Spur and Helical Gear Cutting

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Lecture – 35
Gear Hobbing - I

Welcome viewers to the 15th lecture of the series Spur and Helical Gear Cutting. Last time, when we met for the series of lectures, we were discussing about gear shapers and we solved some numerical problems and multiple choice questions regarding gear shapers. So, in case of gear shapers, we have discussed about spur gear cutting about locations of gearboxes and calculations of gear ratios and several multiple choice questions on different aspects of the problem.

We also discussed about certain machine elements of which one of them, I would like to show here. **(Video Starts: 01:16)** This is a spline shaft with some gears mounted on top. Rotation-wise they are moving together but the moment you move one with respect to the other, they are movable with respect to each other. These are called the spline shafts.

In the actual movement one is free from each other, but rotation wise they are locked with each other. If one has to rotate, the other has to rotate with it. So, I will try to upload several of these clips **(Video Starts: 01:52)** without including them in the lecture because lecture time is precious for us; only 10 hours of lectures do we have.

Therefore, several clips, I will try to collect together and put it on the forums. So that, everybody can open them and see them during your spare time. So, to start with, once again, let us move back to the start of the 15th lecture. So, at that time, we were discussing what about helical gear cutting in case of shapers.

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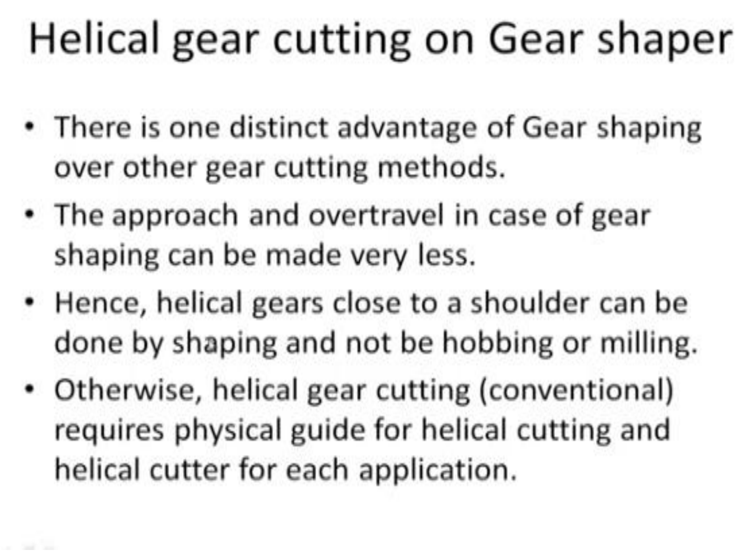

In case of shapers, there is an advantage. What is the advantage? The advantage is that in case of gear shaping will require very little approach and over travel.

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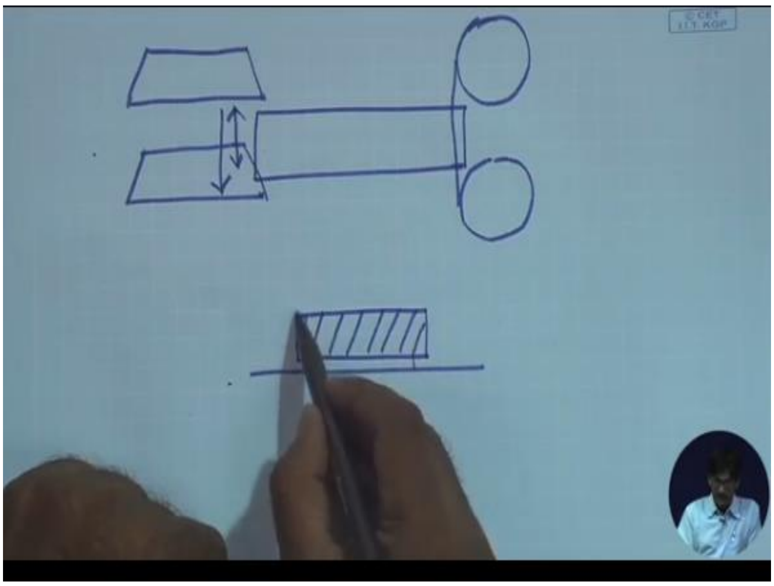

So, that means if you have a look at this particular figure. Suppose, there is one gear. This is the blank and you would like to have movement of the cutter from basically this point to this point. The cutter cannot move beyond, so in case of that the gear shaper cutter is quite useful. This is the gear shaper cutter and it can move from this side to that side. Just this much motion is sufficient for us.

So, that means it is reciprocating. But if you have the hob cutter, we will come to the hob cutter or the milling cutter, it has to start from somewhere here and it has to end up somewhere here that is, it has to move through this particular tooth. And hence, if you have a configuration in which there is a gear right beside a shoulder, say this is a shoulder and there has to be say helical teeth cut on this one.

You have a problem with milling or you have a problem with other methods of gear cutting, but in case of shaping, you can move this way. But in shaping, the problem is the cutter moves up and down in this manner. And for that you need a physical guide, you need a different type of cutter and all these things add up money wise. They become very expensive.

So, that for a particular helix angle, if you require a particular cutter and a particular guide, mechanical guide, it becomes a king's ransom to have the full set and that is why when we discuss gear hobbing especially the aspect of helical cutting of gears. During that, I will make a comparitive study. So, that you will be convinced. Yes, for helical gear cutting, gear hobbing is the answer. Gear hobbing is the answer not gear shaping. So, this thing, we have already discussed, so let us go back.

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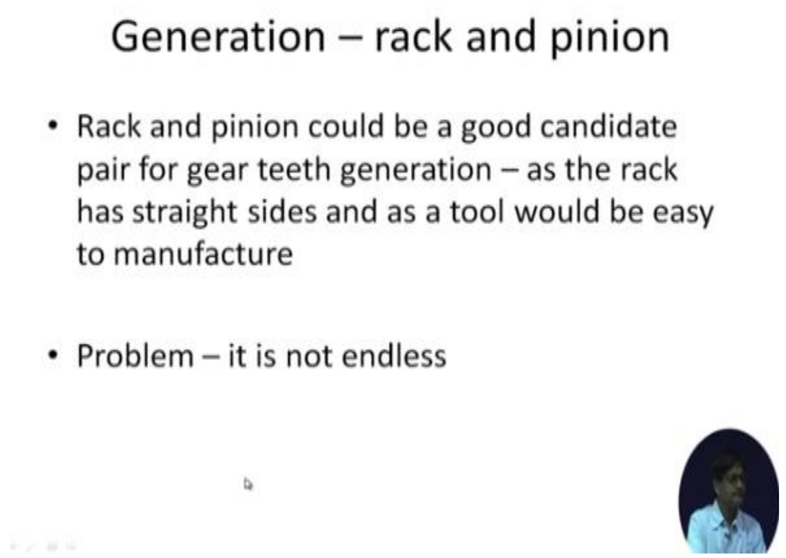

So, let us come back to generation. We were discussing about generation and with respect to generation, we have already had a discussion on gear shaping which is based on generation. What does it utilise? It utilises a pinion cutter that means cutter shaped like a gear and it is rolling against the blank and ultimately converting it to a fully made functional gear.

Now comes the question that in that particular gear cutter that means shaping machine gear cutters, there is still one problem. What is that? Let us have a quick look at that.

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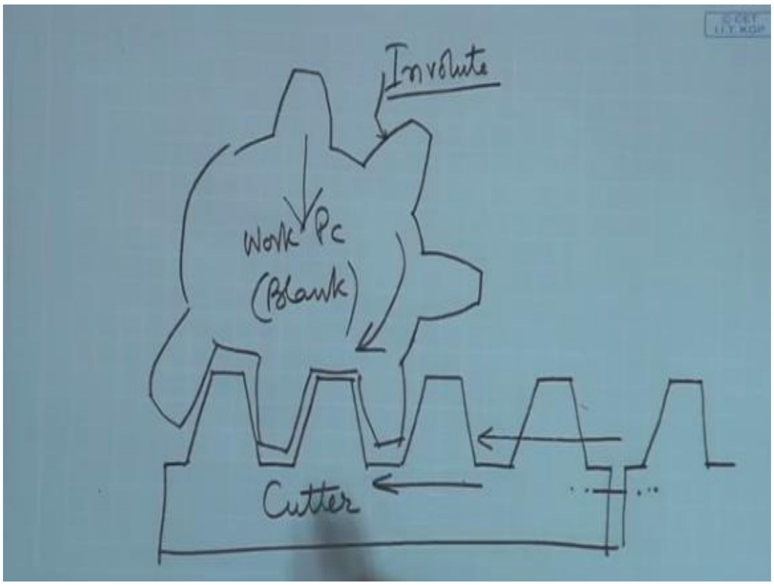

In this figure, the shaper cutter is going to have the exact profile of a gear of that number of teeth and that particular module. So, that means this particular profile has to be an involute, say in case of involute gears; say, 20 degree involute. So, the problem still remains to some extent. If you are interested to cut gears by gear shaping, you have to have a cutter which has a perfect and complex curved form which are difficult to produce.

So, we are talking about difficulty in producing complex curved surfaces and that is exactly what we are coming across in case of gear shaping. The pinion cutter has to have a curved periphery. It has to be extremely accurate because it is giving rise to subsequent gears from the blanks and therefore, we still have a problem. We have to manufacture this particular complex profile.

So, that immediately gives us an idea that if we consider the basic rack which is fitting with these teeth, the rack has an advantage over this. If we can have the cutting element in the form of a rack, it is going to have a very simple profile. This profile is going to be extremely simple. It is a straight line. It is angled. But, how does that matter? It is a straight line. It will be easy to produce this.

But the problem is, if we make this particular say this gear is meshing with this particular rack and again, we have a problem. What is that problem? If we make this the cutter and if we make this the work piece that means a blank which is getting machined into the form of a gear, then of course, we will be providing all the motions. This is rolling against this one. These two motions have to be provided.

The rack has to move up and down which is the reciprocation and all the other things like this has to have radial infeed and this has to have the relieving motion. All that can be provided but the main problem is that while the rack is moving from one side to the other, since it has to be a finite length. At one time, you will find that there are no more teeth left on the rack.

It has moved completely to this side, this particular border has come to this particular portion and there are no more teeth left on this side. So, in that case, there are solutions like Matheson's gear shaper with a cutting element as a rack. You can have it mounted on a chain so, one after the other these are coming and then they are getting recirculated.

The problem is that it is not one complete rigid body and therefore there will be subtle changes in position which will give rise to errors. So, these errors give rise to inaccuracies in the work piece and that should be by all means have avoided. So, how can we have a rack which remains always with available teeth for cutting? Yet, it moves. Just imagine endless rack.

With that idea in mind, we can or other metal cutting scientists hit upon this idea.

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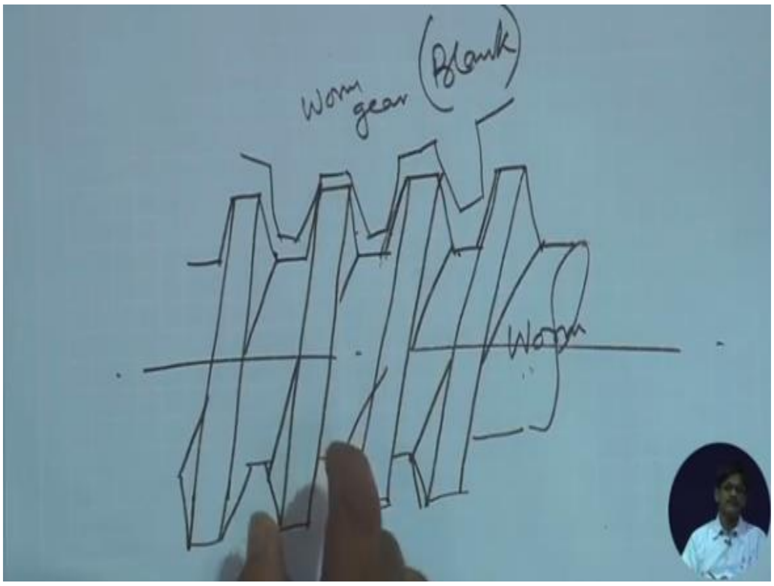

Have a rack; have the virtual work piece here etc. and in order to make this endless, why do not you employ a threaded element? Remember in our childhood days we used to make a very interesting game with you with yourself. What was that game? If you go on rotating a threaded member, this sort of a threaded member, if you go on rotating this holding this one and rotating a threaded member, it would seem as if a wave was passing from one side to the other.

I will definitely introduce a clip in which you will be seeing this. You have done it so many times I am sure in your childhood days that is a threaded member when it is rotated, it would appear to have a wave that means just like a rack movement from one side to the other. So if you rotate a threaded member, it would be just as a rack and that to an endless rack connected to the work piece.

So, this gives us an idea why do not we employ the worm and worm gear arrangement to act as the cutting element and the cut element. So, this will be the worm and this will be the worm gear. We will put the blank here so, that a gear **(12:08)** would be cut instead of the worm gear and we will put the cutter here which will look like a worm but we will produce cutting edges on it.

So this is the idea. I wanted the rack. The rack has straight sides but the rack has finite length. So I replace it with a screw, a threaded element with the same cross section as that of the rack. So, I still have those straight sides which are easy to produce and by virtue of rotation, the endless rack is produced here and the only thing which is left is that I have to bestow upon this particular worm cutting ability.

Cutting ability has to be given to this worm because ordinarily, this screw thread has no cutting edges. It cannot cut like a milling cutter. So, I have to make it a cutter, a worm with cutting edges is called a hob and the process which follows will be called gear hobbing. So, let us have a look.

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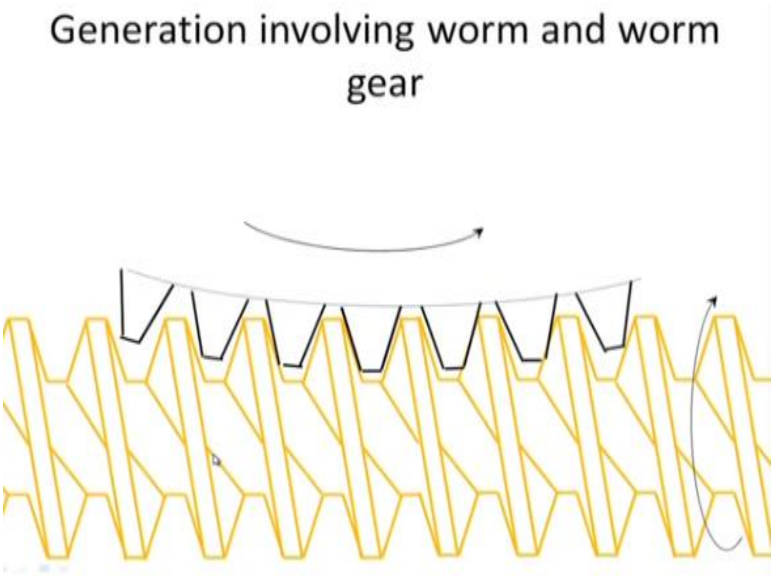

This is it. The blank will be moving this way and the worm will be moving this way and this worm will be converted to a cutter by making some longitudinal gashes. Let us see how it is.

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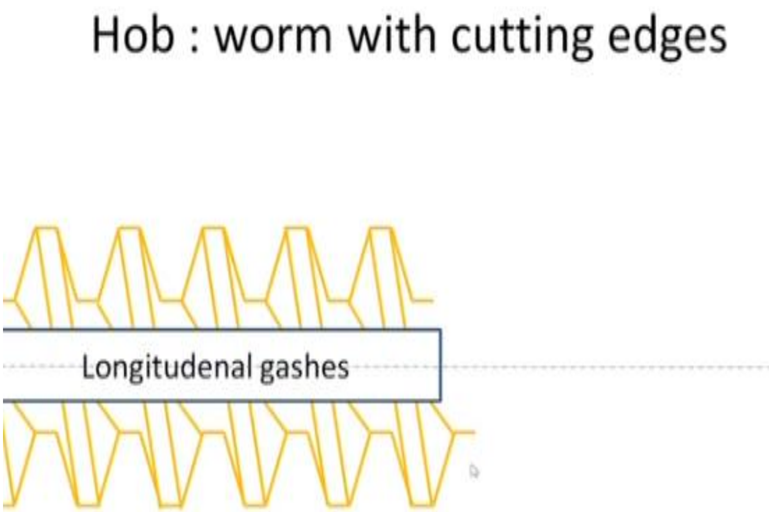

This is the longitudinal gash. Longitudinal gash means, you are removing whatever material is there, to form sharp edges both on this side and that side. How would it look like? It would look somewhat like this.

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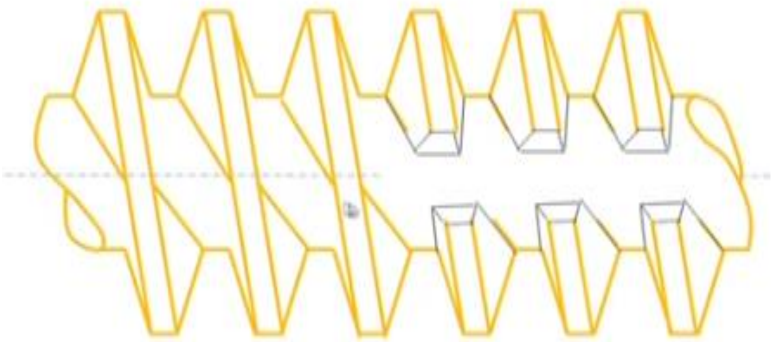

This is the continuous thread and this is the thread cut open and this portion is removed. So, that you have sharp edges existing here. How does it look like from the end?

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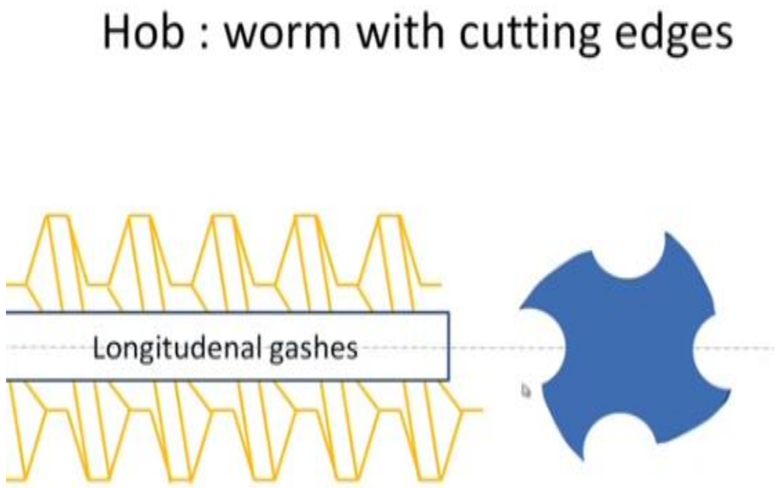

It would look somewhat like this. Longitudinal gash is made one here, one there that means one on some place here. One on the other side, which we cannot see and one on this side. These are the longitudinal gashes that we have made. It opens up cutting edges. This is one cutting edge, a series of those interrupted teeth which are going to have sharp edges.

However, there is yet another thing that we have done here in order to turn it into cutter looking like a milling cutter from the end. Let us have a look.

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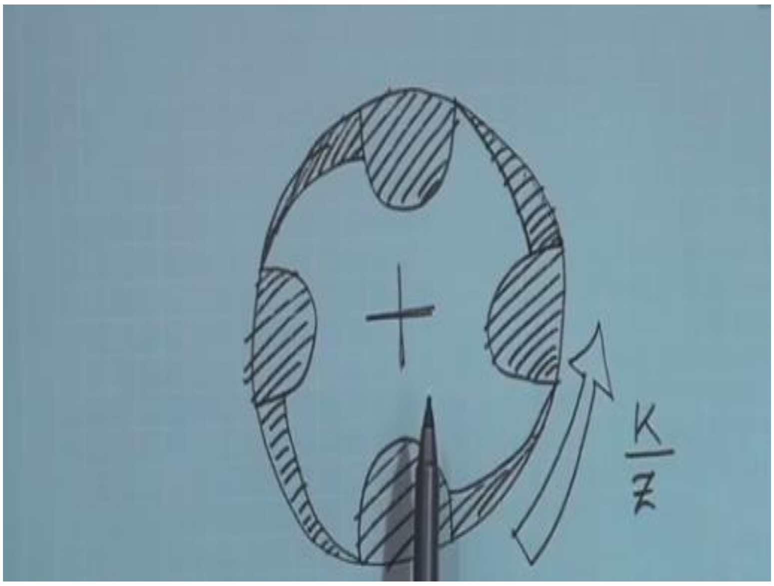

Basically, if you see it on the piece of paper, this is the worm seen from one end. The longitudinal gash opens up these portions. However, if you use this as a cutter, there is a problem. What is that problem? The whole outer periphery which is on the circumference of a single circle, if you rotate about this, all these points will be at the same radius and if you try to cut something with this one, all these points will rub against the finished surface which is not desirable.

So, we put some sort of relief here and cut away these portions; maybe Archimedean spiral or logarithmic spiral just like in case of form relieved cutters in milling. And now if you rotate it this way, it will be capable of removing material by cutting. So, this is gone. This was also gone. So, this makes us the particular hob cross section. So, it is capable of removing material now.

Once we have this sort of a cutter, it still maintains the speed ratio with the work piece. That means, that if you give it a fully formed gear, it will connect up with that particular gear and establish a definite speed ratio equal to $\frac{K}{Z}$ where K is the number of starts on the worm and Z is the number of teeth on the worm gear. We have already discussed this so many times.

So, it still has a perfect speed ratio with a fully formed gear. That means, if we now provide this with a speed and a blank with a speed exactly in the inverse ratio of $\frac{K}{Z}$ and make it move across the cylindrical surface of the work piece or blank, we will get teeth cut by the method of generation. Let us have a look how it works.

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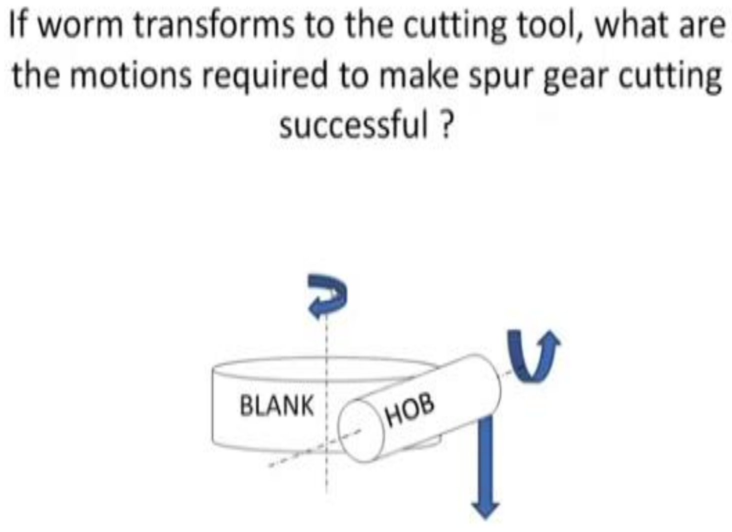

This is the figure. Now, I have replaced the hob profile by a cylinder because now you have the idea how it is made and this is the blank. So, if I provide rotation as if this is a fully formed worm gear and this is still a worm. They will have the speed ratio that they were supposed to have if they had been worm and worm gear. At the same time, I am moving the hob across the face from the top to the bottom of the blank with the interference that means with a depth of cut equal to the total depth of teeth.

In that case, I will find that teeth are going to form on the periphery of the work piece. The work piece is moving and the hob is moving down very slowly past the face of the blank. The blank or the work piece moves, the hob also rotates at a much faster rate and take away material from the periphery so, that you will find initially.

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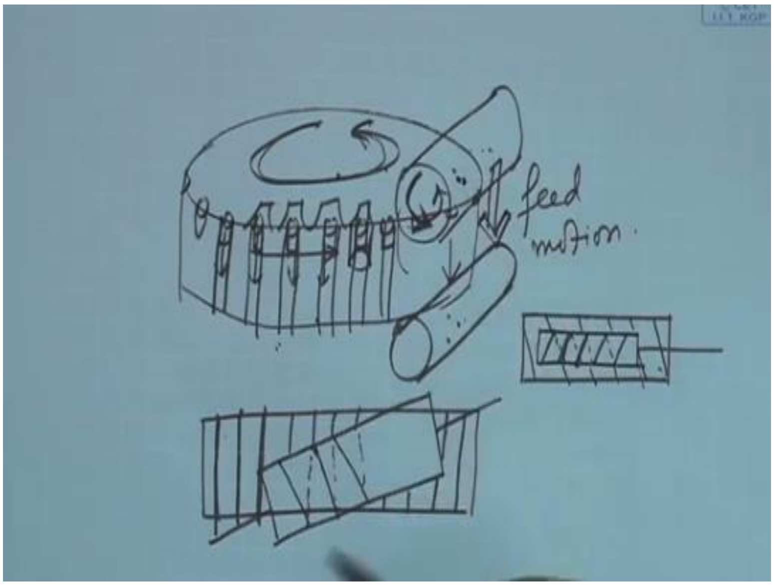

Initially, if this be the work piece and if this be the hob in the beginning so, this one is rotating fast, this one is rotating slowly and initially, it will make small cuts on the part. Small cuts will appear. Next, the hob is continuously going down and these cuts will be extended. After a few more rotations, you will find the cuts are now extended.

This way, it goes on going deeper and deeper that means down in depth and these teeth start getting the full profile this way; maybe up to this point first and that way all of them start getting extended in this direction and ultimately, they will be fully cut when the hob has completely passed beyond. So, this way all of them start getting the cuts and all of them get extended vertically downwards. Why vertically downwards?

Because, they are exactly matched by the property of worm and worm gear. So, this is removing all the material, it finds on its way which does not belong to the worm gear. Just the method of generation that is, it is removing all the material so that the conjugate profile which is formed is nothing but this particular worm gear in our case a fully formed gear. So, these teeth will be formed. I will definitely include a clip of this one, you can see it by opening it up.

So, this way the teeth are formed and the hob from the top to the bottom, it moves. If you move too fast, these teeth are going to be rough. If you move too slow, it is going to take a lot of time but the surface will be quite smooth. So, this downward movement defines the feed. So, this is the feed motion. What about the circular motion of work piece? This defines the indexing motion.

With respect to the hob speed, it defines how many teeth you are going to cut. You remember the ratio of the cutter rotation to the work piece rotation will define the number of teeth being cut. What about the hob rotation? The hob rotation defines the cutting speed. Now you will notice that when we are cutting a spur gear, then typically the hob will be inclined at an angle.

You are cutting teeth like this and you will find that the hob is typically inclined at an angle. You might say, why should the hob be inclined? Because, please recall that when we are cutting, when we are engaging the worm gear with the worm, we draw figures like these. In that case, the worm has a particular thread. So, definitely this thread has a particular helix angle.

This helix angle on the other side has to match. This one has to match. This one has to match with the teeth on the worm gear. So, ordinarily the worm gear teeth will be slightly inclined, if they are supposed to be straight. So, if you are interested to cut straight teeth, in that case you have to make the worm teeth parallel to this direction. So, these are the worm teeth now.

So, if you keep the worm straight, the teeth of the worm gear have to be inclined. So, the worm has to be inclined somewhat in order to get straight teeth. So, we will be learning more of this when we discuss helical hobbing. So, we learn that the worm needs to be rotated and inclined at an angle. The worm with cutting edges has to have rotated a motion to develop cutting speed.

The work piece has to rotate in order to get indexing motion and the hob has to be fed vertically downwards in order to have feed motion. You might say, is this the only possible configuration for hobbing? Answer is no. There can be other methods, but this is one of the most common methods by which hobbing is done. Now, let us have a quick look at the configuration that means the machine layout.

What do I mean by the machine layout? Just as before when we were discussing shapers, we noticed that in case of shapers, you have to provide the machine with a certain amount of versatility. So, that not only can it handle different numbers of teeth, it can be run at different values of cutting speed. It can be run so as to provide different numbers of teeth and it can be run so as to impart different surface finish values on the work piece surface.

In order to provide that versatility, we incorporate gearboxes with the help of which you can have different values of these parameters: cutting speed, number of teeth, surface finish and of course, at the final stage different helix angles. Let us see, this next one.

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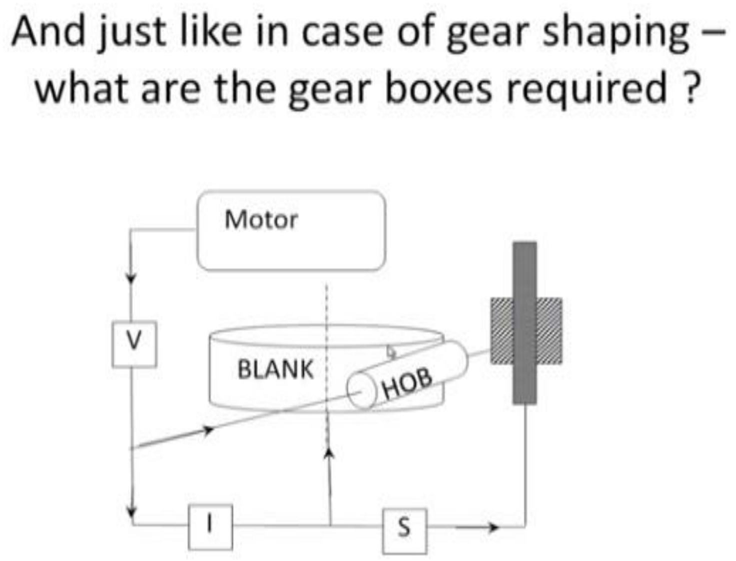

This is the configuration which is proposed for the different gearboxes. So, first of all, this is the preliminary case in which up till now, we are not considering helical machining that means cutting off helical gears. So, what do we have here to start with? We have a single motor. From that single motor, we are having the speed gearbox. So, please note instead of writing U_v as the gearboxes are represented by very small boxes, we could not accommodate U_v. So, we have written V.

So, V stands for speed gearbox; I stand for Index gearbox and S stands for feed gearbox. As, we have discussed in case of shapers, the gearboxes have the same functions. U_v is supposed to control the cutting speed. U_i is supposed to control the number of teeth being cut. U_s is supposed to control the feed in millimetres per revolution of work piece that means, how many millimetres of hob movement will take place vertically downwards; by the time that the blank rotates once.

So, we understand that there are 3 gearboxes and these 3 gearboxes are having these 3 functions. Now, once again, just like gear shaper. Let us have a quick look whether the positions that we have suggested for these gearboxes, whether these locations are unique or there can be other configurations also, which would serve the same purpose.

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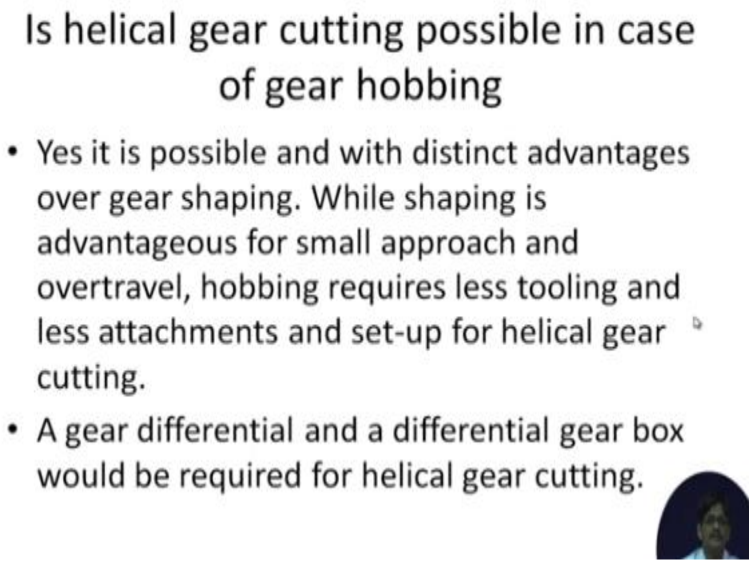

So, what is this? We will come to this one a little later.

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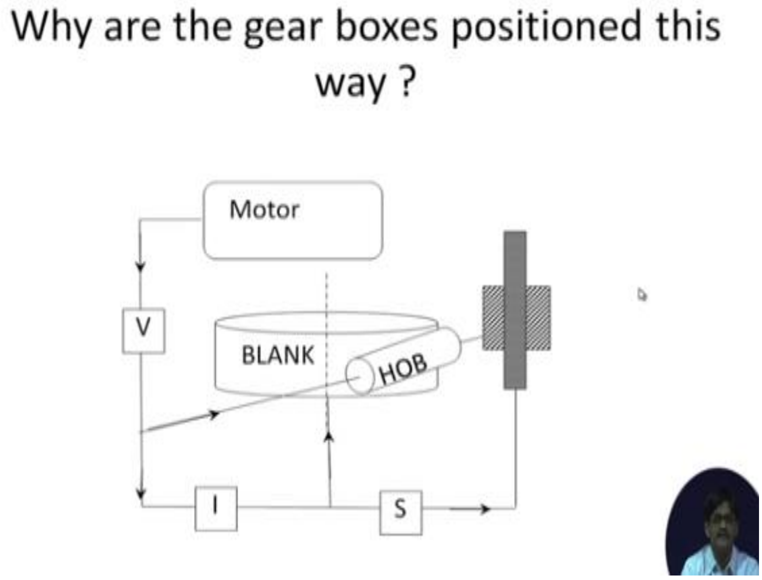

So, let us see, this is the position that we started with and I am taking a different configuration. If you remember the simple rules of gearboxes that we had stated and accepted the last day, it was that the change in one gearbox should only affect the parameter, it is intended to change. It should not affect any other parameters.

So, it means basically one gearbox when it is changed, it should affect only one parameter and it should not affect other parameters. So, with that in mind, let us have a look at this particular configuration. What has been changed here? I have shifted the position of I from this point to this point. What is I supposed to do? I is supposed to change, the number of teeth being cut. So first of all, let us first see what the previous position was and how it was serving its purpose.

Generally, the number of teeth being cut will be decided by the RPM ratio of the hob and the blank. So, let us quickly see what are the machine elements which are in that particular loop. So, starting from the hob rotation, I start from the hob rotation here; hob is rotating and then this is the path and the blank is rotating. This is the path. If anything lies in this path if it is changed it is going to affect the rotational ratio between hob and the blank and that will change the number of teeth.

So, if you look at the previous case, I was there in the loop and in the present case, I still there in the loop, only it has shifted from one position to another. This one and this one. These are the two locations that we are talking about. So, we are saying this is acceptable while this is not. So, let us see what is going wrong here.

If I is placed here and suppose you change the value of I to get a different RPM ratio, unfortunately as it is just ahead of the hob, it will change the RPM of the hob as well and you will start getting a different cutting speed and that is not acceptable as it is going against the basic law of mutually exclusive function of gearboxes. Gearboxes should function in a mutually exclusive manner. So, that is being transgressed.

So, with this we come to the end of the 15th lecture, we will again take up the same discussion that we will pick up the threads in the next lecture. Thank you very much.