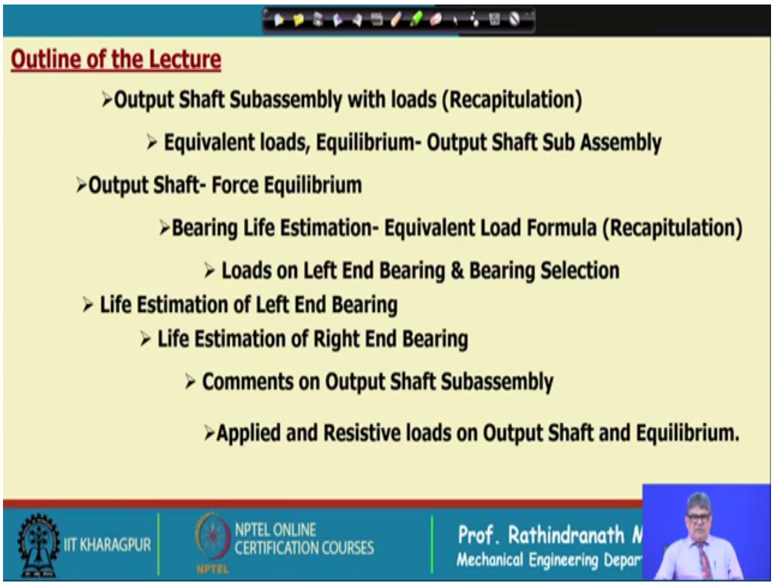
Gear and Gear Unit Design: Theory and Practice
Prof. Rathindranath Maiti
Department of Mechanical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 24
Output Shaft - Bearing Lives

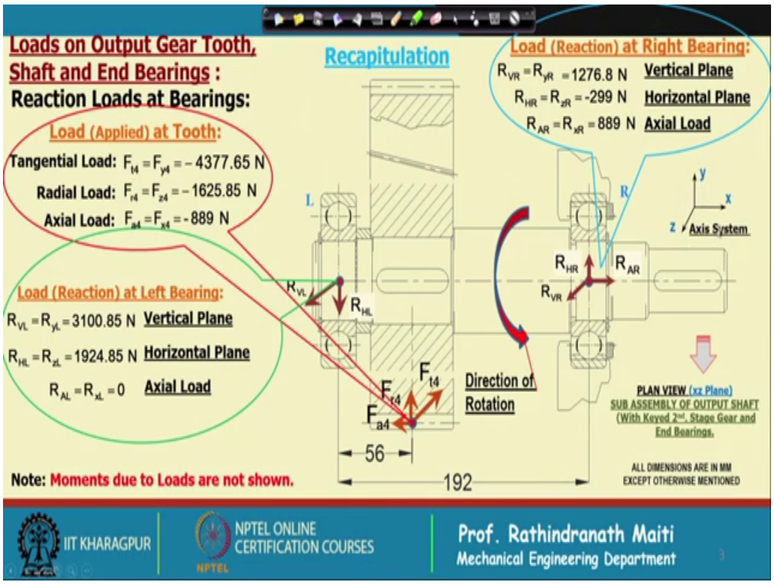
We are continuing with the design of general purpose industrial helical gear reduction unit, this is part 3 and the lecture is being developed in the week 5. In week 5 and this lecture is, lecture number 24 where we will consider the output shaft bearing lives etcetera.

(Refer Slide Time: 00:47)



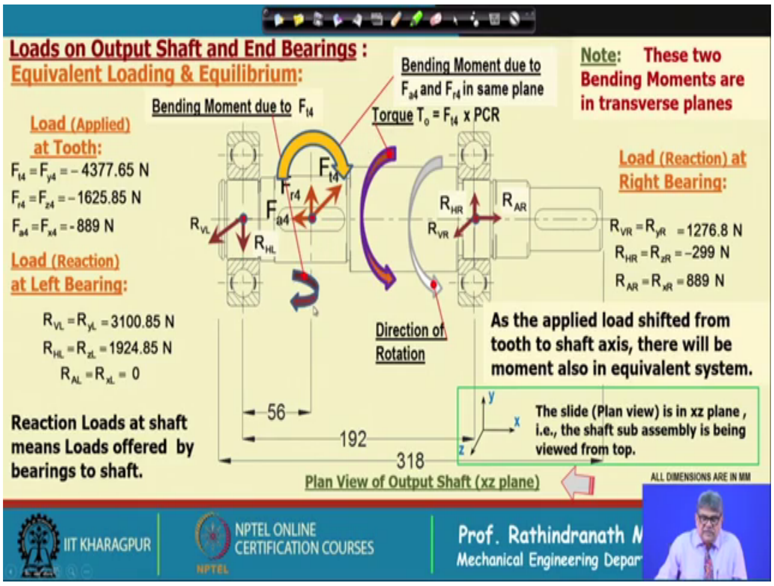
Now in this lecture we I shall cover outputs shaft sub assembly with loads that we already developed, equivalent loads equilibrium output shafts sub assembly, and outputs shaft force equilibrium then bearing life estimation equivalent load formula we will recapitulated and loads on left hand bearing and bearing selection, and then life estimation of left hand bearing and life estimation of right hand bearing, then and we will make some comments on output shafts sub assembly. And also obviously, loading there and then an applied and resistive loads on output shaft and their total equilibrium.

(Refer Slide Time: 01:43)



Now, this already we have developed that what are the force acting on the shaft here it is shown that load acting at the gear, contact point and the load offered by the bearings and the direction of rotation. No moments have shown here and we should remember that this is in the plan view it is in x z plane whereas, the axis system is that; that means, vertical axis is a vertical plane is the x y plane ok.

(Refer Slide Time: 02:30)

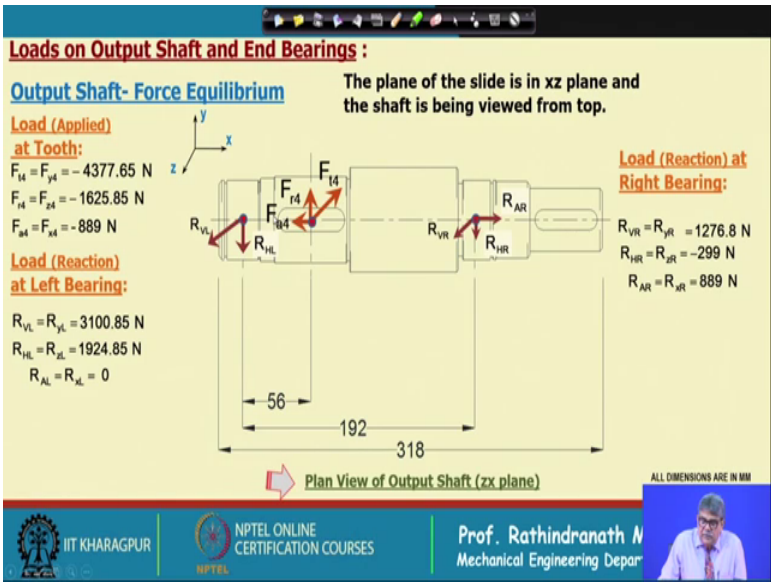


Now, equivalent loading and equilibrium that we have to consider first; now in this slide plan view is in x z plane, this shaft sub assembly being viewed from top we are looking from the a top and then this load already we have shown what is the load diagram.

Now, this load we are moving shifting toward the axis this is the equivalent plan to find out the equivalent plan. Now due to that then we will find that right hand left hand forces are like that. Now as we have shifted the load there definitely to total balance for this shaft, there will be some moment also acting on that not the bending moment, bending moment is different that is acting inside the shaft ok.

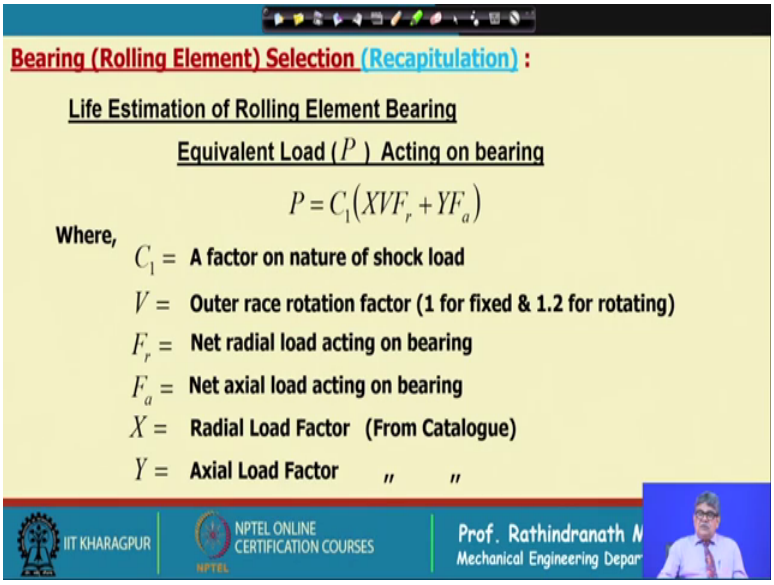
So, here also the direction of rotation of this shaft is shown, reaction loads at shaft means loads offered by bearing to shaft. As the applied load shifted from tooth to shaft axis, there will be moment also in equivalent system, which I have mentioned already mentioned and the dimension is (Refer Time: 04:11) is 167.35 millimetre which is 0.16735 millimetre. So, there will be torque that torque is shown here, but the moment due to this axis is also. So, this is the bending moment, which shown here F t 4 due to this vertical forces tangential force and their bearing reactions and there will be also bending moment due to the F a r and F r 4 in same plane, all these are acting on this shaft and these two bending moments are in transverse plane, we have to see this and this not in the same plane.

(Refer Slide Time: 05:15)



Now, consider only the force and outputs shaft force equilibrium we are considering. So, in that case clearly, that this three set of force at the gear it is on the axis, we this force we are considering it is acting on the axis of the shaft that is applied force F d r F r 4 and F a r 4 and also this is expressed in terms of F y 4, F z 4 and F x 4 and all are in the negative direction such seen in the left hand side top corner and then reaction force at left bearing vertical loads are there and as well as horizontal forces are there, these loads are being offered by the bearing to the shaft and in the right hand side there are three forces one is horizontal direction one is vertical directions and also axial directions, because axial load is being taken by the right bearing.

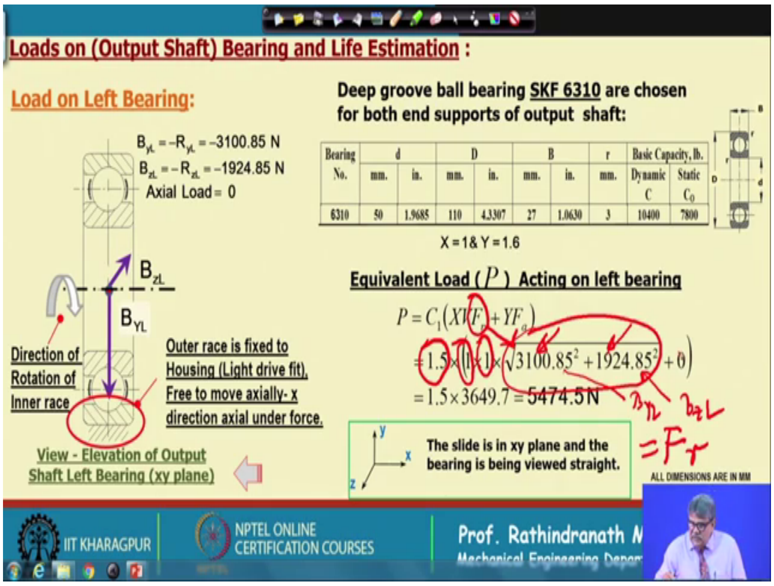
(Refer Slide Time: 06:38)



Now, this is this plan view has in x z plane, that is to show it and now we recapitulate how the equivalent load on the bearing is calculated because the next we are going to calculate or going to estimate the lives of the bearings. So, first of all we will estimate the loads on the bearings and then we will estimate the life. So, first of all we should know what is the equivalent load acting on bearings, that already in week 4 lecture we have described, but very briefly we will go on that that P is the equivalent load on a bearing, where C 1 is a factor which depends on the nature of shock loads and V is the outer race rotation factor, one for fixed and one point two for rotating outer race.

Now, in this case our outer race is fixed. So, we will consider V is 1. So, as well this equation can be considered as P is equal to C 1 into x F 4 plus Y F a eliminating v times totally. F r is the net radial load acting on bearing, this F r do not confuse this F r is now on the acting on the bearing, which is F for the force r for the radial direction. Similarly F a is the net axial load acting on bearing and X is the radial load factor which to be taken from the catalog while will choosing the bearing and y is axial load factor which is also from the catalog.

(Refer Slide Time: 08:28)



Now, first of all we will consider the left bearing on the left bearing this slide is on x y plane.

Now, we have considered this side is on the x y plane; that means, we have considered the vertical plane and bearing also we have considered in the vertical plane because this will be easy to visualize that how the loads are acting. Now this elevation of the outputs shaft left bearing is on the plane of x y plane. So, in that plane the load acting on the shaft which we have shown earlier. So, on the bearing the loads will be opposite on bearing the load the one load is acting in downward directions this is in along the y axis and it is the negative sign as it is acting in the negative directions and this is B stands for bearing load and the horizontal load is acting in the z directions this is also negative z directions.

Now, we have chosen a bearing; a one size higher than the intermediate shaft I already shown I have already shown that the selected bearing is having life in the intermediate shaft having life more than 20 hours, which is double what we are expecting probably there it could be taken the bearing 6308; that means, 40 millimetre their bearing inside their bearing and probably here we could take the 630 945 millimetre bearing ok. Now there are two issues one is the bearing life in some cases, we may find whatever bearing we are using in the intermediate shaft this same bearing can be used for output shaft also. Because in output shaft the r p m reduce very much because usually in the second stage ratio will be more than 4.55 in normal cases may be 6 or even more.

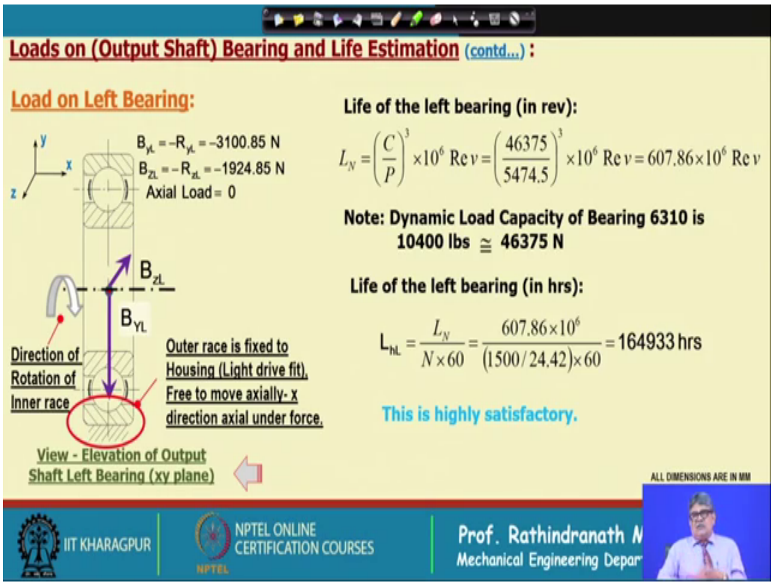
So, speed will be reduced all the load is increasing, but that load what is coming on the shaft that load is nothing, but what is the load on pinion on the intermediate shaft only direction will be opposite. But usually in usual practice you will find the bearing of the output shaft is one size higher than at least one size higher, then the intermediate shaft may be series is different. The main reason is that we need more shaft diameter there to transmit the torque because it is not usually taken the hollow still usually it is taken off mid medium carbon steel to reduce the cost. However, in this case we have taken 6310; that means, shaft diameter is 50 millimetre here it is shown and for which this ball bearing the x factor a radial load factor is 1; however, axial load factor is 1.6 and the direction of rotation is shown here.

Now, outer race for this left bearing this is not axially locked with the housing. It is axially locked with the shaft, but not axially locked with the housing because they are the radial load is high. So, this housing is fitted with light drive fit here I would like to mention the other end also it is with the light d drive fit, but it is constant to move in axial directions. Anyway this light drive fit why we have chosen because with the increase in temperature there will be thermal expansion also in coal country. After operation it will be cooled down there may have contraction of the shaft and then this bearing will move slightly right or left depending on the weather shaft is length is increasing or decreasing, although with mine very small and so that, it can easily move that is why light drive fit it has been taken light drive fit. So, bearing will have no axial load at all and then directly we calculate the equivalent load.

Now, here in this calculation, we have shown that first of all the raised or certain factor is 1 and x factor which is taken from the catalog it is also 1 and the C 1 what we consider for the intermediate shaft? 1.5 as it is there is a soft load medium soft load. So, we have taken it is 1.5, but remember while we can considering the gear design then we have taken that factor is 2 because of the reason, it was having also initial starting to higher starting torque, but that is very momentarily. Please note that for due to that momentary increased torque, there will be also changing this radial loads it will be twice, but that is for a moment. And if we would like to consider if you calculate with that load; that means, multiplying with two it is unnecessarily we have to go for large bearing.

So, it is justified or it is I think there would be no harm,, there will be no effect on the life if we consider carefully here 1.5 factor. But there is no new guideline, detail guideline for selecting this factor. Anyway here we have taken C 1 is equal to 1.5 and then F r this F r we have calculated as you see here that this is under root because this is the load in vertical plane on the bearing, and this load is on the horizontal plane that is here if we calculate this is B y L and this is B z L and resultant of these two is giving the F r for the bearing calculation. So, we have considered this one and finally, this axial load is 0 we have taken axial load is equal to 0 and that load becomes 5474.5 Newton the equivalent load on the bearing.

(Refer Slide Time: 17:01)

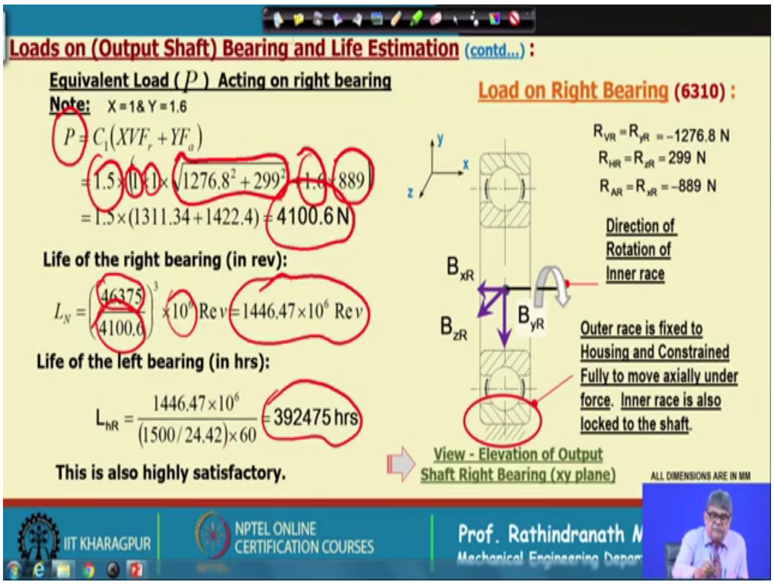


So, this is resultant radial load on bearing as we have already discussed. Now next we will carry on the estimation of life. Now life of the left bearing in number of revolution which is given by C by P to the power cube because this is ball bearing into 10 to the power that much million 10 to the power 6 revolutions. Now in this case the dynamic load capacity of the bearing which is 10400 pounds and that is close to 4637. So, sorry 46375 Newton 46375 Newton. So, bearing life is calculated on that basis and what we find it is very high 607.86 into 10 to the power 6 revolutions. But here if we want to estimate the life of the bearing in hours our output revolution is now 150 divided by 24.42 that is the total transmission ratio. So, this is n and this is in r p m.

So, this is revolution per minute of the output shaft and so, we multiply 62 revolution in hours and then we divide the life in revolution by that value to get this life is very high very high. So, this bearing will not fail, but still I would like to say we can may have to be with this varying because maybe we will require the shaft diameter, there we will discuss a after one or two slides, but this life definitely this is highly satisfactory.

However, we have to because the intermediates shaft is only 22 hours or so, but we have decided after everything ten thousand hours will go for overall when will go for overall it is recommended that all the bearings to be replaced. Even if this bearing is having life more life it should be replaced because with one out bearing and new bearing the life will drastically fall new of the new bearings. Only thing we can change the day this design and we can go for lower series bearing we will see that later.

(Refer Slide Time: 20:21)



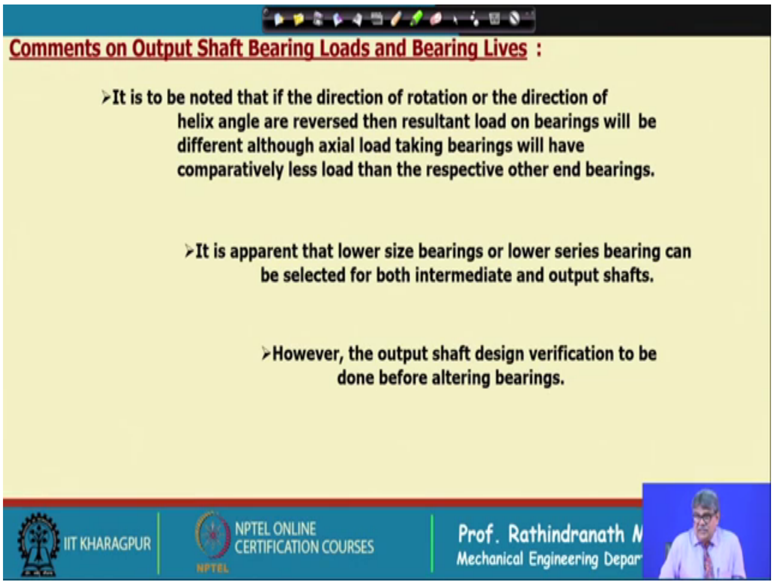
Now, equivalent load; so now, we will consider the right hand side bearing and in the right hand side bearing the same bearing there is also axial load is acting. So, this is what is the, this load what we have shown that is acting on the bearing ok. So, this is having the vertical direction load, horizontal direction load and axial direction load and this is the direction of rotation shown here and this is also shown that output outer race is fixed to housing and constant fully to move axially under force it cannot move any directions outer risk cannot rotate also inner race is also locked to the shaft.

So, inner race can rotate as there are balls rollers are there, but it also cannot move in any direction as it is locked with shaft and outer race is also looked and therefore, the axial load is acting there and the equivalent load estimation, what we have done? We have considered this resultant radial load, radial load to the bearing and here this V factor here this x factor here the C 1 factor and then we have considered y from the catalog 1.6 and the axial load in this case only the magnitudes are to be considered.

Finally, we find this load is 4100.6 that is 4100 Newton that is acting on that bearing which is P equivalent load ok. Now next in the life estimation of the bearing again this we have considered the allowable dynamic load capacity we have considered the equivalent load P and then it is 10 to the power 6 revolutions who we get. So, it is again higher than the left hand side bearing.

And life in hours as you see that, that has become very high and this is also satisfactory.

(Refer Slide Time: 23:45)

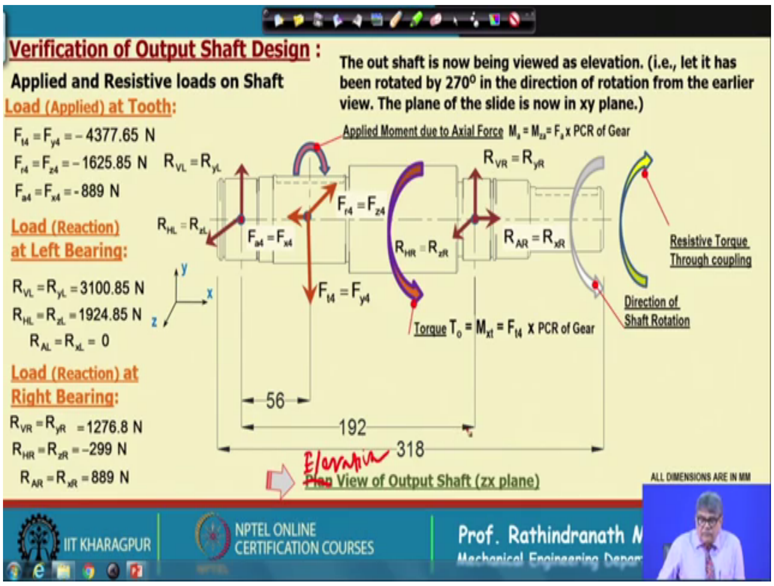


Now, here I would like to make some comments on this. So, far analysis on the output shaft we have made, now it is to be noted that if the direction of rotation or the direction of helix angle are reversed then resultant load on bearing will be different although axial load taking bearing will have comparatively less load than the respective other end bearings.

So, this means that if you change the direction of rotation, then moment due to the axial load will change although for the same torque the radial loads on bearings will remain same. This is one or else keeping the same direction of rotation now if we change the helix direction of helix angle in that case also it will be otherwise.

So, if the bearing life is found to be less it is very close to that what is being expected, then we should check for both we should consider both cases and we should verify the life of the bearings. But in this case as the life's are very high we need not calculate except if we consider the other series bearing which I mentioning here. So, it is apparent that lower size bearings or lower series bearing can be selected for both intermediate and output shaft. Here again, I mention about the intermediate shaft and however, the outputs shaft to a design verification to be done before altering the bearings if you would like to change the bearing at all, first of all we should verify the shaft capacities torque capacity and stresses on the shaft and then we should go for altering the bearing.

(Refer Slide Time: 26:09)



This means now, we should verify the design of this shaft. So, for that we will consider the shaft only and we will check that what is the load there now here again what we have done the output shaft is now being viewed as elevation let it has been rotated by 270 degree in the direction of rotations, what we have considered from the earlier view the plane of this slide is.

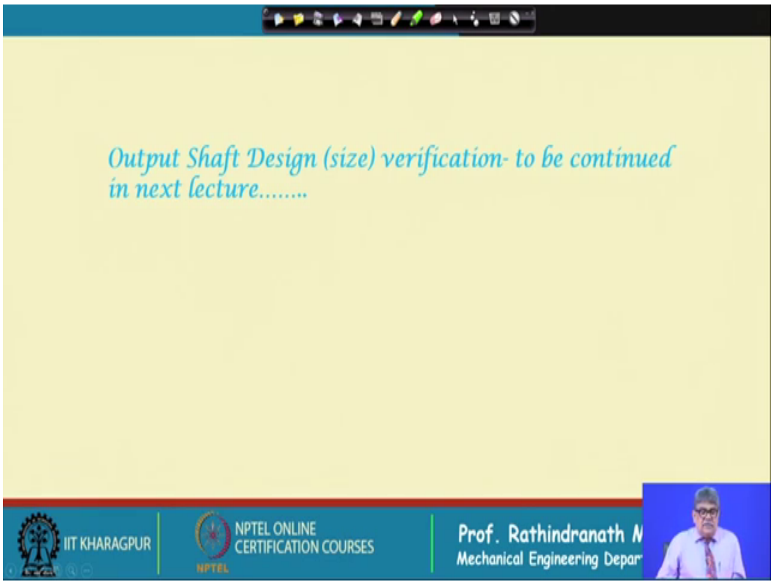
Now x y plane now this shaft so, far we are looking at keeping the shaft on the x y plane. Now what we have done as if we are looking into looking in the vertical directions looking straight to the shaft and in that case as you see this key has come here, here is also the key has come here anyway that is not that important but now, we can say that plan view of output shaft is in the z x, z x plane plan view, but this is in the vertical plane.

So, this is basically now the apply applied moment here, this is being shown here these are the load and so, this is the bearing reaction at the left hand bearing and this is the load at right hand bearing and direction of rotation is shaft is this one, and this is the applied torque and this is the reaction torque resistive torque that is from the coupping from the coming from the coupling; that means, this is coupled to the machine for which we are which we have made this gearbox.

So, if you now look into this resistive torque and this torque in opposite directions, all the forces are in opposite directions. However, do this moment for due to this is taken by the couple which is added to these two forces.

So this is in the radial directions in the z directions and this is actually not the I would like to mention here this is not the plan view this is elevation and this is in the z explained right this is the elevation view of output shaft ok. So, in this slides I have shown what are the total forces acting on the shaft total moments torque etcetera and now we will consider, the these forces torque etcetera where whatever necessary in the in estimation the bending moment of the shaft and from there we will calculate the stresses considering the torque also.

(Refer Slide Time: 30:01)



And these outputs have designed verification to be continued in the next lecture ok. So, so far we have again I repeat that we have developed the output shaft completely, we have developed the output shaft assembly completely and then we have calculated what are the load acting on the bearings, we have estimated the life of the bearings. And finally, we have considered what are the forces acting on the shaft and shaft equilibrium ok.

So, we have to continue in the next lecture.

Thank you.