Metal Cutting and Machine Tools
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Lecture-11
Tool wear and Tool life

Welcome viewers to the 11th lecture of the course metal cutting and machine tools. So, as I had declared the last at the end of the 9th lecture that I would be covering the leftover part of the 9th lecture in the 11th lecture. And I would be dedicating the 10th lecture solely for solution of numerical problems. So, in the last lecture we had some leftover portion of measurement of cutting tools and I will discuss that very quickly and then move on to the discussion of tool life and wear of cutting tools.

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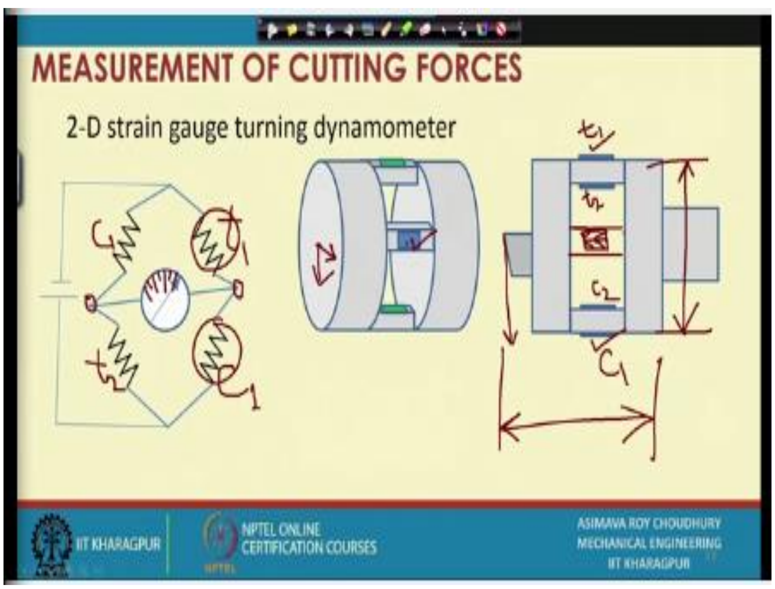

So, to start with, when we were talking of measurement of cutting forces, we discussed the theory of strain gauges and this fact that the strain gauges have a compact. So, we had discussed the theory of strain gauges and understood that dr/r divided by the strain = gauge factor was roughly equal to 2, which showed that there is a relation of proportionality existing between resistance change and strain.

So, this proportionality allows us to measures resistance and accordingly predicts what is the strain, and that means within elastic limit what is the stress and from that what is the force? Naturally, with some known force values we have to calibrate the machine, so that we understand which particular change in resistance stands for what particular force. Now how do we measure this change in resistance and utilize it for our values?

Just use of a single strain gauge will not make the change in resistance, so it we cannot register rather it will not register a marked change. So, for that what we do is we can employ a number of such strain gauges. For example, in this particular structure, shell type structure as you can see the front body and the rear body they are connected by some horizontal beams, the whole body is integral.

So, that if I apply a force downwards, say I am applying a force downwards let me remove this line it is not a straight line at all. If we apply a force downwards, in that case we will observe that all these will be bending as beams with the neutral axis somewhere here and these are bending, and due to the moment caused by this downward force. So, if we have the cutting tool here we are seeing the other view, side view here.

If we have the cutting tool here together with this force acting as the main cutting force, we will be having the bending of all such sections. So, here also there is one such section. Let us see what is going to happen to this? When this is bending, this being the neutral axis, we will have a considerable amount of rather we will have no net change in resistance.

Because if the strain gauge is put here, part of it is above the neutral axis, this part is above the neutral axis it is a going to register a tensile stress. And therefore it is going to have tensile strain and resistance is going to become higher. In this case however it is below the neutral axis and it is going to register what you call it compressive stress and resistance is going to become less.

However, if you consider this particular one, it is definitely going to be tensile; if you consider this particular one it is definitely going to be compressive. This one also since it is more towards the top, this is more towards the bottom tensile compressive. Now what we do is, we generally suppose we have a DC power supply and these other strain gauges. So, if we put a strain gauge in tension at this place another strain gauge in compression at this place.

Ordinarily, if they are all of the same resistance and they are not under any stress, this would register a zero value; this is say a voltmeter or a galvanometer. So, this will register a zero or a null reading, but what does it point to? It points to the fact that at this point and this point the voltage values are the same, because the voltage dropped through this, through that and through this, through that they are the same, so that the voltage is same here.

But the moment we put these 2 under tension, so I might be connected say t_1 here t_1, I might be connecting c_1 here, c_1 like that. So that way, so this is also far away from the neutral axis, so this also will be say t_2, this one will be c_2, t_2. So, if we put these in this manner the advantage is this that we are going to have a distinct drop here which is different from this one.

Because this will be low resistance and this will be high resistance, so voltage will be dropping considerably at this point. This will be high resistance; this will be low resistance, so voltage will not fall so much. So, this way we will register a change here at this particular point and we can read of the value if there are graduations. And we can calibrate it with known values and we can easily find out.

So, this way if we use such strain gauges, it will be easy for us to find out the values of the forces. But what about the force which is coming out of the plane of the paper? Out of the screen, that means this force, this force will be captured by this strain gauge and the corresponding strain gauges in this another beam on that side. So, there is one on this wall, there is one on the inner wall, there are 2 such strain gauges on the corresponding beam on the other side.

So, they will capture this force, so this is generally referred to as the 2 dimensional strain gauge turning dynamometer. So, instead of the ordinary tool if you have this device, then it will be good. And what sort of configuration should it have? If this diameter is made higher then you are going to get more response, more strain because they will be more and more away from the neutral axis.

If this distance is made smaller you are going to have higher rigidity because the overhang is becoming considerably high here. So, all these aspects can be taken into account when we are designing such a strain gauge, I mean strain gauge dynamometer. So, dynamometers are devices for which can be used for measurement of forces, and here we are employing them for measurement of cutting forces, so let us see what we have in store after this.

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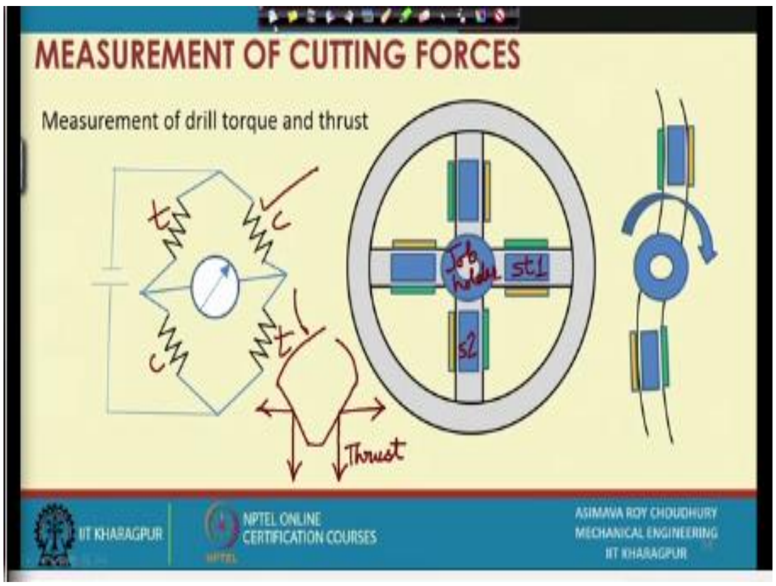

In a similar fashion, we can also have drilling dynamometers. In the drill if you have perfectly made cutting lips of the drill which are symmetric about the central axis, there would be no forces will be balanced in the radial direction, what do I mean by this? Suppose this cutting lip is experiencing this force and it is experiencing that force. So, in that case this will also be experiencing this force, and an opposite and hopefully equal force in this direction.

So, this will be cancelled out but this remains and this is called thrust, you might say what about the force which is perpendicular to the paper, perpendicular to the screen. The force which is perpendicular to the screen that creates a torque while it is cutting, while it is moving, it is removing material and a P_z component if it is considered to be a single point turning tool, the P_z component creates a torque.

So, the torque needs to be measured. Now in this particular configuration what happens is we are having the drill coming from the top, this is the plan view. In the plan view what happens is. In the plan view we are having 4 beams connecting up the central part which is the job holder; this holds the job, drill job. The job is held here and it is drilled from the top surface a drill comes and drills it.

So, that the thrust will be bending them as cantilevers, so if you have strain gauge 1, strain gauge 2 etcetera. All these similarly coloured strain gauges, they will be bending and they will be in tension, all of them in tension. On the bottom side there are similar strain gauges which will be experiencing compression and by the same discussion that we have had they will be registering if we can connect them up just like this wheatstone bridge.

That is compression and compression on these 2 sides, tension and tension on these 2 sides we will be able to measure the value of the drilling thrust in a very elegant manner.

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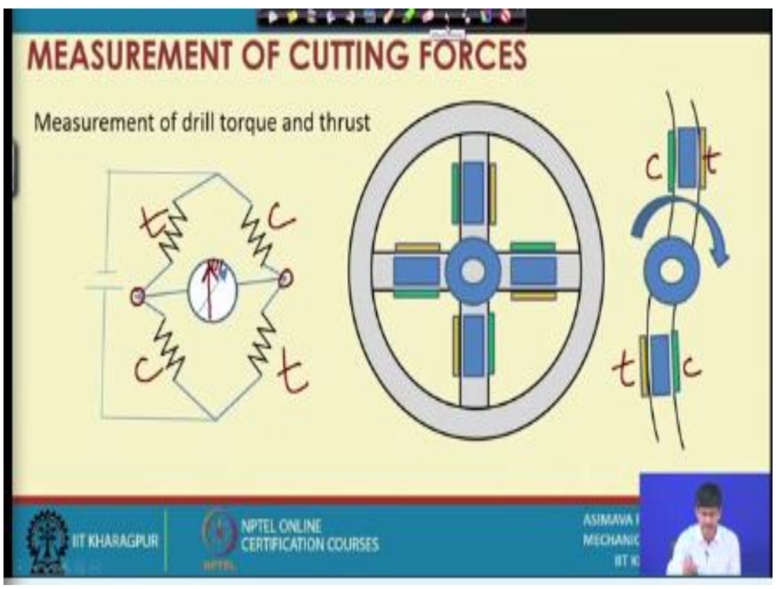

So, this is the way in which we can measure the drilling thrust. What about drilling torque? When the job is being drilled this is the direction of the torque which is applied by the drill on the dynamometer and the dynamometer beams bend when the dynamometer beams are bending this one will be experiencing tension, compression, tension, compression. And from here once again if we connect it properly on the strain measuring bridge, this will register a change from the null position.

Null position means here, there is absolutely same voltage occurring here. The moment they are in compression and tension this will be registering a change and from that change with calibration we can estimate how much is the drilling torque alright. So, these are some of the ways in which cutting forces can be measured. Now I have some discussion on other types of dynamometers also but I will skip them and upload them as offline notes which you can refer to.

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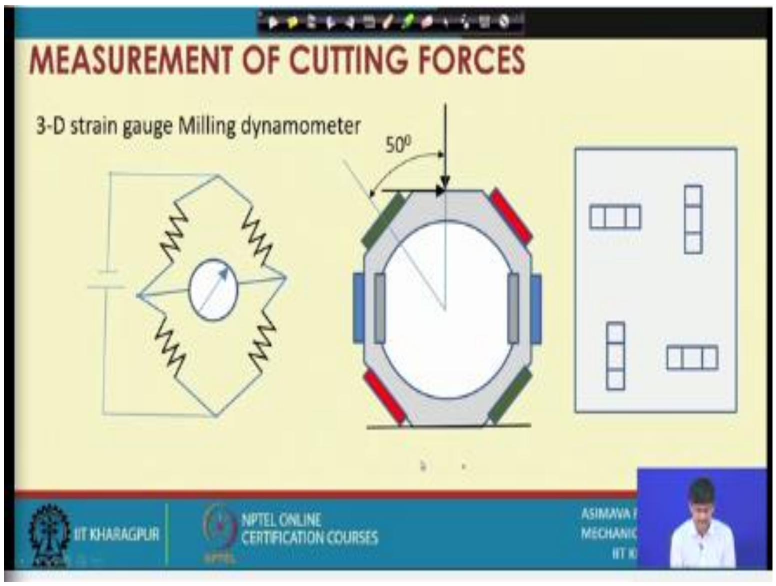

Like milling and grinding dynamometers etcetera, those I will come back but let me start formally today's actual discussion.

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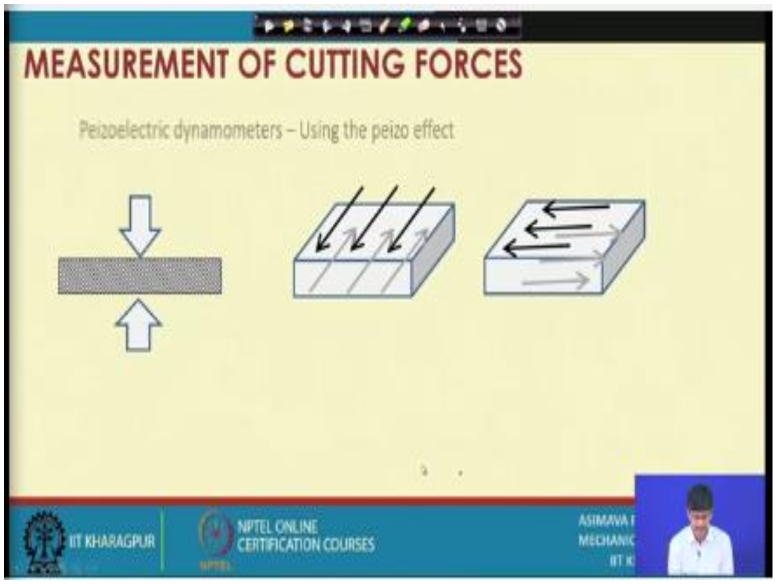

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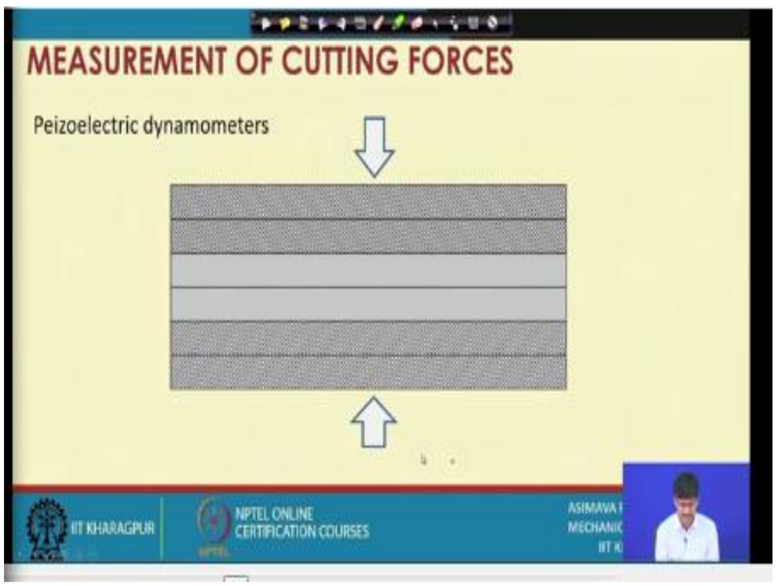

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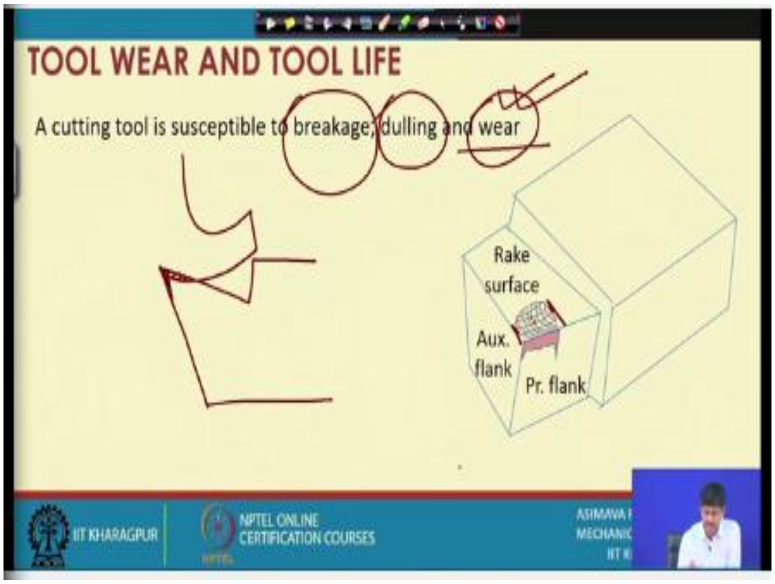

Today's actual discussion was on tool wear and tool life, what do we mean by this? Tool wear means that whenever a tool is being used for removing material, after a few minutes of use if you take out the tool and look at the tip of the tool which is defined by the intersections of the principle flank, auxiliary flank and rake surface. We will notice that it has undergone a change, why so? This is because the tool will be a deteriorating in quality when it is being put to use.

Where the chip is rubbing against the rake surface while moving and also applying a considerable amount of force very frequently in the order of 100s of Newtons. So, the tool surface will undergo first of all a very slow process of wear and tear. So, if it experiences wear and tear what will happen is they will first be rubbing of the principle flank against the tool surface, rubbing of the chip with the rake surface.

So, bottom side of chip will be rubbing against the tool surface, I mean rake surface and the auxiliary surface will also be touched somewhat by the rubbing with the finished surface. So, when the chip is traveling over the rake surface, it tries to maintain its round motion along a circle sort of, let me draw this on this side. If this be the tool, initially it is a sharp tool and the chip is coming and moving, so it tends to rub off this portion.

And on this side the material I mean the friction tries to rub off the principle flank. So, the principle flank is undergoing wear where you can see it is a large notch at the side because that is where the end of the chip is moving and it is having an edge. Edges always create a high amount of wear, so this is the rubbing action of the edge. Here also a sort of edge will form, edges like these, and here I have tried to show a sort of a crater like surface, I mean crater like feature on the surface.

So, this geometric feature is you know slightly it is going down from the rake surface; it is a worn away crater. So, if this happens, after sometime the tool will be rendered unusable, why so? Does it not cut? Yes, it does cut but there will be a number of phenomena which will be occurring because of which the tool might not be usable after that. Generally, wear is not the only phenomenon which is going to occur.

Catastrophic failure might be occurring due to breakage, say in the very beginning itself the tool is not very strong and we did not estimate it and we have said it for cutting and suddenly it breaks off. That is to be avoided at all costs, cutting mesh edge itself individual might be dulling of very fast without this effect manifesting itself before that itself. Those things we are not considering when we are talking of the gradual phenomenon of wear, this takes place very gradually.

But when do we stop using it? What are the indications first of all? I might be getting these are the indications.

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Forces exhibit increase over time, then other things might also happen, suddenly you find the surface finish which is obtained on the workpiece, it is not acceptable, it is deteriorating. There might be vibration and chatter, there can be increase in power consumption etcetera, there can be increase in the sound, there can be too much heat coming out from the colour of the chips etcetera, it can be found out.

So, lots of indicators will be there, showing that the tool has become, reached a particular amount of wear. So, let us have a look, yes.

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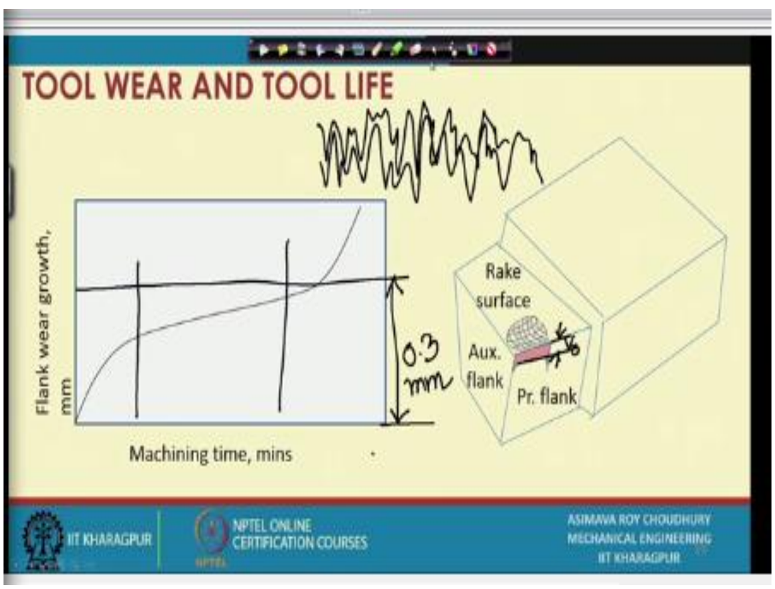

Generally, we are more interested about this flank wear growth. Flank wear growth has a limit after which we generally do not use these turning tools. I mean for that matter all tools, say in case of we keeping our discussion restricted for the time being to turning tools now. So, what happens is when the average flank wear, what do we mean by the average wear? It is not that notch, it is something to do with, this value perhaps average flank wear and we sometimes call it V_b.

So, if we find that this value has reached a particular limit, we generally avoid using the tool and send it either for re-sharpening or we use another insert or another edge of the insert if it is of throwaway type. So, this value is generally restricted to 0.3 mm, just imagine how smaller value it is, but the cutting tool itself is very small 0.3 mm. Now how do we know that? We can either stop the machining and actually look at the tool and find out how much wear it has undergone and from that estimate under a microscope or some device.

Or we can have some online devices which will be predicting that yes, tool has now reached this particular value of 0.3 mm or conditions similar to that have arisen. What is this particular curve? Let us have a look at it. Flank wear in the beginning it grows, when wear is setting in there are lots of ups and downs on the surface. The surface in the micro structural level will show lots of ups and downs.

These will engage with the workpiece asperities and rapid break in wear will take place when these will be broken off or they will be flattened or abraded etcetera. All these phenomena will take place and this is rapid break-in wear. After that once they have been cut down to size they will come a region where a regular wear phenomenon takes place. Generally, if we have a cutting fluid in that case cutting fluid can vastly change the behaviour of contact between 2 say part surfaces.

If direct metal to metal contact is there, in that case most of the time what happens is very rapid wear takes place. But if we can ensure that there is a particular lubricant put in between the 2 and if we can ensure that a film is created of a fluid in between. There is fluid film lubrication which can considerably reduce the amount of wear which is occurring between the 2. However once these particular wear phenomena regular at constant rate the wear phenomena have developed.

After some time, there is catastrophic wear when this cutting edge will collapse, because it is undergoing crater wear on this side, it is undergoing flank wear on this side. And therefore it is separated by a very thin I mean very narrow distance, and after some time rapid wear will take place when this cutting edge will be collapsing. So, in this case we set a limit 0.3 mm to be the average flank wear after which we do not use the tool.

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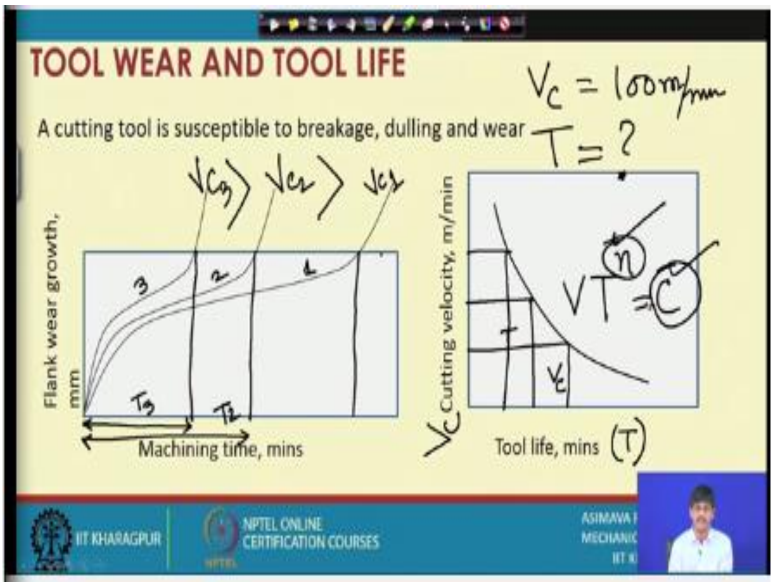

Next, so if we develop such flank wear curves, in that case if we use different values of cutting velocity. Suppose I am using cutting velocity 1, I reach the 0.3 mm at this particular time. If I use cutting velocity 2, I reach this particular limiting flank wear say 0.3 m at this particular time. So, this way if I use cutting velocity 3, I reach that particular limit here. What is the relation between these cutting velocities?

So, obviously cutting velocity 3 must be greater than cutting velocity 2 must be greater than cutting velocity 1. Why? If you use a higher cutting speed then obviously what will happen is, it will undergo a higher rate of wear which is shown by this particular curve. So, this is curve 3, this is curve 2 and this is curve 1, and correspondingly this is that time for which the tool has been usable that is tool life 3, here to here.

And from here to here, this is tool life 2 and that one is tool life 3. So, we understand that if we use a lower value of cutting speed the tool wear is going to be slower, and we are going to get higher tool life. You might say what are the mechanisms of wear which are occurring due to higher speed, I mean which are aggravated due to higher speed. So, wear will be taking place due to a number of reasons and there can be different mechanisms of wear.

That we will be quickly having a look, but let us first complete the mathematical relation between tool life and cutting speed and after that we will be taking of all those particular relationships. Once we establish this particular tool life, well, so what is tool life? Tool life is the time period for which a tool can be used without attaining limiting flank wear of 0.3 mm.

So, this particular time period is called tool life. So, I start with a sharp tool, I stopped when average flank wear has been reached of 0.3 mm. This particular time, corresponding to that velocity of cut is called tool life. So, that if I now plot tool life on this axis, T, I call it T. If I plot tool life along this axis and cutting velocity, let me call it V_c, in that case we understand that there is a particular relationship expressed by the smooth curve, where this value will be equal to say tool life.

And this value will be equal to cutting speed. What is this particular relation? $V*T^n$ = constant, this is called the Taylor's tool life equation. There is an extended form of that also which we will be definitely looking at, but this is the basic relationship $V*T^n = C$. So, C is obviously a constant and n for particular cases it will be constant, now what does it tell us?

It tells us that, if I use different values of cutting speed I can get different values of tool life. And all of them can be satisfied, I mean can be expressed with this particular relationship. For example, if I use say a tool life value of 100. If I use cutting speed 100 m/min and I use the tool life of not tool life, I have to find out the corresponding tool life for it, how can I do that?

So, for that what we have to do is we need to have a value of n and we need to have a value of C, how can this be done? For example, you might be carrying out a number of tests, you can carry out a number of tests and solve for n and C, what are the tests going to be say different values of cutting speed we will be carrying out tests. But I do not know the value of n and C, how can I simply pass the curve?

So, what we do is, first of all we carry out a number of tests and on a log-log paper we can plot those points and pass the best fit curve through a straight line through that. So, on the log-log paper, after we pass a line like that we can have a linear relationship between the terms log V, nlog T and log C. So, from that we can find out the values of n and C in a very simple manner. Like the reading of that line in the form of Y = n x + C and then finding out the corresponding value. So, that part we will be taking up in our next lecture, thank you very much.