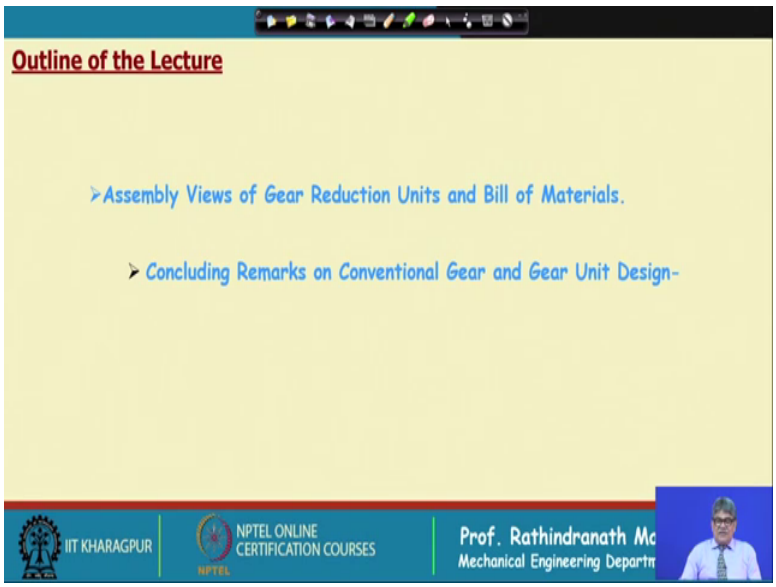
Gear and Gear Unit Design: Theory and Practice
Prof. Rathindranath Maiti
Department of Mechanical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 32
Concluding Remarks on Conventional Gear and Gear Unit Design

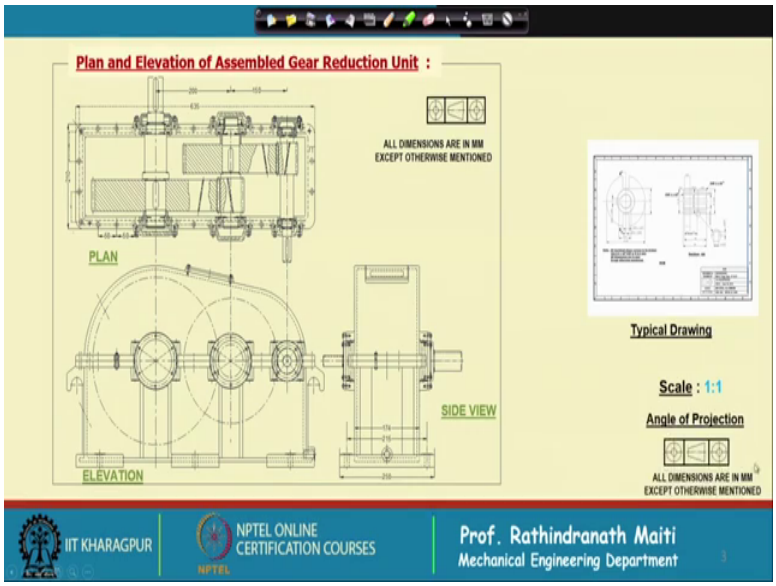
Welcome to week 6 lectures. We are continuing design of general purpose industrial helical gear unit reduction unit, it is part 4 the last part. And this is the last lecture where we shall mostly recapitulate, that how the design of a gear unit is done? Now, outline of this lecture is very simple first of all the in assembly view we have not shown yet the bill of material.

(Refer Slide Time: 00:45)



So, that I will show you first and next we will discuss about the how the gearbox are designed, somewhat we will recapitulate I shall speak about the essential steps.

(Refer Slide Time: 01:05)

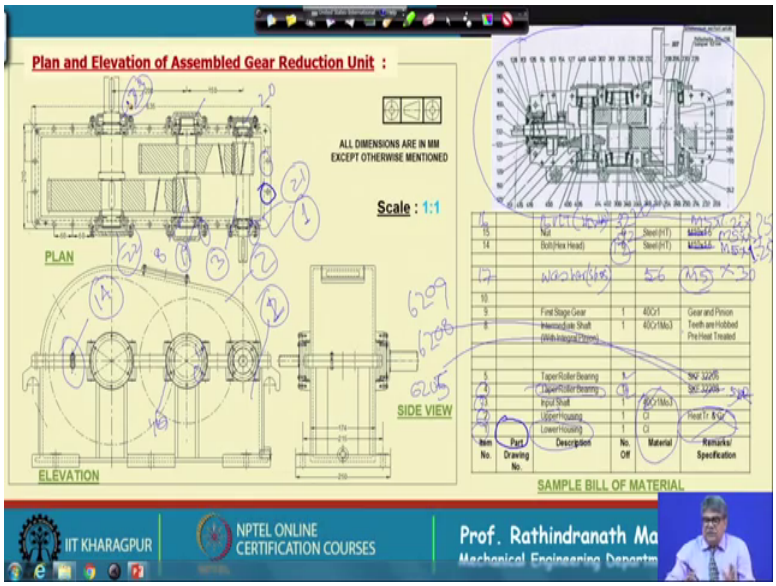


Now, this is the view plan view elevation and side view although not completed, but the gearbox what we have designed in the last page that is considering total reduction ratio 24.42 keeping the input shaft and the intermediate shaft same only the output gear had changed, for that the gearbox will look like this. And I would say this gearbox with a little refinement here and there can be seen for manufacturing ok.

So, after completing this drawing then on the assembly drawing there will be some notes of course, that there should have linkage that next what we need to do? And what are the essential part and on the assembly drawing there will be some major dimensions first of which is not given here which first of all it is overall size of the gear unit, center distances and the this is say for foundation bolt we have 6 numbers as I told that this is a piece like that this is about 127 millimeter width and length is 250 millimeter ok.

That sort of 3 base will be there which will be machined and these bolt holes are 12 millimeter holes are there for m 12 bolt, which 6 bolt will we can put in on the ground or on a structural frame right. So, some information will be there not it will be not just like that some information will be there, but along with that we need also the bill of material.

(Refer Slide Time: 03:24)



So, this typical drawing and the scale and projection all are mentioned here, next we will come to the bill of material sample bill of material. In fact, if we want to give the details of all items, it will look something like this, what is shown here it will look like this. So, we have to give this item number each and every item number here.

This is this drawing and this drawing is same here it is of course, it is 3 stage gearbox more components are there and bevel gear and as I described earlier, in bevel gear there are also possibility that we can put either set 1 or I set 2 here also either we can put solid shaft or hollow shaft, that is why the number and components are more. It will be here in this in our case it will be less of course, but not much I have not shown other things I have not marked at all.

But, bill of material means that you have to give the item number each and every component. There are two ways; one is that you can put 1, 2, 3, 4, 5, 6, etcetera all the components; that means, say suppose if I consider the bolt here all will be of equal size because they are being put like this.

So, for that will be only 1 item number, but the number of maybe we require 24 and bolt nut and spring washer. So, what is done actually this bolt will have a specific length. So, that will get one item number the somewhere some other places say for example, the similar bolt we are using here also for this cover, but this is having different length. So,

that will get another number and if you calculates have suppose here it we need 12 here we may need 6 6 12 plus 4 16 other side 16 so, 32 bolt size.

But, if you come to the nut washer and spring washer they are of same size, that they will get another number and then we will here 12 and here 16 sorry 32 12 plus 32 2 44 nut 44 washer, or if we use the double washer here bottom and top here of course, only one washer here double the number will increase and that will be that will come in the list.

Now, while we are listing it will be like that. So, when I teach the student, then I say that you take the component, which you need to put consider the first one first item give the item number 1 ok, but actually it is not that it is normally it is on the based of what type of component. It is say machining means casting and it is all manufacture we cannot buy it. So, maybe that is carrying 100 series that is carrying the 100 series so; that means, bottom housing maybe 101 top upper one maybe 102 like that.

Say bearing those are bought out item that is carrying 400 series. So, bearing might be 402 412 400 like that, which is given here and see gears those are say 200 series. Similarly, these shafts and other or maybe the small covers in etcetera that is 300 series, but alternatively as I told that you can take the component, which you are, which is the main component and the first component it is like that. Of course, in that way first components will be the shafts finish shaft, then perhaps you have to put the bearing then you have to take the key, then bearing then gears etcetera it may come in that way ok.

We need not follow strictly the assembly sequences, simply what I have done this is again sample I have not given all the item numbers say item number 1 is assigned here you can see this number 1 is assigned to lower housing; that means, this one is number 1 ok. And how many we need only one and then this is material cast iron simply cast iron I have written, but you can specify graded cast iron or something else you can mention there ok.

And, then this column so, we have to make such columns item number here then the part drawing number all details drawing will have separate part number. And there itself sometimes it is written it will be assemble to some component of course, for housing many many components will come over there you may not need it, but this part drawing number you have to mention here in the bill of material. And this lower housing then this is the description, then number 2 is the bottom hydrogen number 2 here sorry I yeah

lower housing. So, this is one actually this is one this and this is the same and upper housing means this 1 2 this is upper housing.

So, you have to put it like this not like this what I am showing and this is cast iron here I have given the heat treatment and ground, but practically this ground is not required in this case it will not be required, but you cannot heat treatment there might have a note or you can leave it no note is required.

Because, on the details drawings there will be note, because after casting sometimes we you may require to for the stress living another heating and normal cooling that might be there or can forget about that no note is required for this. If there is some special remarks that you can put there itself in the column of remarks and specifications. Materials all materials details are given in the detail drawing, but still it is a customary to mention here the, what are that material ok?

Next we come to the input shaft number three; that means this will be number 3. So, input shaft that is E N 19 instead of that the, what is the Indian standard specification that I have written here? This is forty CR 1 MO three; that means, chromium is 1 percents, molybdenum is 3 percents, and 0.4 percents is the carbon. That is the basic and here we have not written any comment, because it not required all comments are given on the detail drawing.

Then, this 4 here as if the I have mentioned here taper roller bearing, but this is a just sample in this case you can write the ball bearing, and this number instead of that say we can put S K F that is the company number or simply you can forget it these that we can put in this bearing number we are using 6 2 0 6 no 0 5 6 2 0 8 and 6 2 0 9. So, this all bearings can come together and each we need in our design in a pair. So, 6 2 0 5 will need 2 numbers, 6 2 0 8 will need 2 numbers, and 6 2 0 9 we will need 2 numbers ok. So, that we can put it here number of is 2 instead of 2 2 2 this number will come over here, it will come over here like this ok.

So, that can be given then what we have taken that intermediate shaft intermediate shaft is this one that number is 8. And this material also mentioned here what it is and gear and pinion teeth are hobbed and preheat treated, this note I have written here, but not necessarily all notes will be in the details, just to show that how to write the any special remarks that you can put it here.

So, that is for the manufacturing items, but if you come to this say bolt and other things suppose the bolt hex head say this you can put say 14 ok. And what we need this is we can count here 1 2 3 4 then 5 6 7 8. So, if you do that for 1 2 3 4 4 4 8 plus 4 12. So, we will simply write here 12 and these are not M 10, we have taken simply M 5 and then this you can mention if it is ordinary one perhaps for M 5 there will be 1 or 1.25 is the pitch that you can mention there and also you can mention the length in this case this length will be around 30 millimeter, we can measure it is in again in the multiple of 5 normally ok.

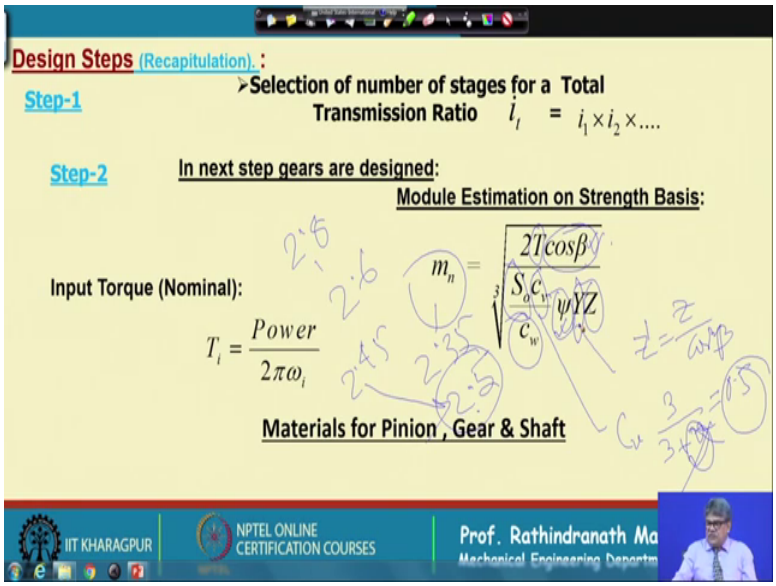
So, that you can mention and these numbers of you have to put 12, but we have here also the same bolt so, these is say 15 or say 16 ok. So, it can come here 16, then bolt again hex head or whatever this you can write here and this will need totally 6 6 12 plus 416. So, we need 32 and here that this these are also M 5 into say 1.2 5 into length will be much less it is around 6 6 12 or say 15 millimeter and that we need 32 numbers.

Then, come to the nut this nut again we need for M 5 and 1.25, but this number now this 32 plus 12 44 sorry we need we will need only for this 12 for this we do not need nut. So, we need 12 nut for M 5, if you think of the washer then we need for this 32 we need 32 washer and for this 12 if 2 24. So, suppose this 17 will come then here we will write washer the spring, this is a spring washer we will use here ok. And, that spring washer is 24 plus 32 we will that is 56 ok, then 56 we will write that M 5 this is for M 5. So, 56 numbers in that way we have to make the bill of material.

That, bill of material sometimes it is furnished with the drawing, but not essential you can keep a note that will have separate identity number and there itself you can make this bill of materials. All components should be furnish there say for cover that will have different identity number. Say for example, here this cover and this cover is same that mine gets A 19 whereas, this is 20, this is 21, this is 22, this is 23 and that detail drawing will be there and direct number will be there.

So, I think I have given some idea about how to make the bill of material and little of the this drawing. So, this is I would say this is the end of the lecturing on the design part of a gear unit.

(Refer Slide Time: 17:55)



Now we shall come into the other part, now we shall simply recapitulate how this gear box is designed?

Now, it is as you have seen we have started the gearbox designing from the third week lectures, third, fourth, fifth, and sixth completely devoted for the design of a just gear unit. You can see that a single problem we have solved we have calculated many many things, we have considered many many things, we have drawn the detail view etcetera etcetera.

And in this designing such gearbox first step is that, first of all you have to know that for what you need the gearbox? And what type of it might be helical it might be (Refer Time: 18:49) etcetera. That decision will be done there and then you either you have the prime mover size that is the power and the shaft size and etcetera. Or you have that how much torque you need to transmit at a particular rpm say it might be the in the output range.

Say for example, you are using this gearbox for a bell conveyor. So, you know that what will be the rpm of the bell conveyor say 200. So, it will be 200 rpm and you know these how much is the torque? So, there it itself you can calculate the how much power it required? And then probably you can multiply with some factor depending on the severity of the operations. Say, multiply with say minimum stock you multiply by 1.5.

So, in that case what will that will give directly the, what is the power of the prime over? Now you can select a suitable rpm of the prime over.

For example, if you go for electric motor normally a 1500 14 50 or 1500 is a good value because most of the motors AC motors, they are made of this rpm general purpose. So, that means, 1500 to 200. So, this is becoming only 7.5 reduction and for that 7.5, then you have to decide can you make it in a single stage 7.5 can be made in a single stage, but 1500 rpm and the 7.5 probably single stage will not be good.

Single stage normally we should not get if the rpm is high not more than 6. So, maybe it for 7.5 you will look for 2 stage gearbox and in that case you will think of making it 2.5 into rest maybe 3 2.5 in first stage or maybe 2.2 5 in the first stage rest in the second stage like that ok.

So, you can decide about that part, whether it helical gear spark gear or bevel gear that decision you have to take depending on the severity though operations and normally gearbox are made of helical bevel are not straight to that preferred normally ok. So, then you select the transmission ratio at first stage and second stage and it is better always when you are starting calculation from the input size you should know what is the nominal torque? That simply divided by what the output torque divided by the what is the reduction ratio you are choosing?

Then depending on the severity you can multiply with multiply with some by some factor with the nominal torque for gear design, when you coming to the shaft design this factor will be different, when you are selecting the bearing that factor will be different. And, it is in that way these are chosen, there is no proper I will may not get any guidebook, because always your load spectrum will not will match with the other one you that needs some experience and some recommendations.

Now, next step you will design the gears ok. Now, while you are designing the gears there are say a different type of formula is suggested by the book, in many cases you will find this is simply it is calculated how much a tooth can take the load ok? So, that is one possibility, other possibility is that better you use this formula we will directly arrived into the module.

Now, torque is known we will consider the design torque nominal torque multiplied by some factors. Then we have selected some number of teeth, because we have selected the ratio initial stage from the recommendation we can select also the helix angle. And as this tooth number and helix angle is known, then we can calculate this Y modified form factor in calculating the formative number of teeth which is this Z dash is equal to Z by cos cube beta that we can calculate.

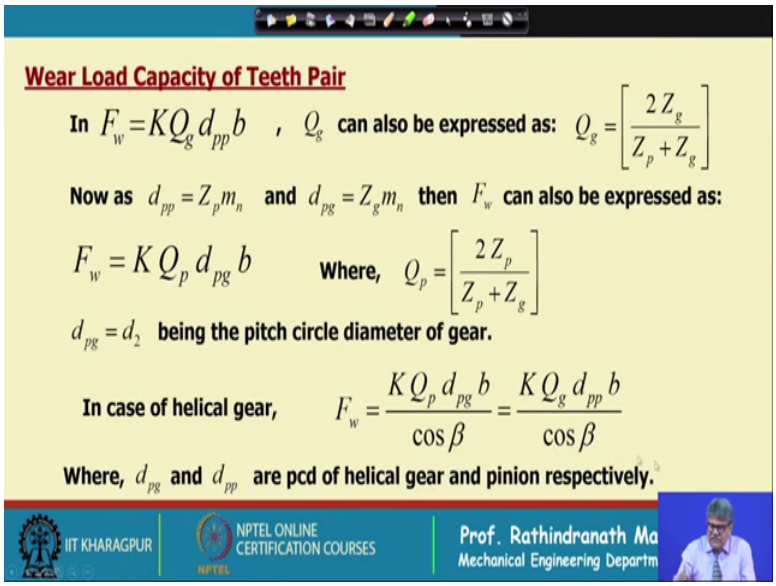
So, these are known vivid factors we can choose the lubrication condition and lubrication on this factor we can choose, the material available material usually this who are manufacturing gears and gear manufacturer, they are having 2 3 materials for pinion 2 3 materials for gear depending on the load another we can choose. And depending on the heat treatment which you can go if it is a ground you can go for one just like that.

Also there is another factor as I told that Y 1 factor into strength of material that on that basis you can decide whether the mating pair pinion or gear to be designed ok, but there is a question how to take this heavy value at the initial stage? C V values it will be say 3 by 3 plus pitch line velocity initially we do not know module how we can take this one, but it really does not matter. So, we start with take simply 0.5 this factor without knowing these just take 0.5.

Then, you put in the first calculation once you calculate it you will get a module suppose you get this module is 2.3 5. So, nearest standard is 2.5 go that go for that and calculate the pitch line velocity calculate v then again you refine it and put it here and get this one for that you may find you are getting, next 2.4 5 and still this will do.

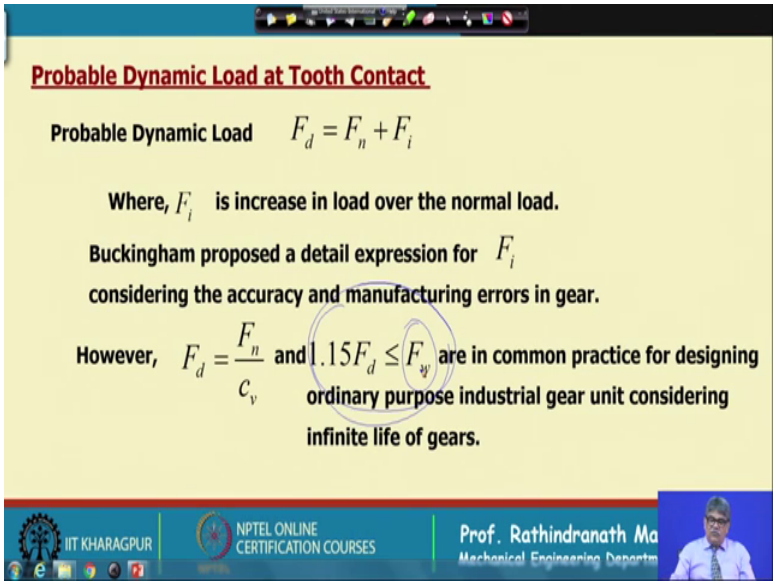
Suppose you get 2.6 still you can come back to 2.5 simply increasing this a little bit or increasing this a little bit, but suppose with this value which the new value of the module what we have got this value in changing in such a way, you have arrived into 2.8 then go for 3 and recalculate it will take hardly 10 15 minutes. So, you can decide on that what module you can select at that stage.

(Refer Slide Time: 26:13)



So, next that already this I have discussed, but you need to find out the wear load capacity of this one, for which this is based on the hertz contacts theory on that basis if you just simply put the number of teeth here, you will get this factor, and this is from the material considerations and this is the geometric diameter etcetera. This is the working width and this values all this put you can find out the where, what is the real load capacity of this material of this gear set.

(Refer Slide Time: 26:56)



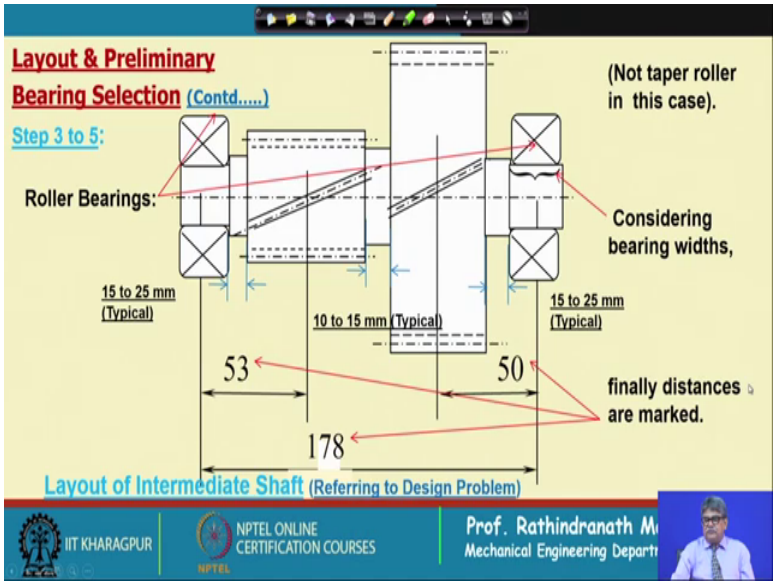
And then so, this is the formula already discussed and then that would be considered, that would be compared with the Probable Dynamic Load. Probable dynamic load will be the it is a it is usually normal load acting and the teeth plus some increment and the load due to the dynamic effect. So, that is given F n by F i there are various formula proposed by various gear researcher.

Buckingham he has put a formula that is widely used, but that has been further refined, but for the general purpose what one can consider that F d is equal to the F t into v sorry C v or F n into c v simply one can take that things. And that C v factor that depends on what is the finish of the gears which I have discussed earlier. So, in that way you can easily calculate F d and then your F d this you need to follow.

What the capacity from wear load consideration, what we have calculated? It should be greater than equal to 1.15 times of the F d calculated F d probable load if not satisfactory then first thing you can increase the hardness of the gears, but while you are increasing the hardness of the gears if that needs the grinding then you have to think twice alternatively you can try if the difference is small you can try with increasing the width, increasing even the module ok.

But, if you find the difference is very high there is no way you have to go for heat treatment you can of course, size the increase the size of the teeth others increasing the module, but that will not be a good design you have to go for heat treatment then ok.

(Refer Slide Time: 29:21)

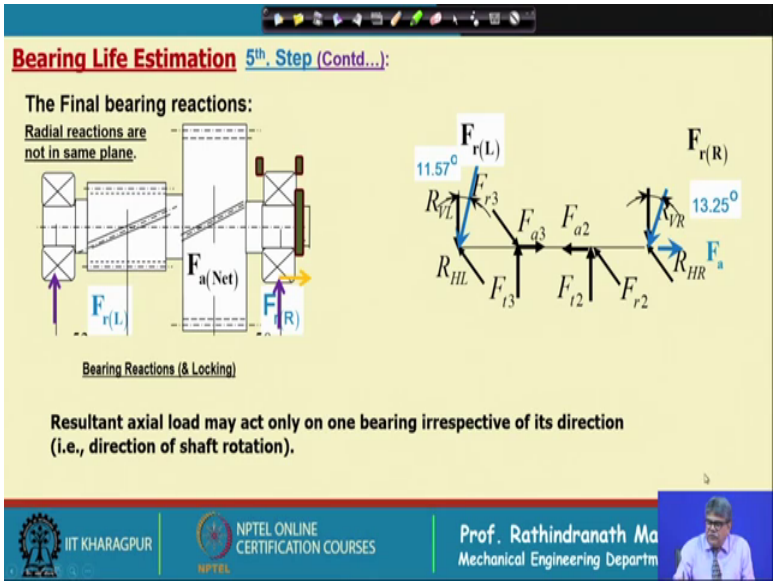


Then, the step 3 to 5 is that first if after designing the gears then you have to make the layout first, because you do not know, where is the support we have only selected design the gears and pinion and then best thing we should consider the intermediate shaft.

Suppose it is a 2 stage then intermediate shaft is 1, if it is a 3 stage then 2 intermediate shaft take any of that and then you put the gear like this say here we have put the pinion and here the first is gear, second stage pinion some gap, what we have mentioned and then I think it is there. So, we can directly go into that.

So, this is bearing you can think of this what type of bearing depending on the load etcetera may be up to 10 kilowatt you can go for only the ball bearings deep groove ball bearings and these are the gap are mentioned. And you can select what might be the series usually it is 18 to or maybe 15 to 25 you can consider you consider anything here and then take these dimensions.

(Refer Slide Time: 30:41)



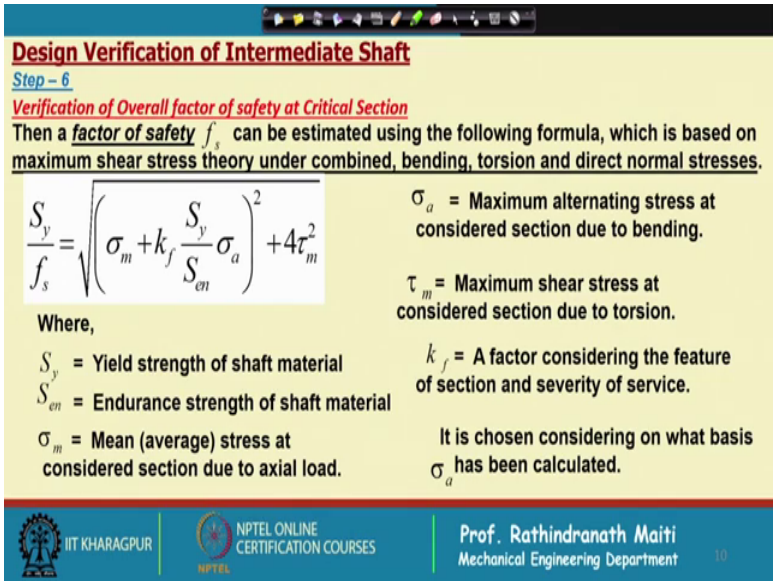
And, then only you can calculate what will be the load coming on the bearing, because now you can calculate from the torque what is the load acting at the contact points? And from there as you know the bearing distances and distances from the mid of the gear a mid of the pinion two different bearings, you can calculate all these loads ok.

But, these loads while you are calculating better to consider dissolve into two planes; horizontal plane and vertical plane; because, resultant is always not in the same

directions. So, it is advisable to calculate these separately for horizontal plane and vertical plane and then while you are coming to particular section you just find out the resultant. For the bearing also it is done in the same way and then we go for the next stage.

You can see this resultant in one is in 13.2 5 degree other is an 11.57 degree these are the resultant ok. And then as I as already discussed that we normally lock the bearing, if it is a ball bearing, if it is a taper load bearing you cannot do it like this you have to lock from the both sides taper load bearing, but for spherical roller for ball bearing you can do lock any one side, this is intentionally locked in this right because here the radial loads are less. So, that you have to decide and then you can see this all loads we have put it there.

(Refer Slide Time: 32:41)



And, then if you think of the shaft design in case of gearbox there is a little scope that you could design the shaft fast than then you can put it there.

Particularly, if the pinion is integral with that so, you have to from the size of the pinion then, if it is integral then you have to step down to the bearings and there is a little scope that you can design the shaft and can put it there. So, normally what is done after making the layout and calculating all the loads bending moment shear force diagram everything is done for the shaft and then using this formula we have already shown this based on the maximum shear stress theory. And, we can already it is discuss, but very quickly you can

see all these are calculated for the critical section and then the factor of safety over the yield strength of that particular material is verified.

Now, how to find out the critical section? What we have to do for we have to compare with the diameter and the factor of safety at a particular section, that is severity suppose there is a key way factor of safety will be more, there is a stiff factor of safety will be something in between, there is a gear factor of safety would be less.

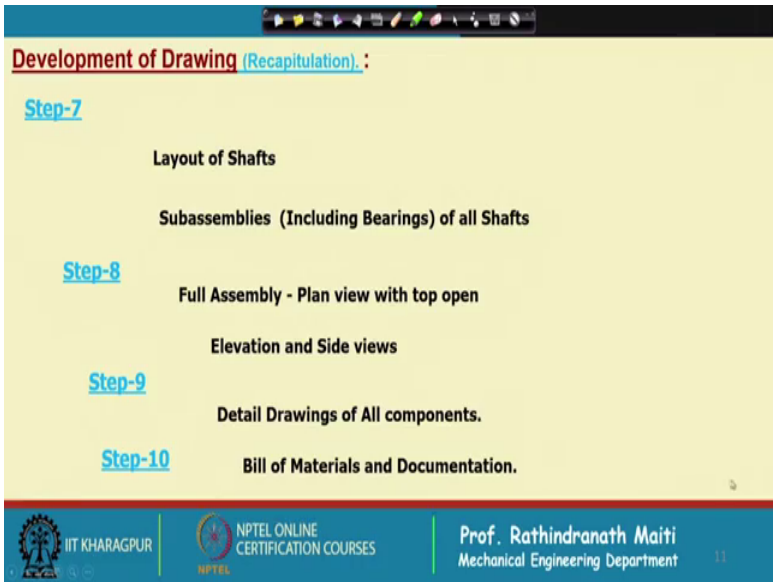
But, if you calculate near the say suppose intermediate shaft at the middle of the pinion there will be the maximum bending moment, but there is also the maximum diameter and factor of safety in that way is not very high because this is a gear tooth, but if you come to the mid of the gear there it is a it is the key way is there and although the bending moment is reduced, but diameter is also reduced.

So, you that section maybe severe than the section mid-section of the pinion. Also in between the gear and pinion there at the step that section maybe the critical one. So, that you have to find out using these all making all such calculations and using this one.

And finally, you can suggest this section is maximum. So, I would suggest for suppose you select 2 3 sections from the experience and then simply you calculate this part alternative stress. Where is the alternative stress, is the highest that that will be the critical section and you calculate the factor of safety for that section, if it is the yield strength of the material what you have selected it is known if this f s is more than 2.5 then it is satisfactory 2.5 or more it is satisfactory.

Usually, you will find the problem in the output shaft because that is a separate material and medium carbon steel in our design also I have shown, later we change that from c 42 we change into c 45.

(Refer Slide Time: 36:22)

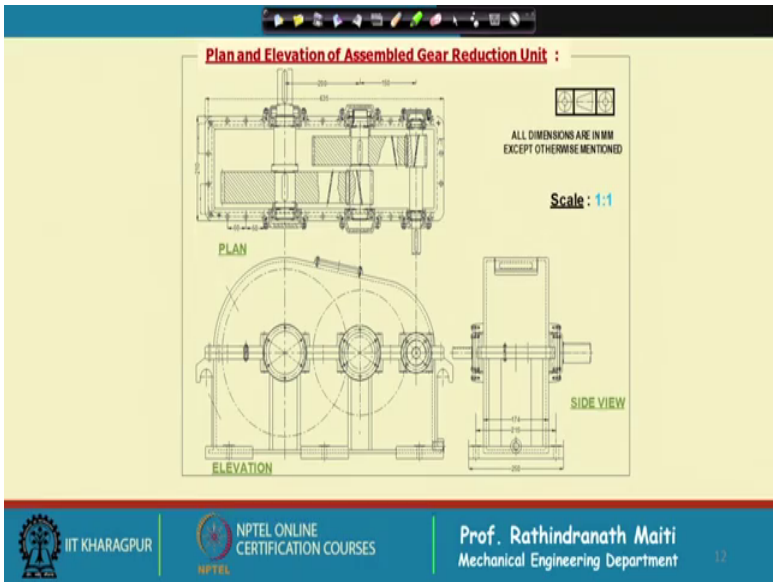


Then step 7 layout of the shaft sub-assemblies of all shafts then step 8 is full assembly plan view and top open elevation and side view step 9 detail drawing of all components and last step bill of materials and documentations. We have to make the report final report of the design calculation everything all documentation, that I would say that is the last step of the gear design.

So, within this 6 week lectures what we have learned that is we have just learned the basic of the design of the gears and a gear unit. How it can be designed and that to with respect to only helical gear, if we consider the bevel gear we will find new things how the loads on coming on the bearings?

How the loads are changing with the direction of rotation keeping the helix angle same? If we change the helix angle then it will be different. If we take the stress part it will be in one way and if we take the spiral bevel it will be different ok,

(Refer Slide Time: 37:29)



But, one thing you should remember if we go for say for example, if you take the first stage bevel second stage helical, then in that case it is better we should go for taper roller bearing. So, that shaft does not move this way or that way, because of the reasons contact of the bevel gear depends on do not allow the movement of the shaft in axial directions we have to keep it form. So, you will find normally that is with the taper roller bearing.

Whereas, if you go for completely helical gear you can do one side locked and other side keep it free. There are many many such issues which you will run through experience and by no means I, can give you all ideas through these lectures, but I only expect that after the 6 weeks of lecture 6 weeks of this instruction perhaps you have learned a little bit, how the gear is designed? How the gearbox is designed? But by no means I have given all the accurate say values of everything this is simply idea.

If when you will join in a company, if you work in a company then you will find they have more much more information's. So, following those information's you have do it even the you will find the formula is different that is given by some other the gear cutting machines, who are manufacturing the gear cutting machines they have proposed something ok. And material specifications also you may find that if you buy the material from country x, country y, for the same material it might be slightly different Heat treatment.

We should be very careful usually that is done by the other party ok. So, you have to give a observation that heat treatment has been done properly forging that has been done properly. So, many many issues are there by no means I can give you all it is not possible it is for your experience. So, this is only basic knowledge. Now there are 2 others weeks now 7th week we will learn little bit about the gear tooth corrections and 8th week we will learn something of special gearing.

So, I hope that you have learned a little bit about the gears at the by the end of this 8 week lectures you will have an idea about the design of the gears how it works and what are the some special type of gears. So, I thank you for your attention to the gear unit design I have completed the gear at unit design with this lecture.

Thank you once again.