Spur and Helical Gear Cutting
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Lecture – 31
Gear Shaping - I

Welcome viewers to the 11th lecture of the course Spur and Helical Gear Cutting. So, we have discussed on the last day some numerical problems in differential indexing and helical gear cutting and today, we are going to start a new topic gear shaping. Gear shaping falls under the category of a number of methods called generation processes.

It is not restricted only to gear cutting. Generation processes can generate different types of profiles and gears fall into that category. Generation process is basically, in colloquial language, it is basically like this. If you are having 2 elements rolling against each other, then one of the elements, that means one of the same mechanical elements in our case, can be obtained by taking the envelope of the conjugate profiles of the other.

So, it means if element A is rolling against element B go on taking the positions of B mapped them continuously one after the other that the successive positions and take the conjugate of that and you will get A.

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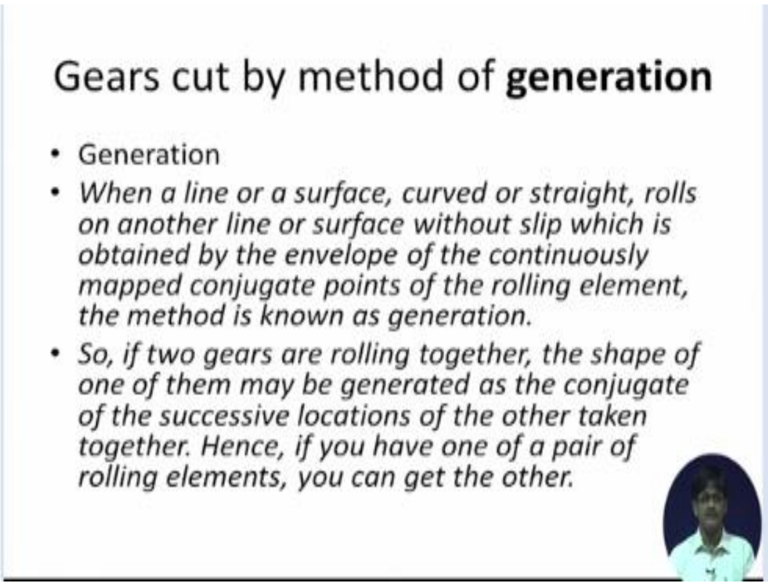

So, let us start formally with the classical definition of generation. When a line or a surface curved or straight rolls on another line or surface without slip which is obtained by the envelope of the continuously mapped conjugate points of the rolling element, the method is known as generation. This definition is taken from principles of machine tools by A Bhattacharya.

So, if we make it in simpler language, so, if 2 gears are rolling together, the shape of one of them may be generated as the conjugate of the successive locations of the other taken together. Hence, if you have one of a pair of rolling elements, you can get the other from the rolling motion of the first one.

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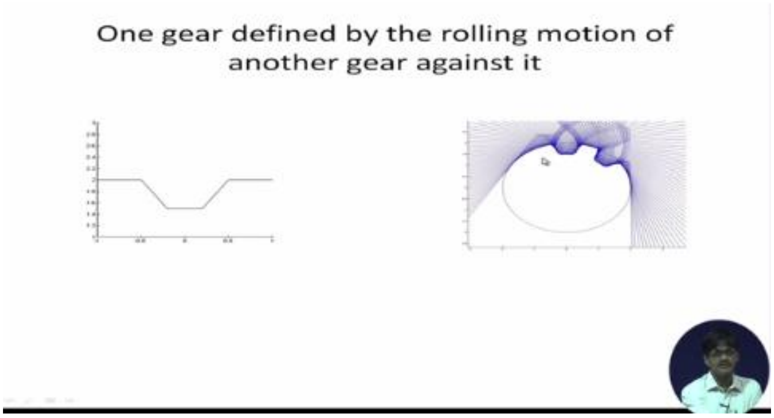

This shows that this is the rack geometry that I have and I am rolling it against. I am moving it as if it is rolling against a virtual gear and the continuous positions of the rack, they are recorded here. And when I am taking the conjugate envelop, this one, conjugate means just the opposite space. So, all these other positions of the rack and when I am taking the conjugate space, I find that it is generating gear tooth shape.

So, this way, if I had allowed the rack to move all around, it would have generated the complete gear teeth profile. Now, let us have a practical demonstration of the same. **(Video Starts: 04:03)** So, if you have a look, this one is the rolling rack and it is generating the surface, the gear tooth profile. I have made a MATLAB programme.

I mean, one of my students Aditya Shriram. Thanks to him. He had generated this programme for generating the gear teeth. **(Video Starts: 04:27)** So, this way as the demonstration shows, if I give all the movements as if they are rolling together, then the continuously mapped conjugate positions of one element would give me the other surface. So, this, utilise in our case to generate gear teeth.

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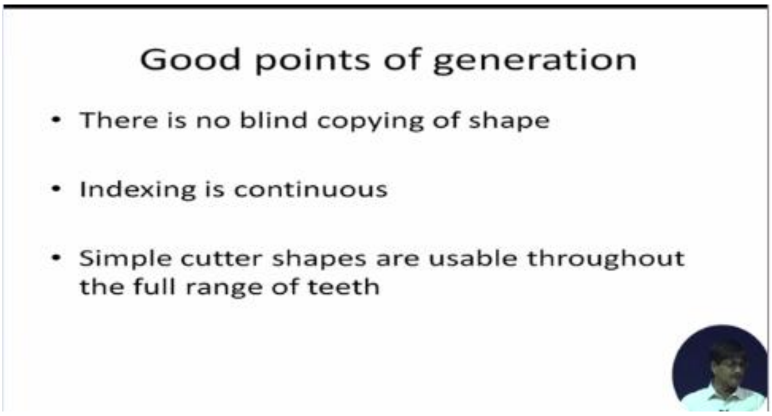

What is the advantage of this particular method? There are distinctly 3 advantages that we have in comparison to milling of gears. First one, there is no blind copying of shape. It is not a gear forming process. Forming essentially means that we are copying one geometry from one cutting element onto the blank surface. So, we are not blindly copying.

If you do blind copying, then the problem is whatever errors you have, they get generated again and again and you have to have different types of cutting elements, a number of cutting elements have to vary in order to develop a number of such shapes because it is blind copy. Variations between the end shapes as per your requirement cannot be obtained by the same cutting element all the time.

Next one is, indexing is continuous the process of indexing that we have learned in case of milling, it is not continuous. Why? Because, we have to stop the cutting process. We have to rotate the gear blank and then only we can start cutting off one more gear tooth space. So, as indexing is discontinuous, inherent errors in discontinuity of a process will bring in inaccuracies in the work-piece.

What sort of inherent errors? One is clamping, unclamping, moving, making mistakes due to backlash error. And then eye estimation of the amount of rotation. I mean we should say a human errors of the estimation of rotation and then inherent errors of the angular spacing of the holes on a whole circle in milling index plate, all these things will be brought in.

In case of methods of generation, discontinuous indexing is not at all existing. It is replaced by continuous indexing that means, while cutting is going on, the tool and the work-piece, they rotate against each other so that the cutting action is distributed over all the teeth. Also, simple cutter shapes are usable throughout the full range of the teeth. So, starting from say 12 to 13 teeth right up to the rack, you can use the same cutter.

This is a big advantage because in case of milling at least, we are having 8 cutters. A set of 8 cutters are handling from 12 to 13 teeth to the rack. So, with this discussion, we come to the conclusion that generation definitely has its advantages over milling of gear teeth.

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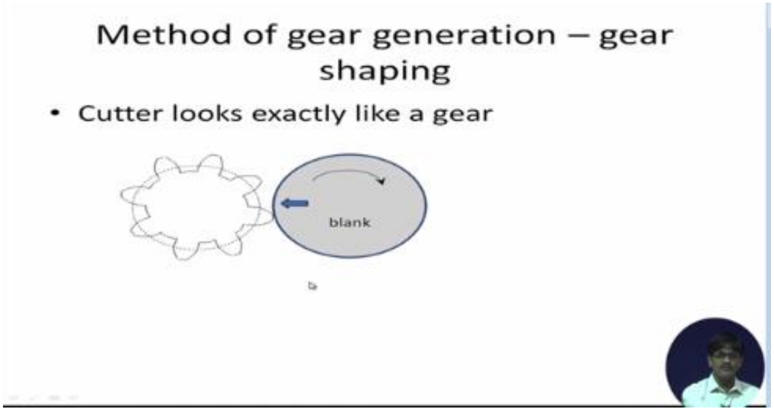

So, let us have a look how the method proceeds in case of gear shaping. This is the cutting element. It is made of absolutely hard rigid material which is not deforming and in contact with it we have the gear blank that is also metallic or it can be plastic or some other material, but it is relatively softer and this one, because conventional cutting is going on so work piece material has to be softer, but it has to be cut.

It cannot be deformed out of shape. No. We essentially have to cut it out of a cylindrical blank material, the gear. So, let us see how the movement proceeds in gear shaping. First of all, this is the cutter; the cutter and the gear land, they are made to touch almost tip to tip and after that cutter rotates, blank rotates and the blank gradually moves forward towards the cutter. Let us see.

I think you can see very slow rotation of the cutter taking place and the blank is also rotating as if they are rolling. Are they rolling together? No. There are no teeth. But they are made to rotate by us individually. I am rotating the cutter. I am rotating the blank. I am making the blank move gradually towards the cutter, so that the interference between them is gradually increasing but if this is made of metal or some other material which is hard, not as hard as the cutter but quite hard.

In that case, this interference will result in some sort of damage or breakage or some kind of metal forming cannot take place just like that. So, this material which is in the interference zone, this would not get removed just like that unless we have a cutting action incorporated. What is that cutting action? Along the axis of the cutter, the cutter goes on reciprocating cutting off everything it meets on its way.

So, in addition to these 3 movements, one is rotation of cutters, rotation of blank and movement of the blank towards the cutter, we also have this movement.

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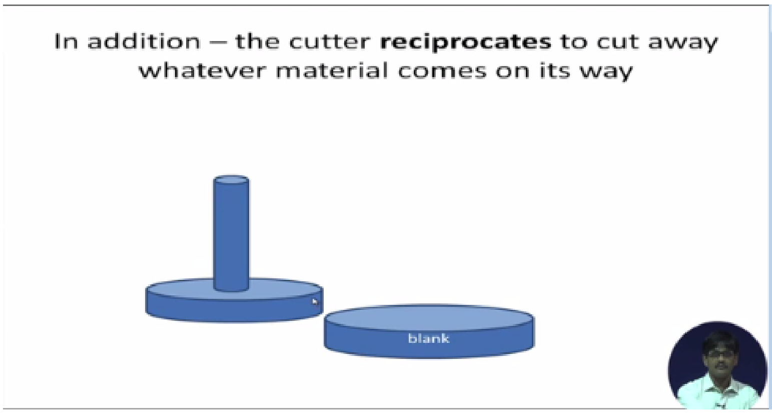

This is the cutter. This is the blank as the cutter is also moving this way together with rotation of the cutters, rotation of the blank as we have seen before and movement of the blank towards the cutter. So, this reciprocation removes all the material the cutter meets on its way. Remember the cutter is having teeth on its periphery and those teeth have sharp edges and they are given cutting angles in order to facilitate material removal.

And also for providing clearance, so that the finished surface of the blank is not touched by the cutter on during its movement.

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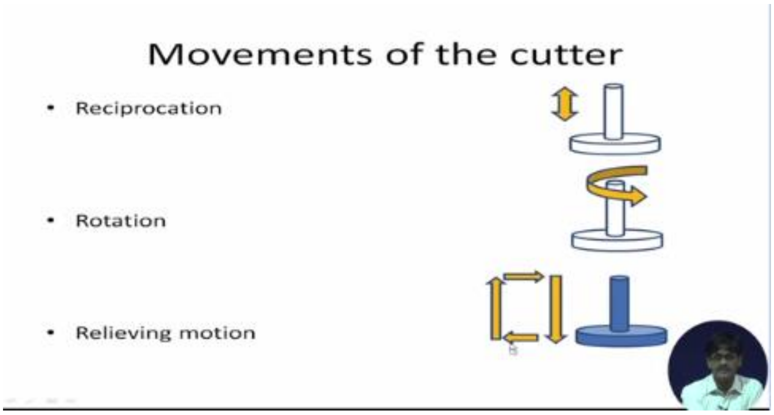

So, what are the movements that we are providing? We are providing as we have seen reciprocation. This reciprocation provides the cutting action. The cutter cuts off all the material it finds on its way and that way, material is removed by cutting action. No pressing, no damaging, no denting, but cutting. In addition to that as we have noticed, the cutter also has a rotation because we have to create a situation in which as if cutter and the work-piece, they are already formed gears.

And they are rotating against each other as if they are rolling together. We are creating that condition. So, in that case, if the cutter removes all the material late meets on its way, it will ultimately give rise to a completely machined gear out of the blank. So, this one is one motion which we have not discussed up till now. When the cutter is moving up, it slightly recedes away from the work-piece, so that it does not rub against the finished surface of the work-piece.

Unnecessarily, this movement would have damaged the finish surface. So, it slightly recedes away and moves up, comes back to the original line of cutting and then comes down and does the next cutting stroke. So, this is a relieving motion. So, how many move movements do we have here? 3.

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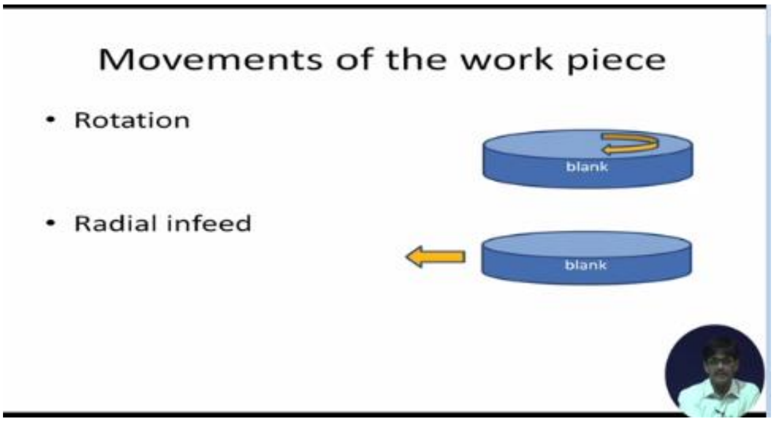

Work piece is also rotating because we are creating a condition of rotation of the cutter and the blank together. So, this motion has to be provided as well and work piece is having radial infeed which we have noticed during the simulation. Why does the work piece have gradual towards the cutter radially it is moving? This is because the cutting action is made to increase slowly from 0 depth of cut to the full depth of cut.

This is because if we give the full depth of cut in the beginning itself, the cutter coming down during its stroke if it meets with the full depth of cut, there will be breakage. Instead of cutting it off, the blank might be broken or the cutter might be damaged. So, gradually this is moved while rotation of the cutter and the work piece and depth of cut increases gradually from 0 to the full.

So, 5 motions in total are required to make this thing work. And we have a machine called the gear shaping machine in which all these movements are incorporated.

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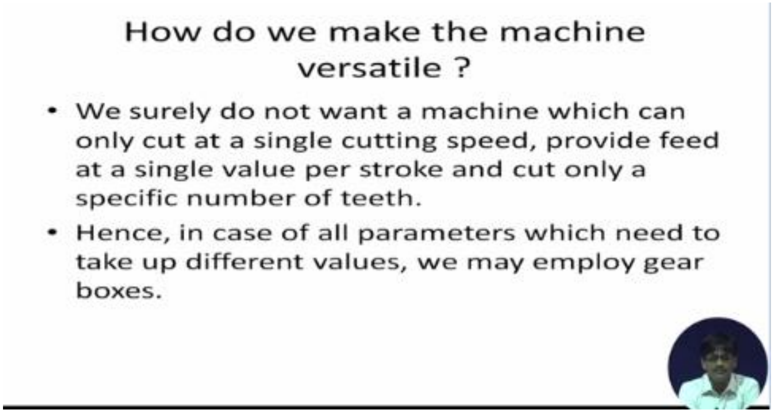

Now, comes the question. Just making a machine in which all these things are possible is not the full solution, I mean people will not be interested in your machine if you make a machine and you say, yes my machine has all these 5 motions, but it has only, one particular motion or one particular strokes per minute, one particular gear can be held and, one particular blank can be held and only a certain number of teeth can cut, maybe it can only cut 50 or 60.

Then what is the use of it? It has to be versatile. You can employ any cutting speed say, within the range of say, 30 metres per minute to say 150 metres per minute. Generally, instead of cutting speed, we employ strokes per minute, which means that you can use say 30 strokes per minute, Yyou can use 300 strokes per minute like that. With the strokes per minute, the cutting speed will increase.

So, why should we have different strokes per minute? Because, you might be using more sophisticated cutting tool which can cut at a higher speed and you will be saving time. You might be cutting the gear out of a blank material which is soft and you can employ a higher cutting speed. So, in those cases, we can employ a higher number of strokes per minute.

What are the other cases where versatility is required? You might be having the requirement of a gear with highly finished surface. In that case, we would have a provision through incorporation of a gearbox in which you can have rough cut gears or you can have finished cut gears that means the surface finish will be either rough or fine.

Now, you might say, why should surface finish be rough? This is because maybe, this is just the rough cutting is to be done and after that, you will be doing a finished cut and during the rough cut, you need not have very fine surface and you can save time by using course feed. So, a feed gearbox is provided with the help of which you can have different feed values and feed is expressed in circumferential movement per stroke of the machine.

So, now, we have strokes per minute, which can be changed by a gearbox which is called speed gearbox. We can have different feed values, millimetres of circumferential movement per stroke. So, 2 gearboxes and if you want to cut different numbers of teeth, if you cannot cut different numbers of teeth, then your machine is practically useless. So, another gearbox is incorporated with the help of which you will be having the provision to cut different numbers of teeth.

So, basically, we are able to incorporate these versatilities with the help of incorporation of gearboxes. Gearboxes will give you distinct and discrete options. It is not infinitely variable, but you can predefine your requirements and accordingly gearboxes can be incorporated, which will be providing you with those facilities. So, we understand that this machine cannot stand alone just with providing the 5 motions, but there have to be gearboxes as well.

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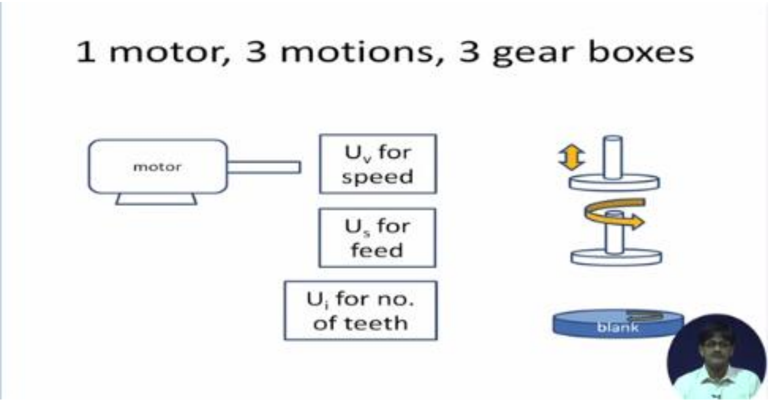

So, that preliminary design of the machine requires, we are cutting down from 5 motions required to 3 motions, we will incorporate those 5 motions definitely, but these 3 motions are the most important ones and we will restrict our discussion first to these 3 and then move on to the incorporation of the other 2. So, this is the motor. There has to be a power source and we are at present working with a single motor that is quite strange.

We have so many motions, why a single motor? We will find that a single motor is also quite capable of providing all the motions that we want. We are incorporating now 3 gearboxes for the 3 motions. What are these? First of all, we named one gearbox U_v for changing this speed, which basically is going to serve the purpose of changing the number of strokes per minute.

U_s for feed value which will basically control the amount of circumferential movement per stroke and we will also have U_i or index gearbox. This is speed gearbox. This is feed gearbox. This is index gearbox. If you have the requirement of cutting different numbers of teeth, you will be having a different setting of the index gearbox. Now, how do we connect these? Let us see.

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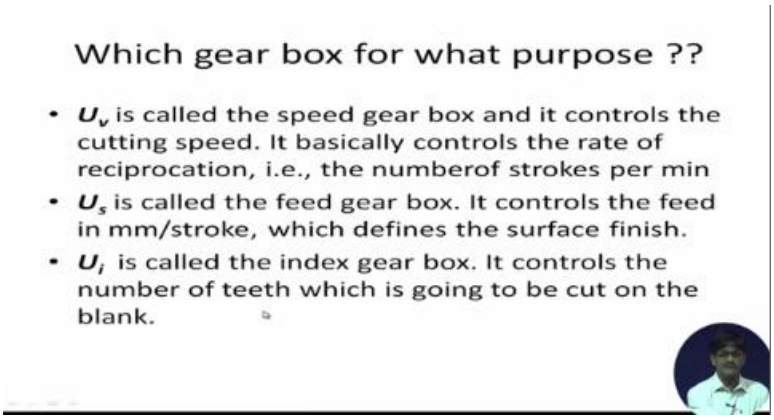

So, we have discussed this thing just now. We need not, so, U v is called speed gearbox and enter basically controls the rate of reciprocation. So, I am skipping this one.

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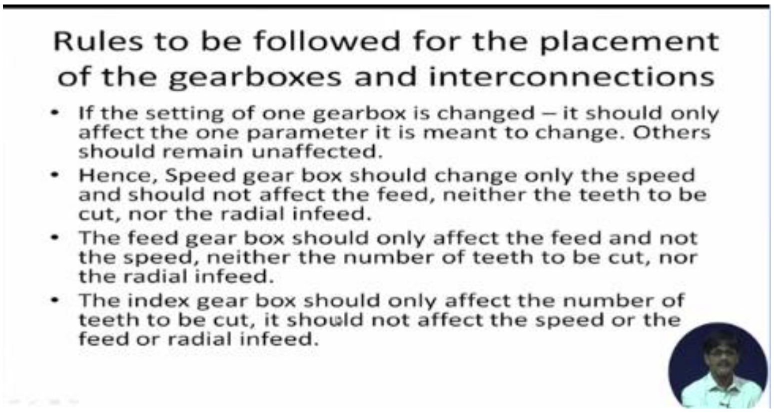

So, the rules that have to be followed for the proper placement of the gearboxes and their interconnections. First of all, what do we mean by these rules? It is inherently understood that the changing of the setting of one gearbox should affect whatever it is supposed to control and nothing else. This is basically what we understand by the rule. So, let us read it up.

If the setting of one gearbox has changed, it should only affect the one parameter it is meant to change, others should remain unaffected that is all and then we give an example. Hence, speed gearbox should change only the speed, that means the number of strokes per minute, and should not affect the feed neither the teeth to be cut nor the radial infeed and if we extend this to the others, it means that the feed gearbox should only affect the feed and not the speed, neither the number of teeth to be cut nor the radial infeed.

The index gearbox should only affect the number of teeth to be cut. It should not affect the speed or the feed or the radial infeed. So, now, we understand that they are mutually exclusive in their functions. The changing of one gearbox should not affect the working of the others.

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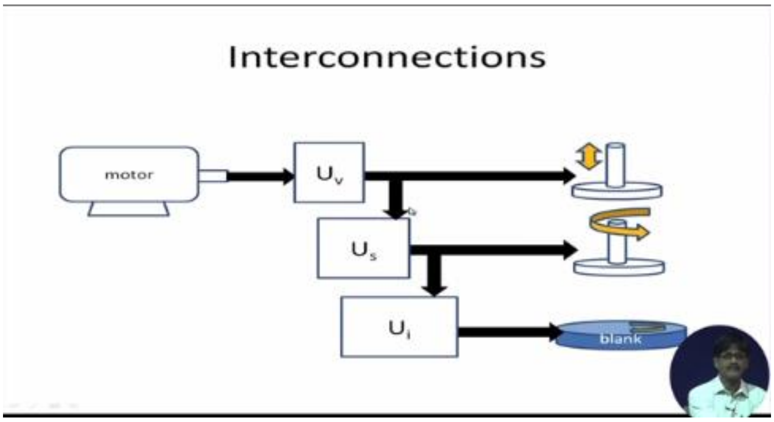

So, let us have a look at this particular interconnection. What do we notice here? The motor is first of all serving U_v, the speed gearbox. So, it means that the power is flowing from the motor to the speed gearbox. How does the power flow? So, the motor shaft is rotating and that shaft goes inside the gearbox U_v there.

There will be a cluster of gears and these cluster of gears will be changing the RPM and a different RPM will be coming out of the gearbox and serving the subsequent machine elements or other gearboxes as the case may be. So, let us have a look. The speed gearbox is being connected directly to the motor. So, that means downstream of the speed gearbox, whatever is there, they are going to be affected by the change in the speed gearbox, but that seems to be exactly the opposite of what we had been planning.

What had we planned? We had planned that the speed gearbox or whatever gearbox, it should only affect the parameter it was supposed to change and nothing else. But obviously, if the speed gearbox is connected upstream of everything. All others would be affected. So, let us look at it and find out what is exactly going on here.

Now, at this juncture, I will just bring back a discussion that we had had regarding the placement of the lead gearboxes namely the speed and the feed gearboxes. I will just draw a figure. Please have a look at the piece of paper.

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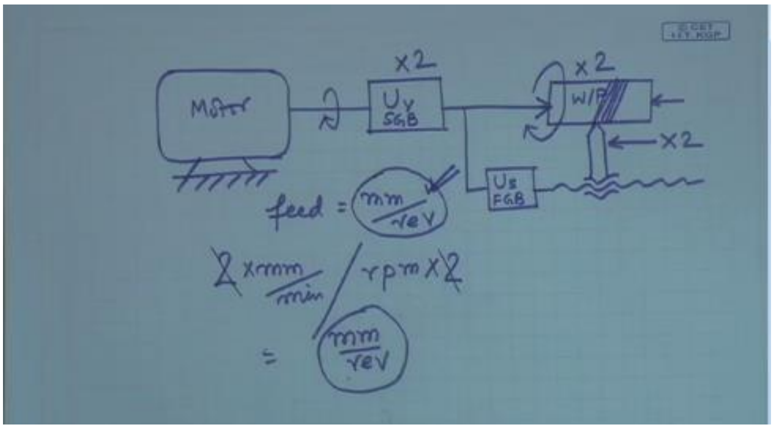

And I think that will make subsequent discussions extremely clear. On the lead, we have a motor from which we are drawing power and if you remember, we have the location of speed gearbox. Let us call it SGB, speed gearbox here and after this, just like as in the gear shaper, we have the spindle to contain the work piece and withdraw the power from here for U_s feed gearbox and from here, you might be having a lead screw.

And you can mount nut and the cutter this way. This was the figure in case of the lead. The same thing was happening. U_v is placed ahead of everything and therefore, if U_v is doubled, suppose I make a setting of the U_v, so that the output RPM is doubled. In that case the rotation of the work piece doubles and the cutting speed is made double exactly what we wanted. The speed cutting speed is doubled.

So, this also becomes multiplied by 2. But, what about this place? This also the movement of this one also appears to have been doubled. This is not we want not what we want. We want that whatever changes U_v will create. It will only be restricted to the change in cutting speed. What about the feed motion? Feed motion is the motion of the cutter past the work piece to extend the cutting action to newer areas of the work piece.

Here, if we notice that, feed is actually remaining same. Why? Because of the definition of feed. Feed is defined in millimetres per revolution, millimetres of tool movement, not per unit time. No, millimetres of tool movement per revolution of work piece $(\frac{\text{mm}}{\text{rev}})$. So, if the work piece rotates once whatever movement the tool has suffered, that is known as the feed and that will remain constant because if this motion in millimetres per minute is getting doubled divided by revolutions per minute of the work piece that is also getting doubled.

$$\frac{2 \times \frac{\text{mm}}{\text{min}}}{\text{rpm} \times 2}$$

The 2 and 2 from the numerator and denominator will cancel. Therefore, millimetres per minute by revolutions per minute, per minute and per minute will cancel and you will have millimetres per revolution, same as before. No multiplying factor is remaining. So, millimetres per minute is remaining same and therefore, we say that feed is not affected. The question is why should we define this one as millimetres per revolution.

We are getting away with it. It remains constant. But, why go for such a unit? This is because this is the factor or the parameter of the variable which defines a very important thing on the work piece, the surface finish. The surface finish is defined by the small amount of movement you are making per revolution of the work piece. This also defines the pitch of the thread you are attempt to think to cut on the lathe.

So, we find that the gearboxes are affecting only the parameters they are supposed to affect in this case by virtue of the definition of feed here. Now, we come back to our discussion on the gear shaper. And have a quick look that exactly the same thing is going to happen. If you look at the figure now, in the figure, U_v is going to double say, U_i double U_v; U_v is going to double the reciprocation rate.

So, the number of strokes per minute becomes double and therefore, speed becomes higher and therefore whatever is passing through U_s that also becomes double. So, the rotations per minute will become double. So, just is before if a certain number of millimetres on this circumference, they were undergoing rotation per stroke that will also double, but number of strokes have also increased twice, so that 2 factor of 2 cancels.

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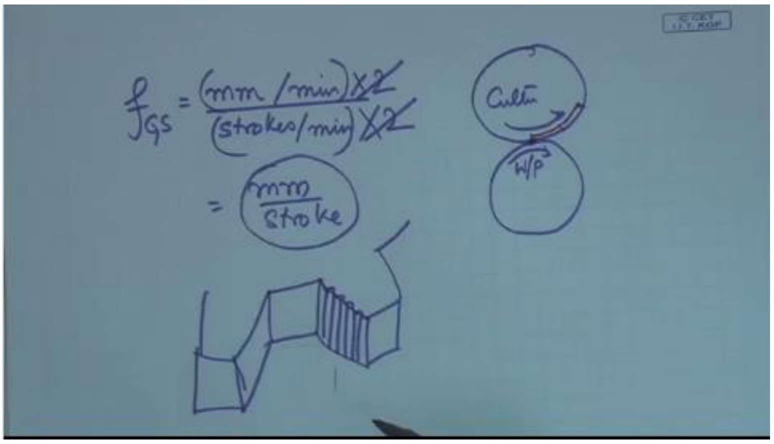

If you kindly have a look here, it is something like this. So, the feed in case of gear shaper, millimetres per minute by strokes per minute, strokes per minute is getting doubled; millimetres per minute circumferential movement, it is like this.

$$f_{GS} = \frac{(^{mm}/_{min})}{(^{strokes}/_{min}) \times 2}$$

This is the cutter. This is the work piece and therefore, this one is rotating against each other and therefore, the movement it suffers.

The movement it suffers per stroke. This becomes double. This becomes double per minute. Suppose, this amount of movement is taking place per minute, that is they are rolling against each other; this amount of movement per minute it is moving. So, now, you will find double the amount of movement is taking place per minute.

So, this is doubled and therefore, these 2 cancel; per minute, per minute cancels and millimetres per stroke will remain as before and therefore, feed is not affected.

$$f_{GS} = \frac{(^{mm}/_{min})}{(^{strokes}/_{min}) \times 2} = \frac{mm}{stroke}$$

And once again, why do we define feed in millimetres per stroke? Because, it defines, the tool is going on moving this way. It defines exactly and while the cutter is rotating it is also moving up and down and therefore, that also defines the roughness of the gear teeth.

I will draw a figure, so that you will agree with me, the roughness left behind on the gear teeth when cutting takes place is like this. Rough surface that the lines of the cut will be like this and this will be rougher. Even a course cut will be there if you use higher value of s.

The cutter has gone this way and cut the material. So, this millimetres per stroke will remain the same even if you double the U_v setting. So, with this, we come to the end of the first lecture on gear shaping. We will again meet in the 12th lecture. Thank you very much.