Gear and Gear Unit Design: Theory and Practice
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Lecture – 18
Bearing Selection - Introduction to Shaft Design Verification

We are continuing with module 4 Design of General Purpose Industrial Helical Gear reduction unit part two. And this is lecture number 18, where I shall cover bearing selection and introduction to shaft design verification. Now already we have calculated the loads on shafts.

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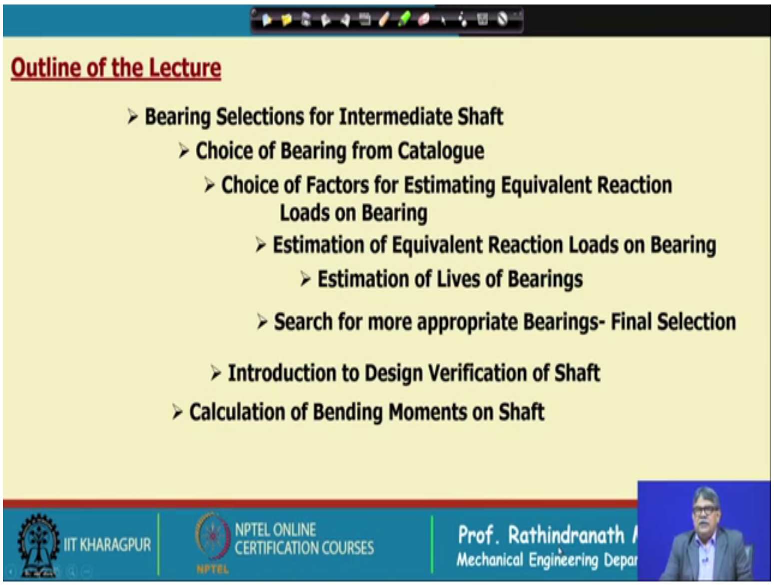

So, now we shall go for bearing selections for intermediate shafts, choice of bearing from catalogue, choice of factors for estimating equivalent reaction loads on bearing, estimation of equivalent reaction loads on bearing, estimation of lives of bearings, search for more appropriate bearings and then final selection of bearings.

Next, we will go into introduction to design verification of shaft calculation of bending moments on shaft also will be introduced.

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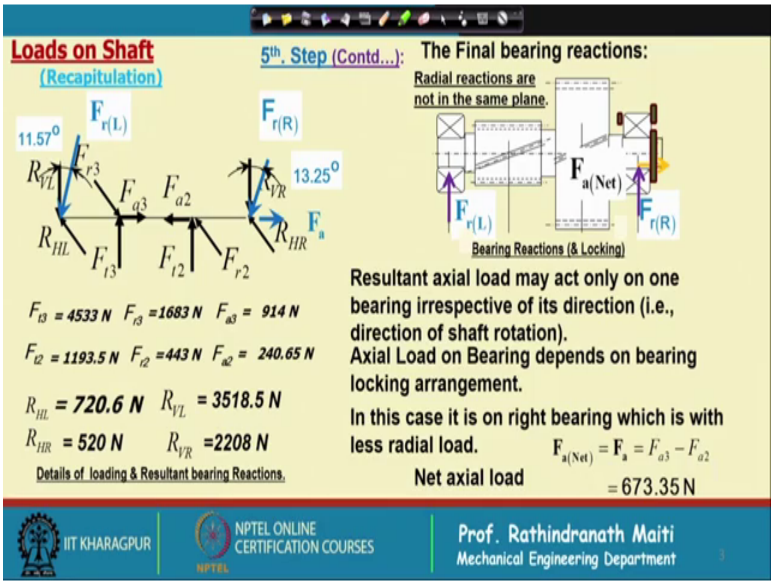

Now, we have a have chosen the intermediate shaft for selection of bearing and design the reason is that, if the intermediate shafts size bearings are finalized at fast; then it will be easy to select the bearings for other two shafts that is input and output shafts in this case, because this is a two stage in case of three stage; obviously, there will be two intermediate shafts in case of two stage gearbox only one intermediate shafts.

Now, we have already calculated the loads on the shaft along with the bearing reactions we have resolved the gear loads that is normal loads on the gears while it is transmitting torque into basically three components. In case of helical gear one is that radial load and then again this radial load, we have result into the two parts horizontal and vertical plane and then axial loads which is acting along the axis of the shafts. In this case after that we have considered the bearings while we have calculated the load we have estimated that bearing width will be within 25 millimetres and from that we have found out the load point of the bearings.

Now, after selection also we will give will arrange the bearing in such a way that will remain same. So, whatever load has been calculated bearing reaction has been calculated that we can accept for the next part; in this case what we will find that this is the vertical load vertical load at left hand bearing and this is the horizontal load at left hand bearing right hand bearing which are given here and also the in horizontal plane at left bearing it is 520 Newton and in sorry in left bearing it is 720.6 Newton and right bearing it is 520

Newton whereas, these are the acting load the tangential load at this tooth we should remember that the this is the plan view top plan view of the gear box.

So, this means that torque is entering from here and going like this going in these directions and direction of rotation we have taken like this. So, at this point the tangential load is acting upward and at that point tangential load on these teeth is also acting upward which is shown here. Now the radial load is acting from this side. So, on this gear it is F r 2 and on this pinion it is acting from the other side which is F r 3 then finally, we have calculated the axial loads intentionally the helix angle had been taken in the same direction directions for both gears this is left hand.

So, for the gear first stage gear. So, for the pinion of second stage also has been taken left hand. So, that this axial force acts in opposite directions say if this is the directions and load is coming upwards then axial load must be in this directions here if this is the directions and load is coming from this side. So, axial load will be in these directions and they will oppose each other and from there this also we have noted down here that what are the radial loads in these directions.

So, final directions will be in this direction as it is higher this value is higher. So, these are the resultant load, because we have resolved the load in vertical and horizontal plane and then again while we are considering the bearing calculations, then we need to consider the resultant of this load as a axial load and interestingly this load are not in same plane although it is shown here in the same plane.

But if we observe this is the angle 13.25 degree whereas, this is 11.57 degree and in first attempt without resolving the forces in horizontal and vertical directions, it could be difficult to find out these two reactions load. Now resultant axial load may act only on one bearing irrespective of its direction of shaft rotations.

Look at this if we rotate the shaft in opposite directions for the same load say, suppose it is rotating in this directions in that case the tangential load will be from the top here also it will be from the top, because it is rotating like this and then the axial force will act in other directions on these two gears, but resultant force definitely we will be opposite in this case if you rotate the direction of rotations now depending on axial load on bearing sorry depending on the bearing locking arrangement axial load may be taken by only one bearing.

So, in this case we have locked this bearing by circlips there are one external circlip from the shafts and the same side. There is another internal circlip also and other side inside the gearbox sides there is another circlip. So, this is one circlip this is another circlip on the housings and this is the circlip on the shaft and this is the strafe where the bearing is held; that means, bearing positionally locked with the shaft as well as with the housing and other side it has been kept free.

So, therefore, whatever may be the direction of rotations the axial load will be taken by this one for clockwise rotation looking from right hand side the resultant force will act in this directions and then this the bearing will be pushed by the shafts.

Whereas in case of rotation in anti clockwise direction looking from the right hand side this acts result an axial load act will in this directions; this means that this load will be transmitted to the bearing by pulling the bearing in this direction as the outer race is fixed and also the inner race is fixed on the shaft. So, thrust load will act accordingly on this shaft.

So, this is important that, how we will lock the bearing and which bearing will subjected to take the axial load, why we have chosen the right hand bearing here? If you look into the loads on pinion for the same torque it will more than the loads on the gear first is gears because the size is bigger. So, reaction loads that a vertical and horizontal loads will be less on right hand side bearing, and if we lock the arrangement what we have done in that way right hand side bearing will take the axial load and finally, we will see that for same size of bearing or even if different life will be more or less same for both the bearing that is a good designers choice.

In this case it is on right bearing which is with less radial load which I have discussed; now you can see this radial load is acting in this direction and this is in by amount it is 673.35 that is F a 3 minus F a 2 which is 673.35 Newton.

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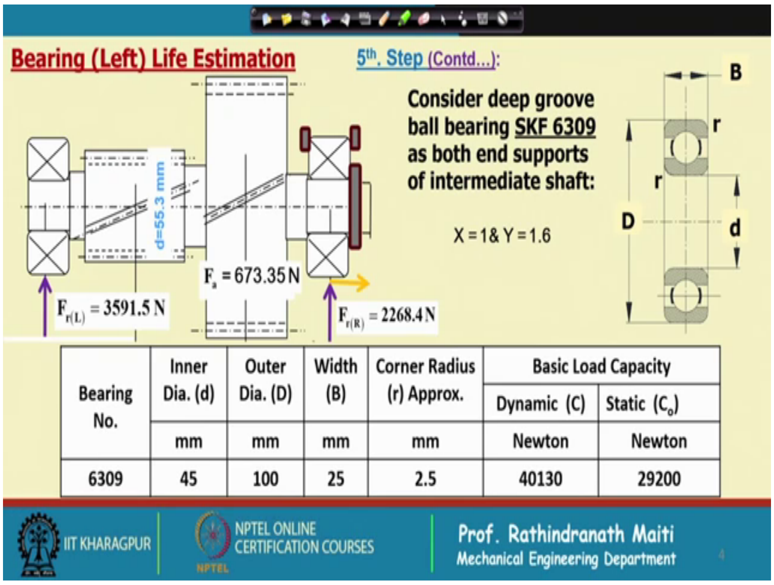

Next we shall consider the bearings are less expensive, but good enough for low range loads. So, in this case we have we are selecting a bearing and we have considered SKF bearing here I would say that other bearing from other company carrying the same bearing number will have the more or less same load capacity and life or other will be more or less same, because they are standardized and they are manufacturing they are manufactured considering the same load condition and as well as the materials heat treatment finishing etcetera.

Now, we have chosen a bearing SKF 6309, what does it mean? I have earlier I have discussed up to the diameter 17 millimetre the number is perhaps 36303 it will not match, but higher numbers 042 higher numbers it will be such that if you multiply with 5 then with the last two digit it will give the internal diameter of the bearing d. In this case 09 into 5 is 45 millimetre; now what is 6363 is a series deep groove ball bearing series starts from 60.

Then 62, then 63 and there is 64 higher this number higher the load carrying capacity of same internal diameter id, but outside diameter will be different depending on the series and I would like to say that 6309 are widely used for gearboxes 60 and 62are normally not and 64 also normally not taken 63 are 63series bearings are widely used.

Now, let us see this is from extract from the escape catalogue and what we find that for bearing number 6309 inner diameter id is 45 millimetre outer diameter is 100 millimetre width is 25 it is matching. What we took for the preliminary layout and then corner radius 2.5 millimetre, this is this information is also important, because while we are finishing the corner the steps of the shaft. So, this dimensions said taken care of they at that corner radius should not be should be less than 2.5; we shall discuss this in details why will make the detail drawings or the assembly drawings.

Now, next with this bearing there is the basic load carrying capacity is given the dynamic load carrying capacity is 40130 Newton whereas, static load carrying capacity 29,200 Newton we should keep in mind by no means the radial load should be more than 2009 29,200 Newton it should be reasonably less than that.

And from the dynamic load, we will cal we will calculate what might be the life first of all we will find out the equivalent load acting on the bearing for that we need two factors which is for this bearings. In fact, it is for the almost all deep groove ball bearings X is equal to 1 and Y is 1.6; X factor is with the radial load and Y factor is with the axial load acting on the bearing.

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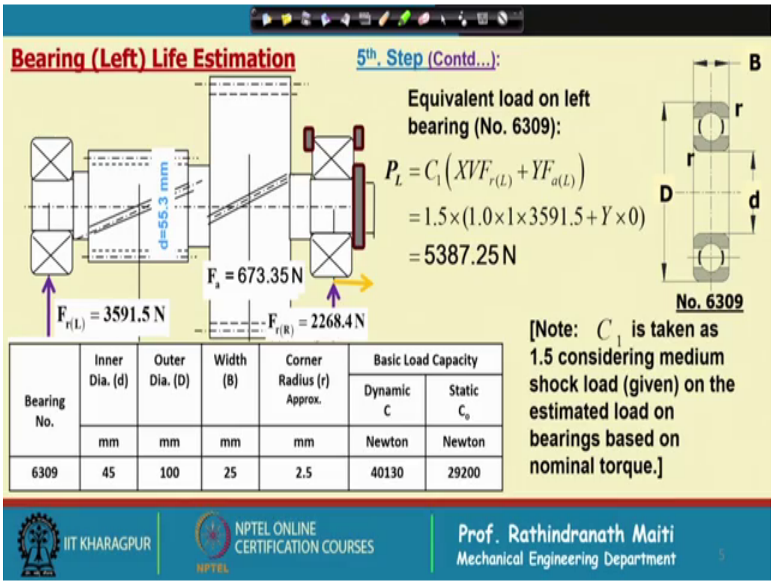

Next we shall find out the equivalent load on left bearing. Now equivalent load V L is given by sometimes it is written P also P ; in that case we consider the left bearing that is why we have given P L is equal to C 1, C 1 the you should remember that C 1 is the factor depending on the load conditions dynamic load conditions.

Then XBF are and in subscript means it is for left X is the factor already I have discussed V is raised rotating in this case for this gearbox it will be one as the outer race is fixed and Y is for axial load. Now, we have already calculated we sorry we have already arranged this bearing in such a way left bearing is not taking any axial load. So, directly F a L is put 0 and whereas, the if F r L which we have already calculated shown here is 3591.5 and this C 1 factor has been taken as 1.5 considering medium shock load which is mentioned in the problem on the estimated load on bearing based on nominal talk.

Here interestingly; I would like to say that in case of gear calculation with the torque we have multiplied by 2; that is from considering the shock load 1 is medium shock load and another point is that starting torque is always 200; the system is like that starting torque is 200. So, for safe design of gears we have considered a multiplication factor or they can say factor of safety also there with the torque we have multiplied with 2, in this case we have not multiplied with the forces any factor because in the bearing calculation we are considering this factor in form of C 1.

However; with these values what we find that on left hand bearing equivalent load is 5387.25 Newton, this is much less than the static load carrying capacity. So, apparently it looks very satisfactory, but now we have to calculate the life of the bearing.

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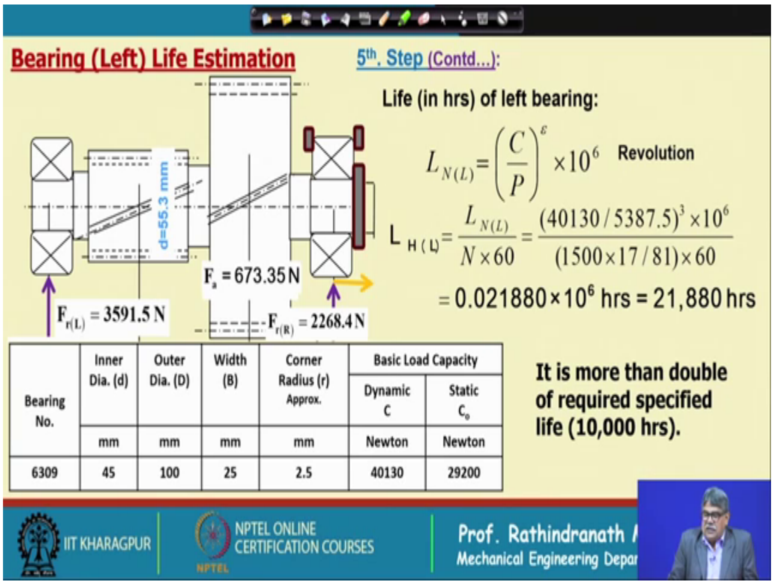

Now, life in hours is given by C by P gripper epsilon into 10 to the power 6 revolution and C here is the dynamic load capacity which is 40130.

So, substituting these values we find we have directly calculated life in hours. So, life in revolution age first of all C by P 40130 divided by 5387.5 to the power for ball bearing this value is 3. So, to the power 3 into 10 to the power 6 divided by the rpm 1500 rpm into the gear ratio 1500 is the input rpm. So, divided by the gear ratio first is gear ratio which is 81 by 17, 1500 divided by the fastest gear ratio that is the rpm of the shaft multiplied 60 means; we are considering this is in sec we have calculating in hours. So, we have divided this by 60 this value is quite high 21,880 hours.

It is more than double of required specified life we are looking for a bearing life 10,000 hours, but what we have found it is 21,880 hours.

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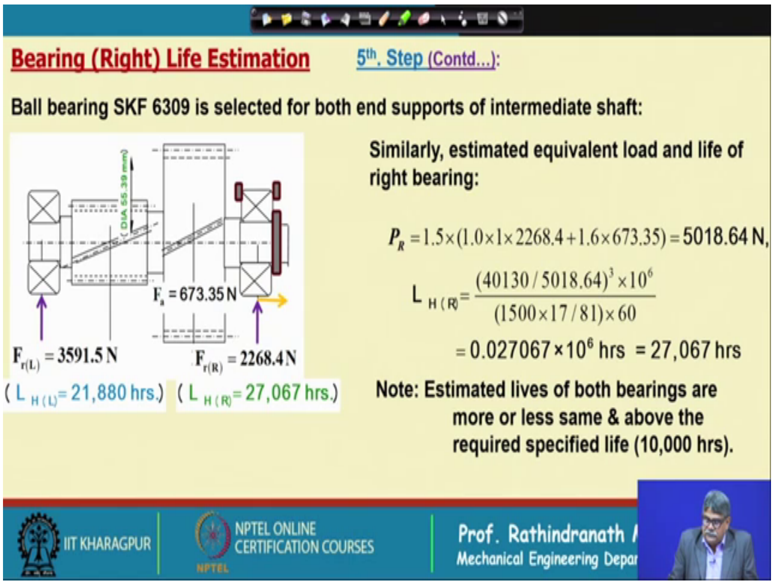

Now, let us see what can be done first of all we estimate the life of the other bearing; that means, right hand bearing in this case the rose the rays rotation factor is 1 as well the X is 1 and the radial load is there 2268.4 and the axial load is acting 673.35, which is multiplied by 1.6, 1.6 is quite high value, but in case of deep groove ball bearing this is in higher side whereas, you will find in case of different bearing and spherical roller bearing this Y factor is less.

So, we are getting the equivalent load on bearing is 5018.64 Newton that is for right hand bearing and the life estimated in the same way the rpm is same for the shaft load carrying capacity is also same, because we have taken the same bearing it is 27,067 hours which is also much higher, but these two values although not same, but close. Now if we would make the locking arrangement, in other directions or the bearing locking is such that this can take load the axial load is taken by both the bearing. In that case life would be different naturally the life of right hand bearing would be more and life of left hand bearing would be less; however, with this arrangement we have somehow made not very close, but still more or less equal.

So, it is justified that when there will be overall both the bearings will be replaced by a new bearing and it is somewhat towards the optimum life of the bearing although this is not a optimization, but somewhat. So, that I have explained why we have locked the right hand bearing what is the results? But only thing is that both the lives are higher than the expected 10,000 hours. So, what we can do we can look for such a bearing.

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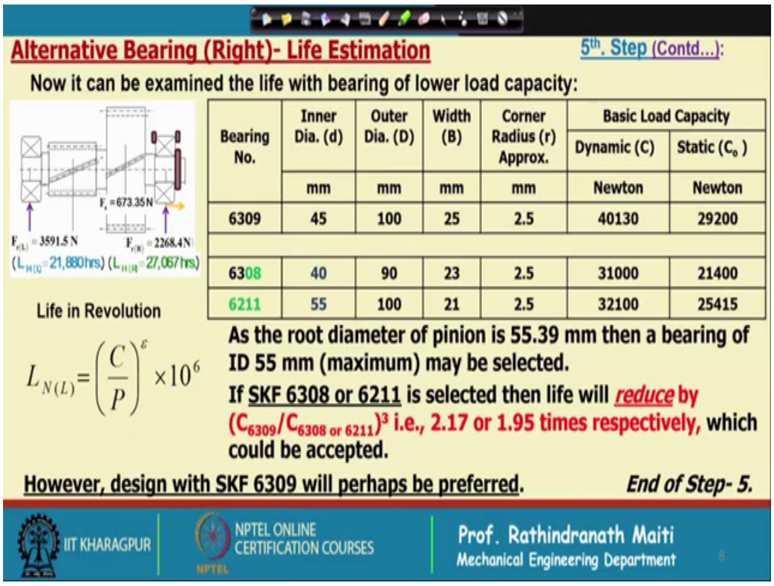

That which would be of less load carrying capacity sorry less dynamic load capacity and we can verify what will be the life. So, what we have done in the same catalogue first of all here it is not difficult to reduce the shaft size at the bearing we have initially taken 45 millimetres at the bearing, where the bearings are sitting. Now we can go for 40 millimetres easily and for that in the same series we get a bearing 6308 series that is for shaft 40 for which width is becoming 23 millimetres, but we shall keep the load centre same. So, we can consider the same loading on the bearings for which the dynamic load carrying capacity is 31,000 and static load carrying capacity is 21,400 Newton.

Alternatively, we can go for the load carrying capacity or sorry dynamic load capacity and static load capacity keeping same as 6,308 close to that we can go for 6211 a one series lower, but in that case shaft diameter is increasing 55 millimetre it is not it will not be a good design because the stepping because the 55 will be very close to the root diameter of the pinion which is integral with the shaft, but still it is possible we can go for that dimensions.

Now, let us verify what will be the life here I have given that a root diameter of the pinion. Second pinion is 55.39 millimetres then a bearing of id 55 may be selected and if you look into the life in hours, what we find that? C by P to the power epsilon into 10 to the power 6, only if we go for other bearings, then C is varying P is remaining same because we are keeping the same load centre and in power there will be 3, because for ball bearings it is 3.

Then we can compare in this way that C for 6309 divided by 6308 or 6 to 1 to the power cube which will give us, how much reduction in the life 2.17. And in other case 1.95 times; that means, if we go for 6308, then left hand bearing life will be 10,000 almost 10,000, because 21 sorry 21,880 hours divided by 2.17, it is slightly more than 10,000 and in case of right hand bearing it will be around 13,000 or. So, with the bearing 6 to 1, 1 it will be divided by almost 2. So, in one case 10,500; 10,000 sorry almost 11,000 in other case it will be around 14,000.

So, these two bearings could be accepted, but looking into the shaft size stapes and more reliable operations, perhaps it is better to be with 6309 bearing 6309. And if you think in terms of cost no doubts 6309 will be expensive than 6211 and 6308, but the difference is very small. So, probably being with 6309 will be better than selecting others. So, this is the end of step 5.

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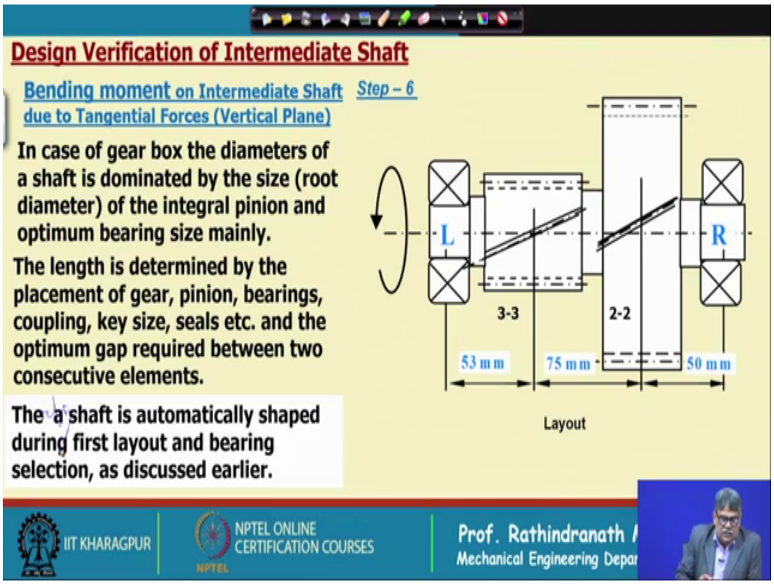

Now, we shall consider the design verification of intermediate shafts. So, to verify the life of the bearings what we should do the life of the shafts or whether shaft stresses in the shafts are satisfactory; what we should do first of all? In case of gearbox the diameters of shaft is dominated by the size root diameter of the integral pinion and optimum bearing size mainly; this is particularly input and intermediate shafts outputs shafts. We can go for other dimension, because that is also material is different because that is not integral with the gears the length is determined by the placement in gears pinion bearings coupling key size seals etc and the optimum gap required between two consecutive elements

The shaft is automatically safe during fast layout and bearing selections. Now, here it is actually it should be therefore, therefore, shaft is automatically saved during fast layout and bearing selection.

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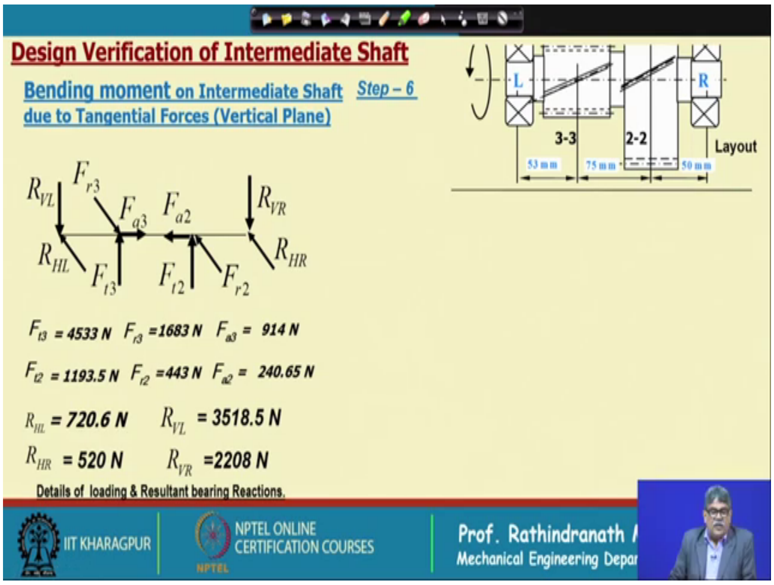

So, now we shall look into the loads on the shafts; this is already we have determined and then, if we consider again we shall calculate the bending moments in the shafts. We shall consider shear force diagram by bending moment diagram. All considering the in plane vertical plane and horizontal plane and then, we will finalize the moment at sections.

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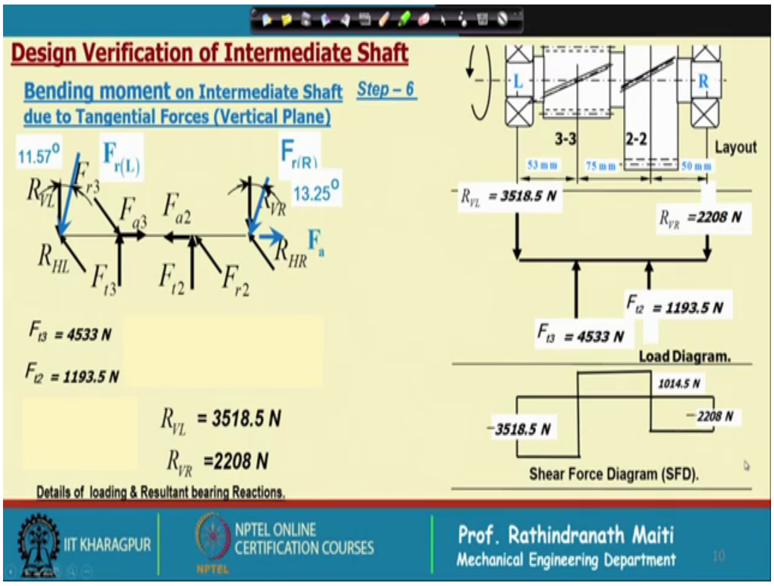

So, for vertical loads what we find? We have simply written the reactions and then we calculate the shear force diagram. Now looking into these and convention, I think the all of you are having the idea of calculating bending shear force diagram and bending moment diagram. In that case shaft is bending in upward directions therefore; we consider the shear force or the negative. So, first we have considered the 3518 at the left hand side.

And then it is coming up to the next point that is the middle of the pinion and there we simply add 4533 Newton, and we reach above the midline in the shear force diagram and from that value 1014 Newton. Again here at this point this value minus 2208, this value is added and we are coming down and then we are reaching here no sorry from this point this is 1014.5 plus 1193.5 which is give Gibbs to 208 and share force diagram. So, I expect that you are having the same idea about the shear force diagram.

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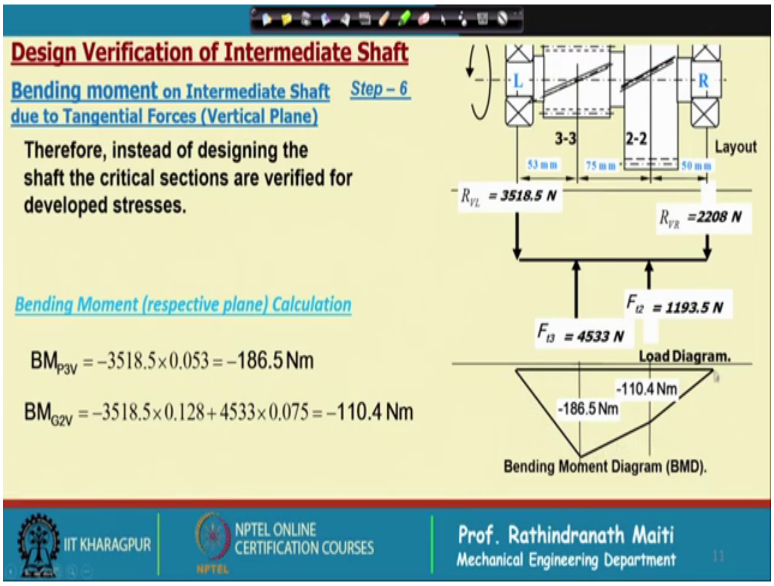

And, similarly for vertical plane we calculate also the shear force sorry we calculate the bending moment diagram. In the bending moment diagram again as it is bending in the upper directions; we draw the bending moment in these directions and these are the bending moment at these two sections. We have considered these two sections as there are bending moments are changing.

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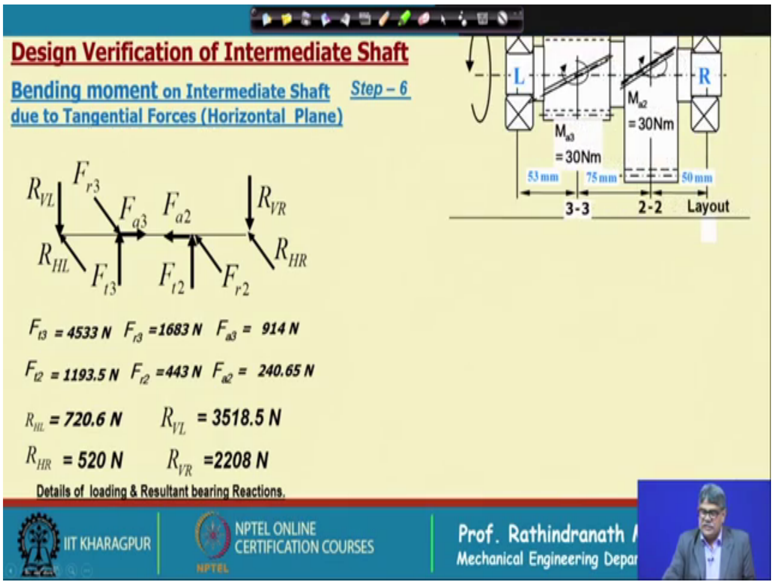

Similarly, for the horizontal plane.

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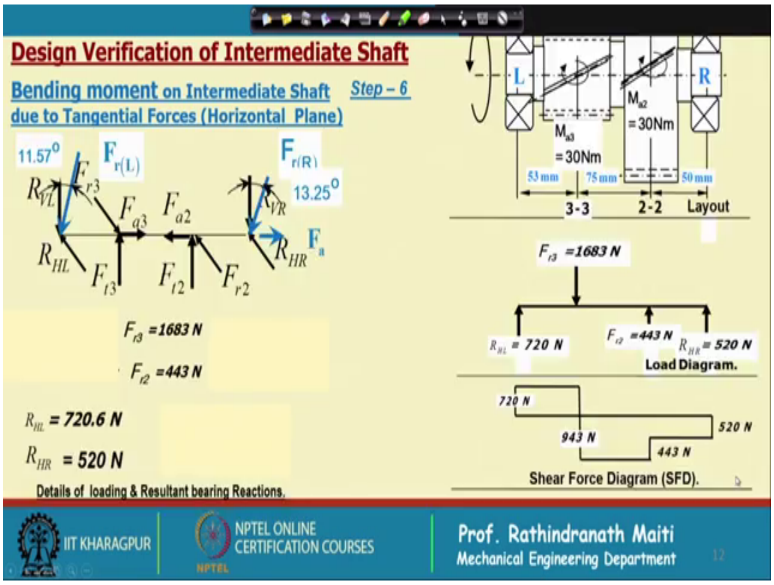

We estimate the first of all we consider the shear force diagram.

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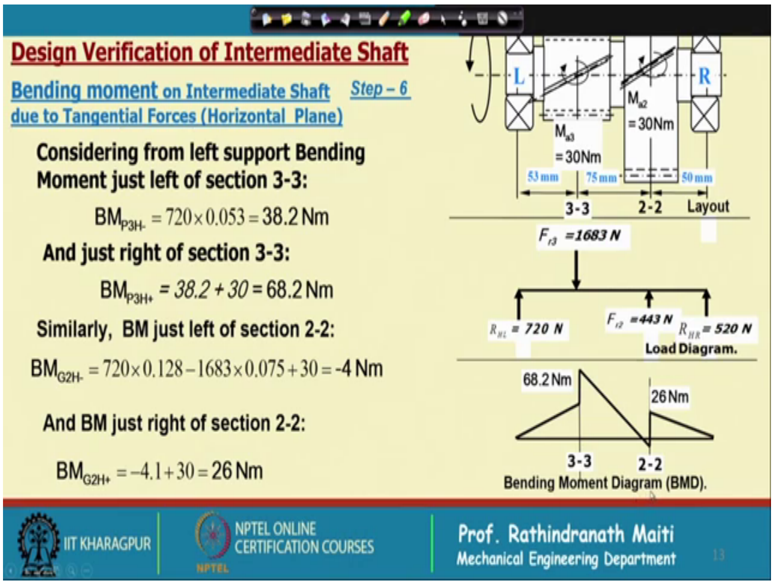

And next we consider the bending moment diagram in the same way, now in bending moment calculation in the horizontal plane this is a horizontal plane, we should not forget about these two moments which is due to the axial load at the pinion and the gears and then final diagram is coming like this. Now we have calculated bending moment and shear force diagram; we have know we know; what are the bending moments there? And now we will find the critical section and we will calculate in the; calculate the stresses there which we shall consider in the next lecture and we end our this lecture here so.

Thank you.