Gear and Gear Unit Design: Theory and Practice
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Lecture - 25
Design Verification of Output Shaft

Welcome to everybody. This is Module 5 that is design of general purpose industrial helical gear reduction unit this is part 3. We are continuing with that and this is lecture number 25, where we shall verify the design of output shaft this means that. We have already developed the outputs shaft gear was designed bearing also we have found out the bearing loads we have verified or those.

However, the shaft as I told that has been designed constructed looking into the bearing position and gear position in between that what should be the step of this shaft etcetera etcetera. Now, we need to verify whether that diameter is satisfactory or somewhere, it is over design in that case we have to reduce the size if possible.

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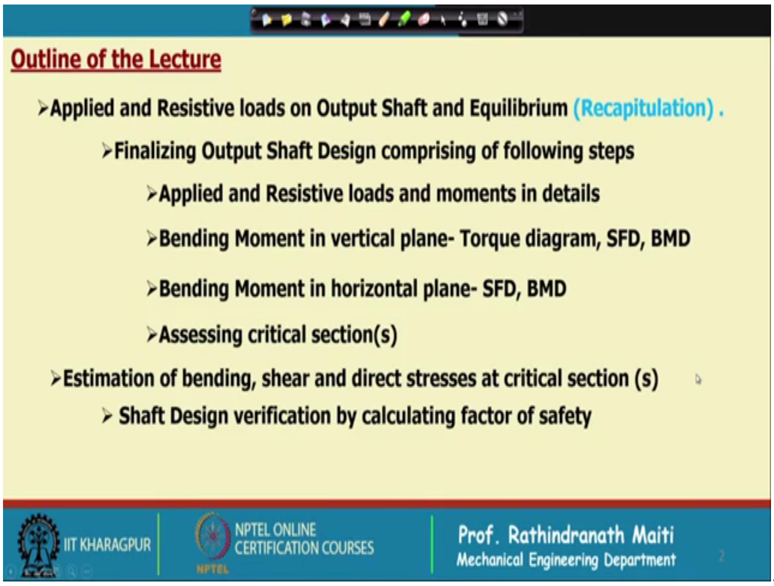

Now, outline of this lecture is that applied and resistive loads on output shaft and equilibrium resistive means the reaction loads, which is also called as reaction load, then finalizing output shaft redesign comprising of the following steps.

So, applied and result resistive loads and moments in details we will consider, then bending moment in vertical plane torque diagram shear force diagram bending moment diagram. Then bending moment in horizontal plane shear force diagram bending moment diagram again, assigning critical sections that we have to find out which one is critical.

Then that for that section estimation of bending shear and direct ration explicit at that critical section, which we have assumed it not necessarily we have assumed 1, it might be among the 2 or 3 sections one of that will be critical. So, that first we have to verify. Then shaft design verification by calculating the factor of safety over the yield strength, this means that what is the stress developed for maximum stress developed in that shaft it is in proportion to the yield strength we have to find out a factor of safety.

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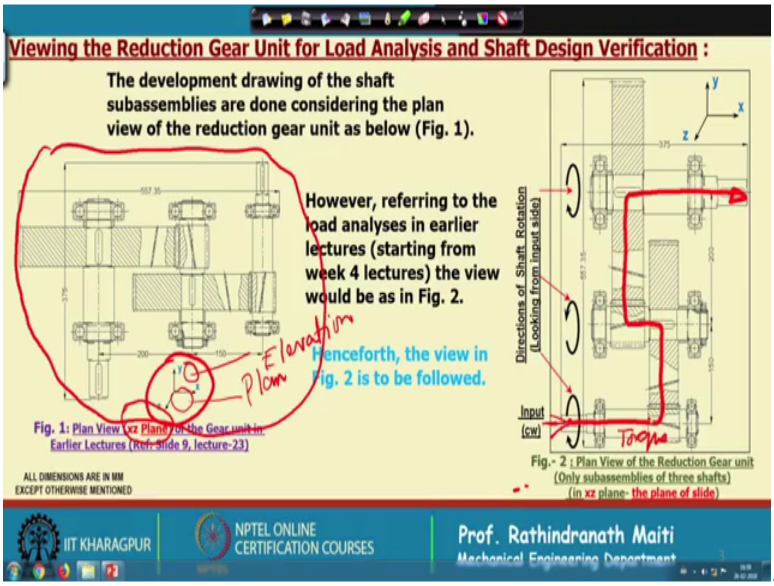

Now, another issue I would like to discuss. Now I axis system is shown this is the axis system. So, this is the axis system x y and z ok. And as you see this figure drawn here it is in x z plane, because this is we have developed the plan view. So, it is in that plane now; that means, this is for plan and this is for y x will be elevation.

So, that is not much a problem to visualize ; however, the when we started lecture week 4 lectures in that case we consider the intermediate shaft, you can say that detailed load calculations etcetera on the intermediate shaft that was done. And in that figure we considered the intermediate shaft. So, that it was in the pinion was in the left side and gear from the first stage one was in the right side. And the pinion from the pinion the torque was entering into the intermediate shaft gear from the bottom ok.

Now, then while we are developing without considering that part, we first developed. So, far what I was showing that this was the drawing we developed, but now I would like to come back to the original concept that intermediate shaft though which we designed and we will now erase the gearbox again in that way. So, that it becomes easy to understand what are the loads acting and flow of torque etcetera etcetera. Now in that way we have redeveloped or modified the figure into which is shown in the right hand side.

Now, here what we find that this is the input this is the input and this input is from in clockwise directions ok. And this is the input and it is rotating in the clockwise direction right and then the helix angle here, that what we consider this was the left hand helix no this is the right and helix and then here is the left hand here is the left hand and then again tigh10 helix through that we have we are transmitting the load to the output. If we consider the torque flow torque is flowing like this and then this is the output. So, we can say this is the torque now as this is important.

Because as we have considered that this is rotating in the clockwise directions and here the helix angle in the pinion for that the axial load will act in one direction, but if we change either the direction of rotation or the direction of helix then this will be opposite.

And that affect the load on the bearing. So, in design we should consider very carefully and we have to ultimately finalize the design on the basis off in which way the bearing shaft etcetera is experience more load or more stress is coming on the shafts and on the bearing and the radial and axial loads are more that will be shown during the calculations. So; henceforth for the remaining lectures and; we shall consider only the feeder 2 ok.

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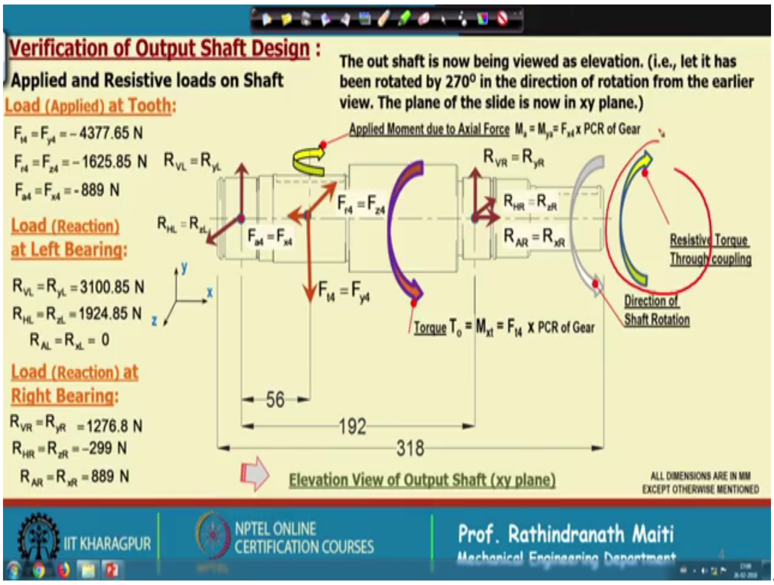

Now, this again if we look into this that now we have taken the elevation part. Elevation part means we are looking the gear everything from the z direction and putting into the x y plane ok.

Now if you look this figure very carefully that what is the key way was here now it has become here ok, because that we have rotated, but we have rotated this shaft in the direction of rotation. So, that is why I have written as if we have rotated the shaft by 270 degree to see this view it could be shown also that the key is here it will not matter much, but still I have tried to put this figure in such a way that. So, that everybody can understand.

Now, so this is the elevation as you told now if we look in from these directions as I told that this is the output shaft and output shaft, if I look from this side that is rotating in the clockwise directions this is this will be shown here after a moment. So, and if we consider that this load was somewhere here ok, because this is rotating in the clockwise directions. So, we are pushing the gear downward that as if the contact was away from these slides and this gear is being pushed downward and therefore, load it is shown like that.

And obviously, the radial load always will go to the axis this means that it has this from this point to it is going to the axis from the top to bottom, we can say the to the centre point and that is why it is shown in this directions ok. And if we consider say this is the direction of rotation and tooth was like this the helix, that it is that right hand perhaps and for that axial force will be in these directions ok.

So, we have assigned the load at that point this is the centre point of the gear. This means that on the x axis this is the centre line and if we divide the width of the gear in 2 parts this point will arrive. So, we have put the load there; that means, from the contact point now we have transferred the load to that point.

Therefore, what will happen as already explained that as load is being transferring? So, that will create a moment, now definitely F 4 will create a moment around the x axis, which is nothing, but the top and radial force as this is passing through this point. So, this will not create any moment apparently except about the bearing which is nothing, but the bending moment later it will come.

And axial force when we transfer directly this will the magnitude of this force will remain same at that axis now that we will create a moment about this vertical axis, which is shown here about this axis. Now that moment we can say this torque is applied also and my torque is moving on this shaft that will not give any reaction to the bearing whereas, this moment will have reaction on the bearing. So, we should consider this node very carefully.

Now, next this moment is it is it is nothing, but the axial force into the pitch circle radius of the gear. Now for that we have the downward force. So, definite downward force the tangential force and that will give a reaction at the left bearing in the upward directions; that means, this reaction load is coming from the bearing, which is in the upward directions that we have designated as this is in the vertical plane.

So, this is R v l and this is in the plane of the slides and as it is the in the y directions. So, we have also can call it R y l ok. And then for the reaction load we have the reaction here in the opposite directions and that is in the z direction that; obviously, not the full half of that these 2 bearings.

So, we are considering the here actually this would be left hand bearings. So, yeah it l for left l for left are for reaction l for left z x z y is the axis and v is for vertical, h for horizontal plane right.

Next if we consider the other end bearing; that means, this is right hand bearing. Then in that right hand bearing, we have the vertical load R v R R y R in the vertical directions and we have the radial lode in the R h R R z R, but here as you if if you look this very carefully, if you observe that this direction of this force and direction of this force is the same.

This I have put in actual direction is acting, but how come this is. So, this is quite interesting that if we consider this moment this moment in the horizontal plane, if we consider only the moment suppose we have applied one moment. Then definitely how this moment will be balanced that has to take a load by the bearings.

So, and this is a couple load. So, this couple will be resolved, one will be depending on the direction of the moment, one will be in the above from this boat another will be inside the boat. So, that will be distributed among 2 bearings. That is why ultimate resultant in the right hand side it has come in the same direction as in the direction of radial force.

So, these are to be calculated very carefully right direction of rotation is also shown and the torque. Now this torque has a told as it is being pushed downward. So, torque is going like this and then definitely we will find that reaction centre; that means, here is a coupling here is a unit this is the in machine is connected through the coupling.

So, that is rotated in this directions looking from this clockwise directions, but definitely it is having the torque it is having the load torque in this directions. So, if we think of the torque it is stacking from this point to it will be transmitted and the torque is like that ok. So, I think this not difficult, but sometimes it is brain teasing which one should understand this very carefully.

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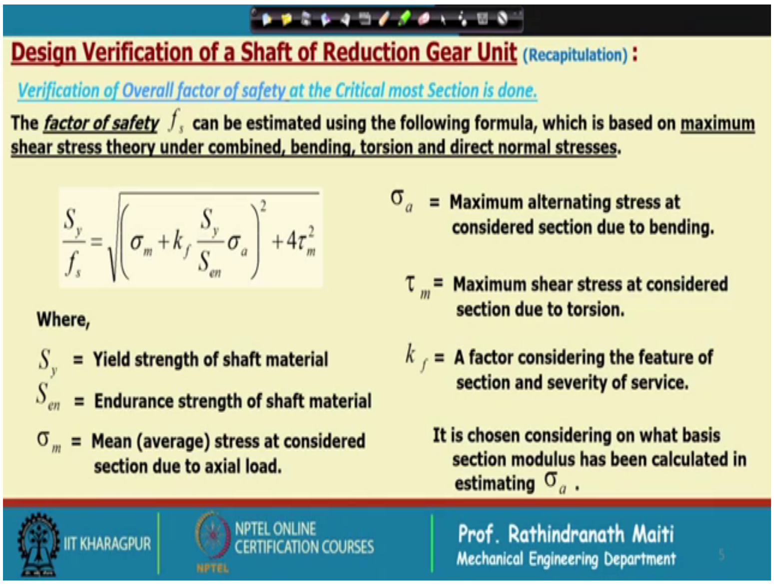

Make next verification of overall factor of safety at the critical most section is done; that means we will do that. Now first of all if you remember that in week 4, we verified the design of the intermediate shaft. We also very I mean we verified the factor of safety there, the same way we will we shall verify the factor of safety here also.

Now this factor of safety that is it is given by this formula, this is based on the maximum shear stress theory and the nomenclatures are as follow. So, I am not repeating as already we have discussed earlier. However, the k f factor we have to choose this k f factor very carefully, because this depends on the section particular section, which we have considered, what is the stress constant concentration there or what is the dynamic? And both we have to consider the nature of dynamics load there as well as the stress concentration factor is there ok.

So, now for this formula we have to calculate the other part. It is chosen considering on what basis section modulus has been calculated in estimating sigma i. So, this means that k a factor not only the load and stress concentration, but also that suppose there is a keyway, but while we are calculating the area moment of inertia we neglect that small area. So, for that some factor must be there ok.

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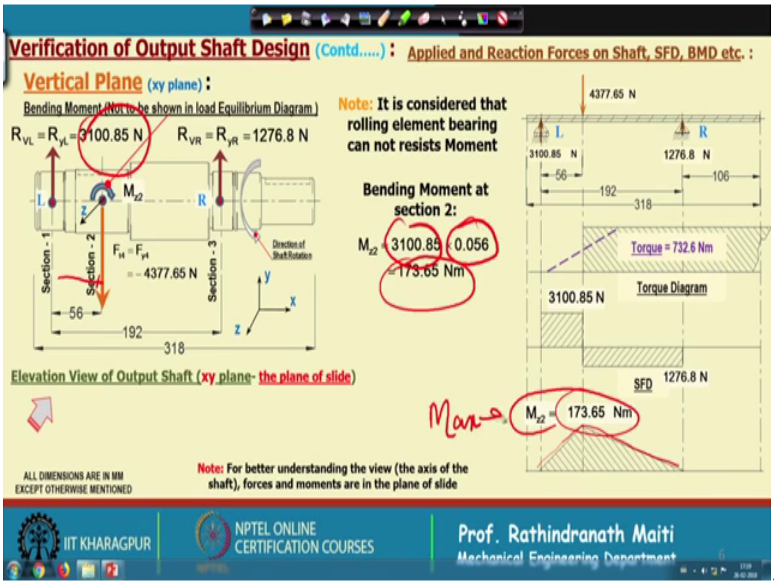

So, that we should follow very carefully, now this is again I have shown that in the vertical plane what are the now the reactions are acting on the shafts.

Now, here I would like to mention that on the shafts, now if we consider only one plane vertical plane there is one applied load for a because there is a single gear and 2 reaction load at 2 bearings. If we consider that only on that basis we can calculate everything, but here what I have shown this also what is the; bending moment that will affect on the shaft, but we should remember then equilibrium diagram this bending moment will not come.

Bending moment is the inner action inside the shaft, which developed the stress it is resistive, but we need not add this to here for the equilibrium of this force equilibrium of the shaft. For the force acting equilibrium this 3 force 1 2 3 at left bearing right bearing and at the centre of the gear is enough. I have shown there their magnitude also directions positive value means it is in the positive directions and negative value of this means in the negative direction; that means, what the axis we have considered on that basis only.

However, while we are drawing the bending moment shear force we may not follow only thing we have to follow that if we come from one side to other sides we should follow one convention only ok. For developing shear force bending moment diagram, I have drawn a very simplified things remember that this bearing say ball bearing we have used ball bearing is not a spherical bearing; that means, if we put a shaft axial inside that bearing and if you try to rotate it will not rotate.

So, in true sense we should consider that as a rigid be a rigid support, but only that can rotate of course, above the x axis, but because this is vary, but for small deflection of such shaft. We can consider that is a simply support that is for the simplicity of the calculations, but due to that error is negligibly small, because all such bearings that can take small spherical actions; that means, this axis in the x x direction shaft and that can rotate about the say y axis or maybe you can consider the z axis a little bit.

Therefore we can consider this is a simply separator and say as you know in the simply supported beam, I have presented here this simply supported beam like this here is one support here is another support. Now in earlier design as we told that load at the bearing, near the gear or near the pinion will be more than other sides while we are resolving this force.

Therefore, intentionally we make the arrangement such that the axial load is taken by the far end bearing, where the radial load and tangential load components will be less. So, in that way I have shown here as if this is fixed this is does not mean it all axis are fixed this is only to present the simply supported beam, but this at this point this shaft cannot move or beam cannot move this way or that way along the x direction it cannot move.

Whereas, on the other hand it is on the ruler so, this can move left words or right words right dimensions are also given and then we have shown there the load in the vertical plane. And then finally, first we have shown here the torque diagram this is the torque.

Now, in the torque diagram as if we are showing that as earlier we told the torque is entering like this and it is going out right. So, here also torque is entering here and it is going out. So, this magnitude some magnitude, we have taken in a scale and you have shown, but truly speaking this torque will gradually increase to way point, this is the width of the gear and if we consider the uniformly distributed load it will gradually increase and then it will move in this directions.

This torque diagram here we have ended it like this, because the torque is being transmitted to the output shaft, this is just to have an idea what is the torque is coming on the shaft; that means, if we consider from this portion to this portion then we have to consider torque. If we would like to consider the left hand side then probably we can reduce the amount of torque proportionately in this form.

Otherwise we can consider that full torque is acting on this shaft from this point to this point right the bending moment diagram. In this case if we consider the strictly this axis conventions probably this may be a little different, but the general convention is that if the load is coming from the top and support is from the bottom.

And then in that case the shaft will (Refer Time: 24:53) bend like this and for that we will consider that this is the shear force diagram; that means, we will consider from this point left point and then it is in the upward directions the magnitude same magnitude is it will come here. It will come up to this point and then it will drop down by 4 3 7 7; that means, this is an up to this point in the negative directions. And then it will again it will go on and there it will go off and this magnitude is shown here.

So, this bending moment diagram edge in the beginning of this course I believe that you have the idea how to develop the bending moment etcetera of this. So, here we have developed this bending moment diagram right. Next the moment bending moment for bending moment calculation for trace such a simple case this we shall simply consider the any load and up to the mid-point, because this is clear that the bending moment will be maximum.

What we have done here, we have considered the late load this one and then this distance this one and we have got this bending moment is about this much. And then this car become very simple here will be the maximum bending moment, this is we can say maximum bending moment right.

So, we know the vertical plane what will be the bending moment what is this shear force and torque. Now again we repeat that why we are doing in this horizontal plane and then vertical plane, then horizontal plane. The reason is that this force is acting resultant force is acting not in the same plane these are at different plane. So, if we had to calculate the if we had to present the bending moment it is very difficult that this bending moment curve will be twisted and that can cannot be present in this plane of paper ok.

So, 3-D view is required for that and to make it very simple because our concern is that we will calculate the maximum bending moment. So, we have developed into two different planes. So, this is bending moment diagram.

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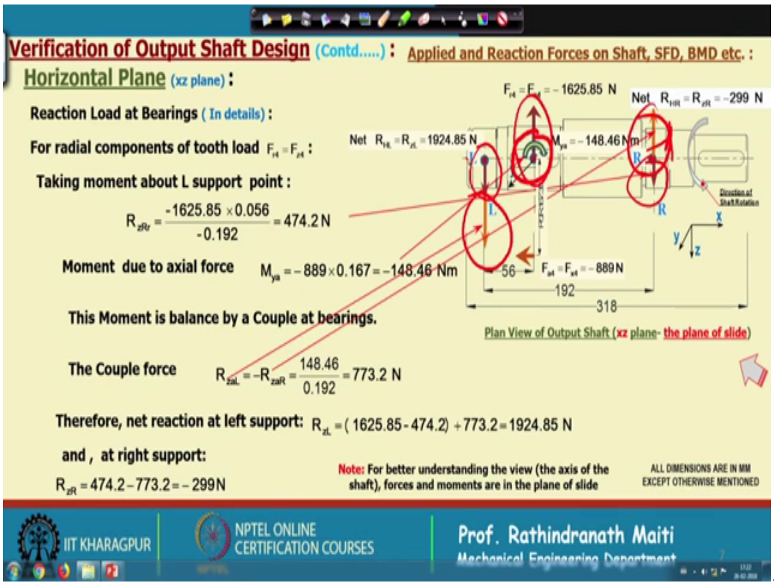

Now, we shall we have considered the horizontal plane. Now in this horizontal planed, this radial load is shown here this is the radial load acting on the shaft and due to that the components are this is the radial load. So, component for that load is this true that we have calculated earlier. Now, there is a coupling also this moment is acting as the moment is acting over here due to this moment we get a coupling force here at these two points. Now, this is the taking the moment about else of what we have calculated this one first this one this is the component of this one ok.

Now, we have considered the moment which is acting over there due to the axial force now this will be resolved into this is balanced by a couple and that couple are calculated one is in this direction and one is in this directions. Now, as if we look into the magnitude this magnitude is more than this and that is way resultant and tilde that will be in these directions only.

So, this means that in these 2 bearings that reactions are in the opposite direction and here is the final force, but how then this shaft is balance shaft is in it is position or balanced because of the reason there is a moment also there is this moment, we can consider that life moment due to the axial force that also you should understand very carefully ok.

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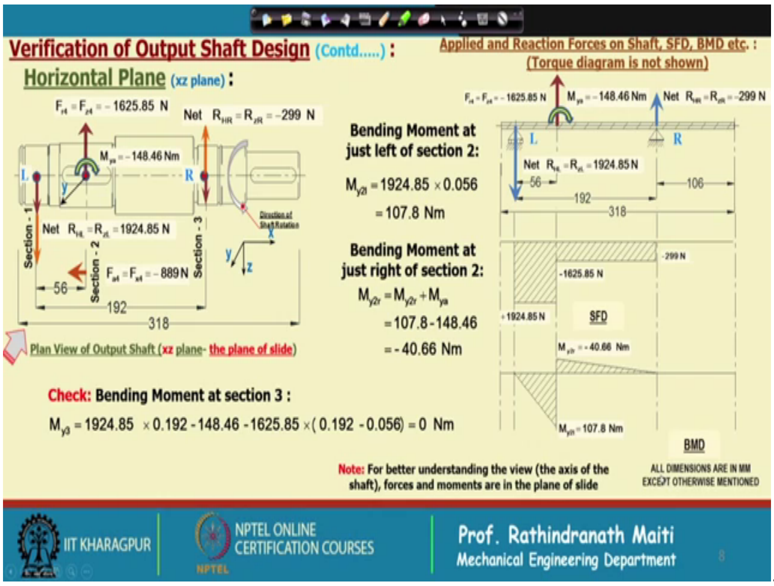

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So, we will now in the horizontal planed the shear force diagram is shown importantly the torque diagram is not shown, we have directly shown the shear force diagram. And in that case as the load in the downward directions we have drawn in that way, but this any convention one can follow; suppose the for this horizontal plane one convention and for vertical plane is another conversion that really will not matter as long as we calculate only the maximum effect, but that if we resultant and from there if you try to find out the resultant directions, then there will be mistakes, but we are not much concern about that part.

So, this is the shear force diagram and if we consider so, bending moment had just left section of 2 we will calculate this force. Now you should remember in this case the another force is added. So, you will find that bending moment is higher than a single load type and we have calculated this one. And then bending moment at the just right hand side of the section 2; section 2 means here this is the section 2 and then we find that here this bending moment is coming up to this point and from there it is going off and then it is again there.

So, what is the maximum bend bending moment if it is asked? Shall I consider this point or shall I consider at this point. Actually at that point the bending moment is such that we need to consider the whole value of this bending moment; that means, this much is the bending moment there which is acting on the shaft. So, that bending moment need to be considered to find out the flexural stress in the shaft. So, again we have shown this calculations.

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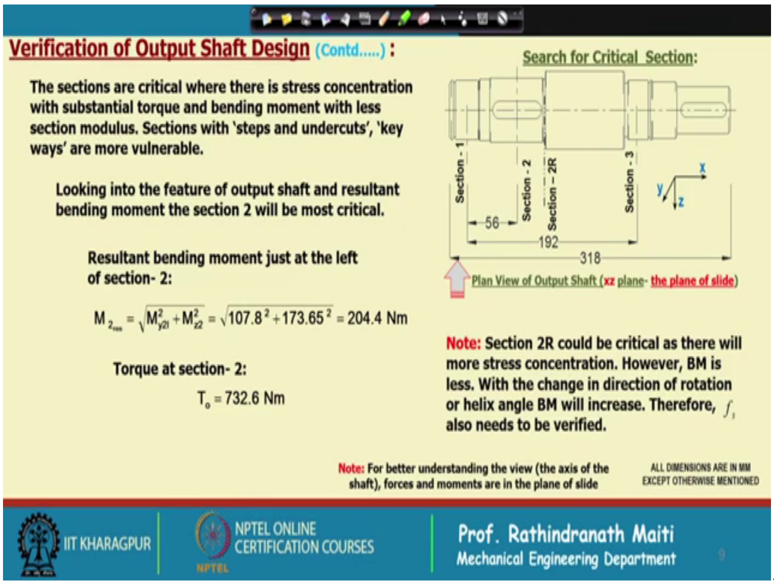

Now, the sections are critical where there is in each stress concentration with substantial torque and bending moment with less sectional modulus, sections with steps and undercuts keyways our more vulnerable.

Now, in this particular shaft if we look into this that here we have the back maximum bending moment at this section as well as there is the keyway and diameter is less than this side diameter of course, and bearing the dimension meter will be less, but if you think of that for such a simple case that here is 1 load 2 bearings 1 load and at the middle 1 load and there is the maximum moment no doubt about it that section will have maximum stress; that means, that the outer fibre of that it will be stress maximum stress as well as there is torque also and, but that is in the form of flexural because this shaft is rotating.

So, we will calculate that part of that section we need not check other sections which one will be critical. If we consider the section 2 R where is the there is a stiff down at that point the moment is relatively less; however, that that section could be considered, but the keyway is not extended up to that point. So, stress concentration if we this consider it will be less then where is the key way of course, in this drawing they are very close together.

So, one can verify both the section at the undercut moment will be slightly less diameter is also slightly less or the stresses and the stresses in the mid-section here right. Looking into the feature the output shaft result in bending moment at the section 2 will be most critical and therefore, we are considering this.

Now, there we are calculating the resultant bending moment. This resultant bending moment nothing, but the what is the bending moment in the horizontal plane and what is the bending moment in the vertical plane? And resultant of that which we have shown here and the torque also present there 732.6 Newton meter truly speaking, that where this the undercut is there section 2 are there torque is maximum torque is maximum, but moment is less on the other hand on section 2 torque will be half of that and moment is maximum.

So, I think if it is for careful design one should calculate both now here I have written section 2 R will be critical as there will be most stress concentration. However, BM is less with the change in direction of rotation of helix angle b m will increase bending moment may increase. Therefore, f s also needs to be verified. Now this means that if we as the key way is very close to that, but if keyway is apart from that probably section 2 R will not be that much critical.

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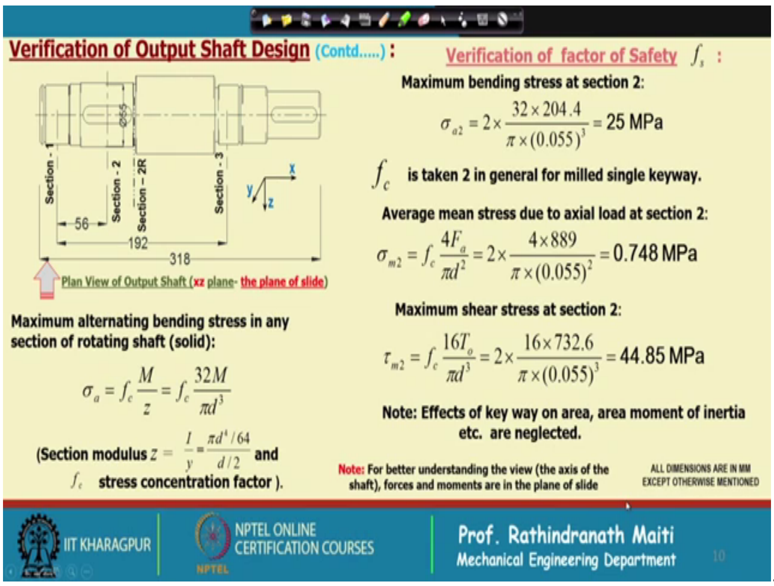
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Now, the verification of the factor of safety in that case we know this formula the sigma a is equal to M by z z is the section modulus more popularly M y by I and f c is a factor that we have multiplied with to calculate this frictional stress.

Now, here again I would like to mention that while we are calculating bending moment etcetera, we have considered the nominal torque not the torque multiplied by some factor, because separately we are multiplying this factor of safety each and every section calculations.

So, that is why it is like that clearly the frictional stress it is calculated it is not much 25 mega Pascal's diameter we have taken 55 millimetre and f c is taken 2 in general for milled single keyway this 2 factor 2 we have considered as it is a milled keyway way. And average means stress due to axial section also we have considered the factor 2 and that is very nominal 0.7 4 8 MP a, that is due to the axial force there will be direct stress on the shaft.

And then finally, torque from the torque we have calculated that 44.8 5 mega Pascal is the shear stress there that is the maximum their effect of keyway on area moment of inertia etcetera neglected and that is included in the factor of safety you can say.

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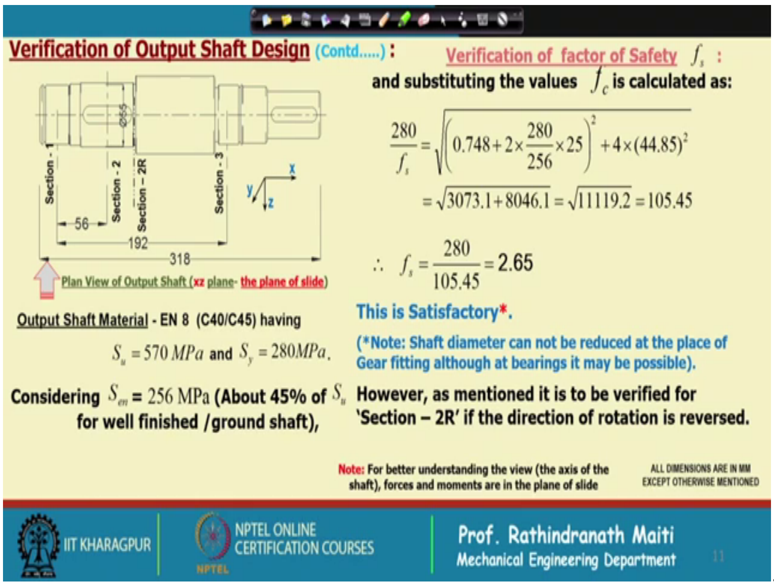

So, material of this shaft is EN 8 that is C 40 or C 45 according to Indian standard EN 8 European national standard and for which the endurance strength we can consider. If it is not given we can consider that this is 45 percent of the ultimate strength and then substitute all the values we calculate the factor of safety, which has become 2.6 5, if you remember the intermediate set it became around 12, but here it has become only 2.6 5 where a very I mean value is it should be minimum 2.5.

Now, here I think you will understand that why we took the larger diameter although the bearing life was higher, but still we are not compromising with the size of this shaft the because of the reason that the factor you can see that it has just satisfactory.

So, we would say that shaft this is satisfactory just satisfactory I would say shaft diameter cannot be reduced at the place of gear fitting although at bearings it may be possible. Now one possibility is that keeping that gear sections intact that is 55 millimetre and the bearing section what we have taken 50 millimetre we can reduce that to 45 millimetre as well and we can choose another bearing maybe, in this bearing from the same series or maybe from the lower series and for which the bearing life will be less, but still it maybe more than 10 000 what we wanted and in that way slight modification of this design can be done.

That for that we need not go for the calculations. So, thank you and in this section we have completed the design of the outputs shaft all the further we have to take a decision, whether we can reduce the diameter at the place of bearings.

Thank you once again.