.

So, since time is short we have to cover other things also I will 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; you know all the gear boxes can be designed what their values should be.

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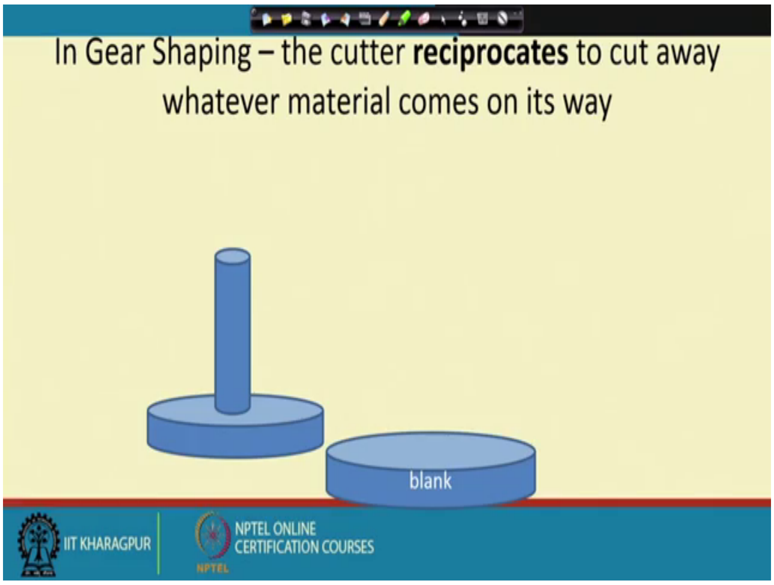

So, now we come to the idea of gear shaping gear shaping can be explained in just one sentence while 2 gears are rotating if one of them. So, if these 2 are rotating together, if one is a solid and the other is made to reciprocate this one-this one will remove all the material it meets on its way and 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 wants 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 stars, etcetera, etcetera, it is very accurate next.

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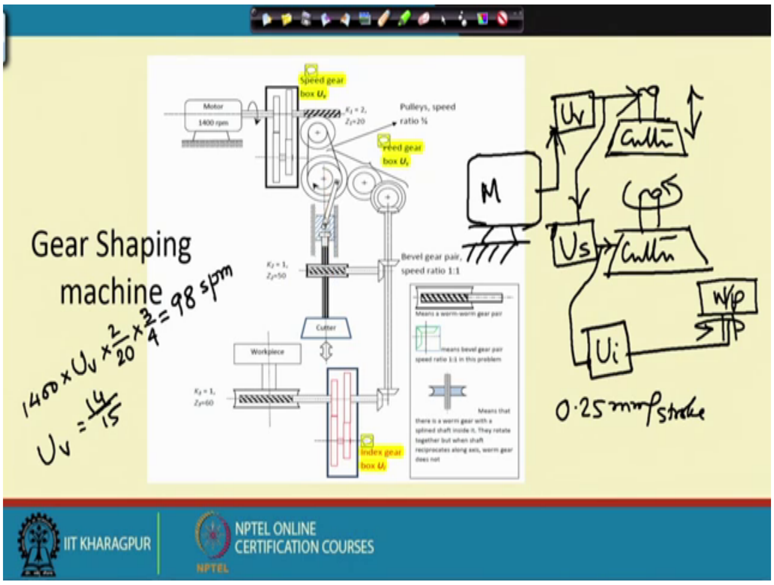

Gear shaping has a structure of this type, let us try to draw the body call it the schematic drawing, since it is not provided here. So, if we notice this is the motor this is the way you can read it this is my motor. Now what are my outputs I am first of all as we discussed the cutter is rotate a were moving up and down.

So, I write cutter the cutter is slightly trapezoidal. So, that it has cutting edges and at the beginning at the front, but otherwise it is just another gear. So, up and down sorry up and down and in order to control this up and down movement; that means, to get different speeds we put here and gearbox. So, U v speed gearbox it controls the speed ok. So, from the motor we will connect to the speed gearbox and that connects to the reciprocation. So, that is it reciprocates, but the cutter on the work piece they are also supposed to you know roll. So, you have to provide rotation for the work piece. So, the work piece is here I mean cutter and the work piece. So, this has to rotate as well and in order to prove a control this rotation we provide yet another gearbox and this is called U s we draw the power from here might say why do you suddenly draw there is a definite reason which I will be explaining . So, we give it to this one for rotation.

So, the work piece also must be rotating. So, for the work piece 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 work piece cutter gets 2 motions up and down and rotation work piece gets one rotation one motion that is the rotation ok. So, that is interesting. So, let us see does it match with this one speed gearbox speed gearbox is here. So, from the motor from the motor speed gearbox yes it matches and after that there are some you know some mechanisms and this one is rotating and this 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 after the speed gearbox the power is taken out and 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 its moving up and down it also rotates how does it do it with a spline shaft I will be you know uploading a figure of the spline shaft so that you can understand also figure of the gear shaper in 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 work piece 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 by Z 2 by 20 multiplied by pulley speed ratio 3 by 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 by 15 please calculate it yourselves, suppose I also set that the rotation of the cutter per minute sorry not per minute 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 point 2 5 millimeters per stroke of the cutter just like feed motion on the led per revolution of the job. So, here first 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 when it executes one stroke then basically sorry then this rotates once. So, we start from here big pulley rotates once. So, feed gear box is getting an input rpm of one.

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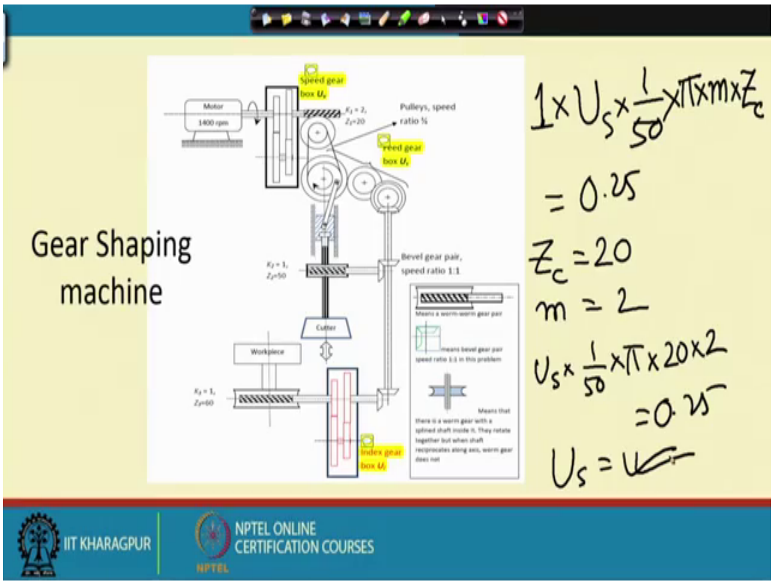

I mean rotation of one not rpm. So, U s 1 is to 1, 1 is to 1, then it enters K by Z equal to 1 by 50. This one is the number of rotations of the cutter per rotation of the cutter the cutter executes a circumferential motion of you know one circumference pi D. So, x rotations will have x into pi D amount of circumferential movement.

So, this is the number of rotations of the cutter multiplied by pi D pi into you know D is equal to in a module into number of T. So, we write module into number of teeth on the cutter equal to 0.25, this is the millimeters of amount of millimeter movement of the circumference of the cutter per stroke feed motion. So, suppose I give you Z c equal to 20 and m is equal to 2. So, you will have U s into 1 by 50 into pi into 20 into 2 equal to 0.25 ok, from here U s can be calculated. So, I will frame questions formal questions on gear Hobbing and gear shaping and provide it to you. So, that you have a; you can have a good idea how these machines work so that the end of the 18th lecture.

Thank you very much.