Elements of Metal Cutting, Machine Tools, Gear Cutting and CNC Machining

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Lecture-27
Simple and Compound Indexing

Welcome viewers to the 7th lecture of the course spur and helical gear cutting. So, last day we had been discussing about indexing in connection with gear cutting, that means on a milling machine we were using a rotary disc type form milling cutter whose form was a conjugate of the tooth space. So, it would be removing the tooth space and after that we would be rotating the gear blank by a certain amount, so that another fresh part is brought in front of the cutter so that the cutter can do this cutting once again. So, we will be having a look at that with the calculations and then moving on to other topics in this regard.

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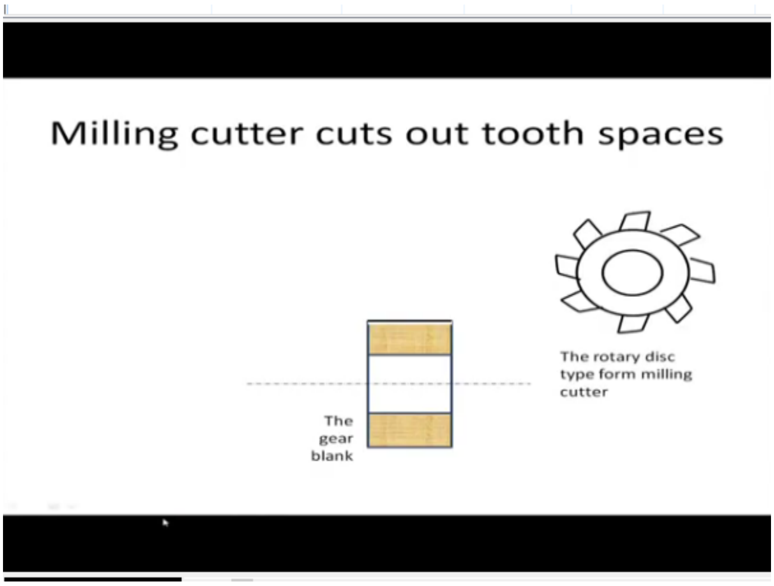

So, this is the cutter, it rotates about this axis, the axis is vertical to the plane of a paper or the screen, so that is why it is called rotary disc type, obviously it is shaped like a disc its width perpendicular to the plane of the screen is much smaller, form milling cutter in the next view we will see the form that it has it is the conjugate, as we said, of the tooth space to be cut off or removed from the gear blank.

This is the gear blank, it has a hole in the middle, it might or might not have a hole but in this case it has a hole, on this hole it can be held by a mandrel and it can be rotated from time to time for bringing in front of the cutter new tooth spaces, potential tooth spaces to be cut off.

So, this is the axis of rotation also happens to be in this case the axis of symmetry of the gear blank.

So, let us see first the cutter rotates and cuts through, that is it, the cutter moves from one side to the other, this is the disc or cylindrical gear blank with its rotational geometric axis the cutter has moved from this side to that side and cut off a tooth space. And the cutter after this will be moved back and then this will be rotated, so let us see the other view.

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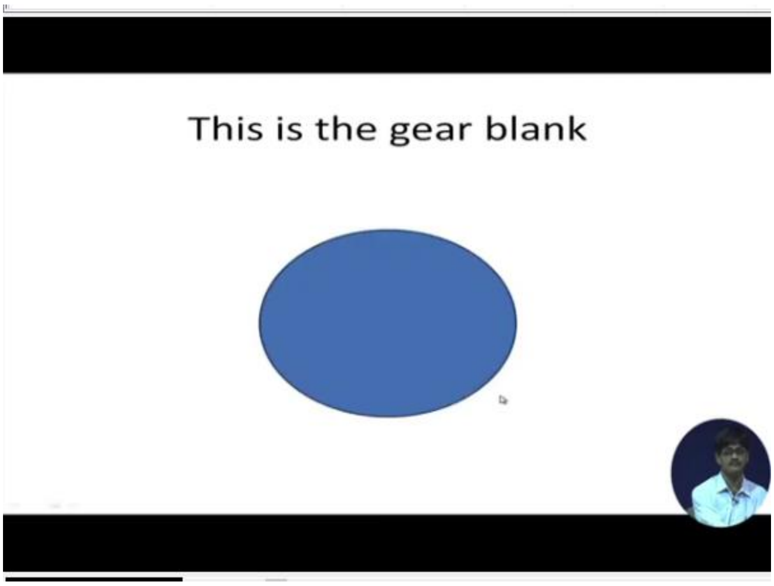

This is the gear blank, solid disc shaped gear blank the other view, this is its rotational axis.

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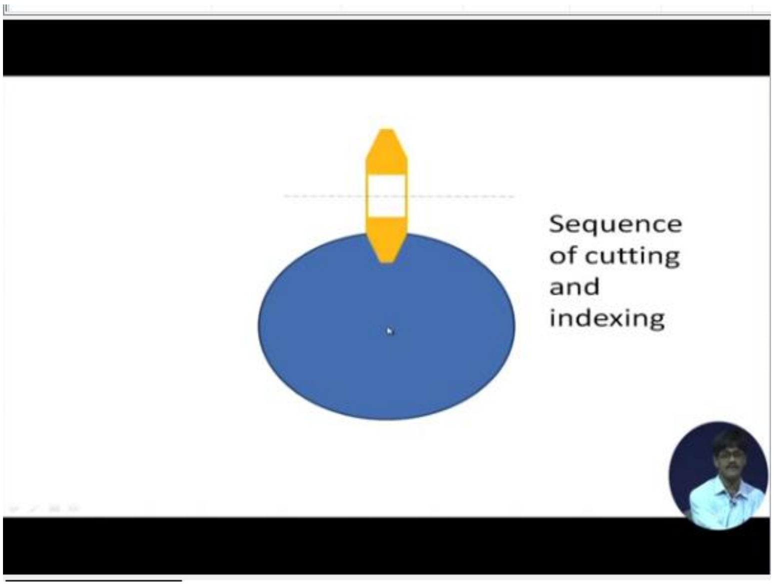

This is the cutter in the other view, this is its rotational axis and these are the teeth in the other view, we saw the cutter which was looking like slitting saw, a circular saw but in the other view it looks like this so that its shape is just the conjugate of the tooth space. So, once it moves through perpendicular to the screen it rotates and moves through and cuts off this particular tooth space, so what remains is this.

After this, since the cutter can only move to and fro this way it is brought back and the workpiece or the blank here is rotated so that this cut off portion moves away from the path of the tool and a new portion is brought in and this angular rotation is exactly calculated, so that the potential tooth space, that is to space to be cut off, is exactly positioned in the part of the cutter, so this is called indexing. So, you will find a lot of effort will be spent for correct angular movement of the gear blank due to indexing, why because on this depends the geometric accuracy of the gear.

If we make a mistake or if there is inherently some mistake in this rotational process or if we suffer from say parallax or due to a large least count etc., so all these things will be leading to errors in the gear teeth and once you have gear errors in the gear teeth they will not function properly. So, after this the second tooth space is taken up by the cutter that is it, so it will again move to and fro and cut off one tooth space like this.

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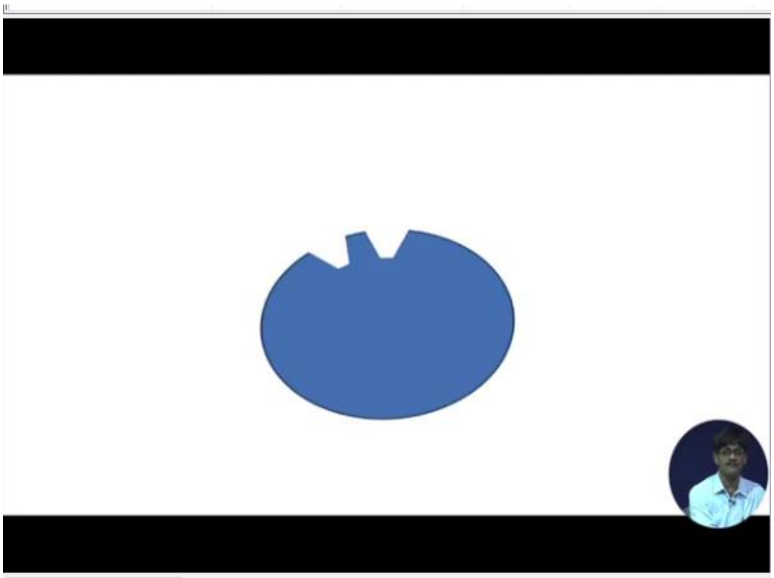

So, this thing goes on getting repeated again and again, so that all the teeth on the periphery of the gear they are cut off, I mean tooth spaces they are cut off and you have a gear properly made. So, this thing involves rotation of the cutter, cutting of material by the cutter by the movement and cutting speed developed by the cutter rotation and this involves indexing. So, let us see one by one what are the possible problems and what are their solutions in this particular process.

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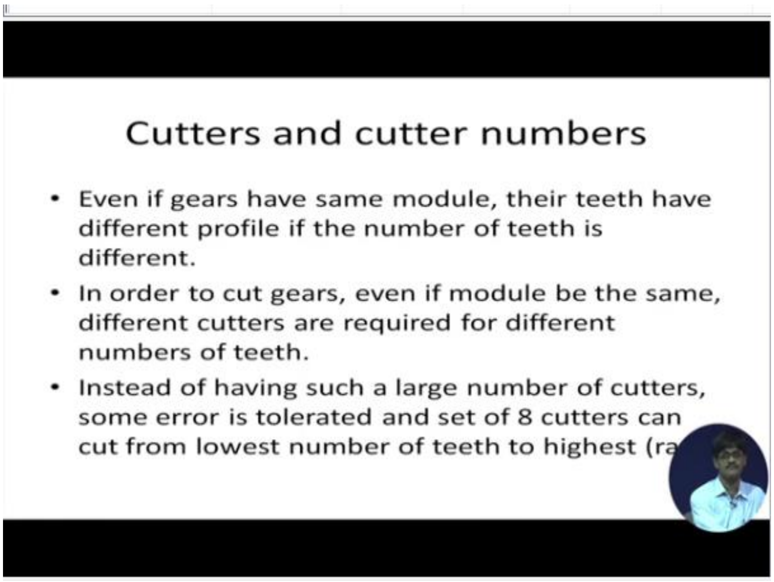

First of all, cutters and cutter numbers, suppose I am having a particular module a set of gears to be cut, let me give an example suppose module is 2, it is a spur gear and I have to cut 20 teeth gear, I have to cut 30 teeth gear, I have to cut 40 teeth gear like that, so if I am cutting gears of different numbers of teeth but the same module do I need a different cutter for them? Let us just go back 1 step.

This tooth space, does it depend upon the number of teeth you are cutting. If it does not we can use the same cutter for all the gears belonging to a particular module why, because if you now have a look at this piece of paper.

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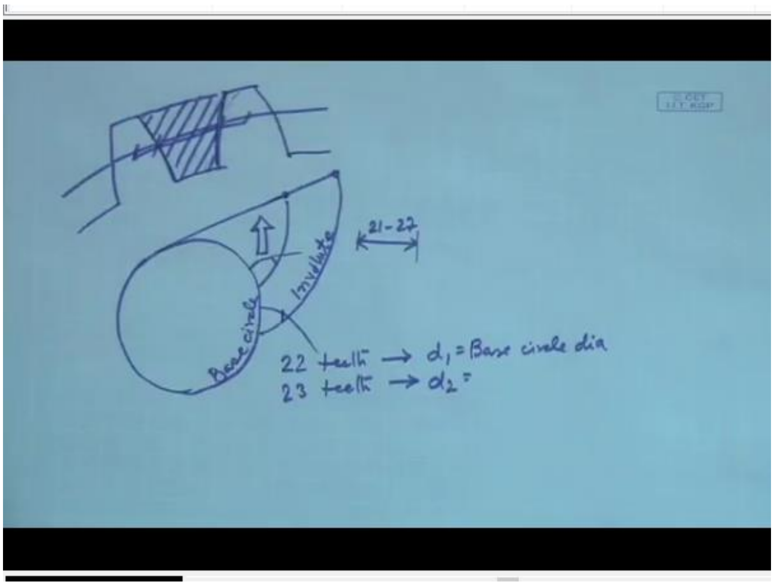

So, let us draw a particular gear tooth, this circumferential distance is dictated by module, in the same way we can say therefore in the tooth space this distance is dictated by module, so if this distance is dictated by module it does not necessarily mean that this shape is dictated by the module. No, what dictates it then? What is dictating it is first of all module and number of teeth why, because take the case of gears which have involutes profile.

So, these are involutes. How do we develop involutes? There are 2 ways of defining involutes, one is if you have a disc, on this disc suppose there is tightly wound wire or thread or something like that and you are unwinding it, so keeping the wire taut, if you go on a and winding it this way the locus of any point on this particular wire describes an involute and there are a lot of interesting properties of these particular curves but what we are involved with is that for every gear teeth they are essentially parts of these involutes, involute on this side and involute on that side.

And part of it we adopt as our gear tooth, this one is also another involute, another gear tooth perhaps like this. What does this involute depend up on? It definitely depends up on the radius of the circle, so this circle is called the base circle, the diameter of the base circle is unique for a particular number of teeth it is related to the pitch diameter by the pressure angle.

I am not going to go into all those details at this moment for the sake of this discussion it will suffice to say that the base circle has a definite diameter for a particular number of teeth for a particular module. So, if you have 22 teeth, you will have a definite diameter of the base circle dia. and your module will be defined by this base circle dia., if you have 23 teeth theoretically speaking yes, this will have a different diameter and therefore it will have a different module and therefore this tooth space is going to be different for each number of teeth.

And that does not sound good for milling because in that case theoretically speaking you have to have one particular cutter for one number of teeth. Another particular cutter for another number of teeth even if they be successive numbers for 21 teeth one cutter because this particular profile is becoming different, because these either going to be very much curved and slanted or they are going to become more and more straight.

They are going to move towards straight lines as we go for a higher and higher number of teeth towards the rack. Therefore, this is bad news for milling, you have to spend an immense amount of money to equip yourself for all the cutters that are required for cutting, all the gear teeth which are included in that particular module. Instead of this practically speaking there is a practical solution to it that is have a set of cutters numbered from 1 to 8 which can cut off certain numbers of teeth kept in a particular class.

Suppose you say 21 to 27 teeth will be cut by a particular cutter. But immediately you will point out then at least, say if there are 6 or 7 gear teeth numbers included here at least for 6 of them it has to be inaccurate. Yes, this point is accepted, a particular amount of error is tolerated so that a practical solution to this problem is obtained. What is the practical solution? You do not spend much money to cut all the numbers of teeth for gears belonging to a particular module.

Just by 8 cutters and that is it, you will be tolerating a definite amount of error, but that is tolerable and engineering tolerance is the idea so that you make ideal or ideal problems have practical solutions. So, we have this concept of cutter number and a set of 8 cutters can tackle all the numbers of teeth belonging to a particular module. So, with this idea we understand that in milling there will be inherent errors, you cannot avoid this.

There will be inherent errors, what are the other sources of errors in case of milling? Another problem with milling is that you have something called discontinuous indexing, that means turning a gear so that new areas get exposed to cutting action. This is definitely disrupted or discontinuous, you do not cut continuously, you cut and then stop losing some bolts, rotate, clamp those bolts once again.

And then start just, think of it there will be definitely some changes in the setting at least in the micron level. So, with this idea in mind we understand the 2 main sources of errors in case of milling can be improper indexing and the use of finite number of cutters to cut the family of gears belonging to a particular module. So, let us move on to now so this is all discussed, we have already discussed these things.

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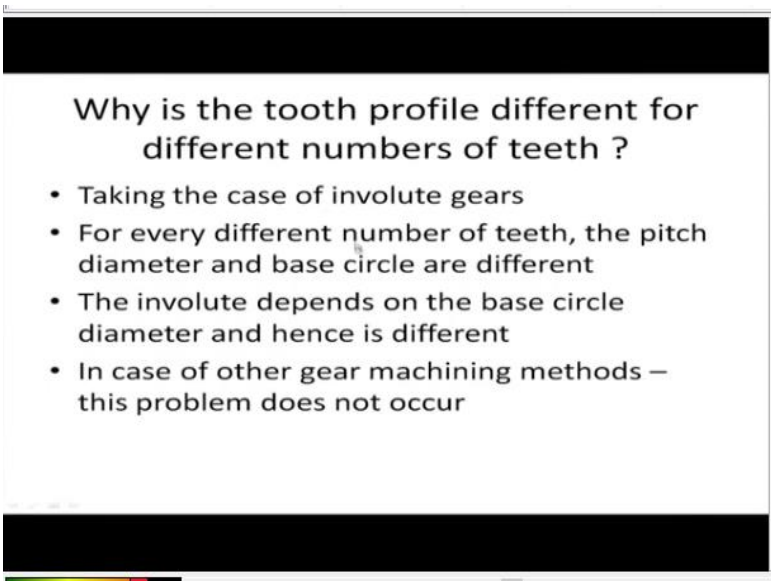

So, let us go on to, this also we have discussed let us go on to, the next particular subject what is that?

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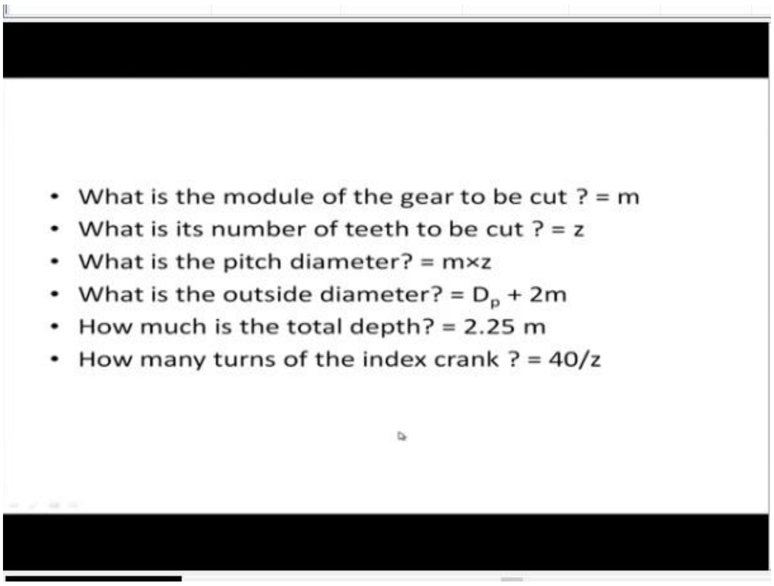

The practical problem of cutting a gear with the help of indexing and this moment we are discussing simple indexing. There can be different types of indexing and as much as possible that is time permitting we will be doing more justice to more important things doing justice within limits to subjects which are not that much used or well-known etc. So, first of all simple indexing.

What is the module of the gear to be cut? Say, m = 2, say for example. What is the number of teeth to be cut is Z, so what we mean to say is that when we are starting to cut a gear this thing has to be supplied to us and what is the type of gear, which has not included here, spur gear, so we are starting with the cutting of a spur gear, when I cut the teeth are all parallel to the axis of rotation. What is the pitch diameter? Pitch diameter we can easily calculate as m into Z, m being known, so let us take a practical problem m = 2.

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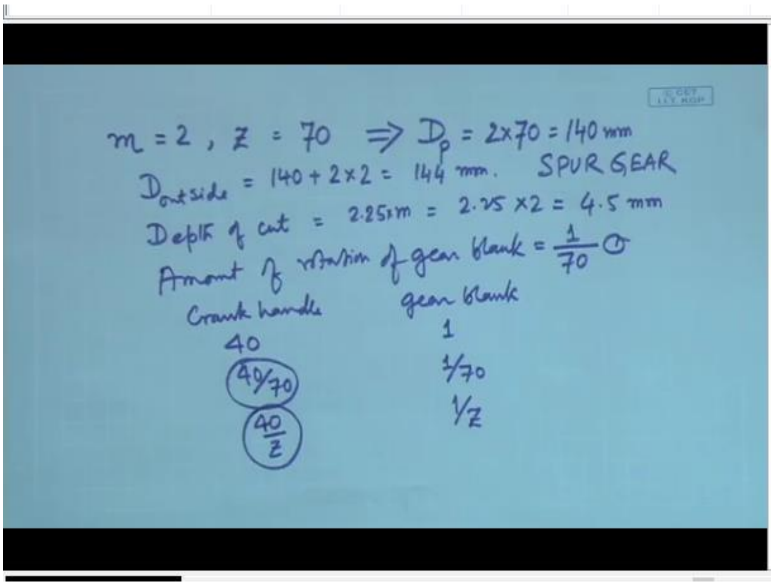

m can also be 2.5, there is nothing wrong with that, Z = 70 and therefore we can say, $D_p = m \times Z = 2 \times 70 = 140$ millimeters, these things are all known to you, nothing very different from what we have been talking about in the previous lectures. Next comes, let us return back to this one again, what is the outside diameter? Now you might be asking why do I need the outside diameter, what am I going to do with that?

Every calculation is actually has its foundation on the pitch diameter. Well outside diameter is required because the operator is going to ask you, suppose you are supervising a milling operation, milling of gear and the operator is taking instructions from you, he will immediately come to you and ask you what is the diameter of the blank that I should select that is it.

Diameter of the blank is not known and it must be equal to the outside diameter of the gear that is why the outside the diameter is important. So, in this case we write outside diameter = 140 (Pitch Diameter) +2 m (module), this thing also we have discussed last day. So,

$$D_{outside} = 140 + 2 \times 2 = 144mm$$

144 millimeters is the outside diameter for spur gear. So, the operator will be satisfied that you to take a disc of 144 millimeters outside diameter.

How much is the total depth that is what the operator is going to come up with as the next question. How much depth do I give when I am cutting? Well, if you are cutting it in a single pass, single pass means that in one cut itself you are cutting right up to the root of the gear, so if you are doing it in a single pass the depth of cut will definitely be equal to the total depth of the gear which is equal to 2.25 modules or $\frac{2.157}{D_p}$ when you are dealing with diameter pitch it is 2.157.

So, that being accepted, 2.25 modules, that is good. So, this time we can calculate depth of cut = 2.25 module = 2.25 × 2 = 4.5 millimeters. So, we understand that from the cutting machining point of view the depth of cut you understood, the diameter of the blank is defined, the operator will definitely ask you that, you have set up the gear as held on the indexing head chuck was between centers whatever be a case. Now how much do I rotate this index crank that you are talking about? So, let us have a look at this particular figure.

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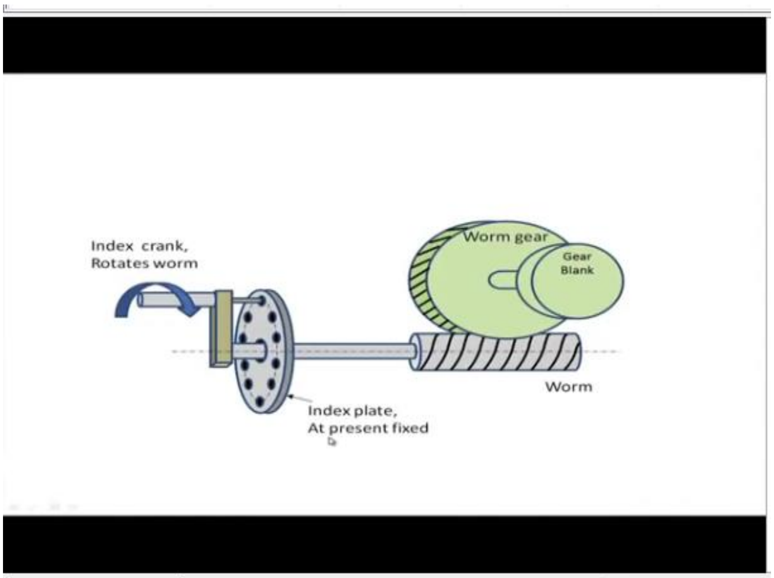

This is what is there inside the indexing head; can you locate your job? Yes, you blank is here. So, that means its axis of rotation is somewhere here and it rotates like this above the axis of rotation and you are here, this is a handle which if you rotate like this is called a crank, so this crank handle if you rotate it, it rotates this handle and this axis is rotated, mind you at this moment it has no connection with this particular plate with holes of the periphery, it is called the index plate.

At this point it is fixed and therefore this handle goes right through as a rotating shaft and rotates this one I hope you can recognize this. This is the worm and it is connected with a worm gear and the worm gear is carrying your job on its own shaft. Mind you this is a very simplified form of the indexing head, you have all sorts of other elements inside which I have not drawn the indexing head might be having a gear train connected with it.

And then there might be spiral gears everything like that which is not essential to the basic idea of indexing they have been eliminated for simplicity. But, if this handle rotating this pin sticking out from its end, it seems to have gone into a hole inside this index plate then the index plate will also be rotating, no, this is only for location for this moment the pin will be retracted from this hole when this handle is rotating at least for this problem.

So, what do we have here? The worm and worm gear as previously discussed have a speed ratio of 40:1. If the worm rotates 40 times, the worm gear rotates once and the workpiece will be rotating once; therefore we can say that overall, if you consider everything in a black box, 40 rotations of the crank handle will give 1 rotation of the gear blank. Now the question is how much do I rotate the gear blank after cutting of every tooth.

If one tooth is machined after that what is the amount of rotation that should be provided to the gear blank? So, immediately you say that if 70 teeth are being cut then the amount of rotation line must be equal to $\frac{1 \text{ rotation}}{70}$, $\frac{1}{70}$ of rotation should be provided to the gear blank.

And therefore we work with unitary method on this side I have the crank handle and on this side I have the gear blank. So, I have:

Crank Handle	Gear blank
40	1
40/70	1/70
40/Z	1/Z

Therefore the crank angle rotation required in case of simple indexing is extremely simple $\frac{40}{70}$ for a 70 tooth gear and therefore if we generalize this as $\frac{1}{Z}$ the magic number of simple indexing becomes obvious $\frac{40}{Z}$. If you have 25 teeth to be cut it will be $\frac{40}{25}$ and therefore let us have a quick look how this can be worked out.

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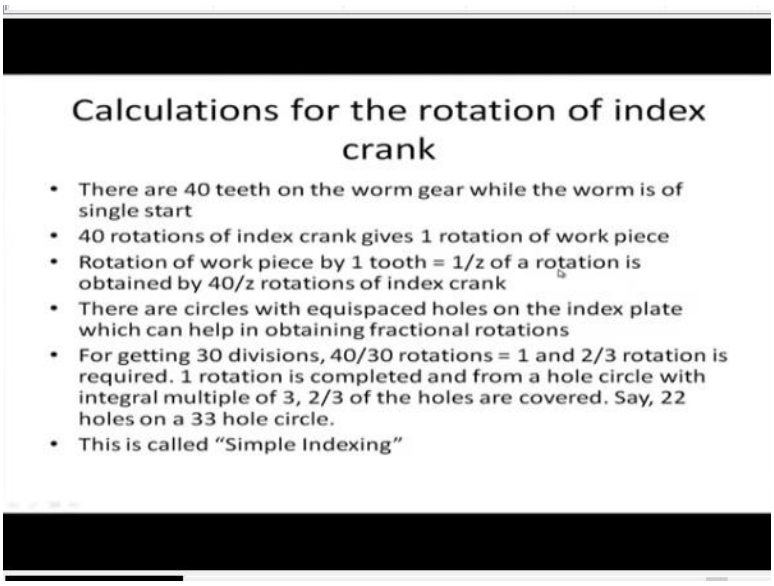

I have written all the discussions that we have made here one by one that is there are 40 teeth and worm gear, 40 rotations etc., all these things are known to you. We need not discuss we can take it up from the 5th point for getting 30 divisions $\frac{40}{30}$. Remember $\frac{40}{Z}$ is the magic number, so if you are cutting 30 teeth $\frac{40}{30}$ rotations.

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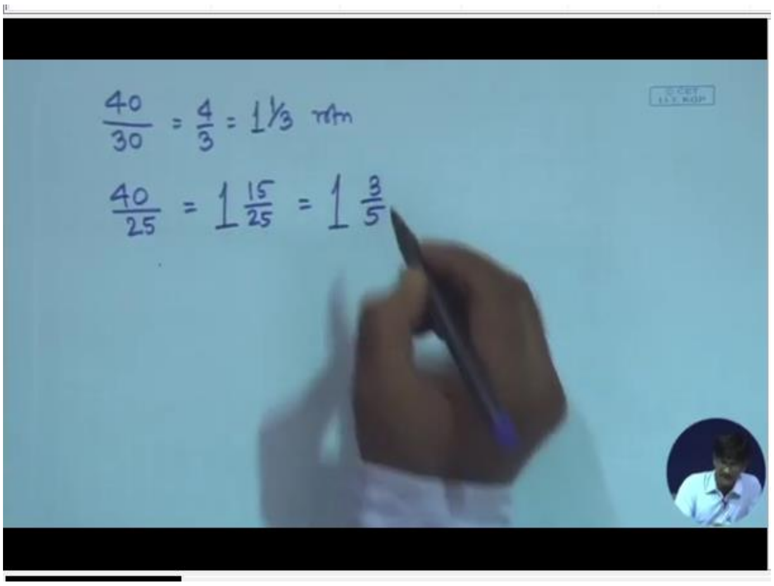

Which is equal to $1\frac{1}{3}$. $1\frac{1}{3}$ of a rotation which can be obtained, how can we obtain this for this one? 40 by 30 that means $1\frac{1}{3}$ of a rotation so I can rotate this crank handle once. And after that in order to obtain $\frac{1}{3}$ of a rotation what we do is we quickly count up the number of holes on this particular hole circle.

Suppose it has 10 holes, that is bad because 10 is not divisible by 3, but luckily there is not just one hole circle on this index plate. The index plate has been purposefully made with a huge number of hole circles incorporating all sorts of prime numbers and other numbers which might be of use to us. For example, suppose there is a 9 hole circle here, just make your imagine a little more flexible and think that, this is a 9 hole circle.

So, we come to the conclusion there might be different numbers of holes on different hole circles, you can have integral multiple of 3, integral multiple of 7, integral multiple of say 13. All sorts of hole circles are available. There might be holes present on this side of this plate. There might be holes present on the other side of the plate which means that the holes are not true, they are just deep enough for this pin to go in.

So, on the other side of the plate also you might utilize it for another set of hole circles, you might have in fact a set of 3 such index place where many more hole circles can be incorporated. So, this way you have a huge set available with you. And suppose this particular hole circle is having integral multiple of 3, say 9 or 12 or 15 like that. If there are 9 holes you can move by 3 holes on it you will be covering one third of a rotation, it is as simple as that.

So, move one rotation full and after that move by 3 holes 1, 2, 3 in a 9 hole circle and you will have achieved $1\frac{1}{3}$ of a rotation. This way we can take care of fractions which are going to occur in case of simple indexing. I hope this idea is clear. So, let us go back to our previous problems. So, 30 divisions, $\frac{40}{30}$, $1\frac{1}{3}$ of rotations, so say 11 holes on a 33 hole circle will do the trick, this is called simple indexing.

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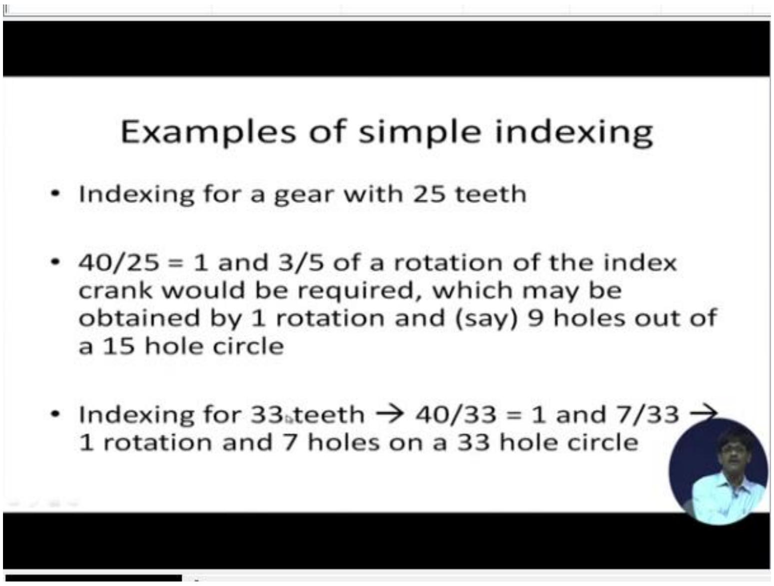

Let us end this lecture with the identification of the typical problems that we come across in simple indexing? Another example, $\frac{40}{25}$ must be equal 1 full and then $\frac{15}{25}$ which is equal to $1\frac{1}{3}$.

$$\frac{40}{25} = 1\frac{15}{25} = 1\frac{1}{3}$$

This much amount of rotation. Coming back to the screen we have 1 and 3 fifth of a rotation of the index crank would be required which may be obtained by 1 rotation and say 9 holes out of a 15 hole circle, $\frac{9}{15} = \frac{3}{5}$ that is it. So, this is understood.

So, the previous example quite clearly shows what the simple indexing and how we can achieve that, coming to another problem suppose you have 33 teeth to the cut. So, the answer is, so in that case $\frac{40}{33}$ which means $1\frac{7}{33}$ which means 1 rotation and 7 holes on a 33 hole circle. Now does that sound good, 7 holes and 33 hole circle are there other solutions to it.

Let us identify what the problem is, this means that you have to have a 33 hole circle, if you do not have a 33 hole circle at least you should have 66 hole circle or even more 99 hole circle that means integral multiples of 33, if you do not have it does it mean that you cannot do it? So, this is an apparent problem of simple indexing. So, whenever you go for higher and higher numbers you will definitely have this problem, because there is a finite size of the index plates.

The index plates cannot be as large as you would like them to be in order to incorporate all the hole circles. So, you have identified one problem that is typically it might be possible that the number of holes required on a hole circle might not be available with you. So, in that case what do you do?

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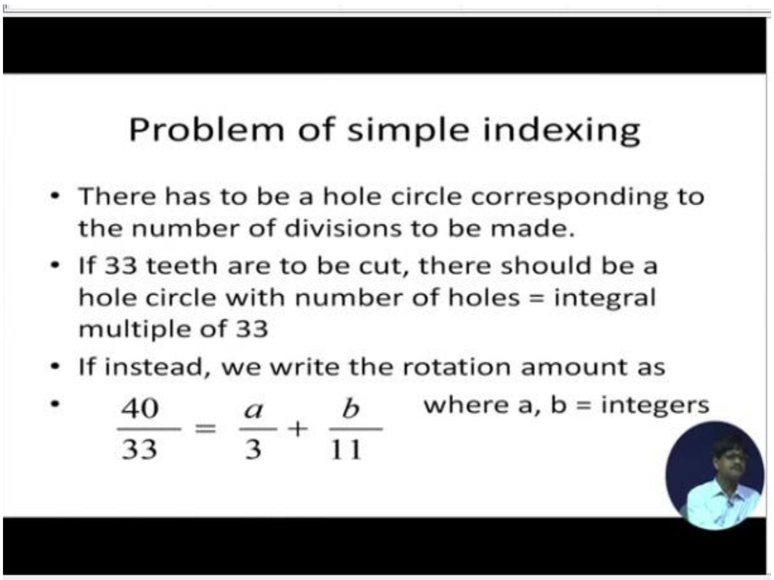

So, in that case we might think of a way of achieving that particular amount of rotation by the help of 2 successive rotations whose algebraic summation would give rise to the required amount of rotation. That we will take up in the next lecture, so for the time being that is it for the 7th lecture, thank you very much.