Mechanics of Machining
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Lecture - 14
Optimization of Machining Processes

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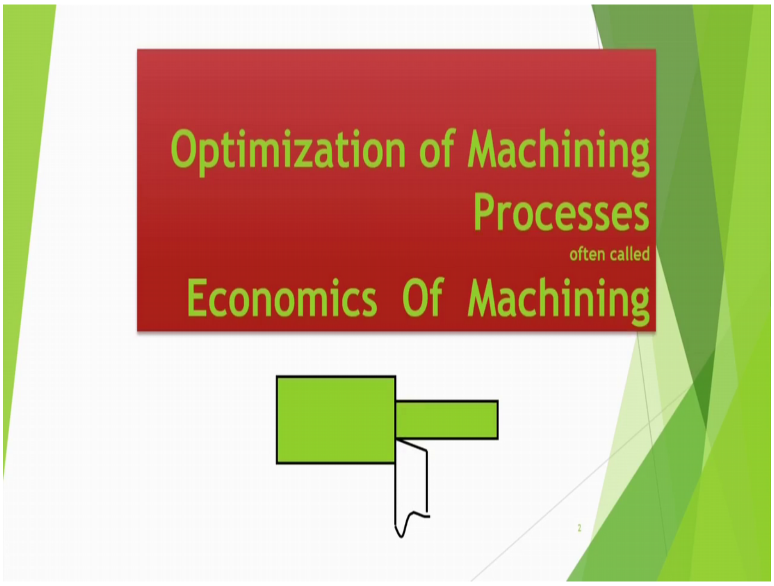

Hello, welcome to the course on Mechanics of Machining. Today it is the 14th lecture, and I discuss about Optimization of Machining Processes. Optimization of machining processes is often called as economics of machining in the books, although it is somewhat (Refer Time: 00:51), but they use word economics of machining, optimization of machining is more appropriate term.

Now, suppose you are doing some turning operation like this, you have to decide that what parameter I should take, what should be my feed, what should be my cutting speed. Considering various types of constraints, so that my cost of production may be less, sometimes I may be worried that my production time should be less, whatever is the objective. So, this process is called Optimization.

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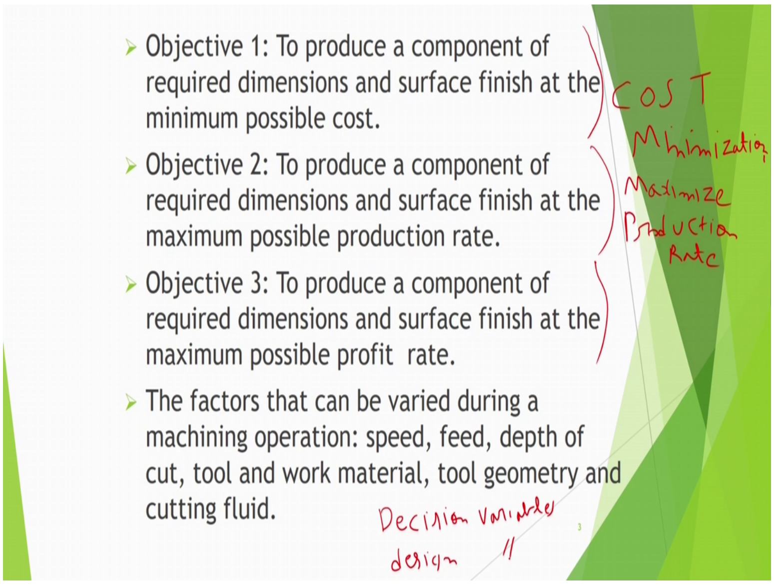

Now, they in any optimization problem, first thing is that you should know: what are your objectives. So, certainly any optimization problem will have at least one objective, we can if we write in the form of mathematics, we call it a objective function. So, we should have one objective. We may have more than one objective also, that is called multi objective problem. Then we have to decide that how to fulfill both the objectives, may be both objectives may not be fulfilled to their fullest extent, but you can decide what type of trade of should I employ that means, at least this objective should be satisfied 90 percent, other objective should also be satisfied by certain percentage like that.

So, here we have got various objectives, like objective 1 can be to produce a component of required dimension and surface finish at the minimum possible cost. So, my objective is basically cost minimization, now this one that is cost minimization is my objective. So, here we say cost minimization, so that can be your objective cost minimization right. And but, we have to also maintain proper dimensions and surface finish, it should not be that I minimize my cost, but then the surface finish as become very poor. So, these are the type of constraint type of thing.

Objective 2 can be to produce a component of required dimension and surface finish at the maximum possible production rate that means, my production rate should be very high, so that means, maximizing production rate, that can be objective function maximize production rate or minimize production time. If production time is less, then the production rate will be high.

Objective 3 is that to produce a component of required dimension and surface finish at the maximum possible profit rate that my profit rate should be very good. Suppose, why this is different from the other things, profit is something different. Suppose, I have produced a component, which is of very low price, is it not in the market, it may be available in 10 rupees, I am producing 5 rupees. So, in a way, I am getting 5 rupee as a profit, because I have reduced my cost rate.

But, if production rate is very low, then I am earning no doubt profit, but that is in a very long time that means, if I am producing suppose only two components per day and I am saving the cost 5 rupees in each component, then total cost saving will become 10 rupees. But, another person is actually suppose he is reducing the cost not by 5 rupee, but only by 3 rupee, but he is making 10 components in that day, so he has basically made a profit of 30 rupees. So, per day profit has increased in that case, so that is called the profit rate in the second case is high. So, profit rate for minimizing, maximizing the profit rate, you have to worry about reducing the cost as well as the production rate, so that is why, profit rate is another objective.

And there can be several other objectives also. So, sometimes objective may be only to produce a good surface finish, and other things can be treated as a constraint, that can be also done. But, mostly we talk about these three objectives; one is minimization of the cost, another objective is maximization of the production rate, and the third objective is maximization of the profit rate. Now, this factors that can be varied during a machining operation, they are called speed cutting speed, you have to decide what cutting speed you have to choose. Then, it can be feed that means, in turning operation how much millimeter the tool will move in one evolution.

And then, it can be depth of cut. Then, it can be tool and work material, means what type of that this is not any quantitative thing, but it may be in the form of a decision that means, I have to machine something, I may have to take a decision, whether I should use this tool for this work or I should use another type of tool material. Then, tool geometry, what should be my geometry, what should be rake angle, what should be leaf angle or clearance angle. And cutting fluid that means, what type of cutting fluid I should be using or I should not use the cutting fluid at all that type of decision also has to be taken.

So, these things if we have to take decision that means, these things are in our hand, we can chose speed, we can use speed, we can use depth of cut. And depending on what decision I take I will be getting a type of may be a cost or I will get particular production rate. So, objective is that I should chose these parameters in such a way, I should decide on these parameter an in such a way, so that I should get my desired objective.

So, therefore, these are called design variables or decision variables. In management, mostly we speak about these things as decision variables. These are decision variables, because we are (Refer Time: 07:43) variables, speed is a variable, but we are taking decision about that, sometimes they are also called as design variable, means I can design the process like that. So, decision variables and design variables have to be chosen depending on the objective that is called the optimization.

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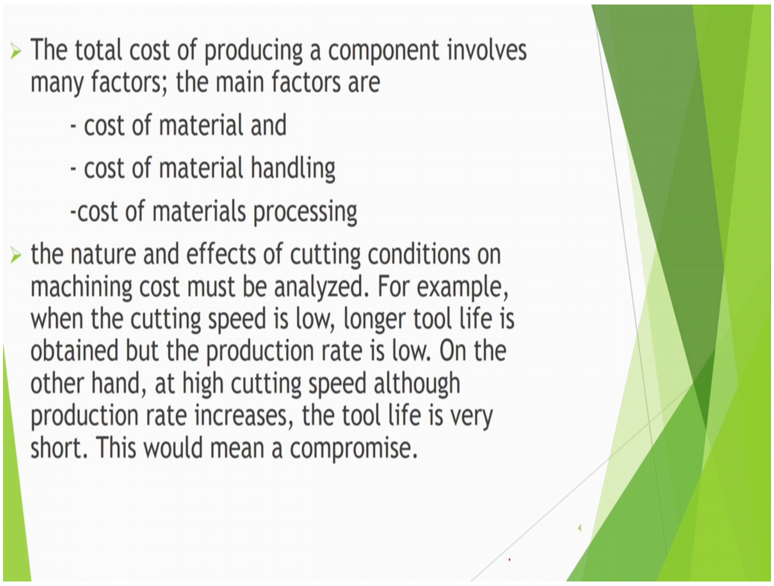

Now, in this total cost of producing a component involves many factors. So, main factors are cost of material. What is the cost of material? Then cost of material handling, then cost of material processing that means actual cost spending machining. Nature and effects of cutting conditions are machining cost must be analyzed. For example, when the cutting speed is low, suppose I can keep the cutting speed very very low, then I will get very high tool life, my tool will not get worned out, but the production rate will be very low. On the other hand, suppose I increase cutting speed, then production rate will be very high, but then the tool life will be very short, so that means, you have to do some compromise, neither this is good nor that is good something in between is good, and that you have to find out.

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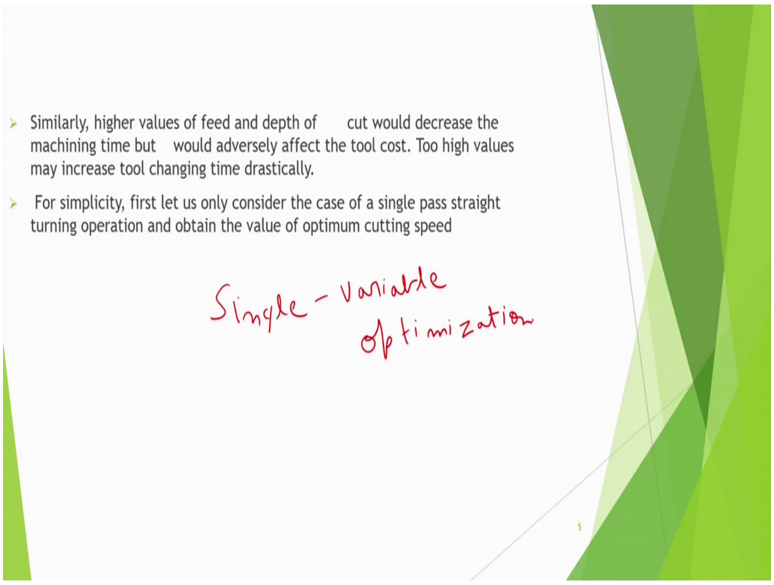

So, similarly higher values of speed and depth of cut would decrease the machining time. If I take high value of feed and high value of depth of cut, more material will be removed, but would adversely affect the tool cost, same thing happens. Moreover, suppose I have to get a required dimension, then I may be constraint to take particular depth also, it is not that you can take any depth, feed you can take of course anything, but you cannot take the depth (Refer Time: 09:29). I have to reduce suppose 10 mm to 8 mm, naturally I have to maximum depth of cut I can take 1 mm, I can decide whether I will do in one pass by taking 1 mm depth of cut, so that 2 mm diameter gets reduced or I can do in two steps that means, two passes.

So, too high value may increase tool changing time drastically, and it will again further it will take more time. So, for simplicity, first let us only consider the case of a single pass straight turning operation and obtain the value of optimum cutting speed. Assume that, the depth of feed and depth of cut is a constant it is kept constant, only we are changing the cutting speed. So, it is a single variable optimization problem single variable optimization that means, my variable is only cutting speed, and I have to do what, I have to minimize may be cutting may be cost.

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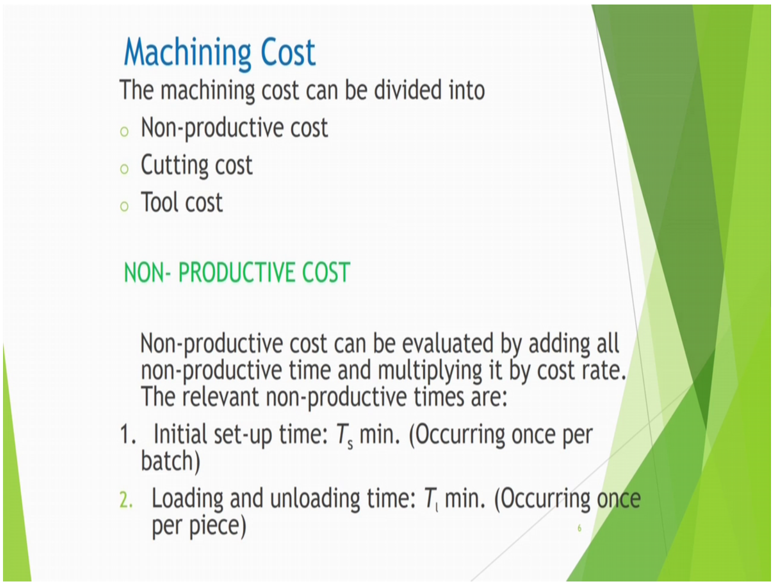

So, this is so, let us first concentrate on the machining cost. Machining cost can be divided into non-productive cost, cutting cost, and tool cost. So, in this what are the non-productive cost, we although it is non-misnomer, because it is not non-productive, it is also essential, but we are using the term non-productive that means, they may not be doing actual machining that time. So, non-productive cost can be evaluated by adding all non-productive time and multiplying it by cost rate that means, what is cost rate means, what is the cost per hour that means, you add non-productive times.

So, relevant non-productive times are initial setup time. You occurring once per batch, you have a batch of hundred components, you need some preparation something it has to be brought from some place, it has to be put properly, all that type of things then machines has to be cleaned, and started things have to be put at appropriate place. Means, whatever you do for initial setting up, you have to put the tool also properly in correct position, this is done once per batch that means, this one. After that, for each piece, you do not do that means, you already have brought mat be (Refer Time: 12:11) in which there are hundred pieces, again and again you do not have to bring it, so that is one initial setup time.

Then loading and unloading time that means, you put the job in the chuck, then it will take some time you will climb it in three jaw chuck, and then after the piece has been made, then you will unclaimed that that is called unloading. So, you will spend some time in loading and unloading also, so that time also has to be considered. So, this is non-productive cost.

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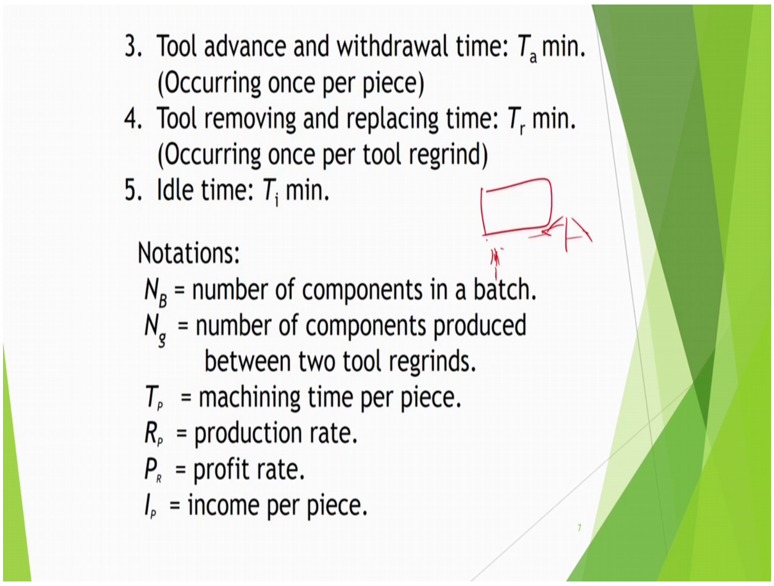

Then tool advance and withdrawal time, it is also occurs once per piece. Previous thing also a loading and unloading is for each piece, and tool advance that means, my tool is advancing, it is come my job is here, but tool is at this location, from here to here, it is approaching. So, some distance it traverse in the air, that time also has to be taken into account, it is not actually doing machining, but it is approaching, and then it has to be withdrawn. So, for withdrawal, I am just moving this much distance to tool. I have machine, I have finished my machining, then my tool is reached up to this. Again, I am bringing my tool to the original position, in that also sometime will be lost, that will be called it occurs once per piece, and that is called withdrawal time.

And tool removing and replacing time it this does not occur after every piece, but it occurs once per tool (Refer Time: 13:43) that means, suppose my tool has become damaged, I have to take it from the machine, and then that particular tool has to be ground, and again it has to be put in the proper position, so that is called tool removing and replacing time, that also has to be taken, but it may will be done once per tool regrinding. May be after making the fifty pieces, tool has to be reground at so, therefore after fifty piece, there will be tool removing and replacing time, per piece time can be obtained by dividing it by 50. And then, there will be some idle time, that also can be per piece that is idle time that is T i we can write, not a counted.

So, let us see that we will explain some mathematics here, but let us be clear about the notations. N B, I am calling as number of components in a batch, suppose a batch of hundred. N S is the number of components produced between two tool regrinds that means, between two tool reground. Suppose, a tool can machine ten components before failing, means before it is a tool life got gets exhausted, and there is a need to regrind it again, so then ten will be the number of components produced between two tool regrinds.

And T P is the machining time per piece per piece this much actual machining. And R P is the production rate. P R is the profit rate. And I P can be called income per piece income per piece, how income you are making or this one. Now, in this case, let us say you so, we have defined the notations machining yeah, now here yeah these notations income per piece is also known that means, how much income you generate by selling one piece.

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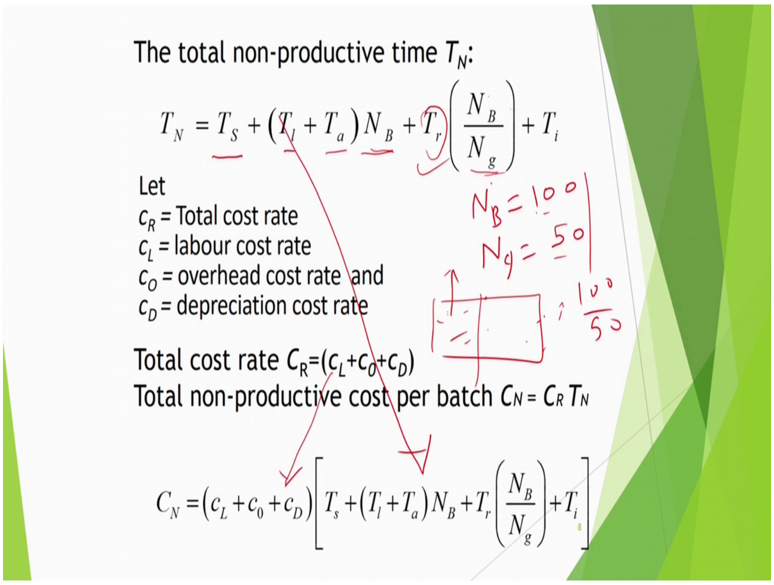

And then, let us discuss that: what is the sum of the total non-productive time; let us call it T n. So, T N is equal to T S plus T l plus T a into N B. T s is the setting time, see T s here is the total setting time. And T l plus T a is what, T l is the loading time, and T a is the was let us see the previous this one, T l t T l was loading and unloading time, and T a was approach time. So, loading plus approach that is for each piece; so, for whole batch, the time will be T l plus T a into N B, because in one batch, there are N B component. But then, there are N B component, and before new grinding, N g tools number of pieces can be produced. So, total number of regrinds will be N B divided by N g ok, and then multiplied by tool replacement time, so that means, if we are considering, suppose there is a batch size of 100 and let us say, so we say that N B is equal to 100, and then N g is equal to suppose it is 50 that means, tool can machine up to this one 50.

So, what I am telling, that supposing I do one grinding suppose I have brand new tool ok, so may be after, so I have produced 50 tools components, and then did one grinding; and another 50 components I produced, I did another grinding. Of course, that batch got exhausted, but suppose you want to put the tool in the means condition means same condition, so that is why, you will do two times grinding. Is it not, because you had hundred pieces, so first these was so many 100 pieces, 50 pieces were made, then you felt a need of regrinding, after again 50 pieces, again you felt the need of regrinding, because other batch will come, for that batch also you need the fresh tool.

So, basically we can say two times I have done grinding. So, how it will come, 100 divided by 50 that is why I am putting N B by N g. So, you got two. And tool replace time is T r, so that means, replace time includes the time in grinding, so that means, 2 into whatever time is going, that much you have to multiply, and then you get this one, and plus T i. T i is the idle time, I have combined the idle time for whole batch. So, this way I have got the total non-productive time.

Now, let us discuss about the cost theme. C R is the total cost rate. And C L is the labour cost rate it rate means, it can be in per hour. And C O is the overhead cost rate, and C D is the depreciation cost rate. Actually overhead cost rate means, suppose the cost of manager, salary of manager etcetera, that will be on monthly basis, but you can decide that in a month there are 25 days, then 25 days multiply by 8 hours, suppose are you say that effectively say 6 hour, so that means, it is about 25 into 6 means 150 hour, so that means, whatever salary he is getting, that you can divide by 150. So, this way, you have to decide about that what will be per hour overhead cost rate. And it is not only just manager salary, other things also like rent of the building, and all these things will be included ok.

And C D is the depreciation cost rate that means, machine is depreciating is there. So, suppose you have purchased machine of 5 lakh, so if you consider very simple rate line depreciation formula, so that machine which is purchased in 5 lakh, that is its cost has to be required in 5 years, if suppose its life is 5 years, so that means, per year 1 lakh depreciation I have to pay account. So, in a year, how many hours are there in which work take place, so you divide by that, then you will say per hour depreciation cost rate. Like that, you have to find out per hour depreciation cost rate.

So, total cost rate will be at 3D combination of this thing; labour cost rate that is means hourly wage of the worker, and then overhead cost rate, and depreciation cost rate will give you total cost rate. And then the total non-productive cost per batch, then will be what, C N will be C R into T N of course. So, T Ns expression I have already obtained here, just plug in the value of C R from here, C R goes here, and T N goes here, and then you get C N is equal to C L plus C 0 plus C D, and that much expression ok. I am not going to repeat, you can see on the screen, that this is what you got the cost.

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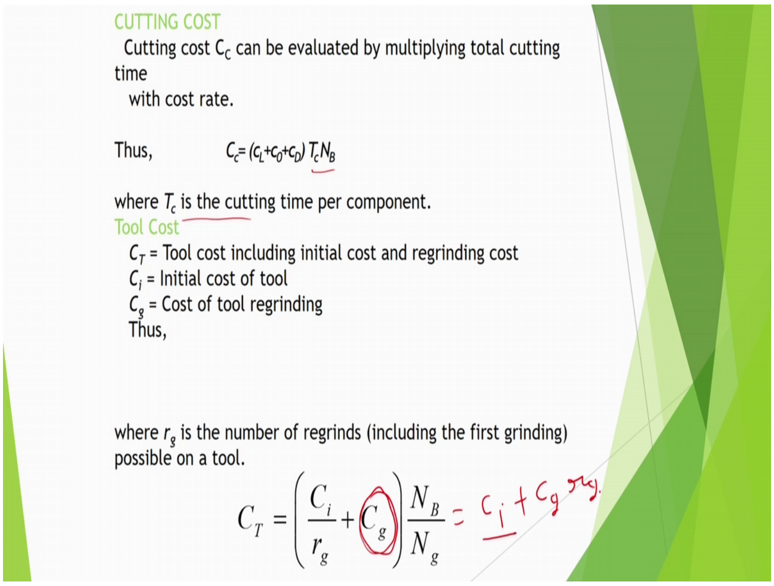

Then, we have to worry now about cutting cost, that was non-productive cost. Actual cutting cost C c means during the cutting operation can be evaluated by multiplying tool cutting time with cost to rate, so that means, cutting cost will be C L means time for loading unloading, then C 0 plus C D, and this will be T C into N B, because T C is the cutting time per component, there are N B component in a batch. So, in a batch, this much cost will be encounter. So, C L is what, C O is what, overhead cost that means, overhead cost will be spend in that period also in which this one. See overhead cost is coming here also in non-productive time also that means, when we are doing setting up or when we are just understanding that how a job will be done, that is also part of the setting, so that overhead cost is here also.

And but, but their loading cost is not there, loading I am indicating by small labour cost is there ok. So, I have put that here labour cost, and then overhead cost C L plus C O and plus C D. C D is the depreciation cost ok. So, here in the overhead cost, I have put this one. So, here you have put C L plus C O plus C D. And in this case, yes just see here that in this case, cost is C L plus C O plus C D multiplied by T C into N B, where T C is the cutting time. Now, loading and unloading time, we have already incorporated. Here, that in this case no, we (Refer Time: 23:16) it is T C is the cutting time. So, in the cutting time, we have to consider that means, we have to consider the cost of actual cutting that means, I have to consider only the cutting time that means, actual machining of that thing.

So, tool cost will be what, this is the cutting cost, and then we have to consider the third thing tool cost. Tool cost is C T is the tool cost including initial cost and regrinding cost. Let us say C i is the initial cost of the tool, and you C g is the cost of tool regrinding. So, thus in this case, you have to say C T is equal to C T is equal to C I by r g that means, suppose I have done two tool regrinds, so I am distributing that initial cost in two parts. And plus C g, C g is the cost of tool regrind that means, actually this was the cost of regrind ok, and but there were number of regrinds were r g. So, initial cost I am distributing equally among all the between all the regrind, so I divide it by C i by r g plus C g into N B by N g that means, N B by N g means, these many times I have to do that.

So, N B by N g will be no doubt, it will be r g, because N B by N B by this one was there, this was R g. So, if I do that like this, then this will be r g. So, they basically I am telling that you have to say C i r g r g gets canceled, and this will be C g into it will be r g, so that means, suppose initial cost was something, but I have ground it two times, so the overall cost has become in that particular batch. Suppose, in that batch, you had to grind two times, then naturally that it will be C i plus C g into r g, that is the way you have to do that. If you are throwing away, you are not grinding. So, there is no cost involved in this one, then naturally you do not have to consider this component, but then you have to consider only the initial cost of that tool, so this way.

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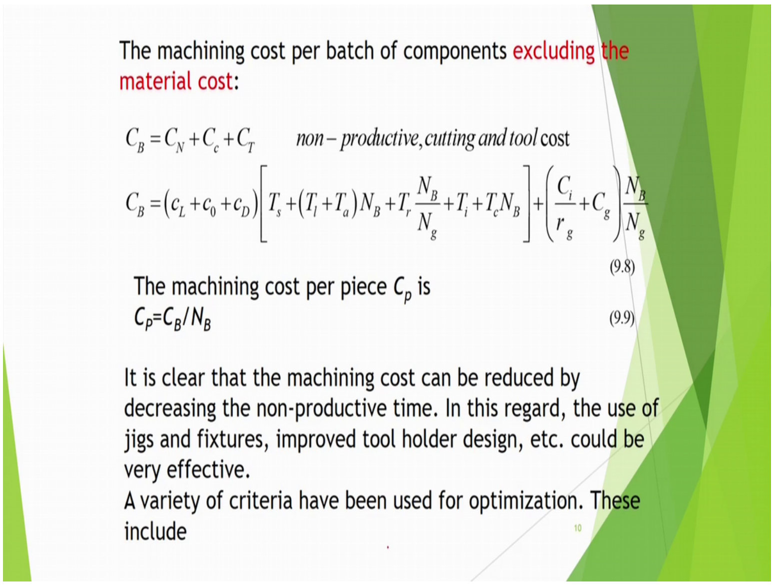

So, machining cost per batch of components, excluding the material cost will be this, so if it C B is equal to this much. So, this is the cost in the manufacturing. And no matter, whatever process we employ, the material cost will be same. So, therefore, right now I need not consider the material cost in my optimization problem, means I just have added non-productive cost, cutting cost, and tool cost.

So, I get this type of expression, C B is equal to this much, I just rearranged everything. And machining cost per piece C P is C P divided by is equal to C B divided by N B, I divide it by N B. So, it is clear, that the machining cost can be reduced by decreasing the non-productive time. In this regard, the use of jigs and fixture, improved tool holder design could be very effective. And a variety of criteria have been used for optimization.

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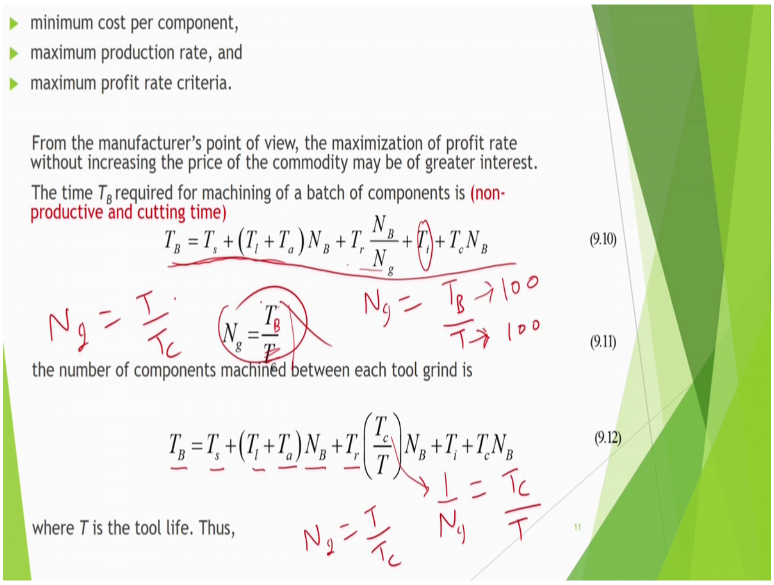

These include, suppose we say minimum cost per component, another can be maximum production rate, and the third can be maximum profit rate criteria. So, from the manufacturer's point of view, the maximization of profit rate without increasing the price of the commodity may be of very great interest. Now, time T B required for machining of a batch of components is non-productive plus cutting time together is given by this.

This we have already discussed in which everything has in included, even the idle time has been included here. And N g is equal to T divided by this one, means N g is equal to T B divided by this one, I think this (Refer Time: 27:34) written N g means number of regrinds that means, number of regrinds, so that is this one N B by N g was equal to r, so that is this one. So, number of components produced in each regrind; so, it should be actually r g type of ok N g, suppose this is T, this is N g, so number of components produced between each tool regrind ok.

So, in this case that if T is the tool life, suppose T is the tool life and my this is the total time required for machining of a batch ok. So, therefore number of components required between this may be N g may be T B divided by T. Suppose, by total time required for machining of a batch of components is actually suppose 100, and then here this tool life is may be 100, so therefore, number of regrinds will be only 1 ok. So, number of so this is what that this one.

So, in this case, now suppose you have T B, so T B is equal to T s T l plus T a multiplied by N B this is T r. And now, I am writing here that T c T c was what T c is the cutting T c is just understand this thing, forget about this equation, just concentrate on equation 9.12 ok. So, in equation 9.12, see here it is written that this one is T r N B by N g. N B is what number of components in a batch, N g is that number of components between two regrinds ok, so N B by N g correct. I am putting N B by N B as it is T r that is T r is the tool replacement time that how much time will be needed in grinding and replacing.

But, here N B instead of N g, I am writing N B by N g that means, 1 by N g is equal to I am writing T c divided by T. T c is the actual time spent in machining, so that means, I am writing instead of 1 by N g, it is this thing or basically I am writing N g is equal to T by T c T by T c. So, this would be I am making it more clear now. This is this should be N g is equal to T by T c T by T c that means, number of components produced in one regrind or in one life of the tool.

If T is the tool life and T c is the machining time, let us say the machining time is same as the tool life, then N g will be one only, because in the one life of the tool only you will be able to make one component. But, suppose the tool life is 20 minute and machining time is only this one machining time is only 10, so this will be then you will be able to make two components. So, this is about that this one, so that means, machining time and tool life. Tool life is more, then you will be this one.

So, if we got to we go back to our N g is the number of components produced between two regrinds, so that is why between two regrinds you will produce these many. And T c is actually then T c must be equal to cost, it should be cutting time per component, it should be then, you should use the cutting time per component. You should not do the mistake of taking T c as the cutting time per batch. Here T B is of course, the cutting time for entire batch. So, T c is this one, that is why you keep understanding each and everything properly, we are doing just arithmetic, but you do not anything any formula you do not run by (Refer Time: 32:21).

So, you see that now it is clear, that T s T B whole batch. For whole batch, I am finding out the time. So, this is T s and whole and T l plus T a into N B, then T r replacement time, T c by T means these are the number of components between two regrinds that is means this whole thing is 1 by N g. And then, this is N B by N g, so that means, this takes care about this. This is idle time for whole batch, then this is T c into N B. N B is the number of components in a batch, and per piece is T c time, so that is why T c into N B you have to do. And then, T is the tool life, I am not using any suffix here.

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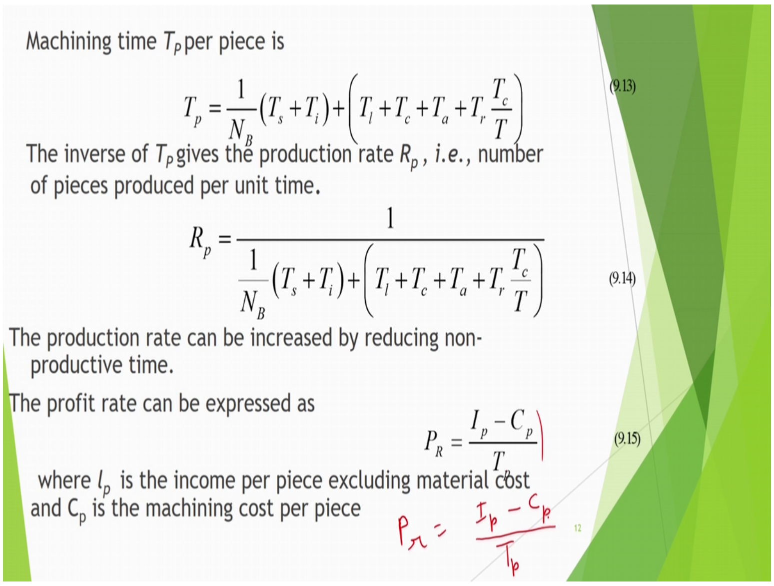

So, thus machining time per piece is now I divide the whole thing by T B, so that means, I divide sorry I divide the whole thing by N B, then I say T p is equal to this much, N B is equal to this much. And inverse of T p gives the production rate that is number of pieces produced per unit time is equal to this much.

So, production rate can be increased by reducing non-productive time. And profit rate can be expressed as I p, suppose I am getting the income per piece excluding material cost, this much I am generating income minus C p is the machining cost per piece. So, I p minus C p by and T is what, T is the suppose machining time per piece. So, T is the so, it is per piece I am having I p minus C p divided by T p, actually it is T p. Here it has shifted in power points, so it is looking this.

I am writing again P r P r I p means per piece how much is the income. Excluding the material portion and means how much I am generating, suppose somebody has given me material, he just ask me to produce that component, and I said give me 100 rupee, but then my actual expenditure was cost was 80 rupee that is cost. So, income is what we get and cost is that why we spend.

So, I made pure profit of I p minus C p means 20 rupees. So, 20 rupees I made profit and divide it by T p that means, suppose this took suppose T p is 2 hour, so 20 rupees I made in 2 hours. So, my profit rate has become 10 rupee per hour. So, like that, it has to be done, that profit rate can be expressed as this one, because one components thing has been made, and I am doing that one component as a timer at time of course, I am not talking about parallel machines and all these things, otherwise those things you can calculate later on. Right now, I am going to see that my in a single machine, how my profit will be more. So, now what happens that this type of so, these are the basic equations. Now, you have to choose whole parameters, you have to minimize these things these functions.

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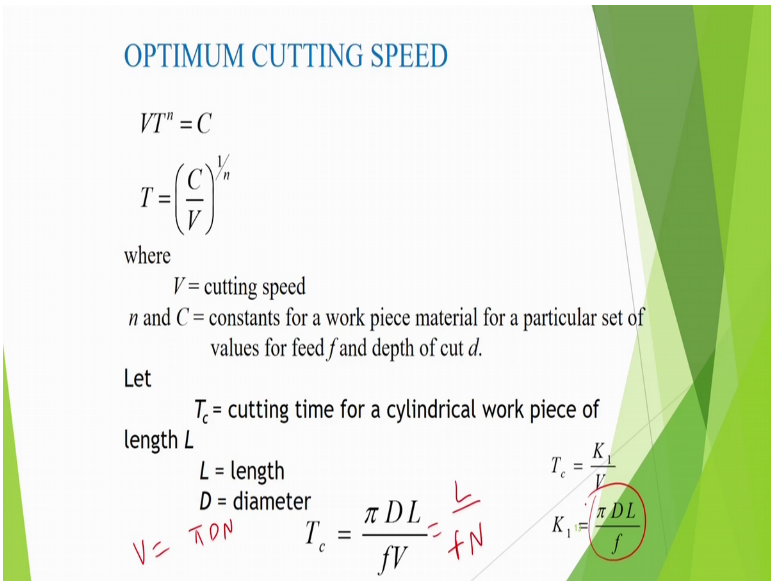

So, here you can use calculus and I am illustrating by one example, suppose you have optimum cutting speed thing you have to find out, so use Taylor's tool life equation VT to the power n is equal to C; T is the tool life, n and C are material dependent constants. So, T is equal to this much, and V is the cutting speed; n and C are constants for a workpiece material for a particular set of workpiece material constants, and also the combination of the tool and workpiece, means it is the constants for a tool, but for a particular workpiece material for a particular set of values of feed and depth of cut.

T c is the cutting time for a cylindrical workpiece of length L. Suppose, its length is L diameter is this, then T c will be pi D L divided by f V. You can easily see that, T c will come out to be pi D L divided by this one, because it will be basically you can say L divided by f N ok. N may be (Refer Time: 36:40) f f is the feet per millimeter per evolution. And L you can you can use another formula V is equal to pi D N pi D N type of thing, then cutting speed. Then from that, you replace N by this, you get pi D L f V. Then, T c can be written as some constant K 1 by V, because for the same job D is fixed, so and f is also suppose fixed, so T c is inversely proportional to V, and where K 1 constant is pi D L by f that expression is there.

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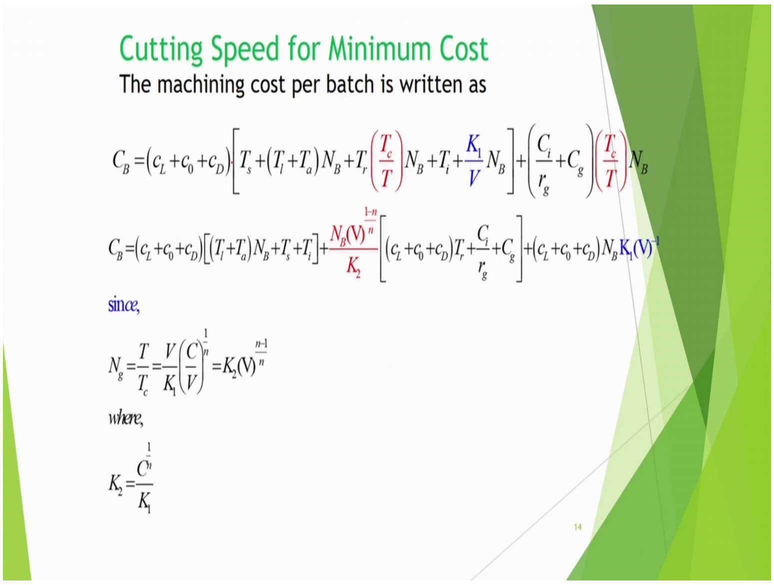

So, this cutting speed for minimum cost can be written how, that I can put the value of T c in this whole thing, and I get this type of expression. Similarly, for T c by T t T c, I have written. And T i can write in terms of T i can write in terms of this one, C by V 1 by n, so I replaced it here. So, I got this type of expression this type of lengthy expression, this you have got. Now, since N g is equal to T by T c that is also expressed in this one in this form, where K 2 is equal to this thing, so I have got this thing. I am writing everything trying to write in the form of velocity.

So, whole thing is now in the form of velocity, and other things are constant, and I have to minimize this cost. So, what should I do, I should do dC B by dV equal to 0, and I will be getting that expression. So, this I will not be doing for that big expression, because it will be here very big expression, but you can also. Once you get the correct values, you can always minimize. You can just do dC B by dV equal to 0, and then solve that equation, you get a particular value of V.

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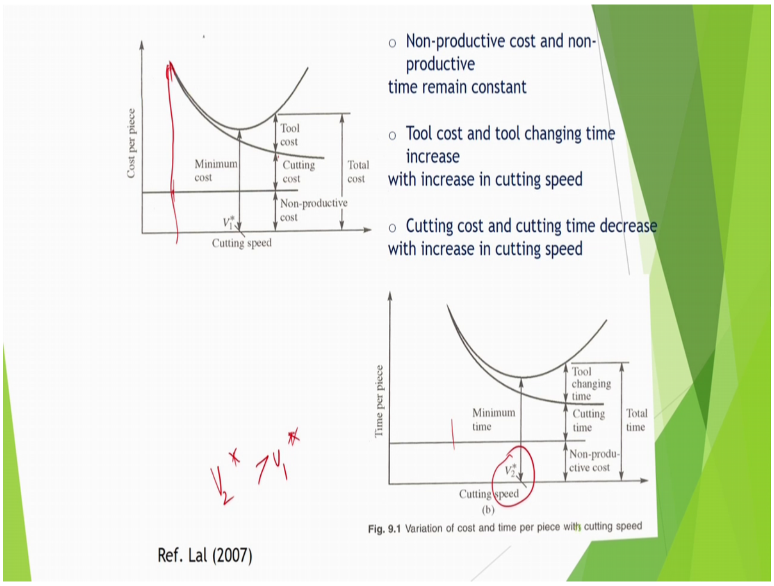

Let us see graphically, what happens. That suppose generally suppose you have I plot cutting speed on x axis and cost per piece on y axis, so I am doing this thing cutting speed and cost per piece. Non-productive cost and non-productive time remains constant, so that is why; here I am having non-productive cost as a constant. But, the cutting cost this one if I say that cutting cost will keep on decreasing that means, tool cost and tool changing time will keep on increasing, so tool cost will keep on increasing, but cutting cost and cutting time will decrease, so that is why, so one factor it decreases. So, overall that summation if I make the total cost, so total cost actually initially it decreases, and then increases that means, there is some optimum cutting speed in between at which the cost will be minimum.

So, here at any location suppose at this point, here the non-productive cost is fix only, cutting cost is this much, but you see that tool cost has increased considerably, because you have now you are operating at a high cutting speed. So, cutting cost is less, because you are not spending much time on the machine, but then the tool has to be replaced again and again, that is why tool cost has increased.

In this location, here your non-productive cost is same, but cutting cost is little bit higher than this, but the tool cost has reduced. In this particular situation, suppose I make it here cutting speed non-productive cost is same, and cutting cost is actually very very high, because you are operating at a very slow speed, so that is why cutting cost is of course, the tool cost is very very low, almost 0, because the tool is not getting failed, so that is why, this thing is also there. So, this type of curve is there.

And same thing about cutting time, suppose it is non-productive time. Now, if I operate at this one, if I increase my cutting speed, my cutting time will decrease, but the tool changing time will increase. So, total time will increase, here also the total time will increase. Why, because here the cutting time will be very high, because you are operating at a low speed. Of course, the tool will not be changed, so tool changing time is almost 0. So, here also you have some optimum. So, you get V 1 star is cost per piece optimum speed for cost per piece, and V 2 star is the optimum speed for minimum time.

And V 2 star will always be V 1 more than V 1 star, this you can even understand from you intrusion, because cost for maximum production (Refer Time: 41:48) this is speed for maximum production rate. You will get only more production rate, if the cutting speed is somewhat high also, but of course, it should not be too high, otherwise then this one. But, still it is it is V 2 star, because here my concern is to minimize the time of machining means increase the production rate, so this V 2 star will always be greater than V 1 star. But, what may happen, that difference between these two may be very small, and profit rate value will for somewhere between V 1 and V 2, so that is the thing.

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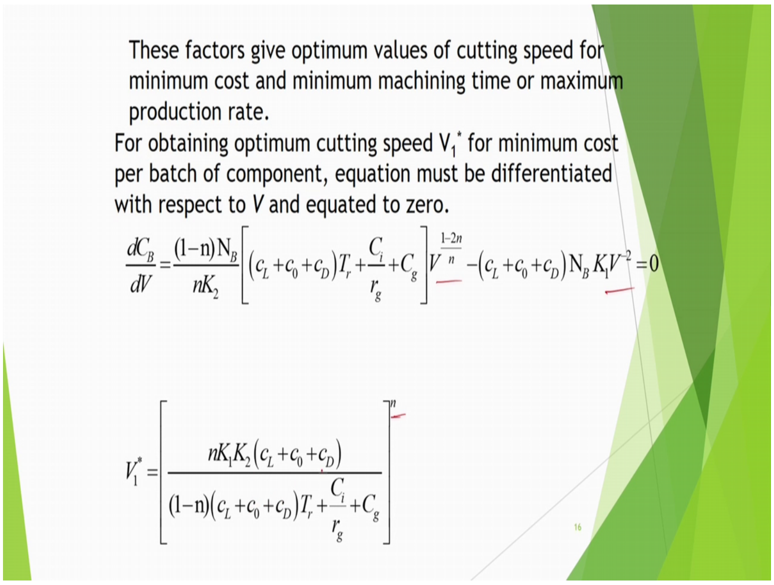

So, these factors give optimum cutting values for cutting speed for minimum cost and minimum machining time or maximum production rate. For obtaining optimum cutting speed V 1 star for minimum cost per batch of component, equation must be differentiated with respect to V and equated to 0. So, we do dC B by dV is equal to this thing. So, we get this type of complicated expression, but here easily it looks only complicated. But, if you do with pen and paper, it is not difficult to just say V will come this side, and ultimately you get some expression V 1 star is equal to this much. So, this expression is there n is the Taylor’s tool life exponent that is also known to me, and all these things are known to me, these are cost data.

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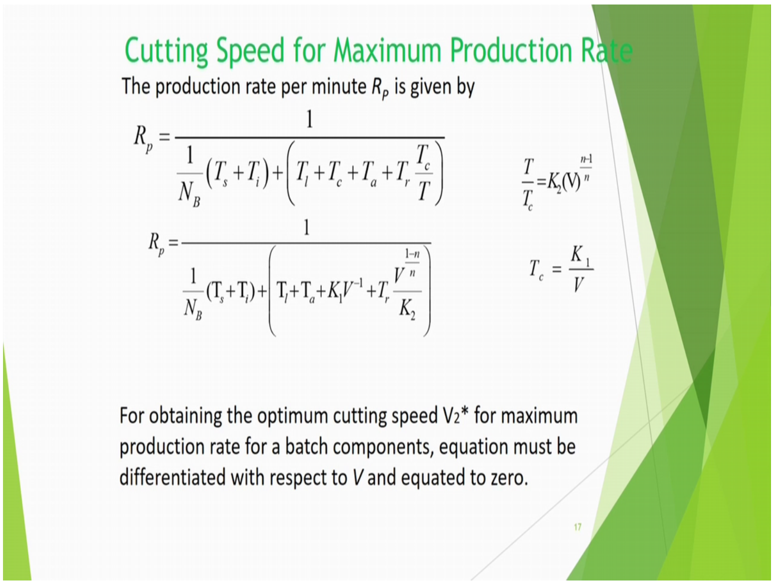

And similarly, cutting speed for maximum production rate is given like this. And R p is equal to this much. For obtaining the optimum cutting speed for maximum production rate for batch components, equation must be differentiated.

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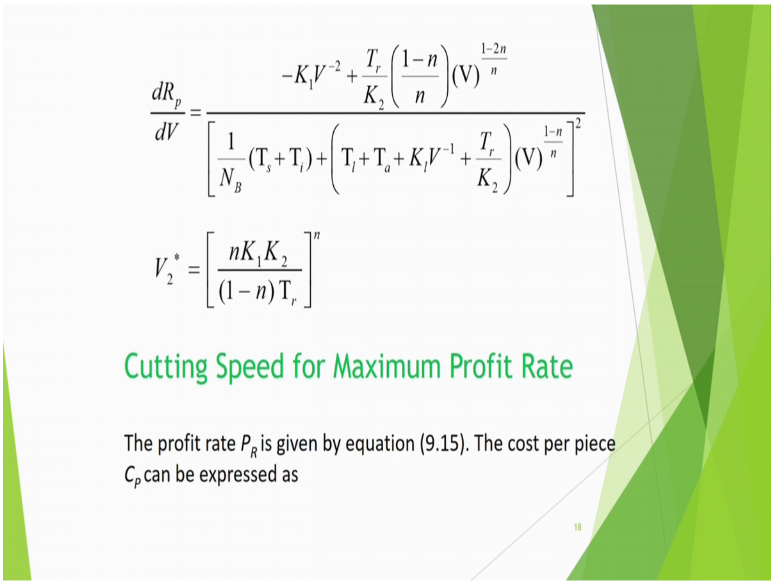

And then, we did this we get this type of thing. So, this is basically optimum (Refer Time: 43:36) V 2 star. Now, you can see mathematically also that V 1 star is smaller, and then V 2 star is slightly more. And cutting speed for maximum profit rate, maximum profit rate is given by equation this one.

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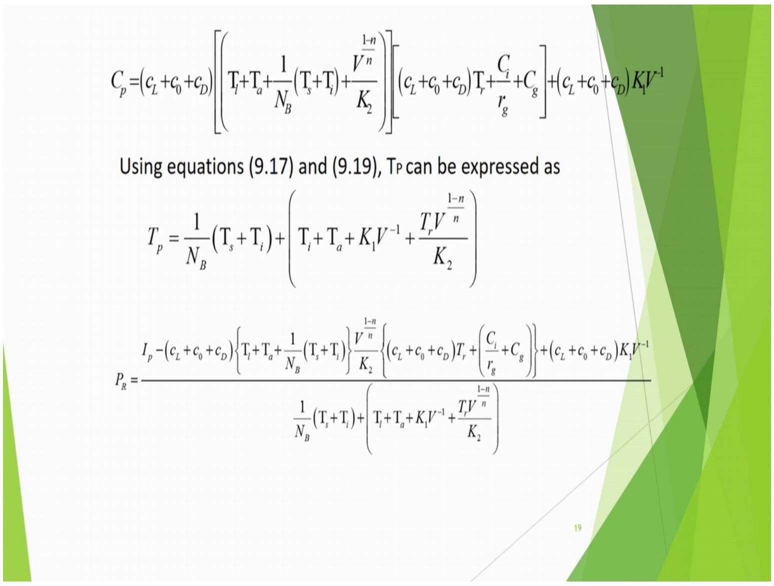

What we have already discussed, and cost per piece has come like this T p was this so I p minus this, divided by this.

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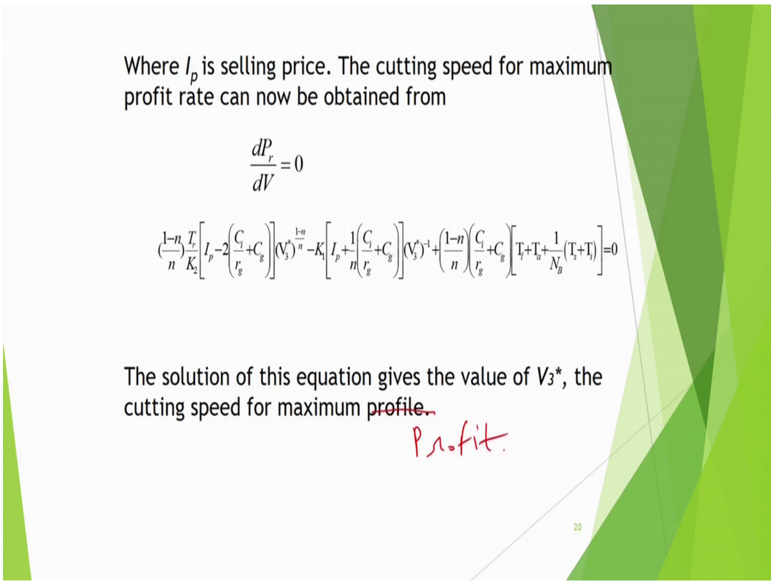

And now again you differentiate it with respect to time, so you say dP r by dV. And you get this type of expression, but the solution of this equation gives the value of V 3 star. Here the solution is little bit difficult may not be what you can, of course get or you get just use any numerical method like bisection method. And we get the cutting speed for maximum profit, not profile, it is maximum profit ok. So, we get maximum profit right.

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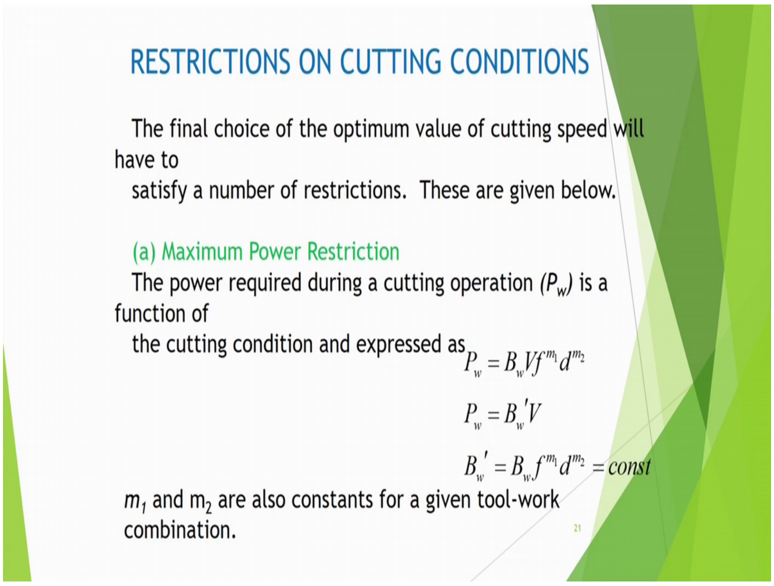

So, this is now these are things, which we have considered, but we in actual scenario, we also have to consider number of constraints. Suppose, I get cutting speed of something, but can I operate this thing. May be, I am getting minimum cost, but I may not be getting minimum, may not be getting good surface finish. So, you have to satisfy number of constraints also in actual practice.

So, these may be like this maximum power restriction your machine is old you cannot operate at a high speed. So, power required during cutting operation is a function of the cutting condition and expressed as P w is equal to B w V may be proportional to V f times some exponent m d times m 2 that depth of cut. So, P w is B w prime into V and B w prime is this much.

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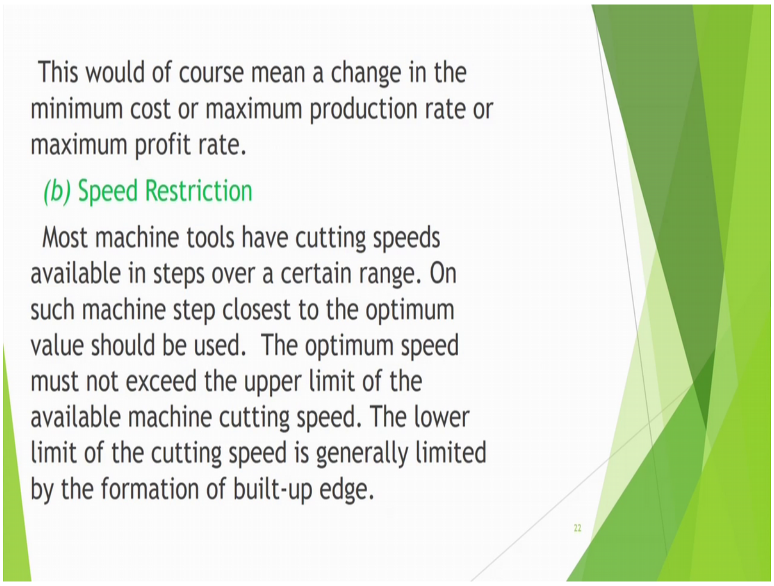

So, this type of thing will be there. So, this would of course mean a change in the maximum cost or maximum production rate or maximum profit rate ok. So, here this one, so suppose you increment that one may be that optimum rate is cutting speed is coming something, but you have restriction because of the power. Then you may have another type of speed restriction most machine tools have cutting speeds available in steps over a certain range.

Suppose, you have 400 after that, it may be only 320, your answer is coming 360. So, you cannot chose 360, you have to choose only say 320, whatever is available on the machine, machine may be having discrete speed. On such machine step closes to the optimum value should be used. And optimum speed must not exceed the upper limit of the available machine cutting speed. Lower limit of the cutting speed is generally limited by the formation of built-up edge. Suppose, you take very low cutting speed, if your by mathematical formula it comes out like this, that very low speed is the optimum speed, but you may not able to use it, because it will create built up edge.

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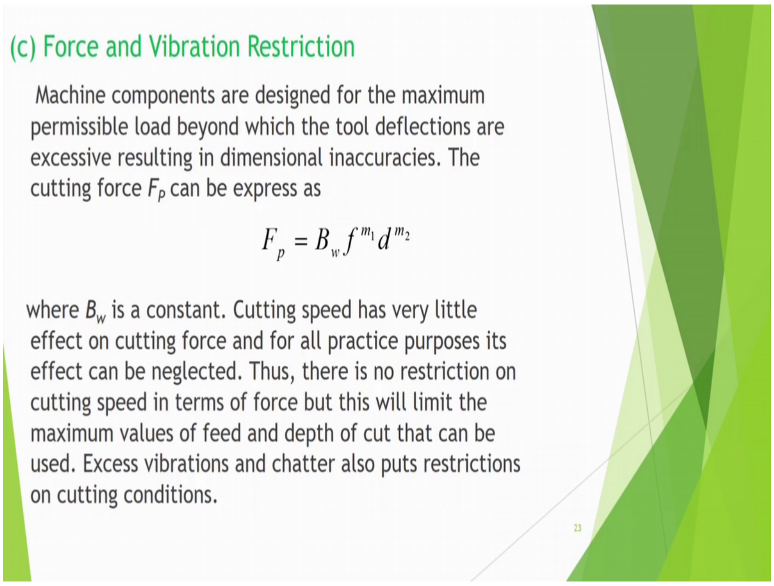

Then, we have force and vibration restrictions. Because, machine components are designed for the maximum permissible load beyond which the tool deflections are excessive. So, job accuracy will be affected. So, cutting force should also be restricted. And cutting force generally can be a function of speed and depth of cut and some constant B w B w may include effect of the cutting speed.

Cutting speed has very little effect on cutting force generally. In fact, in most of the cases, if the cutting speed increases, then cutting force decreases. So, therefore, it is safe to neglect that effect there is no restriction on cutting speed in terms of force, but this will limit the maximum values of speed and depth of cut that can be used. Excessive vibrations and chatter also puts restrictions on cutting condition.

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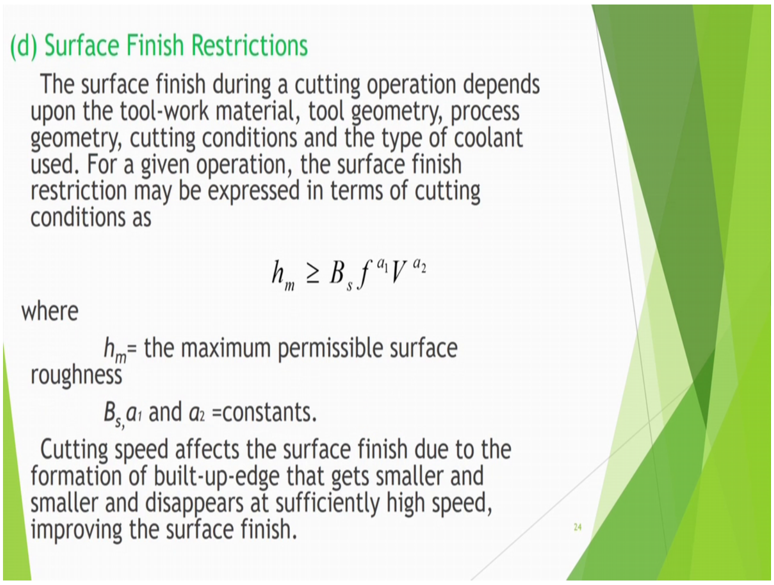

Then, surface finish restriction. You cannot keep very high speed, because the your surface finish will be deteriorated. Surface finish depends on tool work material, tool geometry, process geometry, cutting conditions and the type of coolant. If feed is more, then the surface finish is poor, because roughness is more. So, for a given operation the surface finish restriction may be put like this that h m is the maximum permissible.

Surface, so that means, h m must be greater or equal to B s f to the power something V to the power something. Of course, with increase in cutting speed sometimes the surface roughness, decreases means surface finish improves. So, cutting speed affects the surface finish due to the formation of built-up-edge that gets smaller and smaller and disappears at sufficiently high speed, and improves the surface finish.

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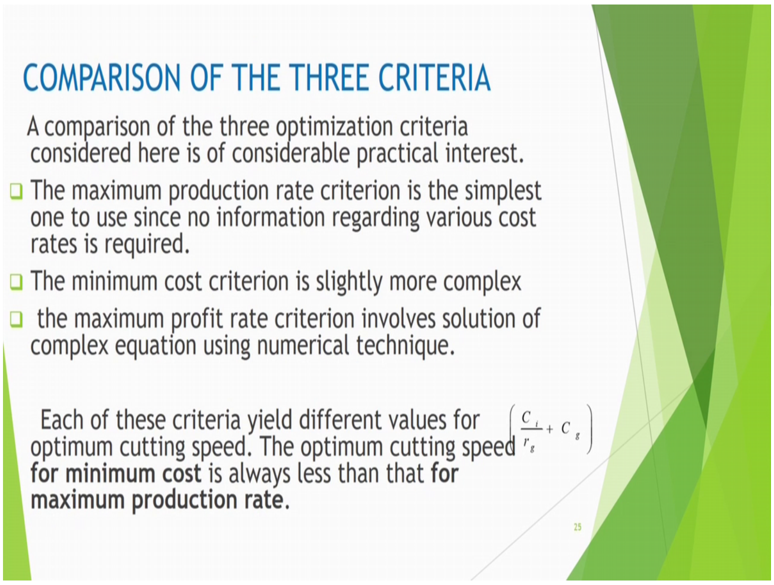

So, these constraints also have to be taken together with that objective. Then comparison of the three criteria a comparison of the three optimization criteria considered here is of considerable particle interest. We have to consider this one. So, maximum production rate criteria is the simplest one to use, since we do not need it any information regarding various cost rates required. So, you can safely say, I need maximum production rate and minimum cost speed is not much different from maximum production rate.

Minimum cost criteria is slightly more complex and maximum profit rate criteria involves solution of complex equation, there you may have to use numerical technique; so, each of these criteria yield different values of optimum cutting speed. The optimum cutting speed for minimum cost is always less than that for maximum production rate. This I have told already, again I am emphasizing that optimum cutting speed for minimum cost is always less than that for maximum production rate.

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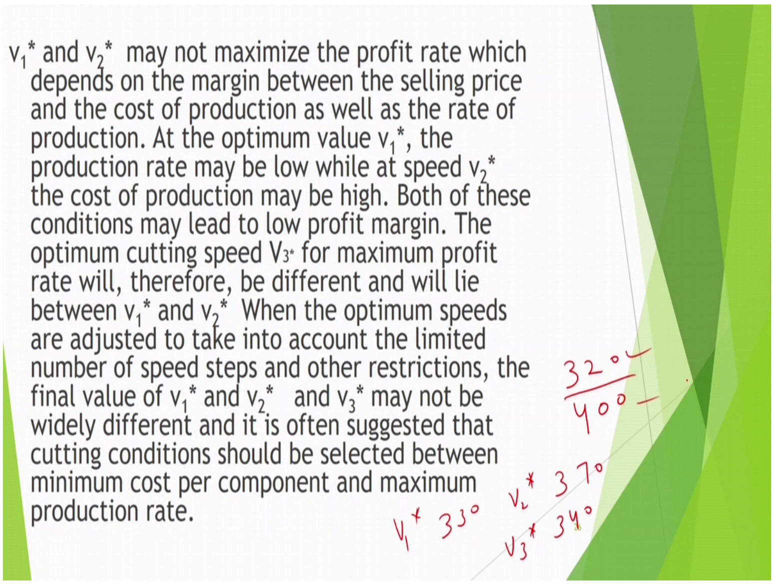

V 1 star and V 2 star may not maximize the profit rate, which depend on the margin between the selling price and the cost of production as well as the rate of production. At the optimum value V 1 star, the production rate may be low while that speed V 2 the cost of production may be high. So, both of these conditions may lead to low profit margin. Optimum cutting speed V 3 star for maximum profit rate will, therefore, be different and will lie between V 1 star and V 2 star.

When the optimum speeds are adjusted to take into account the limited number of speed steps and other restrictions, the final value of V 1 and V 2 and V 3 star may not be widely different, because suppose in between there is difference of suppose V 1 is suppose V 1 is say 330, and V 2 may come suppose 370, and V 3 profit rate in between may be 340, but your speed is one speed is 320, after that you have four 400.

So, what is the use, you can have to you have to choose either 320 or 400, so that is why sometimes, we do not bother much about that. But, now a days modern C and C machines of course, they have variable speed continuous speed there this becomes important. And it is often suggest, so other cases it is often suggested that the cutting conditions should be selected between maximum cost per component and maximum production rate.

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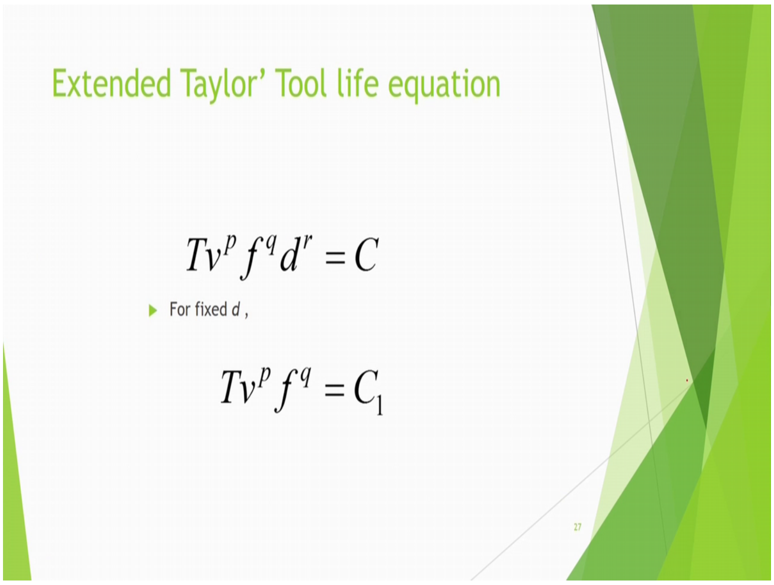

Now, this was the analysis in which we did a single variable optimization. We fixed f and d, and we only adjusted basically the cutting speed, but now we have to consider the effect of heat and depth of cut also. So, we use Taylor's extended tool life equation in which we have T v p f q d r equal to C. And for fixed d, suppose d is sometimes this one you have to do single pass machining. And d is fixed, then you can write this type of equation.

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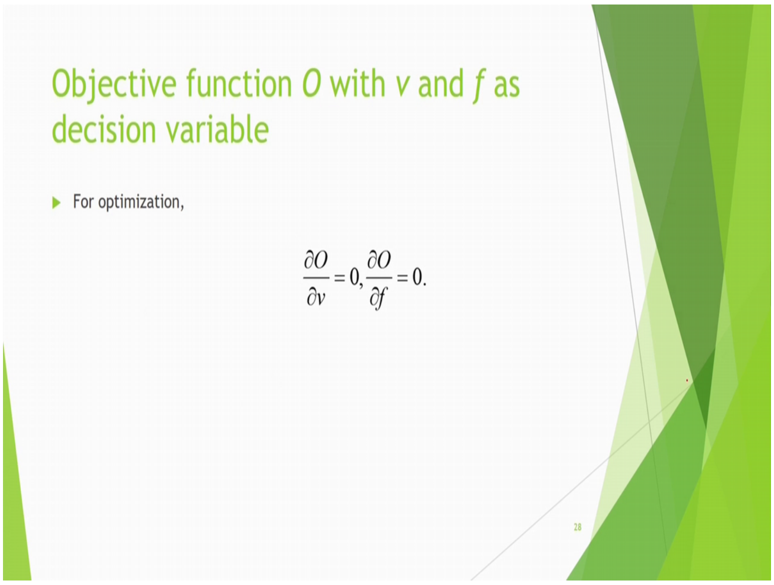

If we do this, then we substitute to do the same type of analysis, but now v and f both will come into the picture in the objective function. So, you have to do two variable optimization. So, for multi variable optimization you can have partial derivative, suppose objective function is O. So, del O by del v equal to 0, and del O by del f equal to 0. So, you will be getting two equations. And these two equations can be solved, and you can get the value of f and v. This type of thing has been discussed in the book of Gosh Mallik and these expressions, but those lengthy expressions. We are not writing here, I am just means it can be easily done.

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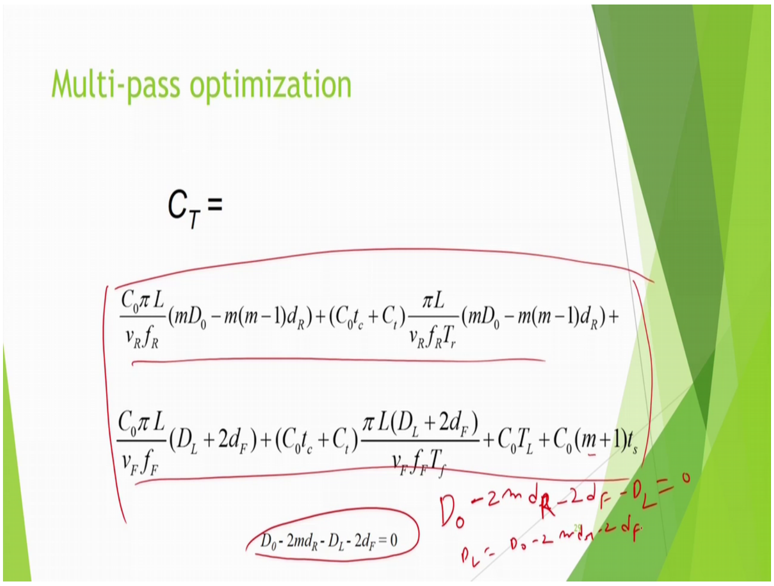

Now, coming to the multi-pass optimization, we talk till now about single-pass optimization. If I am doing the multi-pass optimization, then we have to say that in each passes. Suppose, I am taking say m number of passes, in that m number of passes so we have to write these type of expressions. And we have to say that cutting time, we can find out by considering these things total cost, this is C T is the total cost. And we are having for each pass, and we are having then, we can write these expressions.

I am not going to explain this line by line, but this you can get actually this is these type of expressions are available in research papers, but you see that here, we are considering these things for each one we are considering for each pass. Suppose, suppose t s is the setting time. So, suppose you are having m passes; so, m plus 1 and C 0 into t s setting in

1. And then you are having this type of equations, suppose I am taking equal depth of cut.

So, you have to say like this, this type of equation you will make D 0 was your original diameter, and let us see that 2 m d R minus 2 m d R, suppose depth of cut in each roughing pass is minus 2 2 d m that 2 m d r, so that means, if you take depth of cut d R, your diameter will reduce by 2 d R in one pass, but there are m passes m roughing passes. So, you are getting 2 m d R and minus finishing pass is separate that why here m plus 1. So, 2 d F that is 2 d F and minus D L means final diameter, so of that 1, this should be 0 that means, equation should be satisfied or I can say D L is equal to D 0 minus 2 m d R minus 2 d F that has to be this one done.

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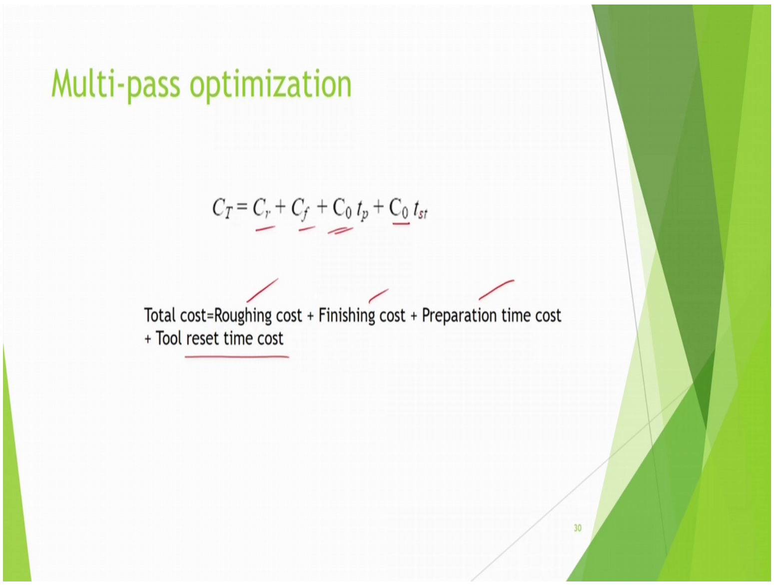

And in multi-pass optimization, you have total cost is basically roughing cost plus finishing cost, and then you can find out preparation time cost and tool is a time cost this type of thing to put. So, (Refer Time: 55:06) this is roughing cost, finishing cost, and then preparation time. Preparation time is t p, and then corresponding cost is C 0 by that rate per head cost and this is overhead here C 0, t st means tool reset time cost and this way, it will go.

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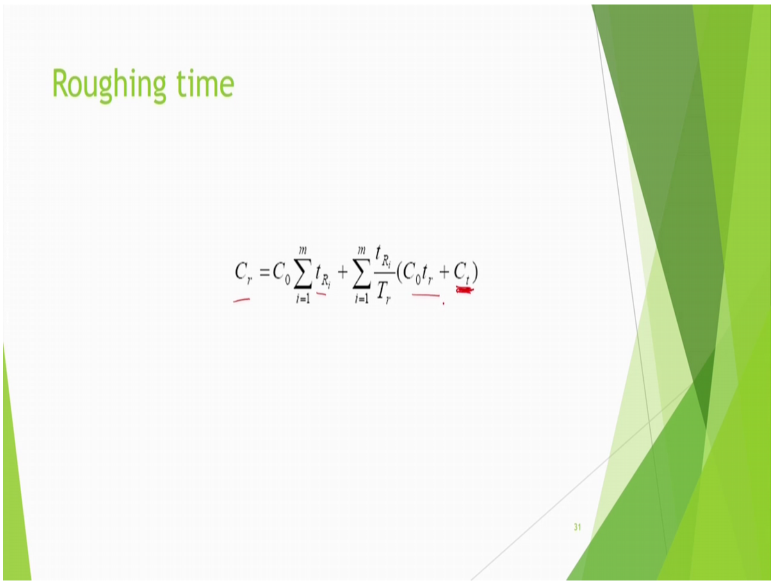

Now, here it will be like this that here roughing time is actually like this, suppose I am finding per piece thing. So, roughing time is I am having suppose one pass the roughing time is T r. So, there are m passes wide or roughing time together multiplied by C 0 and that overhead portion of the cost. And then, you have to say i is equal to 1 to m, then now here it is due to machining that tool changing time cost has come here, this is and then this is C t that means, here the cutting cost C 0 into t r, t r is the tool replacement. And C t was actually the cutting this one and t R i by this one. So, roughing cost is there.

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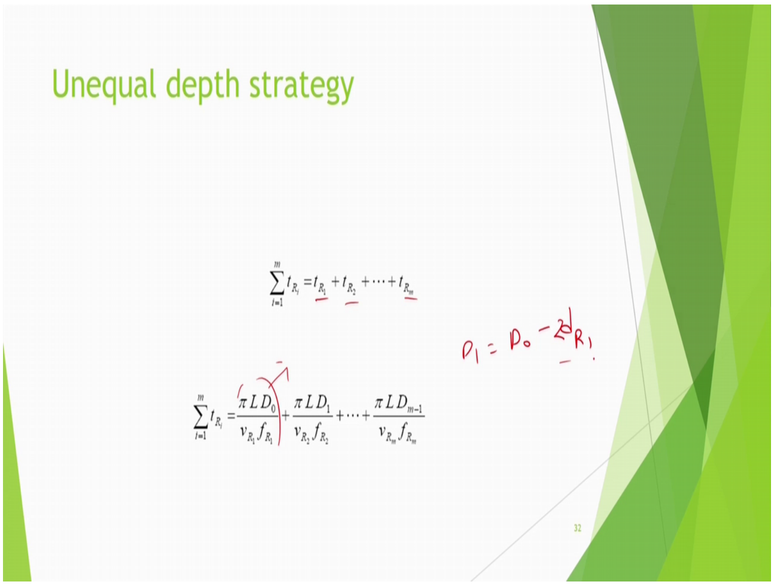

And then, unequal depth of strategy; if you imply, then you can say in each pass I have unequal depth instead of equal many people have done equal depth of cut strategy, so it will be like that. So, this expression will be t R i can be written in this term first pi L by D 0. D 0 is the initial diameter, then diameter has become D 1. D 1 is equal to what, D 0 minus d R 1 that means, in first 2 into 2 d R 1, d R 1 is the depth of cut.

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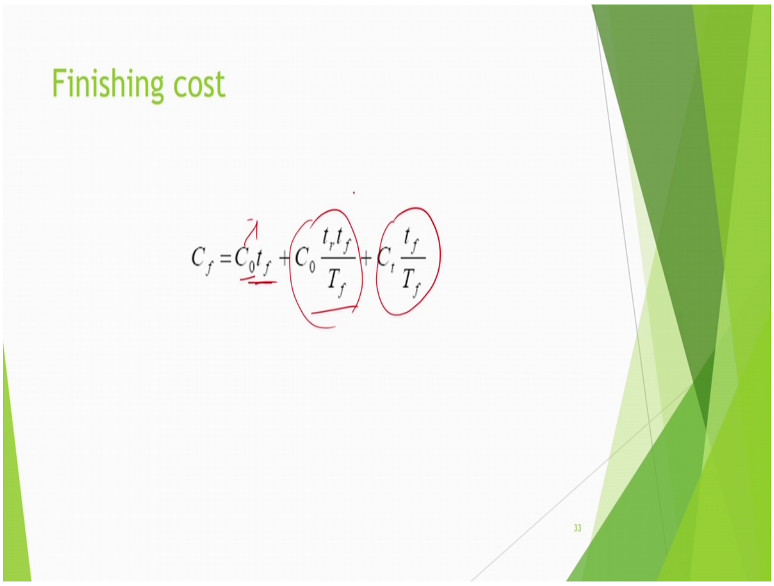

So, this has come like this then finishing cost is C 0 t f plus C 0 tool changing time etcetera, t r by t f T. And then, you have C t t f by T f that means, it is the tool cost, and this C 0 t f that means, it is basically the total operating cost. It is not only the overhead, but it is operating cost. So, C 0 into t f this is actually that one and this is the tool cost. And this was the operating cost, but because of the tool replacement time got lost.

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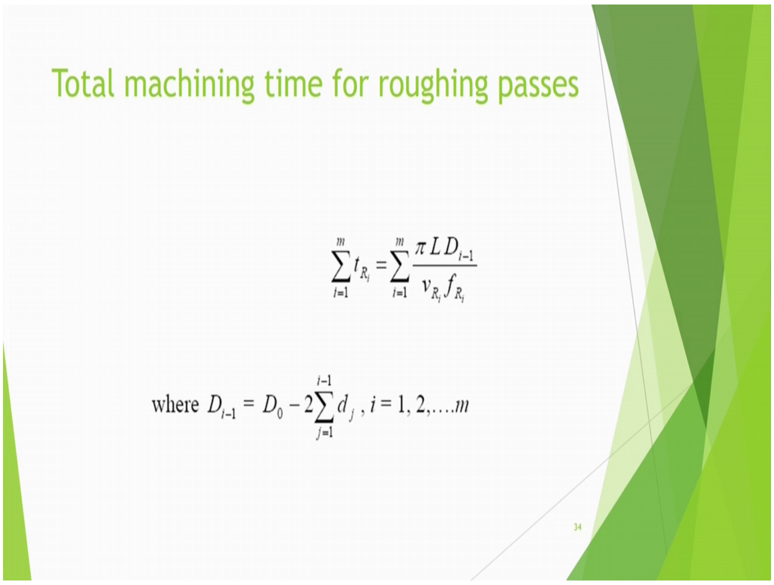

So, like that you make the expression. And total machining time for roughing pass is this, and where D i minus 1 is equal to this, this formula is there.

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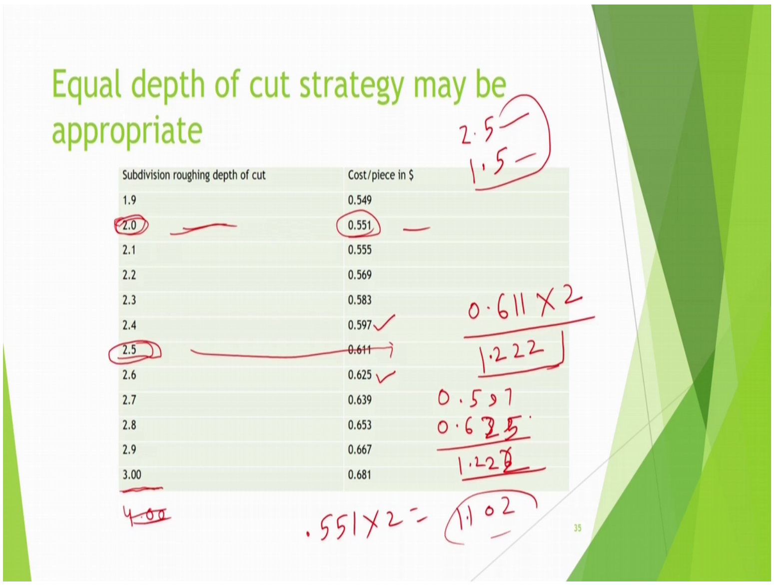

And then, you can actually get, now you can make the strategy. Now, equal you a suppose you can make equal depth of cut strategy or unequal. I have seen one research paper in that he has taken unequal depth of cut strategy. So, suppose two passes are there, and he has taken unequal depth of strategy. And his answer is coming something; he has given this type of table also. But, if you see very carefully, if I have to let us say, I have to reduce that roughing depth or suppose I have to reduce by depth of cut is 3.5 ok.

So, suppose it is like this that here 2.51. And this is these are say cost per pieces in dollar. So, what may happen that it is suppose, I have I have taken suppose I have chosen 2 mm, this one. And if I say that, I take equal depth of cut strategy. So, I take corresponding to 2 mm depth of cut in roughing pass the cost is 0.551. If I remove 4 mm depth of cut that means, I do two process, then my cost will be 0.551 into 2 that means, it will be 2 this, one point say one point 1.102 like that.

Now, here that data is not there, because the table was very big. And I have not seen put it here, that if I do the same job in let us say that, if I take 4 mm, if I do the same thing 4 mm ok. If I do that let us say that, if you if this one is done, by taking yes say 2, 2 into 2 that this one. But, I can do the same thing like this instead of taking 2 mm in both, I can take in 1 pass as 2.5. And another I can take 1.5 in another this one, of course that data is not here. So, 2.5 data is here. So, it may be that this also comes out to be almost same in most of the that means, there are multiple solution.

So, many times people have used this equal depth of unequal depth of cut strategy. And the in order to get a regulate model, but really that difference is not very appropriate in most of the places equal depth of cut strategy may be very very appropriate. And it may be may be very pertinent, so that is what that this point has to be seen into taken into consideration right that means ok, I can say, suppose I have 2.5.

Let us see, if I take 2.5, and then I am having 0.611. And if I do that take 2.5 two times, so this is 2.2 this 1 6 say, so 2, 2 and 2, 6, 12. So, my cost is coming this much dollar, 1.222, 6, 12, 12, 1.222. And if I decide, no I will not take 2.5 in each pass, because I have to remove 5 mm, I have to say take total 5 mm depth of cut. So, first time I did what I took 2.5 mm depth of cut. So, I did this operation two times, my cost was this.

Another person says I will take one time 2.4, another time I will take 2.6. So, he will do what 0.597, and then it has come 0.639. So, it has come 976 no sorry this was 0.625, 0.625 so, 5, 7, 12; 9, 2 12; 6, 5 11 12. So, you see it also came exactly same that means, in a evenly if that mathematically, you have predicted that solution also may be you have done some way. And you may get a solution in which instead of some person has given a solution 2.5, some person has given solution in which says no, in first you take 2.4, next you take 2.6 or vice versa. First you take 2.6 depth of cut, then 2.4. Both are taking total depth of cut as 5 mm, but both are getting the same type of thing on they may not rise that there are multiple solution.

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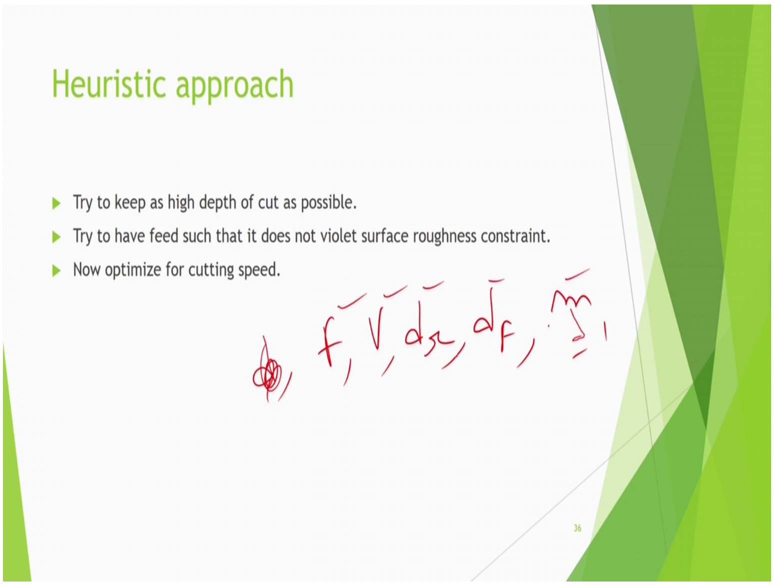

So, in many cases, I have seen the research papers that actually there are multiple solution. At many times, what happens that this area is actually very much investigated, lots of papers have been produced. And sometimes this optimization of machining has acted the benchmark to test different algorithms that which algorithm is better that type of thing. So, from academic point of view it is very good, but I have noted that even the heuristic approach works. What is that heuristic this one that try to keep as high depth of cut as possible. Most of the time, when optimum solution is there, people have take high depth of cut without violating the constraint of course that means, there should not be chatter or excessive vibrations.

And then try to have feed such that it does not violet surface roughness constraint. So, you try to have feed, but you limit it by this one. Because, if you take more feed, then surface roughness will be decreased and then after that you optimize for cutting speed, then you will get this one. So, this is a heuristic type of thing means I first try to keep this one more depth of cut. In fact, I should try to do the operation if possible in one pass only, then I should go to other two passes.

So, all these type of heuristics, it is themselves give that either of idea for that. So, heuristic based optimization methods have been also developed, and those things are also there means applying this method or that method will actually may be very good for academic point of view. And it says that ok, I am getting the solution, but many times that particular solution will only predict the same thing that which I know by even common sense that ok, this feed can be taken this much high. So, you take that one, and then it becomes and then accordingly and then after that cutting speed is only optimized.

So, otherwise in general many people have solved it as a four decision variable problem that means, depth of cut is one variable, no not only depth of cut as one variable. They say feed, then they say cutting speed, then may say ok. Suppose, they follow equal depth of strategy then d r, then for finishing they will say d F. And then, they will say number of passes m. So, you see here itself there are 1, 2, 3, 5 variables are there and out of that one variable m is integer. So, it becomes like a integer, type of programming problem.

So, no doubt that mathematically this is interesting, and you can work out that, but you know that in most of the cases answer will this come this only that no keep m is equal to 1, do not do many passes. And then take depth of cut more like that, so that is how that these practical aspects should also be seen together with the mathematics.

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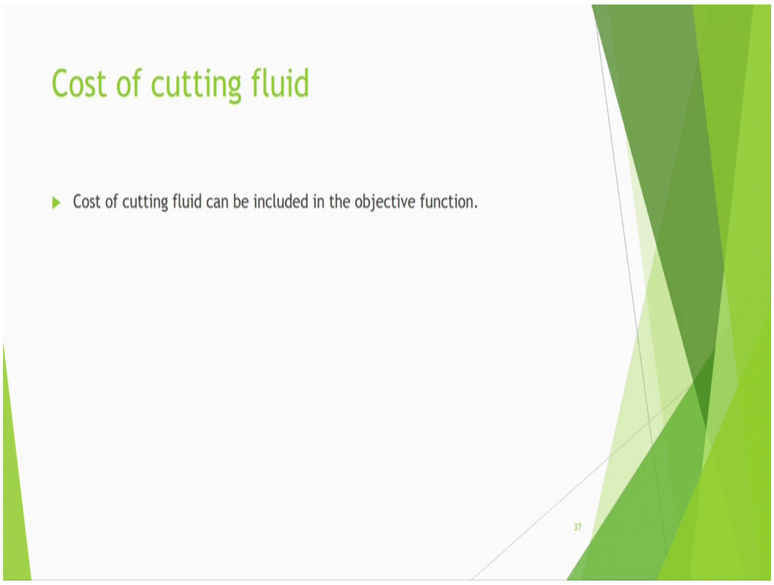

And then, you can consider the cost of cutting fluid. Here, I have not considered the cost of cutting fluid; cost of cutting fluid can also be included in the objective function. So, this can be done.

So, this much for today, we will meet in next class.