Gear and Gear Unit Design: Theory and Practice
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Lecture – 43
Machine Tools Speed Change Gear Unit – II

Welcome to module 8 internal epicyclic another special gearing and we are continuing with machine tool speed change gear unit and this is part 2 of machine tool speed change gear unit.

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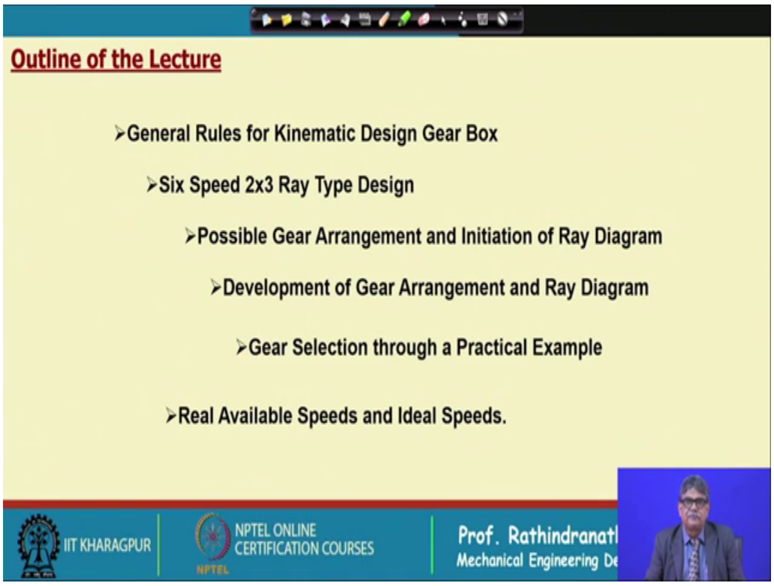

Now in this lecture, I shall cover general rules for kinematic design of gearbox 6 speeds 2 into 3 ray type design possible gear arrangement and initiation of ray diagram, development of gear arrangement and ray diagram, gear selection through a practical example and finally, real available speeds and ideal speeds.

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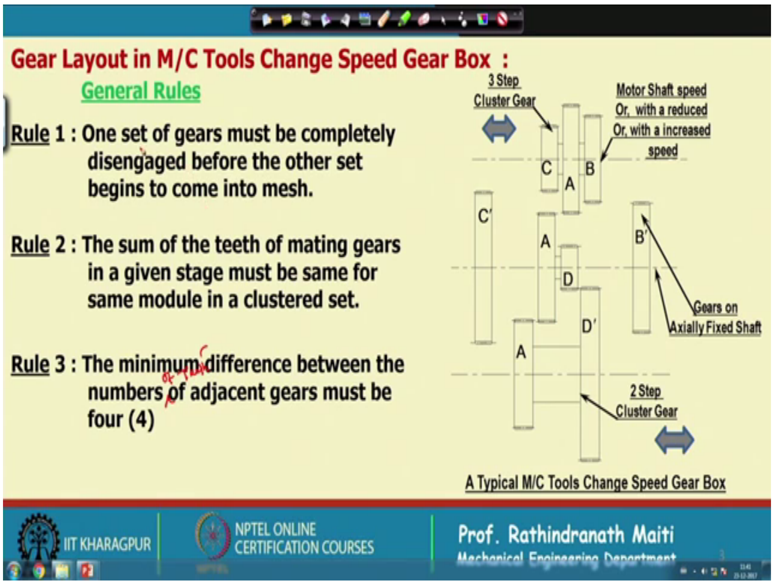

Now, in machine tools change speed gearbox design there are few rules right hand side, I have shown a speed change gear box basically, what we find there are 3 shafts, in top shaft there are 3 gears. These gears are mounted on a cluster which can be moved on the shaft and this is 3 step cluster gears and the shaft might be motor shaft; that means, directly connected to the motor or with a step reduction speed reduction or speed increaser it is connected to the motor this shaft is connected to the motor; that means, this shaft may have the motor speed or more than motor speed or something less than motor speed ok.

In the next shaft second shaft that is in the middle what we find there are 4 gears. In these 4 gears those are fixed on the shaft positionally they cannot be moved axially they can only rotate about the shafts. And in the last shaft what we find again there are 2 gears, which are again on a cluster, which can be moved axially and this as from the diagram as you see by moving the top cluster we can engage A with A B with B dash and C with C dash, A A this is later I shall explain these are of equal teeth number that is it has having on only one the immersion A and A whereas, B and B dash have different it numbers.

Basically these are for reductions so; that means, B dash we will have more number of teeth than B. Similarly C dash is having more number of teeth than C and in the second shaft that is the middle shaft what we find that we have ad B dash and C dash D is engaged with D D dash in lower shaft, and A can be engaged with A ok.

So, this can be moved right hand side or left hand side. However, before going into the design of sub gay gear units, we should know about few rules which need to be followed. Otherwise there will be there may have some problem not immediately in the later stage.

The rule one is that one set of gears must be completely disengaged before the other set begins to come into mesh say if we look into this gears say. For example, when first of all if we move the top one in the left hand side a little bit, then a will be engaged with A. Now, next if we move further C will be engaged with C dash, but before C the C comes into contact with C dash A and A must be completely released. So, this means that we have to give this space what is shown between A and C dash that is to be sufficient. So, that they are disengaged.

Usually, when both are disengaged and in between that and both side perhaps 10 millimeter gaps will do. And also as you see in the clustered all the gears are not adjacent not exactly side by side there is also gap that is necessary, in otherwise there will be there may have some problem of friction in between while one is rotating with respect to the other.

So, this is this rules must be we must follow, next the sum of teeth of mating gears in a given stage must be same for same module in a cluster set. That means, the sum of teeth of mating gears in a given stage this means that say C plus C dash, A plus A dash, B plus B plus B dash must be equal, number of teeth summation of the number of teeth should be equal provided they have equal module and it is to be said at this stage that.

In general not only the modules are taken same, but also the this has taken stripped tooths per year state not a little gears and module; obviously, would be same and there should have interchangeability this means that this B dash can be put in place of D dash if required it is although in a cluster, but possibly they can be replaced. So, interchangeability should be there for that this is one important issue here I would like to remind that they name in case of general gearbox design usually gears are subjected to very high torque. In case of machine tools torque is not very high on the other hand this would be very precision, because material surface finish depends on the dynamics in the cutting process that should be as less as possible and a edge there is not much load probably.

The module 2 or 2.5 for general purpose or machine tools we will do ok. And, if we come to the wind factor in case of state to spur gear usually with factor we take 10 to 15 something like that which is; that means, 10 times module or. So, in case of machine tools keeping this width 10 of the module is sufficient even it can be taken less and all the gears are of equal width also another issue is there while we are selecting the ratio, in case of general purpose gearbox we do not go for exact ratio to our tooth hunting where is in case of machine tools we need not follow that strictly. Also as the precision gears all gears are usually hardened and ground for long life they are also left; that means, for very good machine tools this would be super finished .

Third rule is that the minimum difference between the number of adjacent gears must be 4, this is number of teeth of adjacent gears number of teeth of adjacent gears. This means that number of teeth of adjacent gears must be 4, why because while one gear is passing over the others there will be problem if this difference not there.

This means that if we consider the rule 3 difference between the teeth number A and B because the high size of the top shaft is a gear and then next to that is B. So, in teeth number difference of Z A; that means, Z A minus Z B must be equal to 4 or more.

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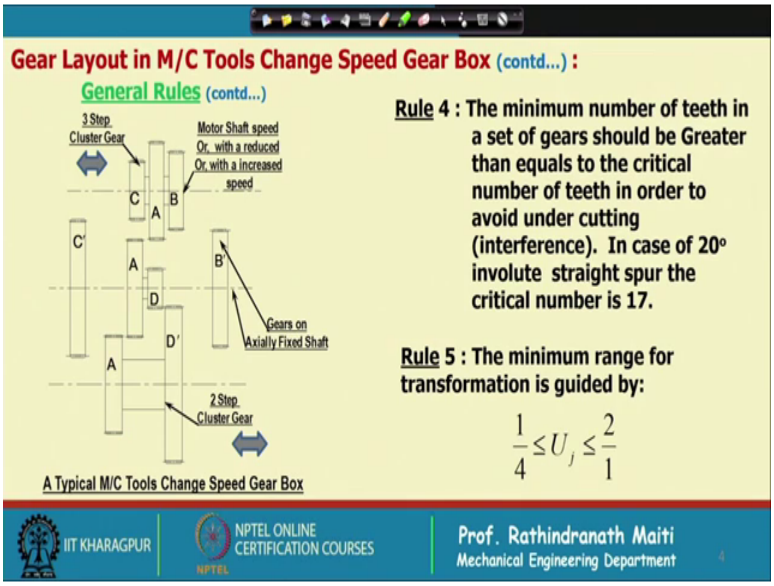

Now, rule 4 is that the minimum number of teeth in a set of gears should be greater than equal to the critical number of teeth in order to avoid undercutting. In case of 20 degree involute states bar gear the critical number is 17 and if we remember for precision gears it is usually taken 18. This means that by no means the teeth number smallest a teeth number of smaller size gear, in such gearbox should be less than 18.

Now, another rule that what we see that speed range point of view the minimum range of transform transformation is guided by 1 by 4 U j 2 by 1. Now this is again this; that means, suppose if we consider in a stage say C by C C dash by C and other is A by A that total range should not be more than 8 that is this side 4 that side 2.

So, that is to be followed; otherwise the gearbox size will be large or some kinematic problem may come in between.

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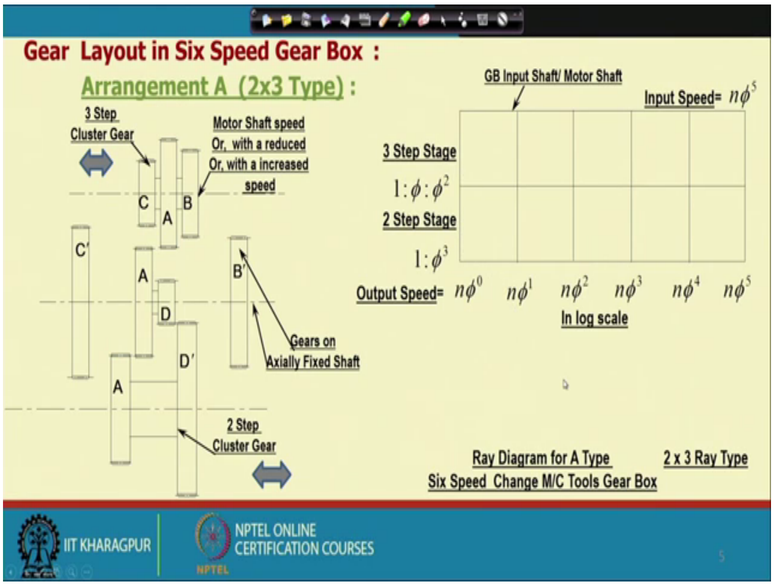

So, following this now we shall go for the arrangement of 2 into 3 type 6 speed gearbox. What does it mean actually 2 into 3 types? This means actually 2 into 3 ray; if we consider the ray diagram in that sketch case we will develop the ray diagram here, what is the diagram? Ray diagram shows that from what to what gear will be connected to get the speeds. I we have already shown there is the 3 shaft in the 6 speed gearbox, that is practically we have drawn a gearbox for 2 into 3 type ray type and in that case at bottom it is called 2 step range and top section is called 3 stage step range.

And then I will show that how the ray diagram is developed and then the speeds are achieved. Now, in 2 step stage that ratio is 1 is 2 phi to the power cube phi is the that is the ratio in GP series and in 3 steps stage it is 1 is to phi is to phi square.

So, now, this is either the motor shaft or the input shaft to the gearbox we would call and input speed we have considered n phi to the power 5; that means, this is the 6th speed highest speed, which may be equal to the motor speed. And the speeds we would like to get 1 is that n phi to the power 5 means what is the speed of the motor that and then it is slightly reduced, then further reduced and ultimately in 6 steps we will get a minimum speeds n phi to the power 0 means n 1.

This means that this either this motor speed or the speed of the shaft will be mentioned as well as the minimum speed will be mentioned and then we have to design this gear box we have to show this ray diagram.

Now, these for this ray diagram we have taken this say box sort of things you can say that this is the graph sits like and here all these distances are same, because this is in the numerically these are gradually increasing by in GP series, but it is in the log scale. So, they are having equal distance. So, first of all for 6 speed gearbox with these 2 steps actually 1 is 3 step stage and 2 step stage 2 stages are there.

So, we will we will consider this is for the ray diagram and then these are the gear sets, we are having this is 2 step stage because connecting this we will get 2 different reduction stages and connecting these 3 we will get 3 reduction stages. So, this is 3 step stage.

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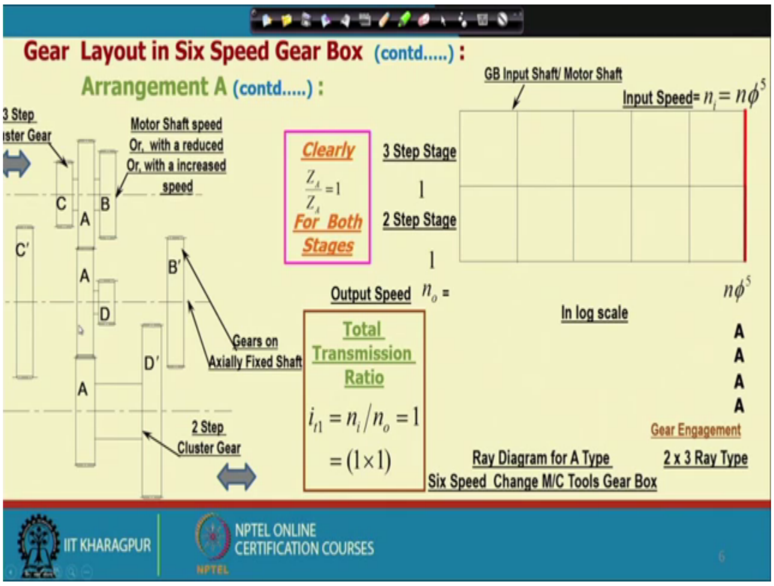

Next, I will show that how this ray diagram as well as gear connection is done. Now, first let us consider that here we have the maximum speed and here that we would like to have this maximum speed. This means that first of all we will estimate what is the total transmission ratio. In this case n input divided by n output is equal to this by this is equal to 1; that means, we will look for in these 2 stage 1 is to 1 say 1 and also in this stage we will look for 1; that means, say here we will look for 1 and as well as. Here in the first these 2 step stage we are looking for 1 as you see in the ray diagram what we have done we have connected from this point to this point, because we are looking for a 1 and the gear is connected in this way.

So, again I will show this say from this stage first of all this is one here we have selected one and one means the ray is dying in the state above because we have to reach here. So, in this stage one and then this gears are moved to connect this one A is connected with A. Next we so, A is connected with A, next again we will go for the same one ratio and this is in here also a gear is available a will be connected with A as you see the A is when being connected with A.

So, this in this stage we have got the total reduction ratio is equal to 1 and clearly that teeth number Z A by Z A is equal to 1 and that is in the both stage that is why we have arrived into here?

So, in this slides what I have shown how the red ray diagram is developed, what are the gear connection arrangement this is the gear engagement corrections and we have also found that what will be the transmission ratio in these 2 steps and here we have shown that how the gears are connected.

Next, we will look for another speed n phi to the power 4.

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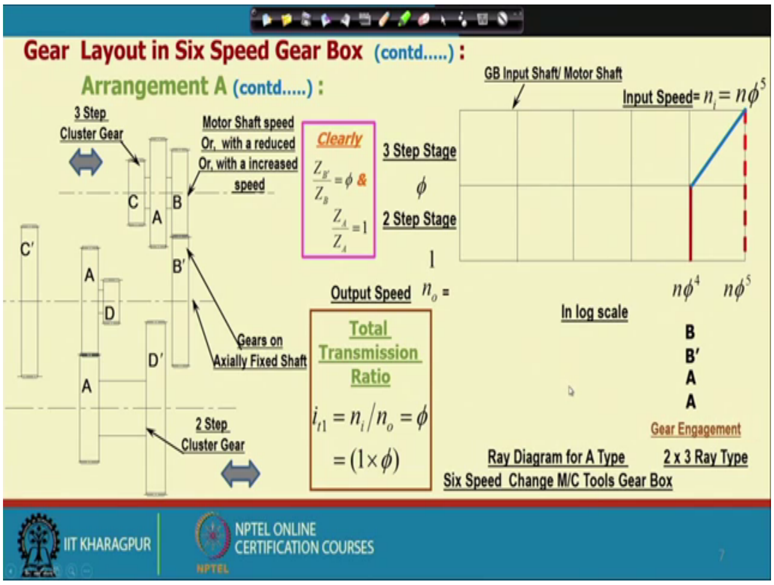

In that case what we find that transmission ratio comparing with the input to output is phi ok. So, we have to find that here we have one, in this stage we have. So, one we are connecting radially and because we have one and another we are having phi to the power cube so that we cannot consider because we need only single phi which is available in this stage in third stage. So, that is achieved by connecting B with B dash.

So, we will connect that 1 and this is the gear connection and we get the transmission of ratio phi and clearly Z B dash by Z B should is phi and Z A by Z A is equal to 1, one may ask the question why C by C dash is not the phi looking into this size.

So, this cannot be this phi this must be we have to look for this ratio, common ratio for this common ratio you have to find Z B dash by Z B ok. And here is the ray diagram ray diagram is that in that stage we have connected one to arrive here and from here we have connected from this point to this point that one step reduction.

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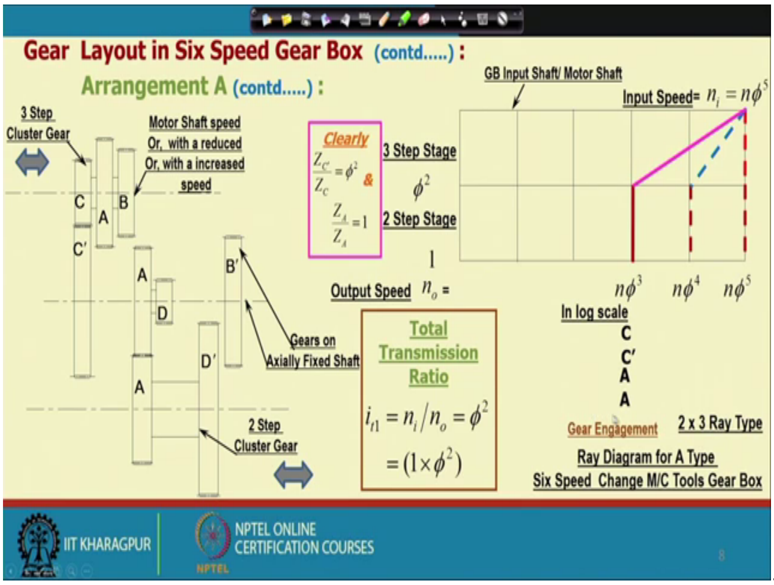

So, next we will look for n phi to the power cube and in the similar way first we find out the transmission ratio, which is again as here in the second step stage the if you remember that phi cube is available and 1 is available.

So, we have to go for one here and in just in this stage we have the phi square. So, we will take phi square from here. So, for that the gear connections are first A A; we are connecting this gear and second phi square means C with C dash ok.

So, this gear connections are shown the ray diagram is shown and clearly we find Z C dash by Z C is equal to phi square j A by Z A is equal to 1. Now, now we shall go for the next step for which we are looking for n phi square as output and in that case transmission ratio again phi cube and here it is so, we looking into these 2 available transmission ratio.

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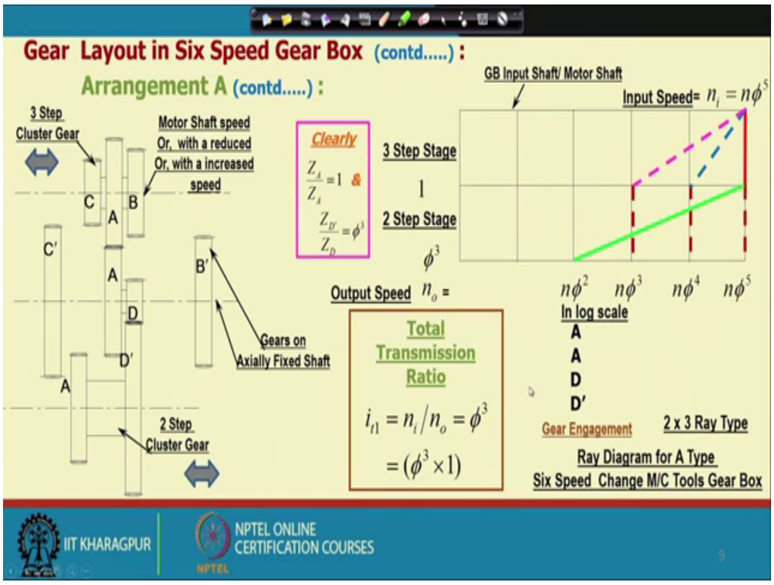

So, first we can have phi cube and then 1 and phi cube is available here.

So, first we get this phi cube from this point to this point and then in that stage we will take 1. So, gear D D D S is connected ok. And in that stage we shall look for 1 by connecting A A and the gear connection is like that. So, again for the this the top stage that is 3 step stage Z A and Z by Z A is equal to 1 and in this stage Z D dash by Z D dash is equal to phi cube.

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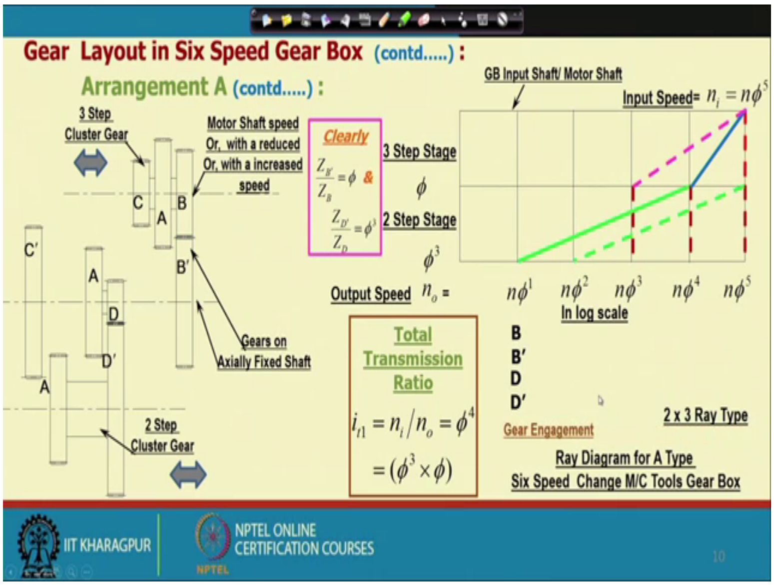

Next, we come to n to the power 5 this is available here. So, it must be 1; oh, this phi cube is available here sorry the transmission total transmission ratio B is coming common ratio to the power 4. So, first we select phi cube here and then for which we connect D with D dash and in the 3 stage step we select this phi and for which we connect BB dash ok. And we are getting we are going for this connections and we are getting these 2 connection to get the desired speed.

Next, what we find Z B dash by Z B phi already it is shown and this is Z dash by Z D is equal to phi cube.

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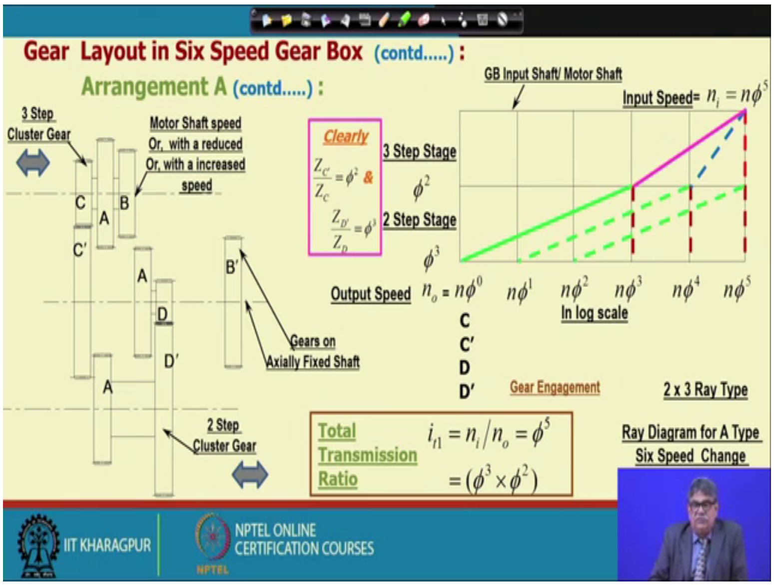

In lastly we find that transmission ratio to reach here to here the total transmission ratio should be phi to the power 5 and looking into this 2 stage in one stage we will get phi cube and other stage we will get phi square. And first stage I mean 2 steps stage we will select this one connecting D D dash and next we will get phi square connecting C by C dash and these are the ratios that already we have found out and this is the gear engagement.

So, in this way we get the different speeds of using this gearbox and the gears are arranged in such a way, that there is all the rules are also followed and here is the ray diagram for these gear connections.

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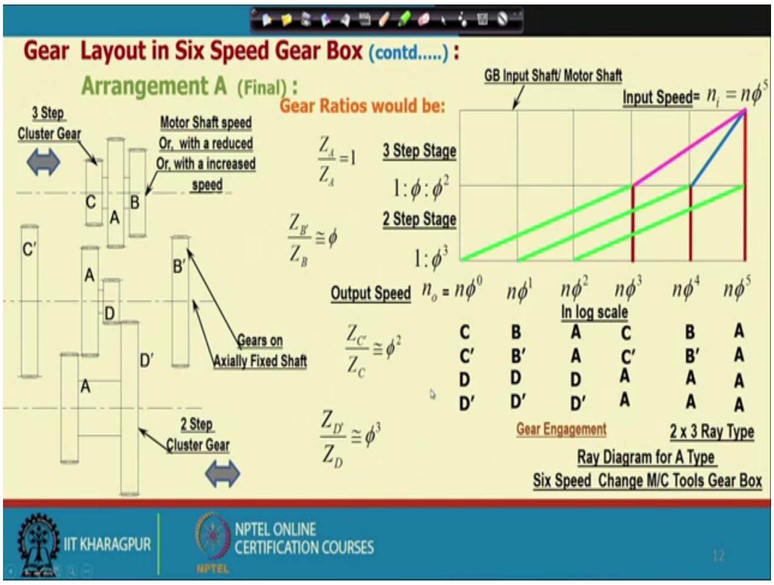

So, if we look in into these finally say this is the gear and no gears are engaged following the rules the gaps are there. Now we can moved these gears and these gears in this and that way and we can get all such connections and all such speeds and the ratios are given here and as we have already found that Z A by Z A is equal to 1, Z B dash by Z B is equal to phi and Z C dash by Z C is equal to phi square and Z D dash by Z D is equal to phi cube.

That means, while we have to select the gears we have to get this ratio, I have shown in case of gear set B B dash C C dash and D D dash, this is approximately equal to reason is that, this tooth numbers should be whole number and it is rare that we will the exact ratio. So, that can be understood from an practical example.

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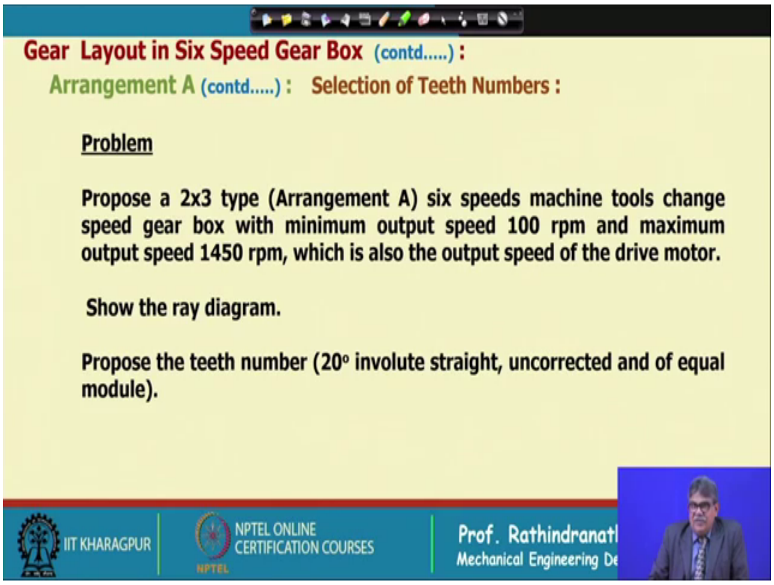

So, now we are considering in a practical problem. Now in this problem it is asked that propose A 2 into 3 type that mean arrangement a we have named as arrangement A, but usually it will be called as 2 into 3 types sometimes 2 into 3 into 1 it is written 1 is that input speed is no reduction or no increase in the speeds , but it is most popularly it is called as 2 into 3 type which I have shown already 6 speeds machine tools change speed gearbox, with minimum output speed of hundred rpm and maximum output speed 14 15 rpm which is also the output speed of the drive motor.

So, we have to propose this one and also we have to show what is the ray diagram and here also it is mentioned that, we have to propose the teeth numbers which is 20 degree involute straight uncorrected and of equal module. Now usually gears who are unconnected because in for the inter changeability purpose though all gears are uncorrected, and they are standard with standard are and them and standard did in them, and as I as already mentioned width are off of equal, and also the super finished gears are super finished and designing such gears teeth the smallest gear with maximum torque materials will be same of gears.

So, take this small smallest gear with maximum torque man this means that we have to find out for which smallest gear that maximum torque is there and then if we design that one all gear should be taken off same module and same width, teeth number will be different materials is also same.

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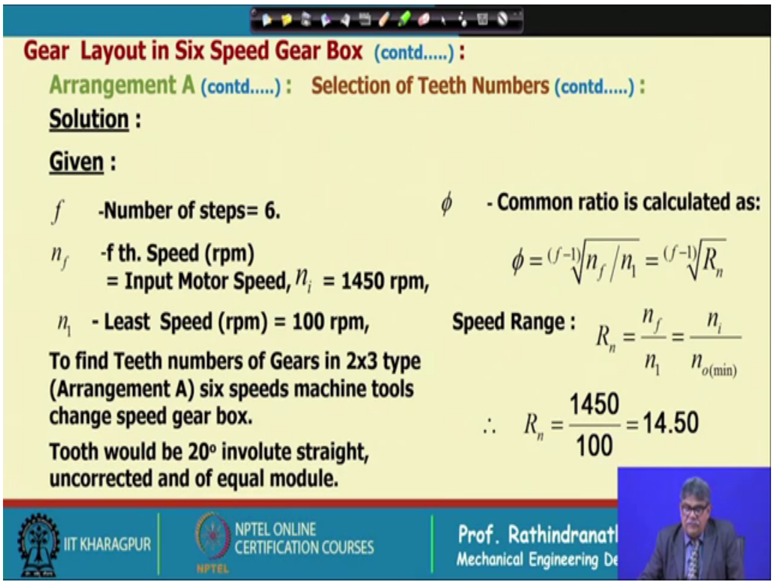

Now, with this problem now if you go into the solution first of all we will find that what are the what are the data is given the given data are if the number of steps is 6 and the final speed is 14 50 rpm, because that is directly to the motor speed which one is to one ratio and the least speed is 100 rpm to find teeth numbers of gears in 2 into 3 type 6 speeds machine tools change speed gearbox, arrangement we have named here for this in this lecture we call it arrangement a tooth would be 20 degree involute state uncorrected and of equal module.

Now, first we find the common ratio in GP series, which we can calculate by using this formula where R n is the speed range which is n f by ni and which is input rpm divided by minimum output rpm. And if we calculate straightway we get that this stage range is speed range is 14 50 by 100. So, it is 14.50.

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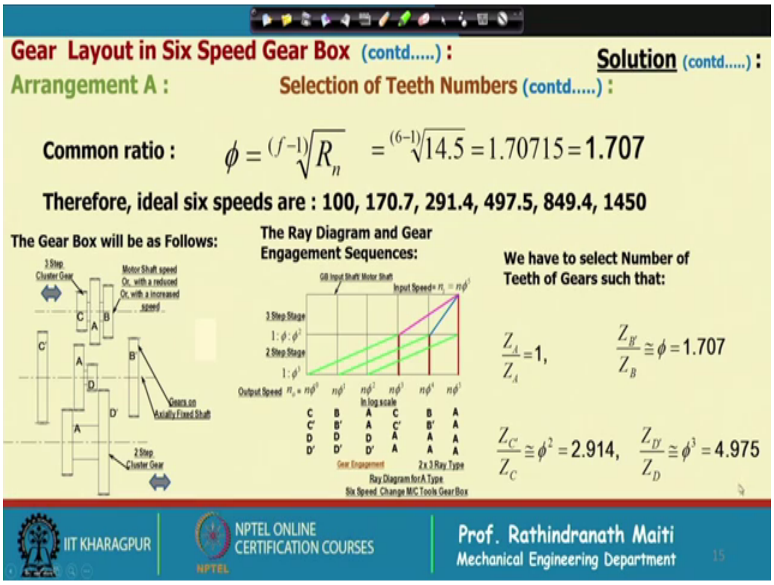

And, then this common ratio is calculated as 1.70715, which can be taken as 1.707. And therefore, considering the minimum speed is 100, then first speed is minimum speed which is specified in into phi to the power 0; that means, phi to the power 1 it is 100.

Then we will multiply by with this speed multiply with the common ratio and we get 170.7, then we multiply the minimum with the phi square and we get 291.4, next phi cube 497.5 and then 100 multiplied by phi to the power 4 he is 849.4 and it is 14 15 last speed is phi to the power 5 is 14 15. And as already mentioned with such an speed suppose if it is used for a lathe and probably it is being machined a stock from 200 to minimum diameter is maybe 10 millimeter. So, that might be in a different steps the machining speed cutting speed can be same more or less same for different steps ok.

So, we will now look for the gear ratio. So, that we get such speed definitely it may not be exact ratio may not be possible. Now again I have shown here that what are the gearbox we are looking for and this is the ray diagram. So, in answering such question you have to draw this ray diagram A A view of this also will be appreciated not of this form it might be more freehand sketch say like this we can make this gear say like this and mating gear maybe like this all gears on a this.

So, we will draw this centerline and gears can be drawn like this. So, answering this best is that draw this 3 center line and these gears in this form and then this ray diagram, color may not is not required to use you can it can be mono color ok.

So, after that we now look for the now we have to select the number of teeth of gears such that Z A by Z A is equal to 1 this one say for ratio 1, and next another next set Z B dash by Z B is equal to 1.707 because this is a give a specified problem. So, common ratio will be 1.707.

Next one with the phi square that Z C and Z C the spear 2.914 and finally, we should have another D dash by Z D phi cube is equal to 4.7975. Again as you see that only in the first case I have given equal to sign here approximately; that means, we are expecting it is preferred that it should be equal to that we will get exact GP ratio.

Otherwise it will be very close to that.

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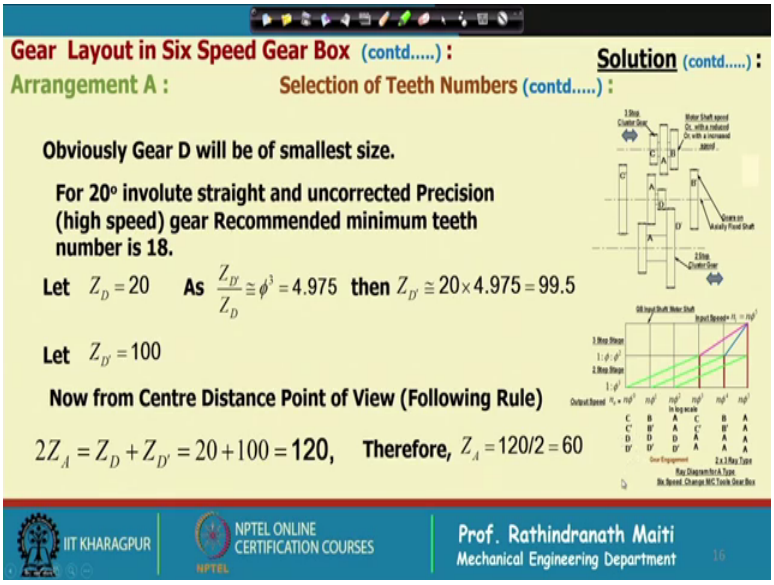

Now let us see what can be done; obviously, gear D as it is having D dash Z D dash by Z D is having the maximum ratio. So, Z D must be the smallest 1 and for 20 degree involute state and uncollected precision gear recommended minimum teeth number is 18 if you remember. So, we can take it is 18 or very close to that sometimes it is preferred that we can take a multiple of 10. So, 20 in this case I have shown that I have taken 20. So, this means that as Z D dash by Z D is equal to phi cube then Z D dash is equal to 20.4.9 7 5. So, we get that Z D dos D dash should be 99.5, but 99.5 cannot be a teeth number.

So, close to that we go for 100 and clearly that ratio becomes phi. This ratio will be phi that will be small later, but one thing one information immediately we will get the center distance between these 2 Z D plus Z D dash is equal to 20 plus 100. So, it is 120. So, that must be equal to the summation of teeth of 2 A gears because in that 2 step stage also same a gears are there clearly Z A is equal to 60. So, in this by so, far what we have got Z D is equal to 20 Z D dash is equal to 100 and Z A is equal to 60.

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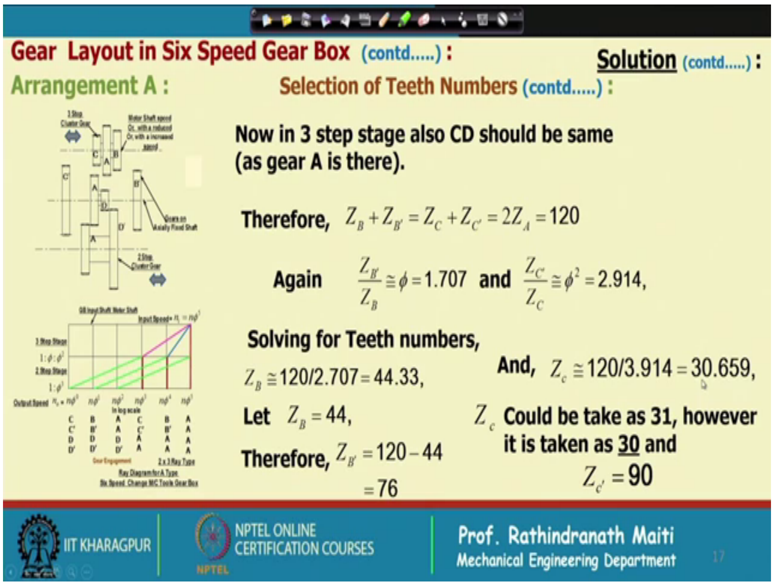

Now, next in 3 step stage also series should be same as gear a is there. So, this means that Z B plus Z B dash is equal to Z C plus Z C dash is equal to twice A Z is equal to 120 the teeth numbers. Now Z B dash by Z B is equal to 1.707 and Z C dash by Z C is equal to phi square is equal to 2.914. So, using these 2 equations in a set and above that these 2 equation in a set. We will find Z B should be equal to 44.33 if you would like to keep exact ratio, but it is not possible.

So, we will we can go for either 44 or we can go for 45 also 45. In that case to somewhat the even number helps in more interest changeability, we have kept the teeth number 44 Z B and clearly Z B dash will be 76 and similarly, Z C will be we can go for 30 it could be taken as 31 also.

But, we have taken thirty and we by in that way is Z C dash 20 minus 30 is equal to 90.

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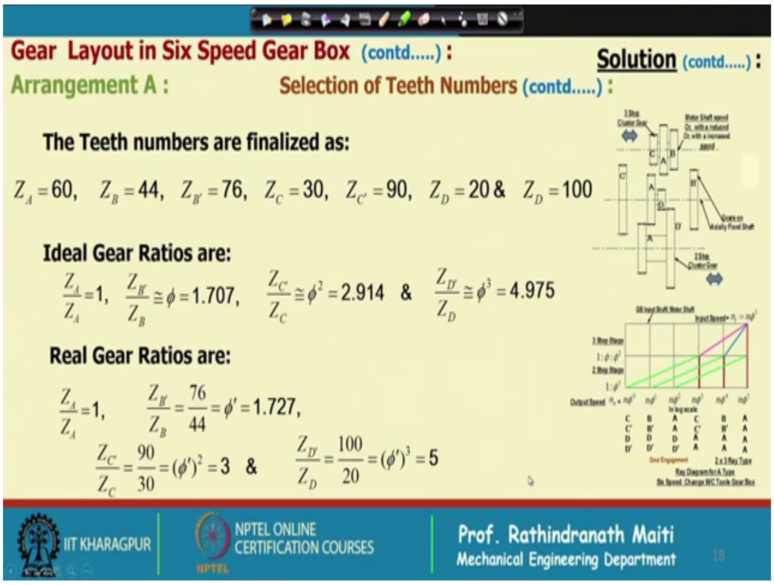

Now, with this so, far what we have done we have found out the teeth number of gears, which can be taken for this gearbox maintaining all the rules and ideal gears ratios are as already we have discussed these are shown here. And real ratios are say here it is 1.707, but we are getting 1.7 to 7; we have mentioned it is a phi dash, this is close to common ratio, but not exactly.

And next that phi square you can say that this is this becomes 3; obviously, square of this not equal to 3, but we are getting 90 by 30 teeth numbers are 90 by 30, which we are getting 3 here and actually it was 2.904 in reality. And in last phi cube stage we have got the ratio is equal to 5 where actual requirement was 4.975.

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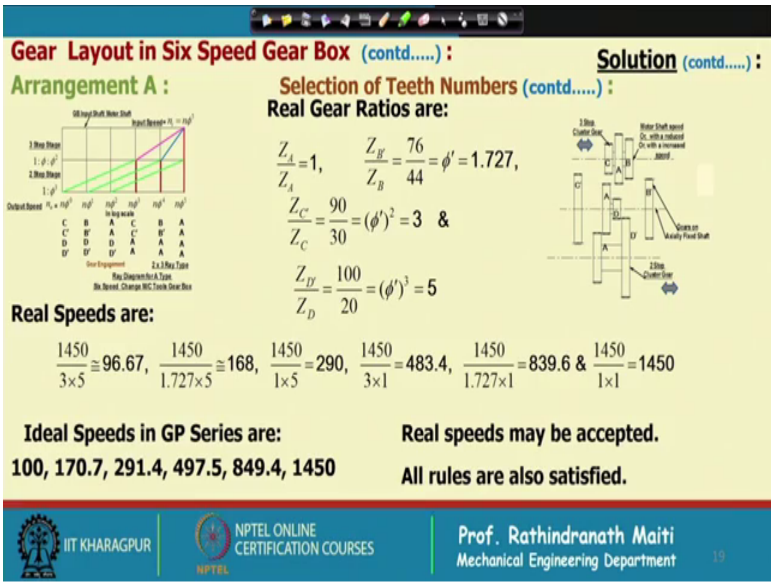

Now, with this real speeds available speeds are 96.67; 168, 290, 483.4, 839.6 and 1450, these 6 speeds will give get remember that motor speed cannot be changed considering that as the ideal and speeds and constant. We will divide the speeds everywhere it is like that not considering the n 0 is equal to 100, we will consider this speed and by the speed ratio we will find out all the available speeds.

And if we compare with this in first case difference is 3; it is less and in the next case, it is less than 2 difference, but here the difference a no in third speeds also difference is 1.4. However, in the fourth speed it is the difference is very high it is 483.4; whereas, it is 497.5 and in this case difference is 10 and in the last stage of course, there is no difference.

Now, these differences considering the material process and there the allowable variations, real speed may be accepted this speeds is accepted in designer all rules are also satisfied. However, still say take considering the tooth number is 18 or 22 instead of 20 we may find these ratios are better or using this instead of 44 in is for Z e, we can go for 45, we may have better teeth number although interchangeability possibility of interchangeability we will reduce.

So, with this lecture I have given an idea that how to design a 6 speed gearbox design means in that case we have only selected the teeth numbers and as I told that design of the gear for the gearbox, we can follow the same procedure as we have already learned and in this case usually you will find that module we will come very very small because torque is small and gears are hardened and ground materials are also of sufficient strength alloy steel, width of course, we can go less, but usually the module is taken 2.5 which is satisfactory in general for purpose machine tools ok.

Thank you.