Metal Cutting and Machine Tools
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Lecture-17
Milling Machines

Welcome viewers to the 17th lecture in the series metal cutting and machine tools. So, in this particular lecture, we have discussions on the special machining features of milling machines which is indexing. Milling machines on the whole, they might be used for direct stock removal; that means, you have a slab of material, you want to remove material from it to reach a smaller size or a desired size and shape.

You might be cutting special types of shapes on it by different types of cutters like you might be cutting a T slot, you might be cutting say different types of other shapes like say a bevel or say you might be doing some kind of spot facing. Apart from that the versatility of the milling machine is vastly increased, if some indexing facility is incorporated.

In indexing basically means here sort of dividing say circumference into some equal number of divisions. If this is done there are many application engineering items which have vast application in which there are geometrical features distributed over their respective circumferences at regular intervals. One very common example is the gear. On the gear, we have similar successive features distributed on the surface on the circumference which are called gear teeth.

In a particular gear the teeth are of similar shape and size. So, if the machining is successfully done for one such gear or one such tooth or rather a tooth space, if we find the method of rotating the gear at equal angular intervals, we can successively remove all those tooth spaces and ultimately realize the gear. So, we will be learning something about simple indexing, differential indexing etcetera, today. So, let us move right away to our problem 17th lecture milling machines indexing.

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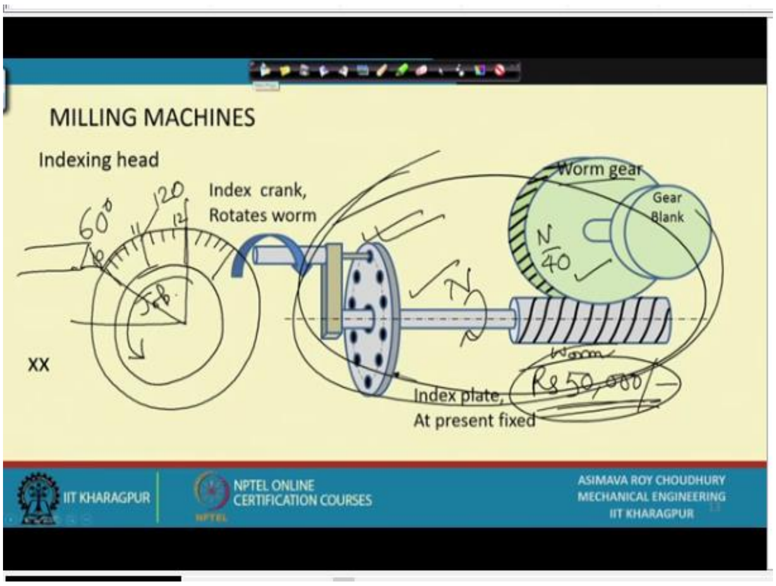

Milling machines, first of all the indexing head, what is this indexing head that we are talking about. First of all, let us see; what is our ultimate end use? This is a gear blank, it might be something different, it might be a cylinder on which we want to cut 4 sides at equal intervals, it might be say a hexagon to be produced from a cylinder or it might be as we have indicated a gear blank.

So, we have already seen what a gear looks like and we have already studied what a worm and worm gear is. So, let me just add here this one is a worm and this one is a worm gear and we have studied about worm and worm gear that is they can provide us with drastic reductions in rotation. For example, if I am having say N rotations, here I might be able to get say N by 40 rotations. That is no problem at all; I can reduce the amount of rotation 40 times.

So, on the milling machine table we place a device which will be capable of providing us with equal successive rotations of on this gear blank or for that matter any such item of our interest, but first question is why are we doing this? We are doing it for getting equal angular rotations of a body, but is not there some simpler way of doing it, what simpler way because this seems to be quite complex.

I do not know what purpose, it is supposed to serve, but it is definitely going to be very costly. This is our indexing head and it is going to cost you to the tune of say several tens of thousands of rupees because already I can identify it has worm and worm gear. That is going to be quite costly because the worm gear material and the manufacturing costs are going to be high.

There is going to be a shaft connecting it to this did this one which looks like some perforations at equal intervals on its circumference that is also not going to be very easy to manufacture and that will be costly and there is a crank handle sort of a thing probably with this handle you can go round and round here. So, that is also going to cost you quite a bit of money.

So, I will place a say guess figure maybe you will be down by 50,000 rupees and that is that is indeed quite a huge amount of money. So, spending 50,000 rupees just for rotating this at equal intervals I can buy a watch dial. How much would have watch dial cost? Nowadays watches are quite I mean clocks wall clocks are quite inexpensive and you can have this one for say 100 rupees, just imagine 50,000 rupees and 100 rupees.

I stick it to this to do this job of mine. So, my job is having this watch dial connected to it and I put a pointer here steady pointer which does not shift from its position and someone says can you rotate the job by 60º, I say this is no problem at all if there are 360 divisions or whatever number of divisions is there it must be an lcm of this particular 60 that you are talking about same.

Maybe 120 divisions are here, see we assume that say 120 such divisions are here. So, I go halfway and that way I can get 60º suppose someone wants 60º. So, in that case, this is 90º and if you take 2 hours so 12 'o' clock, 11 'o' clock, 10 'o' clock, this will be 60º. So, I simply move from 10 to 12, I am able to rotate it by 60º. So, why should I go for this? This has 2 distinct advantage actually because of which we do it, what are these?

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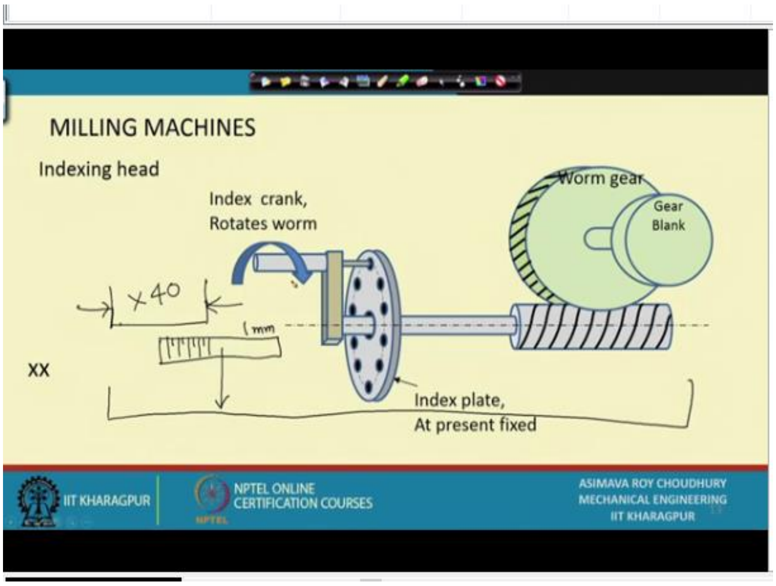

These are first of all if you want fractions of rotation this will allow it you to do that and next is that generally what happens is if there are very small amounts of rotation or the fractions are the whole number I mean apart from the whole number the fractional part is very small. So, for small rotations what happens is you will incur a lot of errors. In order to do away with these errors, we blow up the rotation which is required, it is something like suppose you have to measure this distance. I give you a scale for that whose least count is quite high say 1 millimeter.

Therefore, you can make a maximum error of 2 millimeters for measuring this distance has to be measured I mean you can make a quite a bit of error because these are comparable. So, instead of directly measuring it suppose I multiplied by 40 by some mechanism I accurately increase this distance to this much and then I use the same scale for measuring it, your percentage error will come down, because your least count is still remaining same, but you are measuring a larger distance, so, the percentage error that you incur that is going to come down. So, that is why whatever we want to measure this angle through which I have to rotate I make it much larger here.

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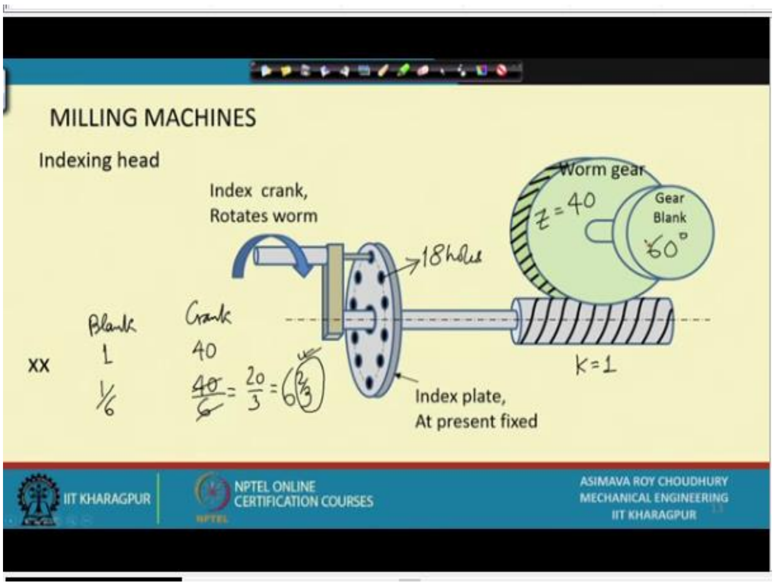

In what way I choose a worm with say k = 1, number of starts equal to 1 and this one with number of teeth equal to 40. Therefore, have if the blank rotates once this crank has to rotate 40 times in order to implement it. I rotate here 40 times, the worm rotates 40 times, this will only rotate once. So, I magnified the amount of rotation which is there on the blank; blank 1, crank 40 times.

So, in that case if I want to rotate it by 60 degrees; that means, I have to rotate it by one sixth of a rotation which means that the crank will rotate 40 by 6th of a rotation which is equal to this will cancel 20 divided by 3 = 6 and two thirds of a rotation. So, if I rotate this one by two thirds 6 and two thirds of a rotation, I will get exactly 60º of rotation here.

So, how do I do it? Well I can rotate 6 times very accurately because I come back to the same position, but how do I rotate this two thirds, for that something very clever has been done here. I make here a number of holes very accurately made an equi-spaced which is a multiple of 3. Say, let us take 18, say 18 holes are there, if 18 holes are there, if I start from this point and count 12 holes I will have covered exactly two thirds of a rotation.

So, this way I make up that particular movement. So, if I am moving by 6 full rotations and two thirds of a rotation I will be exactly moving by 60º here. So, this is the basic idea of simple indexing. So, since time is short let us take a problem. So, I say I have to rotate by say how much we have done 6º oh we should take a trivial case also suppose I have to rotate 4 times.

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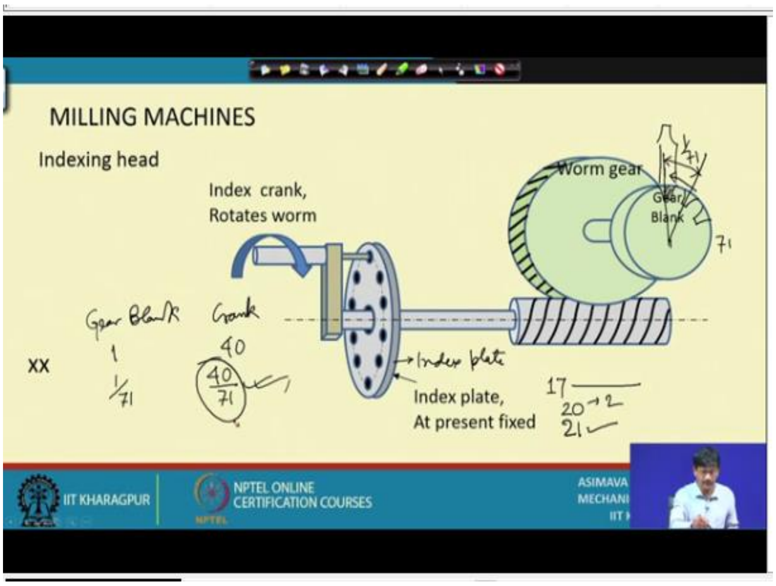

Four times, I want to rotate by 90º. So, once again we say 90º of movement; that means, how much, blank and crank. Crank means this handle which is moving round and round here. So, if I have to move by one fourth of a rotation I must be moving 40 by fourth of a rotation. Remember 1 rotation, 40 rotations, one fourth rotation 40 by 4 rotations unitary method.

So, 10 rotations, this is the simplest one. So, 10 rotations will give me 90º, 60º will be obtained by 6 and two thirds of a rotation. So, it seems everything is solved no. So, while I am skipping some of the discussions on simple indexing this one is important. Suppose I do not have the number which is required what is that. So, let us take the case of a gear.

In gears this is quite possible I take up the problem of machining a gear in which there are. So, let me write gear blank, 1 rotation, 40 rotations on the crank. So, previously I think you have already noticed if this goes round, this shaft goes round and the worm goes round and the job rotates 1, 40. So, suppose I have 71 teeth on the gear, so it has to rotate 1 by 71 of a rotation between machining.

The basic idea is this I will machine out this part then I will machine out this part then I will machine out this part. So, I will cut this out with a cutter which looks like this and then I will bring this one here which has not been cut up till now and then I will cut it, then I will bring this one here cut it like that. So, 1 by 71st of a rotation has to be realized. If there are 71 teeth this particular rotation is 1 by 71, this rotation is 1 by 71.

This will be obtained by 40 by 71. Now, how do I get 40 by 71, it is easy on a 71 holes circle you move by 40 holes and that will exactly give you that fractional movement, but as you would have it 71 is not here. So, you will say why 71 has not been included? That is because you might be having the requirement of having numbers of holes varying from 1 to 1 is of course, hypothetical.

So, varying from maybe say 17 or 15 right up to say infinity. So, for the initial prime numbers you can have them covered by if you are taking say for example 20, this covers 2, if you have 20-hole circle this takes care of 2, this takes care of 5 like that. So, if you are taking 21 holes that takes care of 3, that takes care of 7, but 71 has not been included because it is not possible to include all the prime numbers, they are unending.

So, this is left out. So, in that case what do we do? In that case what we actually do is that we obtain differential motion up till now this body which is called the index plate. Index plate is not moving up till now, but now we have to make it move in order to obtain these fractions which are not there. So, let us quickly have a look what we are talking about.

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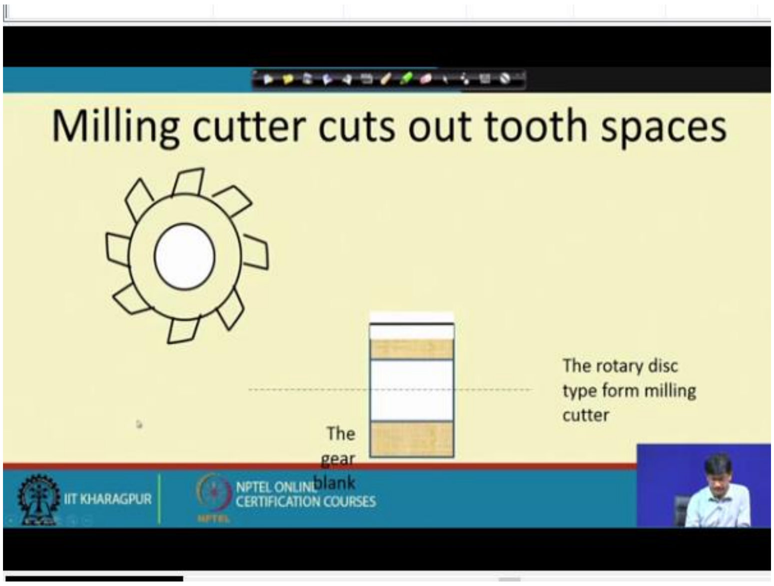

Next we will come to this one I would like to show you something first. How does a gear cutter cut out those spaces? So, this is the cutter and this one is the gear blank where the cuts will have to take place this way. Here what we intend to do is in the other view this, if you look at it this way, you will be seeing a smooth circular body and we have to cut the teeth this way and this is going to cut it right through and go back.

So, let us see how it does it. That is it; this white portion shows the material which is removed by this cutter which moves right through.

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So, how this is done? Now let us see the other view, this is the cutter. It cuts the material then this is what you do by indexing, you shift it exactly by 1 by 71 of rotation. So, that a potential portion has come, the cutter again appears and removes it, please consider the drawing because it is not very accurate. So, this is what we are doing. So, we have to make it possible to rotate by this amount every time.

Every time I cut a tooth these are either 71 teeth here 1 by 71; 1 by 71; this rotation has to be given successively 71 times. So, now, that we have understood what is to be done, let us see how it is done. So, we had started from here. So, let us move on forward once again this body has to rotate now in order to make up rotations which are 1 by 71. So, first of all what do we have we have this set up with us and do what are the number of holes that we have that might help us 71 is a prime number. So, it does not help that way also, but say I have to provide you with something.

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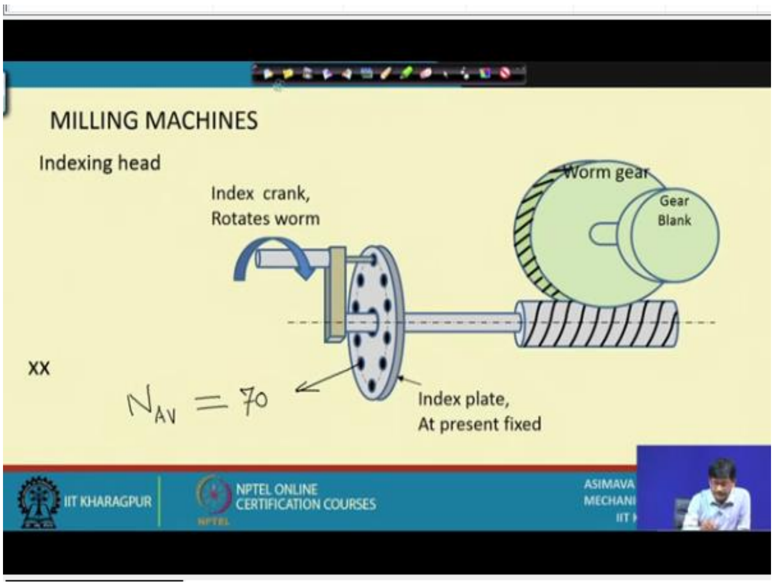

So, I say that the nearest number of holes which I provide you is 71 and I write here N available, the available number of holes which are present here which is nearest it is 70, but what do we do with that? If we use that we are not going to get 71 teeth, we again were going to get 70 teeth and that is going to mean that the gear won't be cut very accurately. So, let us see what is the possible solution?

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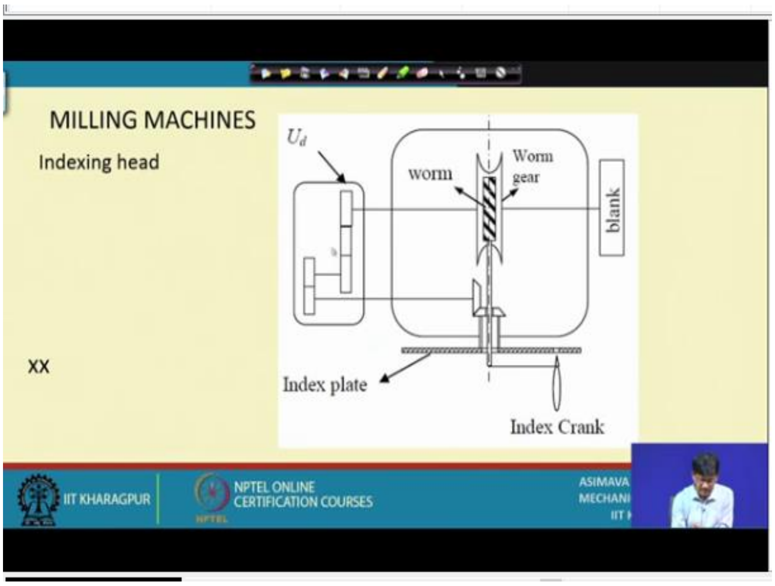

The possible solution is this, first of all see what we were talking about, this is the index crank, this index crank was being rotated, we are seen in a different perspective, we are seeing it from the top. This index crank rotates, this rotates the worm, this rotates the worm gear and this is your gear blank. Now what we do is we extend this shaft connecting the worm gear with the blank backwards and take a feedback we pass it through a gearbox remember gearboxes.

So, gearboxes will be giving simply a changed rotations per minute at the output in relation with the input. I get a changed value here and with the help of 2 bevel gears I rotate the index plate. So, the index plate is not stationary now, it is rotating, but why are we doing it by the differential motion of the crank motion and the index plate motion we are going to get what is called the ratio 1 by 71.

Now what do we mean by this? What we mean is we can see it here itself, if I am having say index crank this way, let us pass on to the next figure I think we will get better chance of understanding this.

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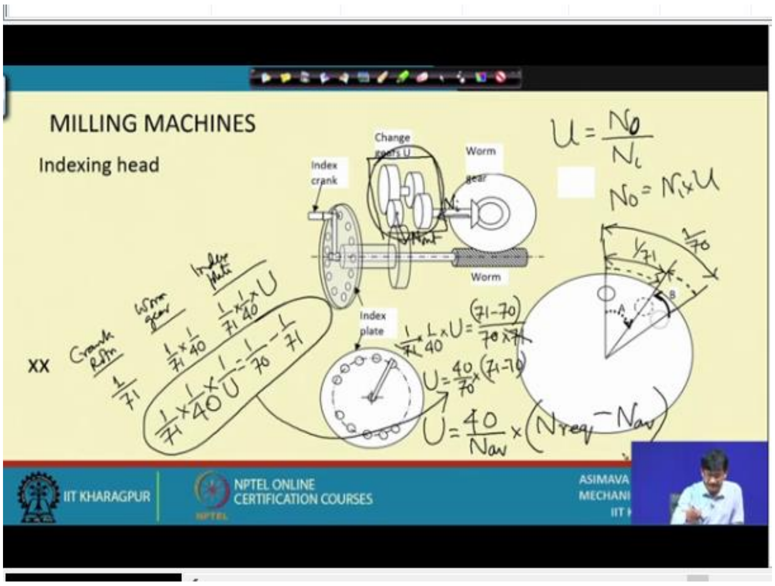

Ye So, if I am having this sort of I have drawn it in 2 dimensions in the sense that this is the index crank, this is the index plate, right goes the worm through and this worm is connected to the worm gear and here with the help of bevel gears I have turned the rotation and these are the change gears which allow me to rotate the index plate. Previously this index plate was stationary and the index crank was going all around.

This was the index crank going all around. Now, the index crank will rotate and together with that this index plate will also rotate. Index crank will rotate and the index plate will rotate and they will rotate at different speeds, if that be so, in that case what is going to happen is suppose these holes are existing on the 70-hole circle. So, this is the first hole.

So, this is the second hole on the 70-hole circle second hole. So, we can say this particular angle or rotation must be 1 by 70 equal to 1 by N available as we discussed previously. What is this one then? This one is the hypothetical; it does not exist, but suppose I say that if 71-hole circle had to be in existing this would have been the position of the second hole starting from this one.

This would have been the position of the second hole. So, let me draw it. Then this one only, this is the virtual hole, it is not there, but this rotation would have been 1/71. This is what I want to achieve, if the crank can be moved from here to here, my job is done. If this rotation can be achieved by the crank my job is done, but what happens when the crank comes this way and it reaches this position it does not find a hole.

The hole is far off; if it travels further down then it will be actually traveling 1/70 and our job is not fulfilled. So, by the time the crank comes from here to reach this position why not make the plate move back exactly by this amount, that is you pre plan the process so, that when this crank reaches the virtual position of 1/71 second hole this index plate will rotate backwards and reach this position. So, that it will actually place a hole here for the crank to locate itself.

So, I can achieve fractional movements of 1/71 this way. So, let us do a quick calculation. Suppose I think that the problem is solved and therefore, crank rotation is 1/71; that means if I have achieved it how is it achieved by placing of these gearboxes. This is the only external element here. So, we can frame the problem this way what should be these change gears, so that this will happen.

So, suppose I say that yes this is happening, I mean that case I am getting 1/71 rotation because this is turning back and placing a hole here and therefore, I have achieved this rotation. This rotation will be transferred unchanged to the worm, but on the worm gear it will be different. So, I write on the worm gear the corresponding rotation will be 1/71 * 1/40.

For shifting from the worm gear 1 is to 1 bevel gear and then the gearbox, suppose the gearbox ratio is 'u'; remember gearbox ratio u is equal to output RPM for the gearbox by input rpm. What is the input RPM? Input RPM is this and what is the output RPM, output rpm is here So, this is the gearbox. Input coming here, output going there. So, N_{out}/N_{in} therefore, $N_{out} = N_i * u$. N_i is this one coming from the worm gear.

Therefore, we can say that this rotation which is given here it is transferred to the index plate. So, index plate directly we can write it is equal to 1/71 * 1/40 * u; what is the value of 'u'? I do not know that we are going to solve only. So, index plate rotation I have found from this approach and from known values. We know that it should be this much; the index plate in this particular time should be rotating this much and what is this one.

This must be equal to since the larger rotation was 1/70. So, it should be equal to 1/70 – 1/71. So, let us equate that, 1/71 * 1/40 * u should be equal to 1/70 – 1/71 that said. This is the basic equation that we follow. And from here we get a lot of things will cancel out and we will get 1/71 * 1/40 * u = 71 - 70; which is 1 here, I am just keeping it for generalization divided by 70 * 71; 71 will cancel out and we will get u = 40 divided by 70 * (71 – 70).

Now, there is scope for generalization we can write therefore, for any problem it is equal to $(40/N_{available}) * (N_{required} - N_{available})$ that is it. That means, this is the relation $(40/N_{available}) * (N_{required} - N_{available})$. For certain cases this sign might change, but this is the general expression and how much is it coming to be in this case our particular case of discussion 40/70 * 1.

So, 40/70 = 4/7. So, if we implement a change gear ratio here of 4/7, this will make sure that the index plate will rotate back in such a way that fractional rotations of 1/71 will be possible and once that is possible a cutting a 71 teeth gear will not be a problem at all. So, what we learned from this exercise is that if we have a device by the help of which we can divide circumferences into equal number of divisions in that case a number of machining applications become possible in case of milling.

And possibly the most the most variedly used application is the case of gear cutting and on the milling machine we saw a special type of tool which can be used which has the conjugate profile of the tooth space it can remove the tooth spaces one by one. So, this method is quite versatile, but mind you for production of accurate gears. This method is not applicable, no. This is generally used for maintenance.

This is generally used for one off production 1 or 2; that means, someone gives you an order you have a small shop and someone gives you an order I want 5 pieces of these gears then you make it for him, but if you are having making gears for say automobile gearboxes etcetera, you will never dream of using the milling machine no, it should not be used, they are not very accurate. So, in the small amount of time that we have I would like to introduce another idea which is this we have already seen.

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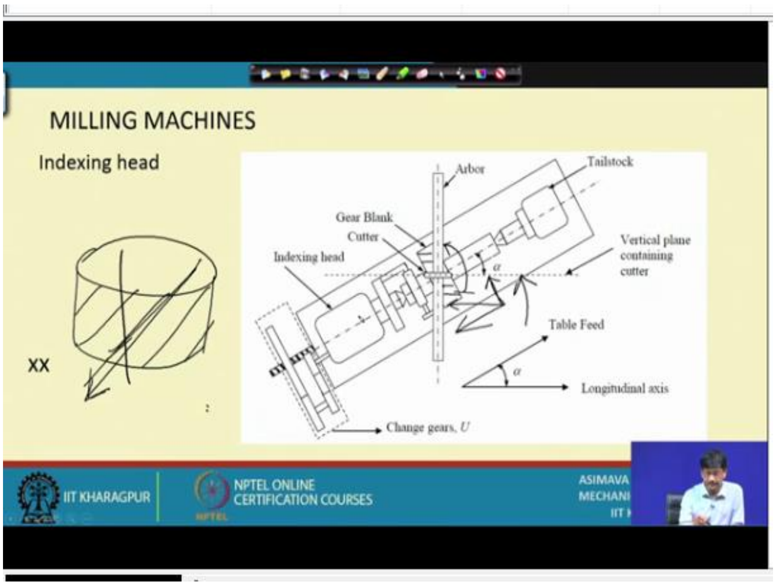

This gives us I will just discuss in brief, this gives us the possibility of using the indexing head and the universality of the milling machine; that means, the ability to rotate about a vertical axis to carry out a machining process called helical milling. What is helical milling? Helical milling means the ability of the milling machine or the application of the milling machine to cut a helix.

Now why on earth would I like to cut a helix? Am I trying to cut a helical thread; while that is possible this method is more applicable, in case of cutting of helical gears, what is a helical gear? A helical gear typically looks like this. This is a cylinder and the teeth are placed this way. Now why would you suddenly require teeth which are helical? It has a number of advantages when power is being transmitted from one gear to another.

At a particular time in case of straight spur gears, wherever the teeth are straight and parallel to the axis maybe only one tooth would be doing the active transmission of power from one gear to another and it will be under quite a heavy load. But if you take a section you might find 2 or even 3 teeth taking part in the transmission of power in case of helical gears and also their operation is much more silent and they are less prone to shock loading etcetera, etcetera.

Number of advantages are there because of which machining of helical gears is one of the most commonly carried out practices in machining. What is basically the setup? The setup is like this as we can see; obviously, one particular feature is that the table is rotated, why is the table rotated because we need to pass the cutter this way now. So, the cutter has to orient itself.

This is the cutter, it has to orient itself at a particular angle to the gear blank, this is the gear blank**.** So, the table will be moving this way, if the table moves this way, but still the cutter is not oriented in that direction if we have to move this way and if these are the teeth. If this is the orientation of the teeth motion is not taking place that way. So, the relative motion of the tool and the work piece will not be in the direction that has been shown it is not in this direction.

So, how is that made possible? Together with that the cutter is also rotating. So, a motion component of the cutter, the cutter is rotating this way. A motion component of the cutter comes from the peripheral speed of the cutter. Together with these 2 combine to have a relative motion exactly in the direction of the cutter teeth, a work piece teeth. So, the cutter smoothly passes in the direction of the helical path demarcated this way.

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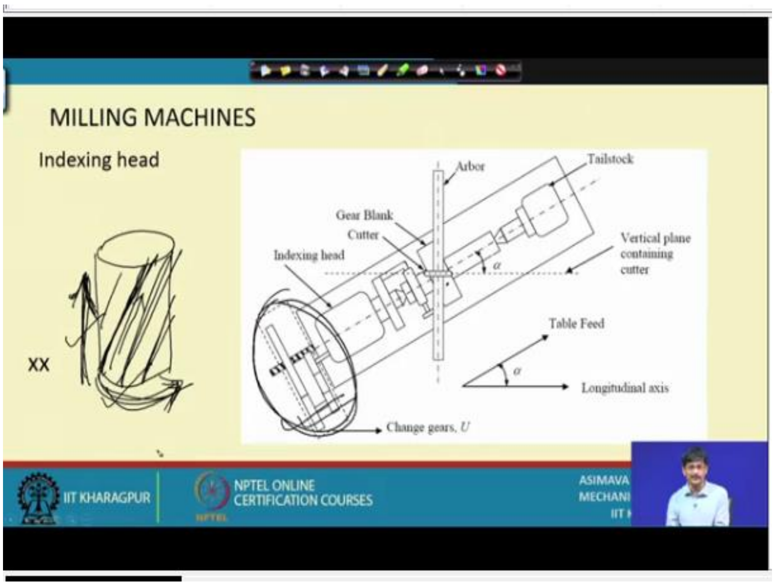

Next what is this? if you have to have helical motion, if this is a gear and if this is to be the ultimate cut teeth in that case the cutting element has to have this relative motion with respect to the work piece. Helical motion that way is obtained by the combination of circular motion and straight line motion. Straight line motion can be given by the longitudinal movement of the table, but who is giving this circular motion.

Circular motion is given by the rotation of the blank. Mind you; you will always rise along the same straight line; I mean this helix will always have the same helix angle on a particular diameter. If these 2 motions have a definite ratio between them how to establish a connection between rotational work piece and the longitudinal motion of the table? These are the 2 motions. Longitudinal motion of the table, rotation of the work piece.

So, for that longitudinal motion of the table is obtained by the rotation of the lead screw. Remember there is the lead screw we discussed so much. So, this screw will rotate and make the table move. This table through these gears will be connected to the indexing head and from the indexing head output rotation is obtained. So, lead screw gearbox then index plate, worm, worm gear, blank.

This way we are establishing a connection between rotation of the work piece and the table movement. Unless these are connected or definite relation between these 2 would not be there and a constant angle helix will not be cut. So, this is what is done; we put a gearbox here which establishes a definite relation between these 2 depending upon the requirements. The requirements might be cut a 15^{o} helix angle on a gear.

I mean cut of 15^{o} teeth on a helical gear, for that a definite gearbox will establish a particular relation between the longitudinal motion and the vertical motion. That is what we are going to discuss in the next class. So, for the time being as the time is over for this lecture. Thank you very much.