Elements of Metal Cutting, Machine Tools, Gear Cutting and CNC Machining
Prof. Asimava Roy Choudhury
Department of Mechanical Engineering
Indian Institute of Technology-Kharagpur

Lecture-26
Numerical Problems Milling of Helical Gears

Welcome viewers to the 6th lecture of the series spur and helical gear cutting. So, last time when we met, we were discussing our question.

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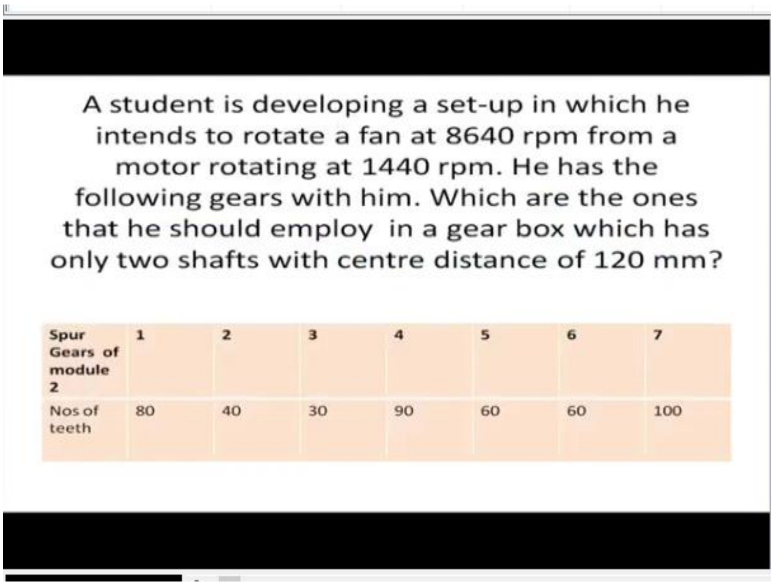

Spur Gears of module 2	1	2	3	4	5	6	7
Nos of teeth	80	40	30	90	60	60	100

This was that a student is developing a set-up in which he intends to create a fan at 8640 rpm from a motor rotating at 1440 rpm. He has the following gears with him which are the ones that he should employ in a gear box which has only 2 shafts with centre distance of 120 millimeters.

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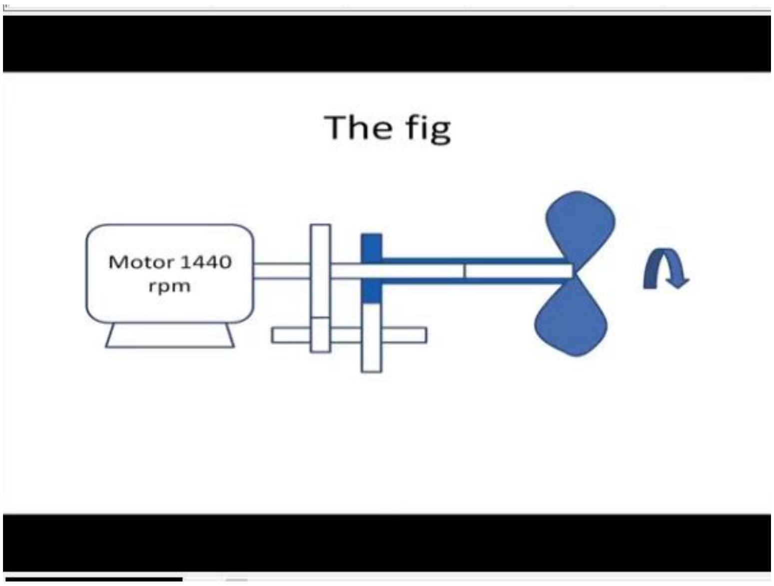

So, we discussed a possible configuration in which the motor is rotating here and there are 2 gears which are increasing the RPM in this ugly shaft, these 2 gears are sharing the RPM and this is finally giving it to another gear which is loosely fitted on this shaft and connected to the fan, so that ultimately the fan rotates at the required RPM. What sort of increase is there? So, if you divide the RPM.

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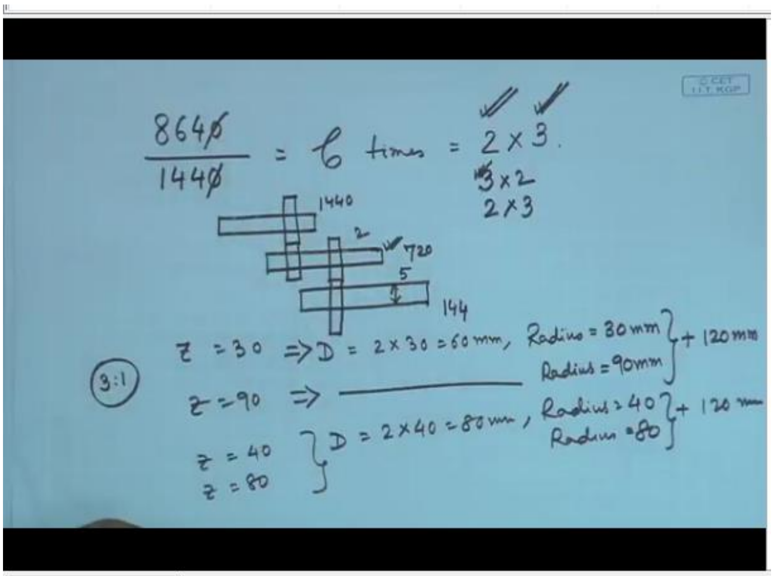

Let us work it out on the piece of paper $\frac{8640 \text{ rpm}}{1440 \text{ rpm}}$, if you calculate you will find 6 times increase of RPM is required and as shown in the figure it has been provided that we should try to achieve it in 2 steps. Now this is 2 x 3, so let us have a multiplication of the RPM 2 times and then the multiplication in 3 times but we first do 3 and then 2 or then 2 and then 3, or does it really matter if I am doing 2 first and 3 next etc.

Generally what happens is, if you have say in the general case of 3 shafts and say you are bringing down the RPM, the rule is generally, do the first reduction as a smaller ratio and then do the next reduction. That means if you are working at 1440 rpm and from there if you have to reach say how much? Let us divide 1440 by 10, so this becomes 144 rpm if it is to be reached, so it is 2 x 5, so it is better to have 5 reduction here.

Of course 5 reduction is extremely difficult in one stage hypothetically let us say if you want to reduce the speed by a factor of 5 here and by a factor of 2 here it is good. Because the intermediate shaft will be rotating at a high RPM in that case 720 rpm. Less is the RPM more is the torque. And therefore, more is the diameter of the shaft in order to withstand that torque. That is the problem because you would have to spend more money for making the shaft because it will be more robust in size, had you had 5 time reduction here the RPM would have been less than 720 and you would have had to employ a much larger diameter shaft in order to withstand the torque which would have appeared here.

So, the rule in sliding clusters is that, have smaller reductions first and larger reductions as close as possible to the final stage. In this case however we are making the RPM higher and higher, so initially we are rotating a smaller RPMs and then we are going for higher RPMs. So, higher the RPM less is the torque and therefore let us have this one first so that when we are in the shaft number 2 we are having a much higher RPM, it has to withstand less torque.

And therefore let us have a reduction of 3 first and then a reduction of 2, if you now go back to the problem and let us look at the computer screen and look at the values, can we have look at the computer screen please. So, if you look at the values of the spur gears, numbers of teeth available in that case spur gear of module 2 is provided and let us see whether they have a number of teeth which is 1:3, yes, 30 and 90 but will they fit in 120 millimeters center distance.

Their diameters are so Z = 30, diameter = 2 x 30 = 60 millimeters and radius = 30 millimeters and Z = 90. Naturally, we can pass all these, we can say radius will be equal to naturally 3 times of this, how much is that? It will be 90 millimeters. This one when added together will give us 120 millimeters center distance, so this is quite satisfactory. We can use 30 teeth gear with 90 teeth gear and achieve 3:1 speed increase. And therefore we can also use Z = 40 and Z = 80 where combined they will give radii of, this diameter will be equal to 2 x 40 = 80 millimeters.

Therefore radius will be equal to 40 millimeters and this radius of the larger one nothing will be 80 and therefore this will be adding up to 120 millimeters center distance. This can be used, so we will use 30 and 90 gear and we will use 40 and 80 gear and that way the RPM will be increased to 6 times its previous value. So, let us have a look at the figure once again. This one will be 90 teeth, 30 teeth, 80 teeth, 40 teeth and therefore the fan will be rotating at the required speed.

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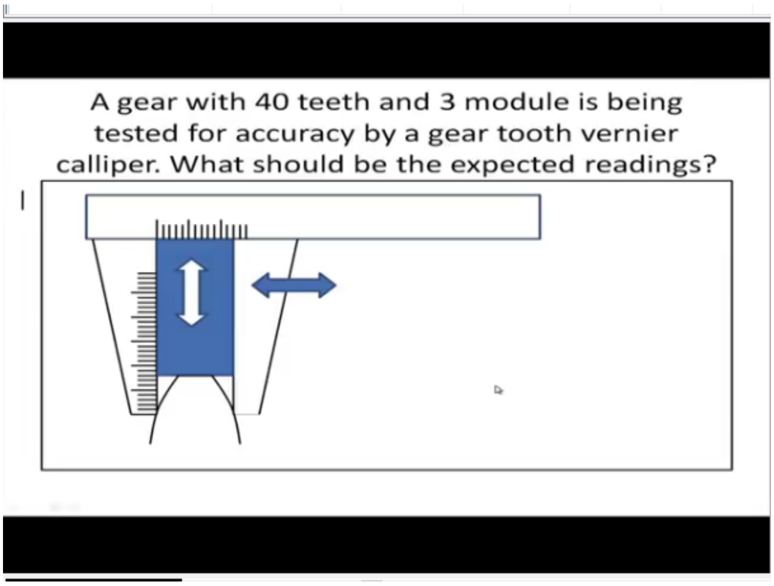

So, after this I had another problem which we will discuss later on. Let us formally start the 6th lecture.

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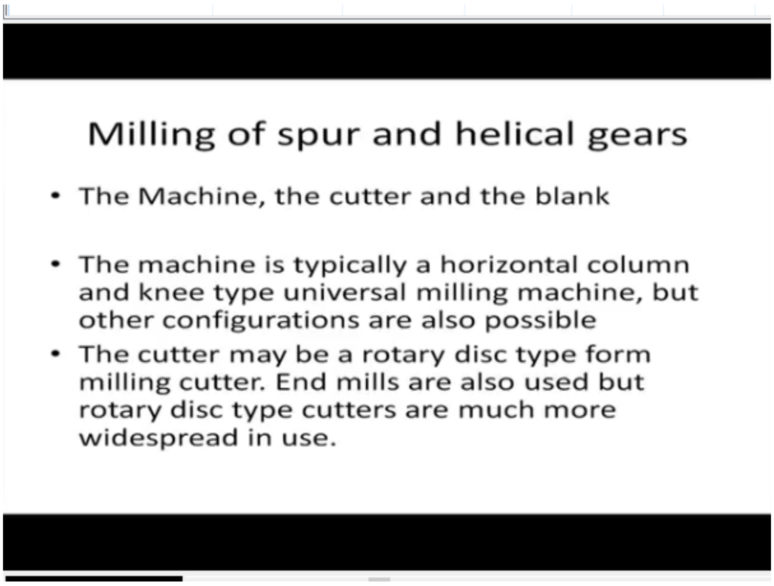

The question which we have left behind I will definitely provide the discussion and answer to you in subsequent lectures. Milling of spur and helical gears, so what do we do in case of milling of spur and helical gears? First of all we have a milling machine, we carry out milling operation and there is a specific type of cutter or other cutters and we take a blank which is generally a disc shaped cylinder with a certain amount of thickness which is equal to the width of the gear.

And we cut away certain portions from this blank so that the teeth remain, the material which is there on the tooth spaces that is removed and only the teeth remain, so cutting off some material is required, if you have a look at this particular figure this is how it is done.

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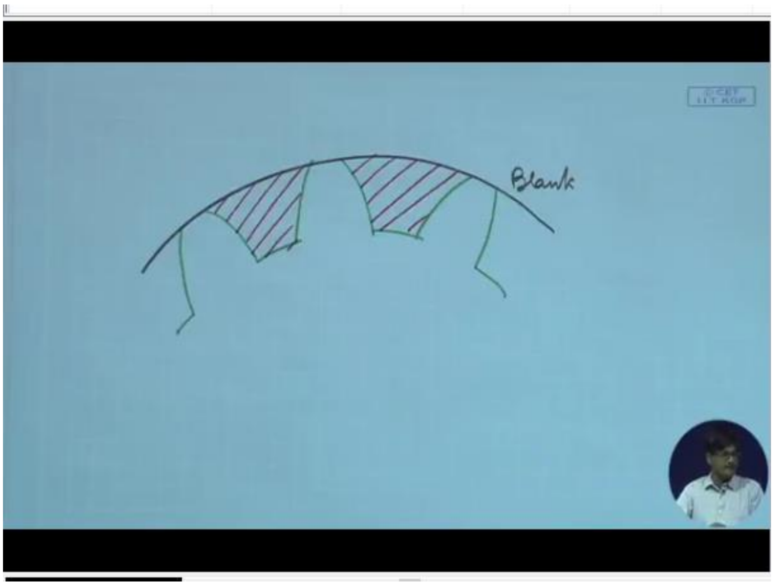

This is the original blank; this is the blank which means the material from which we are going to cut out some extra material, so that only that which is required remains. What is required? These are the teeth which are required, this is what is required. So, there is some material which is not required which can be quickly identified as this part. This has to be removed and it is on the milling machine that we do the removal of these tooth space material.

So, if this has to be done what do we have as a machine as the cutter etc.. Let us go through them one by one. First of all the machine is typically a horizontal column and knee type universal milling machine but other configurations are also possible, there are many other configurations like fixed bed type, vertical milling machine, omniversal milling machine so many other.

But the one that we have identified here this will serve its purpose quite well for both spur gears and helical gears, so let us move through them one by one. Horizontal milling machine; horizontal milling machine means whether cutter rotational axis is horizontal. So, this identifies basically the configuration of the cutter in space its axis of rotation is horizontal, will vertical milling machine do? Yes, you can set it up that way but this combination of all these specifications that is definitely going to serve the purpose.

Column and knee type; column and knee type is basically referring to the structure of the milling machine where there is an upright or vertical column which supports the table on which you are putting the job. And that also contains the vertical screw which can be utilized to make the table move up and down. Let us have a quick look at that.

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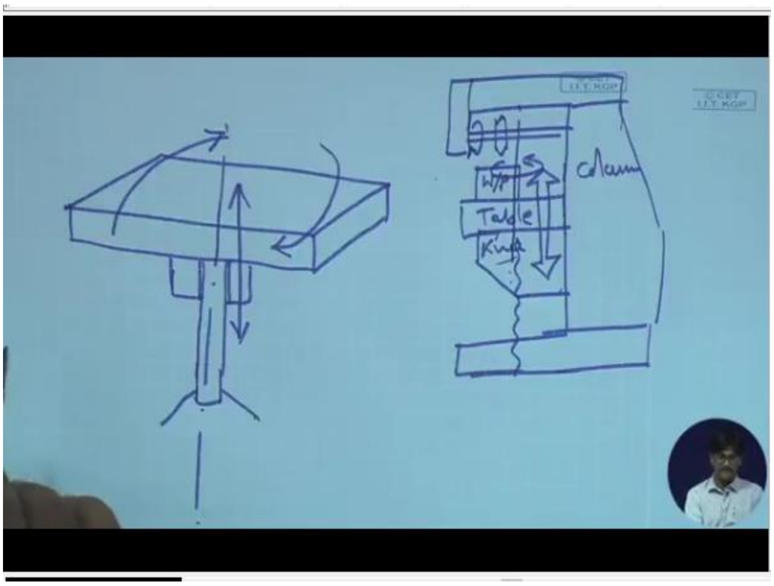

This is your table and you will have a column sort of thing, so let us draw it this way and here you will have a device to all the mechanisms. So, not a very good depiction let me draw it a fresh table and there is 1 provision for a vertical screw and this vertical screw is supported here and there is a provision to have a nut here which makes the table move up and down.

So, this whole thing when seen from the side looks like this table and screw and it can move on the milling machine up and down. But what is the column that we are talking about? This is the column, this is the table and this is called the knee and the cutter can be supported on a shaft colon Arbor this is the cutter and you have the milling machine. Cutter is rotating by the rotation of this particular shaft and you can put your job here, your workpiece.

If you want to move the workpiece down this vertical screw can operate and the whole thing can come down and this column and knee type structure allows the operator to interact with the machine very easily, it is an open type of structure, you want to move the job up move this up, want to move the job down move this down, you can move it longitudinally in a horizontal plane, you can move it transverse on a horizontal plane.

This is extremely accessible, so for manually operating machines this column and knee type configuration is extremely easy to operate. So, for a machine this is the case and what about universal machine. For universal machines, a rotation about the vertical axis is possible, you can rotate the table about the vertical axis, this is the vertical axis. The table can be rotated this way. This is extremely useful for cutting of helical gears.

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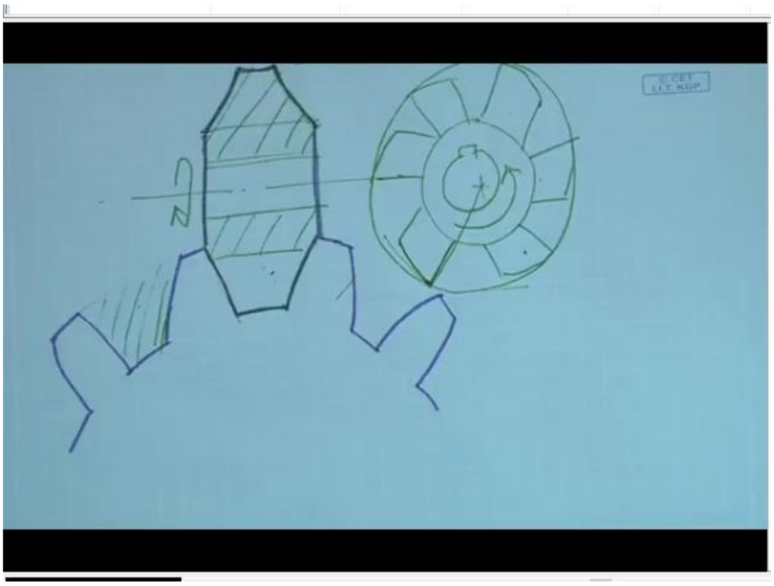

Now the cutter, how does the cutter look like? The cutter looks like, I want to cut off this portion, so the cutter exactly conforms to this particular shape; rather let us use a different color, this is the cutter. So, it looks like this in what way this is its axis of rotation, it might not move right up to this portion because there will be teeth like this. Why have I given no section line here?

Actually here also there will be no section line because you may be cutting only the body portion or the teeth. How do the teeth look like? So, this is one view of it. The teeth would be looking like this. So, this is the basic body on that these would be the teeth. So, this is the cutter, it rotates this way and removes material. So, this is one view and this is the other view.

So, from the side it looks like this, I mean, from the end it looks like this. It rotates this way and from the other side it looks like this it rotates this way it has a hole inside and there is one key way, what is the advantage of this cutter? It is doing a just copying a form which is already made on it, this is exactly conforming to the gap which is to be cut here. Somebody has already done it for you this sort of complex involute profile has been machined on it when it has been made.

On the other side you can see the teeth here, what is this one? It is slightly moving away from the circle along an Archimedean spiral to provide clearance and the rake angle can be say 90 degrees, so on this side we have the rake angle and on this side we have the clearance angle,. An Archimedean spiral ensures that the clearance angle will more or less remain constant. If it is logarithm spiral it will be absolutely retained, the clearance angle.

Anyway so this one will be rotating and here it will be rotating this way and removing all this material. So, once this has been done it is removed, this one is rotated, so that the next material to be removed this part, this one comes here and again the cutter is used to pass through while rotating and remove this particular material, this is what is done in case of milling, you have the job this way.

The cutter goes through cuts the material, you rotate the job, cutter comes, cuts the material, you again rotate the job like that. So, it simply cut, rotate, cut, rotate, cut, rotate like that, this process of rotation is called indexing.

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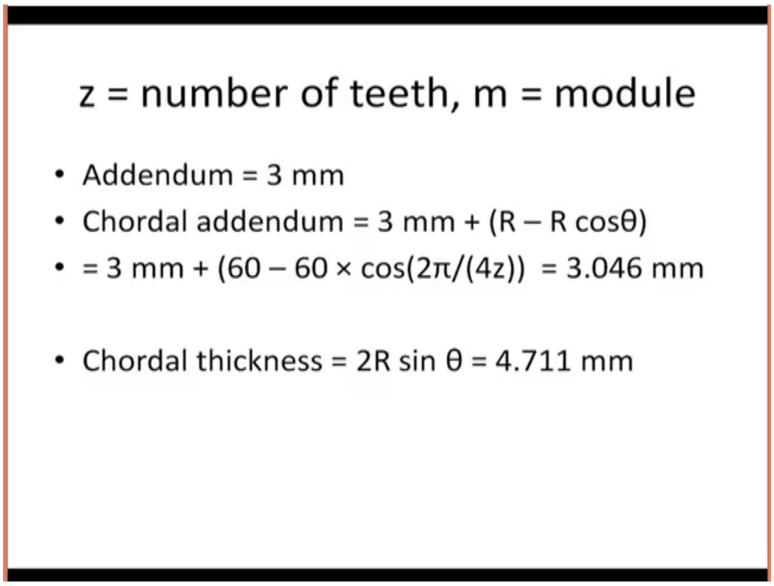

So, let us have a quick look at other aspects of the cutter, the machine and other attachments. So, this sort of cutter is known as rotary disc type form milling cutter, it rotates it is shaped like a disc and it has a form imparted on it which it will be reproducing on the blank in order to form the gear. However end milling cutters are also possible. The end milling cutter will be cutting this way let me draw a figure to show you.

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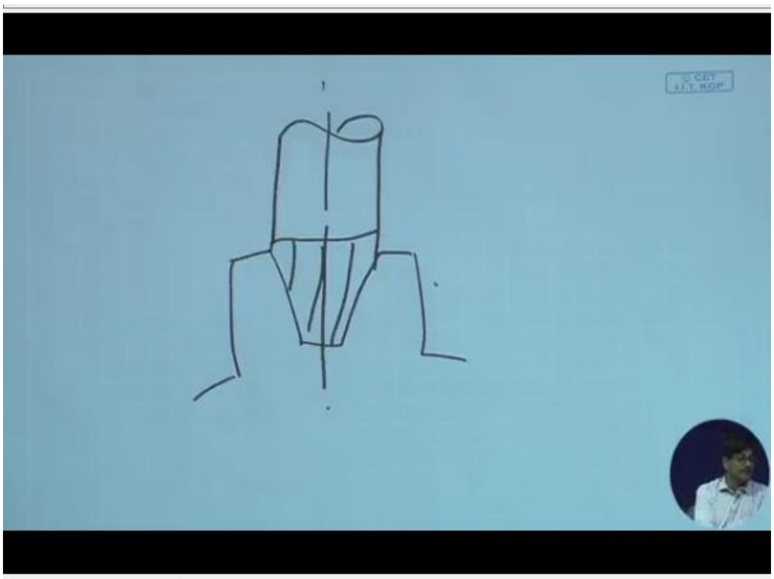

Have a look please, this is the end milling cutter, it rotates this way and removes material, it is not as popular as the other configuration of rotary disc type form milling cutter.

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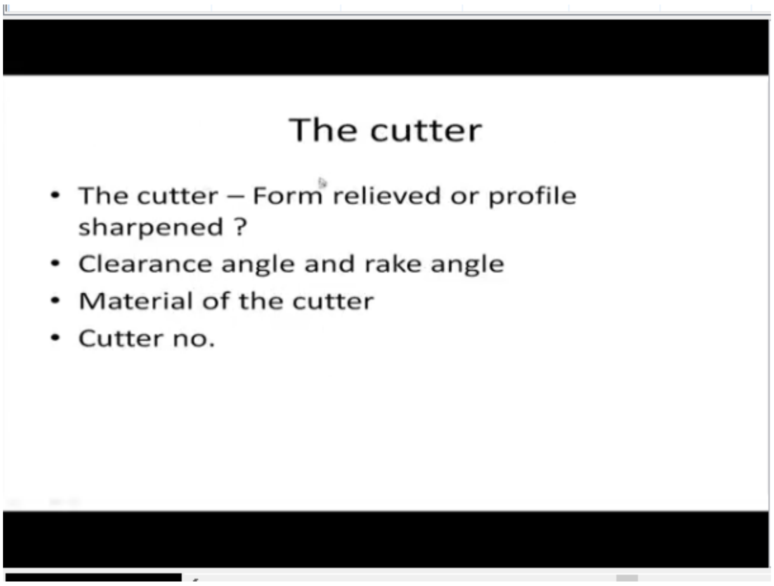

Now so we have discussed almost everything about the cutter, as we discussed it is a form milling cutter, so it is it falls under the category of form relieved cutters where the sharpening is done on the rake surface, never on the clearance surface because the clearing surface is having a definite form it cannot be disturbed and only the material cutter has not been discussed, it can be made of high speed steel, it can be made of carbides etc. Cutter number we will take up a little later.

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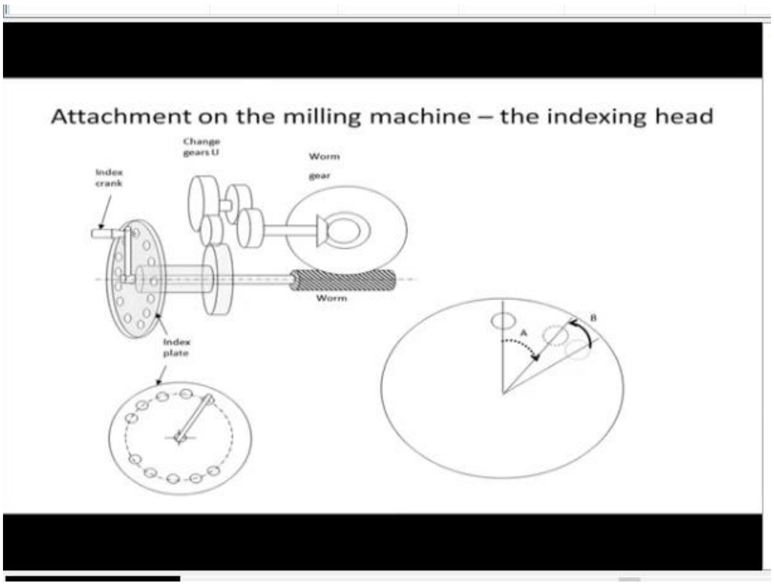

Now about an attachment which is extremely essential for the milling operation to be carried out, please look at this particular figure. We will come to this figure a little later; first let me try to explain on this hand drawn figure why this attachment is required.

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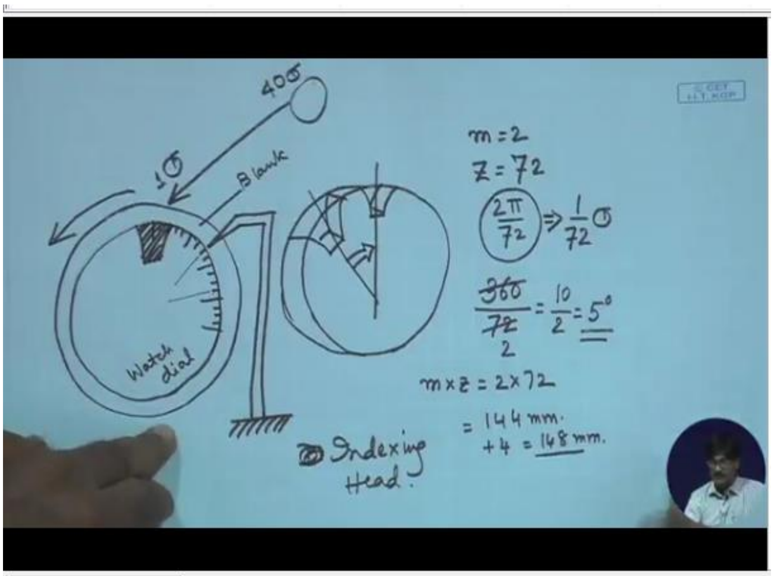

If you look at this particular gear, if I have to remove this material in order to create teeth, in that case after this has been cut I have to give it a rotation of this much and here I have to give a rotation up till this point, how do I give that? So, let us do some calculations to find out how much this rotation is supposed to be. So, once again let us take some specifications say module equal to 2, numbers of teeth equal to 72.

In that case the rotation should move the gear by an angle $\frac{2\pi}{72}$, this is the angle to be rotated through, basically it corresponds to one by these many radians equal to it corresponds to $\frac{1}{72}$ of a rotation. So, how do I do that? Well the easiest thing would be let us have some sort of a dial made, suppose you go to the nearby watch shop, watch repair and new watch selling and ask them, do you have the dial of a watch, available as a piece of paper?

They will say yes but what do you want to do with? Well you have your own plans you buy it and you paste it on the blank. So, this is your blank and this is your watch dial, you have pasted it and then you have a marker or a small marking needle and you put it on some fixed object, once one tooth has been cut, this tooth has been cut that is very good, what do you do?

So, you have to cut 72 teeth, you understand 360 is one rotation divided by 72 means how much? 36 goes into 72 how many times twice so 36, 72 they cancel out you have 10 above and I have 2 in the denominator so that you have 5 degrees.

$$\frac{360}{72} = \frac{10}{2} = 5^{\circ}$$

So, for each tooth to be cut a 5 degree rotation is required between 2 cuts, you cut 1 tooth then you rotate it by 5 degrees you can be able to cut another tooth.

This is the basic idea. Just 5 degrees you might be asking yourself but mind you the diameter of the job is $m \times Z = 2 \times 72$ and that makes it 144 millimeters, on top of that add 4 millimeters for the outer diameter and it is really 148 millimeters outer diameter quite large, about this much diameter. So, on that 5 degrees rotation would be a substantial amount of circumferential movement.

And therefore 5 degrees is no problem you start from here you will be counting 1 degree, 2 degree, 3 degree, 4 degree, 5 degree, if these are representing degrees from here to here rotation would be given. So, you will say that is it, I solved the whole problem of milling, just a dial like this fixed up, loosen the bolts which are holding it in place for cutting, move by 5 degrees on that watch dial and clamp it once again and cut.

There is one problem, life will not always be so smooth, it might end up in a very difficult to handle fraction. And secondly whenever you are moving like this without vernier, without anything it is difficult to control the manual errors that you will always be making because you will be making eye estimations, you will be making parallax error due to eye estimations. You might be going for backlash error, all these things errors are there, this is very difficult to handle these things.

But if you have a mechanism of reducing this error you will be in a much better position. So, what we do is we have a device which can rotate this; I can rotate this blank but from a source where a huge amount of rotation will be giving rise to this one rotation of this blank. So, I will have more control, if you asked me to move by 1 degree which is difficult or say 0.5 degree which is difficult.

Instead on that initial rotating object high rotational handle or crank, I will give 20 rotations. So, that those 20 rotations will correspond to may be half a rotation here, so if you want to move very small angular distances, I will actually convert it from a large angular distance where my percentage errors will be much less, suppose I am always making an error of half a degree everywhere.

Or say not half a degree, half a degree is quite high, say 1 minute, 1 degree = 60 minute = 60 $\times$ to 60 seconds. So, suppose I am always making an error of 1 minute, if you make an error of 1 minute here it gets directly transmitted to the job. But if you have a rotational device which is here and it is having, say 40 rotations of this is giving 1 rotation here, 1 minute error will be reduced by a factor of 40 when you come to the actual job.

So, such a device is called an indexing head which converts a large amount of rotation to a very small amount of rotation by gears. Once again so we will end this lecture by having a quick look at such an indexing head.

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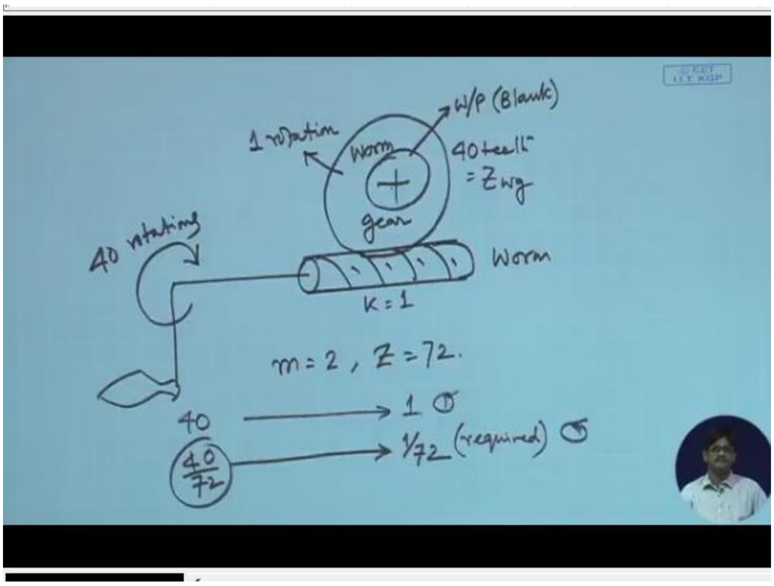

The indexing head basically consists of, this is the main working part of it, this is a worm, now you are quite conversant with the worm and the worm gear can be here up, can be here to the side etc., let us draw it up, it has a worm gear connected to it. What is worm gear doing? This one has say 40 teeth and this one is say k = 1. So, if I give 40 rotations here, this is going to give me one rotation only.

So if m = 2 and Z = 72, I have 40 rotations giving rise to 1 rotation, I have $\frac{1}{72}$ of rotation which is required, this is required on the workpiece and I am having the workpiece here itself, workpiece means the blank on which you are cutting gears. On the same shaft as that of the worm, it rotates with the worm the workpiece. So, $\frac{1}{72}$ of a rotation is required.

This is a symbol of rotations, $\frac{1}{72}$ of a rotation is required, $\frac{1}{72}$ here in order to cut the next tooth, so this will be obtained by $\frac{40}{72}$. $\frac{40}{72}$ rotations you give to the worm here by this particular handle and you immediately have the job rotating by $\frac{1}{72}$ rotations. So, with this we stop here, next step we will take up the details of milling to finish spur gear milling and after that use of differential indexing is called simple indexing, we will take up differential indexing and after that we will take up cutting of helical gears, thank you very much, thank you.