Design of Mechanical Transmission Systems

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Week – 05

Lecture – 15

Lecture 15_ Automobile Gearbox: Bearing Selection and Gearbox Losses

We will continue the problem in lecture 15. We have covered various aspects as discussed earlier the operations of engine, types, ray diagram, kinematic diagram, number of teeth in each gear, gear failures, gear material selection, module calculation, shaft design, lubrication selection. So, these are the thing we have covered and today we are going to discuss about lubrication method including bearing selection, gear box losses and gear casing and finally, gear box mounting aspects. All those the blue color topics we are going to discuss in today's lecture.

You can see that the lubrication right how is going to be applied in the gear box. This is the spray type. What you have seen on the left side is a spray type, on the right side is a bath type both are different. Bath means the gears should be fully immersed. You can see this is the pinion which is the one which is fully immersed such a way that the lubrication is circulated whereas, in the spray system right only the small amount of lubricant is there up to may be covering the base circle of the pinion right base circle from there it will make a contact and whatever the lubricant remaining it is come back with the free gravity or else you can have a jet. Using the jet, you can apply a lubricant where they are going to have a contact.

So, the bath lubrication system this is simplest system limited to pitch and velocity when it is approximately 17 m/s. The gear should dip into the oil bath above twice the tooth depth to provide adequate splash for pinions and bearings to reduce the losses due to churning and the moment you increase the speed splash loop system can be extended up to 25 m/s but the provided should have a proper cooling system including breathers to avoid churning losses. Normally I am talking about circulation lubrication system normally when the pitch line velocity more than 25 m/s when you have a high velocity right in that case you can have a circulation lubrication method for gear boxes with the artificial bearings spraying oil at the gear mesh only and relaying the splash to lubricate the bearings permissible up to a maximum pitch line velocity of 35 m/s. If the speed is increased above 35 m/s then the both gears and bearings should use pressurized feed which is the feedback system right pressurized feedback system in another words called as a circulation method. If pitch line velocity less than or equal to 40 m/s there you need to have a oil jet should be placed on the incoming side of the gear bus because whenever the gear meshing right at the inside you will have a more heat right inside you will have more heat so you have to focus to reduce that and you have to focus or you reduce that and the pitch velocity above 40 m/s more oil is needed more for cooling aspect than the lubrication aspect. Obviously, the contact will be more the number of contacts will be more as increasing the speed so the heat generation would be more. So, we have to give adequate lubricant instead of not just lubricating purpose it should remove the heating aspect. So that is how we do the energy balance. If gears are operating at very high speed above 85 m/s the amount of oil is carried to incoming gear meshing not adequate and then of gear mesh. So, in that case to avoid this $2/3$ of oil flow outside the gear mesh for cooling aspect $1/3$ alone inside for the lubrication aspect. As you aware of that initially in the previous slides I have told the purpose of lubricant it is not only to develop a film between the two surfaces but it also removes the heat. The two purposes two main purpose for any lubricant so as we increasing the speed the heat generation would be more. You may ask question so we take that we have two palms repeat slowly do you feel heat? Do not. If you do very faster what happens? You will feel the heat generation why it is happening because you are not allowing the time enough time to heat it to speed. That is what happens so the heat is keep accumulating as moving as rubbing in a higher velocity. So that obviously would generate more heat. So, this is what precisely happening. So, at a higher velocity the $2/3$ of oil flow outside gear mesh for cooling aspect $1/3$ of oil flow inside the gear mesh for lubrication happens. If velocity more than 100 m/s circulation must be providing optimum number of and location for jet such where jet will precisely flow the lubricant.

Quantity of lubrication that is also very critical. So, this is standard equation this is,

$$V_L = P/c$$

Where, P is the power input in as power, c equal to constant will tell you what is that mean, V_L is the amount of lubrication. For example, we have a gear box in various applications starting from machine tool to automobile even you can space application but also you can be there. So where do you expect more quality of oil where do you expect more quality of less quality of oil. Obviously in the space application the lubricant has to be as small as possible. The next is automobile then machine tool gear box. So, in fact if you look at you can see this is the c the equation maybe I will go back. $V_L = P/c$. c is the constant normally per as power okay gal/min is clearly given. So, for you can see that 200, 400, 800 and 1000. So, 200 is obvious general that means adequate lubricant amount industrial application. The moment the c is increasing the quantity of lube is decreased. So, it is for adequate aviation aspect and if it is 800 it will be lean condition where you need to have a light and high aviation space application. This is again for 1000 starved at special condition. For your general gear box automobile gear box right is falls under this category. Anything on the aviation is falls under 400 and 800 right.

Now we will move on to the gear box losses. This is the general equation,

$$\eta = \frac{P_{in} - P_L}{P_{in}}$$

η is the efficiency, P is the power input and P_L is the power output. You can see again this gear loss there are so many gear losses are there. You can see the power loss in gear teeth engagement, power loss in bearings, power loss in seals and power loss due to churning. When two teeth are contact each other this happening through friction right. So that will create a loss that is power loss in gear teeth engagement. Second is when you have bearings again, they rotate right the bearings rotate against the friction. So, the bearings also constitute friction losses. Then seals which is prevent any leakage in the gear box they will also constitute a power loss. These three, I am talking about gear, bearing and seals are related to your load aspect. They are related to load factor. Churning nothing do with the load but it is related to the speed. Churning it is like you know you are making a speed. Higher the speed the sharing between the lubricant higher internal friction will be higher. Obviously, the heat generation will be there the moment you have heat generation the viscous reduces. Remember higher viscosity low speed high speed for high low viscosity the same thing right. The churning also will cause a loss. Let me ask question you have four losses among these four losses which would be more is it from a gear or is it from bearings or seals are churning right. Obviously, it would from gears right because that is the one which making a contact right. They are the more the gears more the power loss. Where, bearing is limited so as seals also maybe you can see this is the equation.

$$P_g = P * \left(\frac{0.1}{Z_1 \cos\alpha} + \frac{0.3}{V + 0.2}\right)$$

Power loss in gear teeth engagement which is the you can see this is the equation you see that right. Z_1 is number of teeth is engaged and V is your pitch and velocity you can see that velocity of gear which a pitch line velocity. P is the power input and α is the pressure angle right. This is for single stage the above equation for single stage if multiple stage then each stage should be multiply with the first stage. So that you will have cumulative power loss. So, normally the equation it is a simplified here usually will have a friction coefficient. Usually, will have friction coefficient. Again, the friction coefficient is variable depends on the surface roughness, lubrication, flash temperature and bulk temperature of the material. So many factors are there. So, I do not want to give very complex equation for your understanding I have given the very simple equation for power loss in gear meshing aspect.

Then this is standard equation power loss in bearings.

$$T_b = 0.5 * \mu * P * d$$

You can see here, T_b is the frictional torque bearing torque, μ is your coefficient of friction you can see it taken from the SKF catalog. P is the equivalent load I will tell you what is that mean equivalent load when we discuss about the bearing's aspect. d is the bore diameter okay d is the bore diameter this is for the bearing loss in bearings. Yeah, you can see that. So, this is taken from the SKF catalog right. There is coefficient of friction is given can if you look at the least coefficient of friction where you would be expert right. The least coefficient of friction probably is your self-aligning ball bearing you can see this is the one. Then next one would be the thrust ball bearing okay. Then you will have a deep groove ball bearing and spherical ball bearing. So, depends on the application you have to choose the bearings for your gear box selection. Yeah, still we are continuing with the power loss in bearings.

$$P_b = 10^{-4} * T_b * N$$

T_b is the frictional torque, N is the number of speeds in the shaft aspect that is one more equation.

And this is for the churning aspect yeah, the churning aspect will come lot of aspect okay. Your,

$$P_{ch} = cbV\left(\frac{200V\eta}{Z_1 + Z_2}\right)^{0.5}$$

V is the velocity given and these two teeth the one number of teeth of drive and driven respectively, Z_1 and Z_2. And, η is the viscosity of the oil at operating temperature. It should be in centipoise okay we have done. Then more importantly we are talking about the face width okay. If you have the more surface right more surface that means more surface has to be interact with the lubricant for churning. Churning means nothing but your keep rotating okay you have assuming that you have a box filled with the lubricant put the gear and keep rotate right what happen if you have your face width with smaller what happened your losses churning will be smaller, higher the size higher the churning loss. So again, that depends on the thickness of your gear thickness here it means face width okay. So, you can see the b is given face width, c is the factor normally again depends on the what type of operation you are going to use whether you going for use the splash aspect whether you going to use the splash aspect right 0.009 it is already taken experimentally then 0.006 for the spray lubrication aspect.

Finally, we will come for a power loss in seals this you can see that,

$$P_S = T_S * \omega$$

T_S is the frictional torque in seal, and ω is the angular velocity of the shaft and from T_S right depends on μ, F_r, r,

$$T_S = \mu F_r r$$

Where, μ equal to seal friction, F_r is the radial lip load and r is the radius of the shaft. So standard equation for a frictional torque aspect right and if look at this is I have taken this is the comparison power loss in the whole of gear box for different speed. Obviously higher the speed higher power loss that you can see the trend among them the large amount of fraction it goes to your gear meshing you can see that this is gear meshing. Then next is churning okay then you will have the bearing aspect right the bearing and the seal and finally that is called synchronizer. So, it is a synchronous gear which is going to have another loss also but so far, we discussed only for the gearing, churning, bearing and seal. So, you can see right more the gears more the power loss yeah. Let me ask question what is the typical efficiency of the gear box? Is it 80% ,85%, 90% or 95% or above 95%? Usually, the standard gear box efficiency 90 to 95% already optimized fully optimized. So, anything if you want to improve the optimization to increase efficiency you can do maximum of 1% that is the big achievement okay that is the big achievement and people are doing lot of aspects.

And now we will move on to the gear box housing consideration. Remember the gear box it is not only power transmission it should give the structural support also right. So, in that aspect we need to find how to place them that is also very important. You can see so the following requirements have to be taken in account when designing the housing. Absorbed acting operational forces and moments. Guarantee the exact position of the shafts and the gear wheels. Gear wheel means gears. Relative to each other in the various operating states. Ensure good heat conduction and radiation. Insulating and damping the gear box noises. Easy to fit and remove and should be rigid layout and should provide good strength characteristics combined with the low weight. You do not want to have very high weight okay. And this you can see there is a how to mount them right. So, you can see this is the through housing and this is called end loaded okay. Normally we will go for the top loaded housing this is what preferred one okay. The reason is compared to other things precise production in one clamping operation very easy to fit and you can split two offs. You can make it you can see that they are joined through two shafts arrangement two offs' things okay. So, but this is very expensive though okay. It is very expensive that is the only disadvantage. This is the way you have to arrange which way to want to do that. And you can see this is the typical jet of eco split which is two off I said right. It is a commercial vehicle gear wheel look with the loading housing aspect. And the lot of research going on this called windage tray this is called the this is called windage tray say that okay. If you look at inside, they will have intricate path will be there. So that it will guide lubricant to flow to the respective ways also okay. The lot of CFD analysis done to design the windage tray aspect that is another research level. But this is only for your understanding. We are not focusing above the gearbox casing design aspect. You can see the again housing the large gearbox housing generally casting made from cast iron or steel. Cast iron is rigid metal with excellent vibration damping properties. And fabricated steel gearbox is used special cases. Gearbox used for transmission vehicles are often made from cast aluminum for light weight aspect. Smaller tiny gearbox units are made from variety of materials including cast zinc alloys okay. And if you look at very interestingly when you talk about the gearbox cost your housing alone will take 36%. The gears are 22%. The shaft is 20% and bearings 10%. The others are 12%. So, 35% one third of the price goes to your housing itself. Because that is a complex that is very complex. It should have lot of intricate the flow aspects also. This is the mounting aspect. Foot mounted below horizontal force and flange mounted on the prime mover. Shaft mounted with the torque arm to prevent rotation of gearbox right. And you can do the same foot mounted on the vertical surface. You can see this floor mounted gearbox, top mounted gearbox, shaft mounted sideways gearbox okay. This is the through shaft arrangement mounted gearbox. And this is gearbox place mounted flange mounted on motor aspect. Tell me which one is the easier most preferred one. Floor mounted gearbox right. The floor mounted is the much easier okay. Whereas this is carrying the additional loads. You can see that the top mounted one. And this also this is the problem. It is vertically you are loading the gearbox. That is not advisable. So similar way the shaft mounted also. It is the most preferred either go for a floor mounted or gearbox flange mounted on the motor aspect. Have you seen how the gearbox is mounted in the automobile gearbox? Okay. Maybe we will see it when you go for the transport lab. At the time you will understand. Maybe if you get a chance have a look. Right. And maybe I will go back here. So, assuming you taken the floor mounted gearbox. So, which one which part of the side the gearbox should be thicker other parts will be thinner. Can you guess? The one which making to the floor contact right. The bottom that that should be thicker. Okay. That is the one is holding the entire thing. Whereas the side way at top you can have a smaller thickness of the casing aspect. You can see that the casing right. This again non-case-hardened gears and case-hardened gears depends on the things. This is just the guidelines. It can be variable. Right. And if you look at if you have a good welded construction and steel casing your thickness will be reduced. The above table for lower of thickness of the gearbox. Okay. That is what I said the bottom of the thickness t_1. Right. And within that t_2 is the wall thickness of the upper half. t_3 is the thickness of the mating flanges of casing and the thickness of the bottom flange t_4. Look at this what is happening. Okay. So, this is the standard thickness where it is going to be connected t_1. The t_2 normally lesser than the your t_1. Then, t_3 will be thickness of the mating flanges because that is going to support you need to have a higher thickness than the lower half thickness. And the bottom flange remembers the entire load is taken that should be even more higher. You can see that two times of your t_1. Again, depends which way you wanted to mount them. Okay.

Now we will move on to the bearing selection. Just it is going to give a information because already you would have learned from your undergraduate course. The purpose of bearings okay to reduce the friction where the shafts, gears or wheels are used to provide high load tolerance.

Application we have so many applications starting from cars, trucks, heavy trucks, helicopters, aero planes, train and so on. Okay. What I want to say this starting from your bicycle to aircraft you need to have a bearing. Right. So, the purpose is to make your power attachment smoother with the lesser friction aspect. Right. Industries including from milling, mining, oil and gas, extraction, production, gear drives, health, positioning control, windmills, and food processing everywhere you have a bearing. In fact, I do extensively the wind turbine gearbox failure aspect. It is a premature failure aspect where I do extensively research and also, I do lot of collaborative work from international companies for wind turbine. This is the bearing selection chart. So, you can see this. This is taken from engineering tribology by John Williams. Depends on the two factors your load carrying capacity and the rotors which will be based on that what type of bearing you should use it. Okay. So, you can have a dry marginally lubricant bearing. Fluid film bearings nothing but you are talking about journal bearing. You can say this is JV fluid film bearings and rolling element bearing is your normal rolling element bearings. Right. The moment you use the medium speed and medium load you preferred you can have a fluid film bearing. You can see this is the scale. You can see here in this region all are you can go for the rolling and bearings. The moment you go for the highest speed, higher load capacity there you can go for your journal bearing aspect. You can see that the journal bearing. Right. Anything beyond certain speed where you will have a buckling effect, a bursting effect okay you cannot have it. So, you have to choose based on the load and the speed operation select the type of bearing. Okay. That is gentle but, in our case, gearbox usually we prefer to have a rolling element bearing. This is the various comparison between the fluid film bearing nothing but journal bearing. Right. And this is the REB rolling element bearing.

So, I am just going to compare only these two aspects. Right. More importantly okay the rolling element bearing starting friction is very less whereas journal bearing they have to start with the contact. The moment you have contact your friction is higher. So, starting friction is higher for the journal bearing. The moment you start operating the running friction they are same. The running friction is they are same. You can operate at very high velocity for the journal bearing where the rolling element will restrict it to medium velocity. That is what the chart also shows. And very importantly you can go for the high load in journal bearing. The rolling element also high load you can do that whereas the life is infinite life for the rolling journal bearing. Because adenine effect due to adenine effect the shaft is lifted. So, there is no contact. So, you can use infinite time journal bearing. But that is not possible in rolling element. So, rolling element subjected to rolling contact fatigue RCF. So that is inevitable. That is whereas in journal bearing we can have a finite life. So that is the difference. You can see that. Of course, the lubrication you need to have more for journal bearing and less for the rolling element bearing. More importantly I wanted to talk about this called critical speed right. We are talking about critical speed where the vibration will come into the picture in journal bearing whereas that is not needed for your rolling element bearing. Stiffness aspect I am talking about stiffness aspect. And other thing is the journal bearing will have a high cost whereas the rolling element bearing is readily available on the shaft floor. That is how you can do that. And this is anti-friction bearing. These are again information talking about various aspects. Friction resistance will be less than journal bearing. Ball or rollers are rolling contact and sliding friction eliminated and replaced by much lower friction. In plane bearing, when you say plane bearing is called about journal bearing, the starting resistance is much larger than the running resistance due to absence of oil film. I already have explained that. Can support combined radial load and axial load. Yeah. That is very important for rolling element whereas that is not possible in the journal bearing. In ball and rolling bearings, the initial resistance to moisture only slightly more than the resistance to continuous running. Shaft alignment can be made with the greater accuracy in the rolling element whereas that is not possible in the journal bearing. Right. Less sensitive to interruption of lubrication. Heavy momentary overload can be carried out without failure in rolling element. That is not possible in the journal bearing. Okay. This is what I said. No self-excited instability whereas instability or critical speed or whirling speed would happen in the journal bearing. So, the stability is a big problem for journal bearing. Yeah. Okay. This rolling element classification based on the load either you can have a radial load bearings or else thrust bearing for axial loads then when you have combined then you will have a combination. You can see that rolling element bearing classified into ball bearings can be used high speed operation. The roller bearing can be used for greater load aspect. Okay. Let me ask question. Which one will carry more if you have a sphere, if you have cylinder which will carry most load on the flat surface? Cylinder. Because cylinder is a line configuration. Right. Whereas a sphere is the point configuration. Okay. So, for same load point configuration will have the load will be very heavy. Right. Whereas that is distributed, uniformly distributed over the line. That is why the roller bearing which is our line contact can withstand more weight compared to your ball bearings. Okay. That is information.

And I have some samples you can see this. This is actually a deep groove ball bearing you can see that. Usually, this is called inner race or bore diameter. Okay. This is your outer race. Right. You can see there is balls are there inside. There is a passage also. That is why it is a groove. Right. The balls are placed uniformly and again with the caging. The caging is allowed to retain the ball so that it won't move away either direction. So, this is deep groove ball bearing can be used both radial load and axial loads. You can see that. This is one information. Yeah. Maybe I will share later. And this is another information you can see that. Can you see this is a roller bearing. Cylindrical. Right. So, this is again you have outer race. There should be inner race and they are placed nice cage aspect. You can see that. This is your cylindrical bearings for higher load application. Again, very interestingly this is double row ball bearing. This is double row because of there are two rows you can see that. And also, this is self-aligning. Whatever the shaft alignment right. If the shaft is straight is fine. If not little bit inclination misalignment still this bearing can able to take the misalignment aspects. So that is why it is called self-aligning ball bearing. So, in fact there are so many types are available but I am just I have only three bearings. Later stage I can show other type also. Right. You can see that you can rotate. So that is by giving that that kind of flexibility it takes if you have two shafts, they are not collinear the misalignment can be taken out. So that is the purpose. Not only that it can withstand both radial as well as axial load. Yeah. This is self-aligning ball double row ball bearing.

You can see that there is a yeah nomenclature. This is your width. This is your width right. As I said you can see that and this is your outer ring and this is your inner ring and these things called shoulder. Yeah, this thing you can see that. This is called shoulder and the corner radius. Yeah, inner ring ball raised. You can see this is the deep groove. You can see that. This is you can see like a groove kind of arrangement. Same thing here is also there but yeah when I pass it through you can look at it and you have separator or retainer case. This is called retainer case so that I will keep it aligned along when rotators. Let me ask one common question. When the bearings used in the application would you expect both inner race and outer race to rotate or any given time one race should be rotated? One depends on the application either you want to use it in a race or out race. Depends on one okay. Depends on the application you have at any given time only one race will be rotated. Again, this is again you can see that deep groove, filling notch, angular contact to take the misalignment, shielded, sealed and the external self-aligning which is what we have seen it and double row okay self-aligning double row also you can see that. Thrust bearing mostly thrust bearing for axial loads and self-aligning thrust bearing again for the axial loads plus radial loads. These are the type of roller bearings. You can see the cylindrical. This is the tapered. Look at the shape very tapered in position. Again, tapered but thrust aspect and this is the needle bearing. See when the radial load is limited, for me space is limited then I can have a very thin bearings which is called a needle bearing. Again, you can see this angular cylindrical bearing and this is a spherical bearing. You can see that so many things. Yeah. So again, for low and medium you can go for ball bearings. If you want a heavy speed, heavy loads, large shaft diameter then you can go cylindrical and tapered bearings. Misalignment between the axis of shaft then you can go for self-aligning and spherical roll ball bearing. For low and medium axial loads, axial load and thrust bearing okay already I have explained these things. For heavy axial loads, cylindrical roller thrust bearing can be used. For combined axial and radial loads, you can go for a deep groove angular contact and spherical roller bearings. For high-speed application, deep groove, angular cylindrical bearings are suitable okay. So always you have to look at the rigidity also. Rigidity controls the selection of bearings in certain application like machine tool spindles. Double row cylindrical roller bearings or tapper roller bearings are used under these conditions. For household application you cannot have a very nice high noise. So, though the noise become criteria for selection of bearings usually you can use deep groove ball bearings for household application. These are chart for understanding about various aspects radial load, axial load, combined load, high speed, high accuracy, noise and rigidity aspect. Similarly, you can see for other bearings also with the angular misalignment, ring separability, use fixed or all this aspect okay. These are self-explanatory. I will just skip okay. Yeah, this is the coefficient of friction depends on the application what type of your bearing are you going to use it. Because this is the very important for your bearing loss you have to use it right.

Yeah, more importantly bearing code okay. You will have a code of bearing type, code for the cross section and code for the bore size. For look at this number 1 for self-aligning, 2 spherical rollers bearing, 3 for tapper roller bearing, 5 thrust ball bearing, 6 for deep groove ball bearing, 7 single row, 8 cylindrical, N is the special type line cylindrical, T is the metric tappet. Depends on the numbers you have to do that. You can see here when the 6 is there, last 4 digit the last digit should be multiply with the 5. If you multiply with the 5, 6 × 5, 30 that is your bore diameter okay. That is the bore diameter. Then the in between digit will talk about diameter series. Then 6 indicate about the type of the bearing deep groove ball bearing. Similarly, if you look at 7305, 5 × 5, 25 that should be the bore diameter. This is for diameter series and 7 is the deep groove ball bearing. That is another thing. Now you have a special series. 4 digits sorry this is the 5 digits, 0 and 9, 9 × 5, 45 is the bore diameter, 2 is the diameter series and 0 is the width series and 3 for the tappet roller bearing. NU2314, 14 × 5, 70 mm is the bore diameter. Then we have a diameter series and width series and this is for the lips. This is called lips. This portion is called lips. That is lips aspect. N is the cylindrical roller bearings aspect.

Now, this is very important. This is for load carrying capacity. Load carrying capacity. The static load carrying capacity of bearing defined as the static load which corresponds to a total permanent deformation of balls and races at the most heavily stressed point of contact should be equal to 0.001 of the ball diameters. This is the standard equation. Mainly I will go for the important equation is your load carrying capacity L_{10}. That is the one we talk about the life of the bearing L_{10} okay.

$$L_{10} = \left(\frac{C}{P}\right)^n$$

It is defined assuming that you have 100 bearings. The 100 bearings go for the, fatigue test right. So, they go for fatigue test for 1 million cycles right. In that 90 million 90% of bearing should not show any evidence of the pitting aspect. That means only 10 % can fail. That is the reason called L_{10} life. The dynamic load carrying capacity of bearing is defined as the radial load in radial bearings or thrust load in thrust bearing that can be carried for a minimum life of 1 million cycles without showing any evidence of pitting right. So, L_{10} equal to your related bearing life in million revolutions. *C* is the dynamic load carrying capacity. *P* is the equivalent load dynamic load. When I say equivalent load because of bearing subjected to two loads right, axial load and radial load. And 3 for bar bearing, $10/3$for roller bearing. Now you know that this is your point contact right. So obviously you can have a certain load whereas you can go for higher load when you have a line contact. This is what you can see that. For air cut application, the quality of the life bearing even was stringent. So, they will have called L_1 life. That means 99% bearing should complete 1 million cycles without showing evidence of pitting. Yeah. So again, with respect to number of hours, same thing modified with respect to number of hours.

$$C = P * \left(\frac{60 * N * L_{10\,h}}{10^6}\right)^{1/n}$$

And this is equivalent load,

$$P = XVF_r + YF_a$$

As I said F_r is the radial load and F_a is your thrust load. These are the factors. Again, if your inner race rotates, *V* equal to 1. If your outer race rotates, *V* equal to 1.2. This is how we have to calculate the equivalent dynamic load. This is the way to how to identify if you have combined load and axial loads aspect. This is the taken from X, Y from Shigley book. And this is a typical life of the bearings in various application. Automobile cost 50 million cycles. Trucks 100. Trolley cost 500 million when rail road cars will be 1000 million cycles. Yeah. You can see that these are various application. Various application supposes typically a bearing life will be 20 years. Suppose to be 20 years. Okay. I am just wanted to point out only two aspects. Instrument apparatus which are only infrequently used for demonstration devices 500 hours. The next thing is you can say this 500 to 2000 hour for aircraft engine. What I want to say that aircraft industry is very stringent. The reliability is very important. So, there you can't afford to have bearings to fail. So, they use a very high-quality standard because of that there is though the bearing can able to withstand for 20,000 hours but you don't want to but only restricted to 500 to 2000 hours. Similarly for a precision the accuracy is very important for a precision aspect. Right? So there also bearing life is limited. But as we move on to the where reliability is not much consideration there the number of hours is more. Reliability means catastrophic failures where is not going to be where is going to be least there the bearing life can have a higher length higher number of hours. I think that's the end of the bearing selection.

I will stop now. Tomorrow onwards we are going to for a brake system design. Okay. Thank you.