Tribology

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Lecture No. # 34
Bearing Lubrication

Welcome to 34 th lecture of video video course on Tribology. The topic of present lecture is bearing lubrication. We know very well lubrication is required to reduce friction and reduce wear, interesting day. In rolling element bearings, quantity of the lubricant which is required is much lesser than other kind of Tribo pairs. Major reason is that there is rolling motion, and apply load is a lesser in the situation, even there is no lubricant, bearing will work. But the applied load is in larger side and higher side, then lubricants plays important role; it shares load. We can say the viscosity changes from liquid side to the semi solid side or from semi solid to the solid side, and it shares load.

So, in other word, because of the lubricant, load carrying capacity of the Tribo pair increases. So, we require essentially lubrication. In last lecture, we studied about the friction, and we found lubricant is also source of friction. So, interestingly there is a more like a some sort of controversy is happening the lubrication is required and lubrication is not required. In totality, lubrication is more important, if we do not provide any lubrication, then there is a possibility of more stress concentration, high localized stresses. From that point of view lubrication is important, it divides zones or we say it distributes the pressure, and reduce localization. It gives more comfort, it is more even distribution. From that point of view, lubrication is important.

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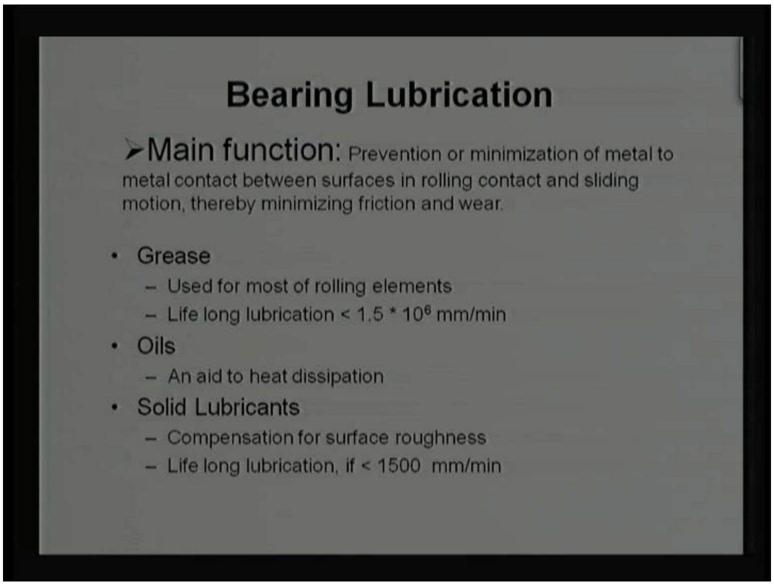

How to think about the lubrication? How to analyze that lubrication mechanism? How to quantify how much lubrication is really required? I do not know the parameters, which will be deciding how much lubricant is essential when we are talking about the rolling element bearing; when we are talking about the ball bearing and we are talking about roller bearings. See in this case, this slide shows that the bearing lubrication is important to prevent or to minimize metal to metal contact. That means, there is if there is a lubrication, then wear will reduce or we have studied bearing life from (( )) point of view.

If there is no lubrication, there will be wear and if there is a wear, clearance will increase. It is increase in the clearance, load zone will decrease or we say that load which is imposed in the rolling element; that zone will decrease. If the load zone is decreasing for same load naturally, maximum value of load on per ball will increase. So, from that point of view, lubrication is important and sees that we have three kinds of lubrication. We can use the grease; that is a semi solid most widely used. There are some limits and we say that if velocity in mm per minute is lesser than 1.5 into 10 is to 6. This kind of grease can survive forever; we need not to change it.

But the load is increasing; in that situation, there is a possibility of squeezing out. So, we need to replace or we say we need to refill the grease in that zone. But grease will remain active; it will be useful; it will not die or we say that when we discuss about the grease earlier, we say that grease is made of thickness and lubricating oil. Lubricating oil has a main function of lubrication. Why? Thickness; they generally retain the lubricating oil; they try to keep lubricating oil at a place, where it is required. But if the squeezing action is more, there is a possibility of bleeding; what we say the bleeding and the lubricating oil is coming out of mash or with the fiber structure of grease.

Then we have oil; lubricating or the liquid oil, we say wherever there is a more heat dissipation requirement or heat generation is on higher side and we want more and more convection heat transfer. In this situation, lubricating oil is going to play a major role. It does not have only the lubrication function, but this will be having cooling function also. Sometime we use solid lubricant and mostly most commonly solid lubricants are used for the cages, we know. In rolling elements let us take a example of ball or roller, when they come into contact with the cage, contact area is a relatively larger and cage may be stationary bounded to the outer ring or bounded to the inner ring or may be just free floating.

In those situations, sliding will be higher. To reduce a sliding, we require lubricant; we can use a liquid lubricant; we can use a grease lubricant. But we know, because of the cage; because of the sliding at the cage surface, that friction is coming out. So, why not we should use a solid lubricant? And the main purpose of the cage is only guiding mechanism; it does not bear much load. So, impose load on a cage is much smaller. So, we can use a solid lubricant. I will say whole cage is made of a solid lubricant and is more like we can make whole cage of the polymers or we use a thin sheet. But coat it with carbon graphite or we can coat with the molybdenum disulfide. So, those kinds of lubrications are possible.

Sometime we use solid lubricant in greases; that is why we know the moly grease; where we know if there are applied load is on the higher side. So, to reduce the friction or we say the molybdenum disulphide works as a anti friction agent in that situations. And ofcourse, we say that this solid lubricant will survive will be useful for speed lesser than 1500 mm per minute. We can compare this 1500 mm per minute with 1.5 into 10 is to 6 mm per minute; there is a huge gap; one thousand time gap. Or we can say for a lower speed operation, solid lubricant can be used easily. They can mix with liquid lubricant; they can mix with a solid semi solid lubricant and even the cages can be made with the solid lubricants.

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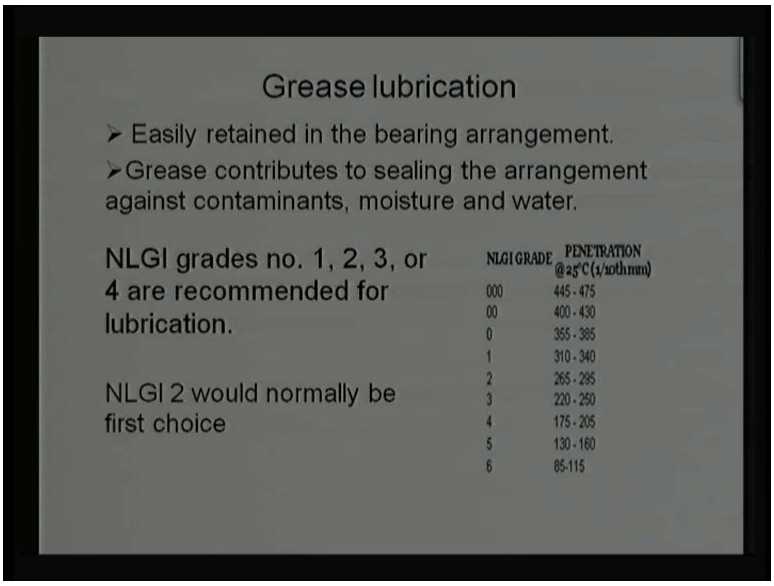

Now, when we talk about the grease lubrication, we have studied in our earlier classes what is an NLGI grade. How do we specify grease through the NLGI? What do we say? It is important to retain this grease in bearing. But it will not be easy to retain low NLGI grade grease. However, another word if I talk about 000 NLGI grade, it is more like a liquid lubricant; that grease cannot be retained. Because the depth of the penetration and the kind of grease is more than 45.5 mm, squeezing will be very fast; we say that it will not be able to retain within the bearing. Coming to the NLGI 1, again there the penetration is very high. So, that is why we use most commonly NLGI 2, NLGI 3.

Again depends on the requirement, we can change our choice and if grease has been used to avoid the contamination, then we need to use thicker grease. However, my choice is always we should go ahead with all options open. We can think about NLGI 1; we can think about NLGI 2; we can think about NLGI 3 and 4; 5 and 6 are rare cases. Similarly, triple 0, triple 0 and 0 NLGI grade are rear cases. We most commonly use NLGI 1 to 4. Question comes, should I start with the 1? Should I start with the 2 or 3 or 4? My recommendation with that is that you start always with the NLGI 2 grade. Make it a first choice.

If choice is not satisfactory, then we can think about the 1 or 3 and subsequently, again if I think about NLGI 3 and it is still I am not getting a reliable result; desirable results. Then I can think about NLGI 4. So, we can go and steps start with NLGI 2. If performance is good, load carrying capacity is much on higher side. Then I can think about NLGI 1, if bleeding or leakage of the grease is not a primary issue. But if the leakage of the grease is a primary issue and we want to retain the grease and we want to avoid dust involvement of the say foreign particles coming in the bearing, then we can think about NLGI 3 grease.

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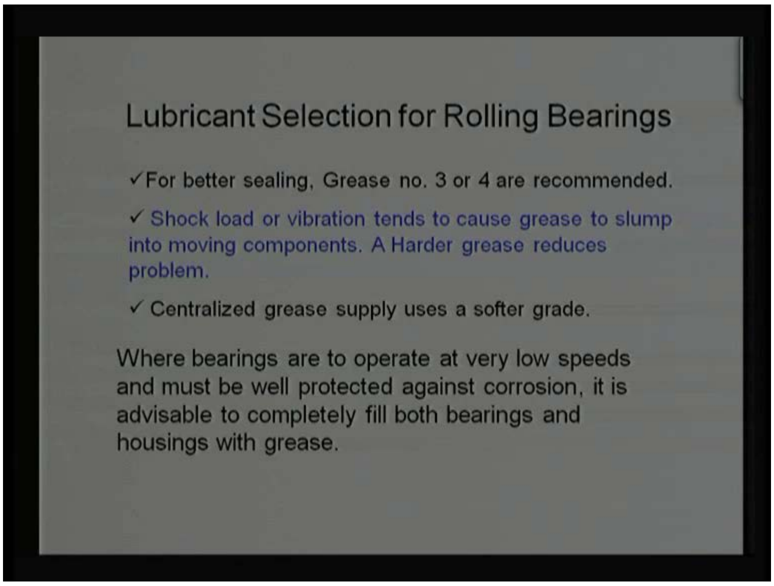

Now, there are some merits and demerits, which have been listed on this slide. We say for better sealing; we can use a seal also. But for better sealing, by grease itself we can think about NLGI 3 or 4. Naturally NLGI 4 is a harder than NLGI 3. NLGI 3 is a harder than NLGI 2. When the grease is harder, it is difficult to display easily. If it is not able to we are not able to displays easily, naturally they can act as a sealing agent, or they will act as a seal. Sometime we have a more clearance; the bearing has a more clearance. So, rolling element and inner ring rolling elements and outer ring have a larger clearance. In those situations, vibration will be one of the major problems.

If that is a situation and external load is in vibration side; so, that it is it is going to induce more and more vibrations, then we should use harder grease. But if we want to do this grease lubrication by automation or we say that there are 1000 bearings and we want to re lubricate those bearings once in the 7 days, once in a 14 days something like that, then we need to think about the centralized grease system. And whenever there is a centralized grease system, we need to go ahead with the softer grease; lesser NLGI grade. Instead on NLGI 2, we will prefer NLGI grade 1; because pumping of NLGI 1 is a lesser offer or we say efforts required to pump NLGI grade 1 will be lesser than NLGI 2.

So, overall power consumptions will reduce and in addition, there is a good thing about NLGI 1. It will be having high heat conductivity capabilities, because circulation system is slightly faster. Now, say there are other situations also; if bearing is operating in very very low speed, squeezing out of the lubricant will not be the dominating factor and we need to prevent against the water in grease; I can say correction. Then it will be advisable to use thicker grease and fill whole space available space with greases. Why do we mention here? Because there is always worry, how much grease need to be supplied.

And this situation says if speed of operation is on lower side and we want protection against the corrosion and we say the dust. We can use the thicker grease, because there will not be much problem ready to friction and in addition to that, we can fill whole grease whole bearing space with grease. We will not leave any space without grease. But that is not always recommended or we say that most commonly we do not use a full space filled with filled with grease. We generally required a space, which is we use grease lesser than 50 percent of available space. We want to give a room to rolling elements to misalignments. So, there should not be much problem.

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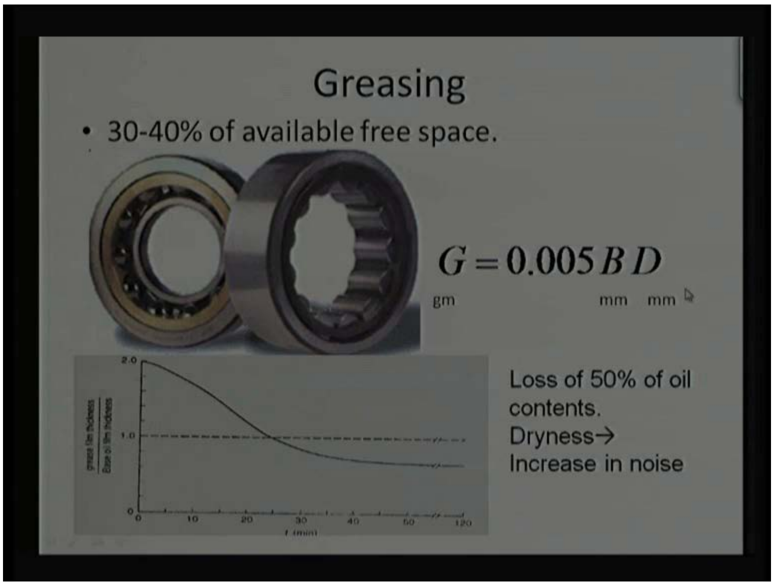

And that is why we recommend 30 to 40 percent in normal cases; 30 to 40 percent of available free space should be utilized by grease. When I am talking about free space naturally question comes, what is the free space? We can show this diagram. This is a ball bearing and this is a roller bearing. When we talk about the inner ring of the roller bearing, naturally this space will be empty. Space between the cage and inner ring, and where the rolling elements are not occupying the space. So, that is available space will be there. It can be geometrically calculated. Similarly, it will happen that rollers and outer ring and they are guided with a cage.

And they have a different profile, naturally some space will remain there and that space if I sum up completely space and we just take only 30 to 40 percent of that space; that should be filled with grease. That will be more than sufficient for ordinary purposes. But if the space is available, there is a possibility of dust particles coming and sitting in the bearing may damage the bearing surfaces. That is why we say that if speed of operation is slow and there is more possibility of the ingress of the water or ingress of the particles. Then we should use more amount of the grease. Now, another interesting thing about the grease is that once you start grease operation initially, film thickness will be larger side.

Reason being, most of the grease is available wherever it is required. But after certain hours of operation or certain minutes of operation, that grease will be displaced from the centre portion. It will be move towards the ends of the bearing. So, in that situation available grease wherever it is required will reduce and because of that, the film thickness will reduce; ofcourse, it will leads to a certain value. But this may be harmful; reduction of the available grease lower than expected; will increase the friction force; may cause more wear of the bearing. That is why we need to refill the bearing space, which is essentially required.

Now, how much time that can come with simulation through experiments? Quite possible; this is happening after 6 hours of operation or happening after 10 hours of operation or after 20 hours of operation and wherever it happens, we need to refurnish grease or we need to resupply grease; that is why say 9 times. How to quantify? This many times you say 50 percent of oil content; also 50 percent of the grease is lost or grease oil is also leaked out; bearing has bleeded. In those situations, we need to regrease the bearing; because the bearing will be otherwise dry and that dryness is going to increase the noise, which is many times unbearable. You must have heard about the bearing noise.

Whenever the bearing of the fan is not making noise, we need to do either we should relubricate or we do… it should change the bearing, whichever the case if the bearing has failed. It will also cause a noise if the grease is depleted, reduced; it will cause a noise. And thumb rule says we can supply grease in grams; calculated with this formula say 0.005 times of length into D. Now, this is the length; this may be bore diameter and when we calculate grease from this, it can be per hour; it can be per shift; it can be per month; per week depending on the requirement. Generally, it has been estimated per hour basis. Grease should be calculated and maybe whenever you have a time or whenever a (( )) person has a time, he can refurnish that grease this much that much grease in this case. Now, we talked about the grease and we say that grease is made of the thickness and lubricating oil and thickness have a main job of retaining the lubricating oil. But lubricating oil, which is retained in the thickness, has the main job of the lubrication. Naturally, we need to give more emphasis on the lubricating oil. And whenever we talk about hydrodynamic lubrication or elasto hydrodynamic lubrication, viscosity is going to play major role. And naturally, we need to choose proper lubricating oil having appropriate viscosity. Sometime we say lubricant oil need to have a high viscosity index particularly for bearing operations and we have studied the viscosity index is the index is to find out what is the temperature sensitivity.

Lesser temperature sensitivity; that means, higher vi and we generally recommend high vi oil for grease operation or for bearing lubrication operation.

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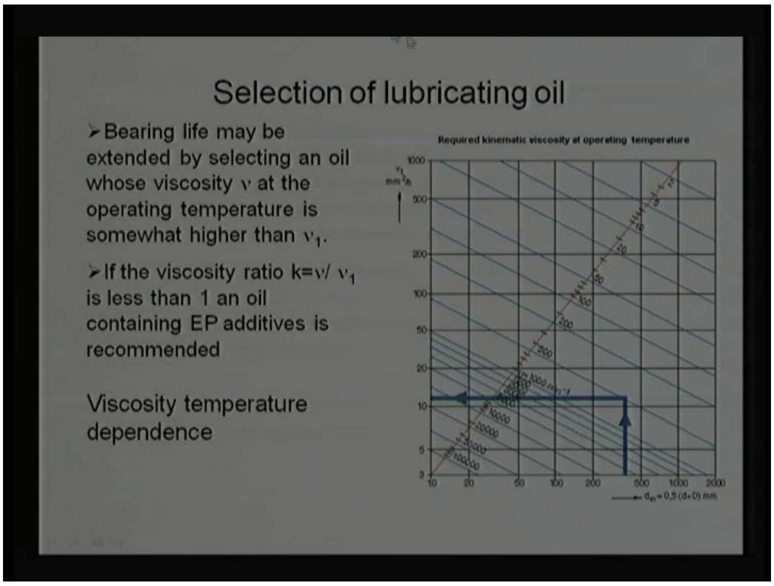

This is a one table generally provided by manufacturer of the bearing, and indicates what kind of bearing oil should be selected or what should be the viscosity of that bearing oil or that lubricating oil. This chart is in x and y direction and x direction is indicated with a d m; d m is a mean diameter; bore diameter and maximum diameter; while y is showing kinematic viscosity or centi viscosity in centistokes, which also can be represented mm square per unit second and this shows that if I know d m, I know the operating speed.

These all lines are showing the operating speed like 2 RPM, 50 RPM, 100 RPM, 500 RPM. So, if I know the operating speed of bearing; if I know mean diameter, we can figure out what will be viscosity or what will be the required viscosity; again this viscosity may be minimum value. We can choose lubricating oil, which has a higher viscosity than this viscosity. Sometime we do not have that kind of grease or there is a possibility we have abundant quantity of other grease, which is showing slightly lesser than this viscosity. Even in those situations, we can recommend that grease or that lubricating oil; but mixed with EP additives; extreme pressure additives.

Reason being, we choose thinner oil than required. Metal to metal contact possibility will increase. In those situations, we need to use EP additives with lubricating oil with grease. That is written over here. We say that bearing life may be extended by selecting an oil whose viscosity nu; that is kinematic viscosity at the operating temperature is somewhat higher than nu 1. This is giving me result of nu 1 and if we say nu 1 is maybe say 12 centistokes 13 centistokes, we should choose a viscosity slightly more than that. Or we say this can be treated as a minimum value; we recommend higher value than this.

As I mentioned earlier, if that viscosity is not available or we have some other viscosity of lubricating oil, which has a viscosity of slightly lesser than nu 1; In those situations, we should recommend EP additives to be mixed with the lubricating oil with greases. Apart from this, selection criteria we know there is a temperature criteria and that is why we need to know what is operating temperature. There is a possibility that operating temperature bearing operating temperature 60 degree, 70 degree, 80 degree, 90 degree and then operating temperature can come with a simulation or doing experimental study.

Not necessary; when we mount a bearing, it will remain at the room temperature. There is a possibility of external heat source. Some heat is generated or overall environment is heated to the higher temperature to 70 degree, 80 degree, 90 degree. In those situations, we need to choose lubricating oil, which is compatible with the temperature; because viscosity of lubricating oil is very sensitive towards temperature. Even though we select high vi oil having high viscosity high viscosity index or lesser sensitive towards temperature is still we need to know what is sensitivity of that oil towards the towards the temperature.

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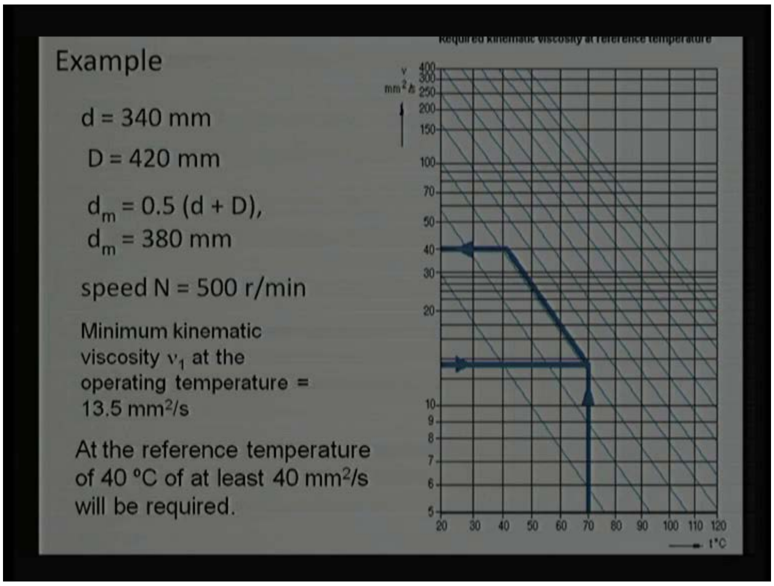

One catalog suggested this kind of table. We say if we know operating temperature, do experiment; find out, what is the operating temperature. If we know the operating temperature, and we know this axis or we say that speed related operation, and we also know what is desirable viscosity of lubricating oil, which can be picked up from the previous slide graph. If I know like in this case if this is 13.5 centistokes, viscosity which is desirable at operating temperature, and I know the operating temperature as 70 degree. Wherever it intersects, I draw a vertical line, I draw horizontal line wherever intersection happens, and these lines are parallel; they are not going to change.

So, I draw a line parallel to this and line coming from the operating from the room temperature; the room temperature is 40 degree centigrade. If I draw a vertical line from this and line parallel to one of this line from here. Wherever intersection happens, draw a line horizontal to that; that is going to give us what will be the viscosity or what which kind of the oil should be selected. Even though here viscosity are viscosity is desirable for operation is only 13.5 centistokes, but we are going to choose oil having viscosity of 40 centistokes that at the room temperature. Because we know as temperature increases, as the temperature is going to increases this side, viscosity of lubricant is decreasing.

And we want minimum viscosity, which is desirable at operating temperature; not at the room temperature. We should not commit a mistake. We figure out 13.5 viscosity is required and we are going to choose the lubricating oil based on that we need to do. Make it we say useful of the operating temperature or we can use this kind of chart or any numerical relation or algebraic relation we have studied that voglus relation we have studied the volgel's relation. We can use those relation to figure out what will be the operating viscosity to be selected what viscosity can be selected or which should be selected. Now, let us take an example here.

See, assume that bore diameter is 340 mm and o d is a 420 mm. We can figure out what will be the mean diameter that is turning out to be 380 mm. So, what we require 380 mm over here. So, this is 10, 20, 100, 200 and somewhere here it will come 380. 380 we draw a vertical line and again here we have we know what is the operating speed; operating speed is 500 RPM. So, I draw a vertical line wherever it will intersect 500; I mark over here. Now, from this point we draw a horizontal line; that horizontal line is going to give us what will be the viscosity; what is operating viscosity and that is turning out to be here is 13.5 centistokes.

Our unit of centistokes is mm square per unit second. That is why it is represented 13.5 mm square per second; this is a desirable viscosity. Now, we know very well we need to see what is the operating temperature. If operating temperature is the room temperature, we will go ahead with this kind of viscosity selection itself. But if operating temperature is the higher side, we say instead of 40 degree operating temperature, it is 70 degree and we need to select the bearing that is a atmospheric pressure temperature; that which is 50 degree centigrade. So, what we do in this case 70, you draw a vertical line.

Wherever intersect with this line and may be in this case also the 13.5 viscosity, which has been selected; draw horizontal line; draw vertical line. Wherever the intersection happens, draw parallel line to one of this line and this room temperature atmospheric temperature, draw vertical line form this; wherever interests from that point, we draw horizontal line. So, this is viscosity and that viscosity is turning out to be 40 centistokes.

We should choose lubricating oil with this kind of viscosity; that will be important for us. It is essential to go ahead with proper selection of lubrication.

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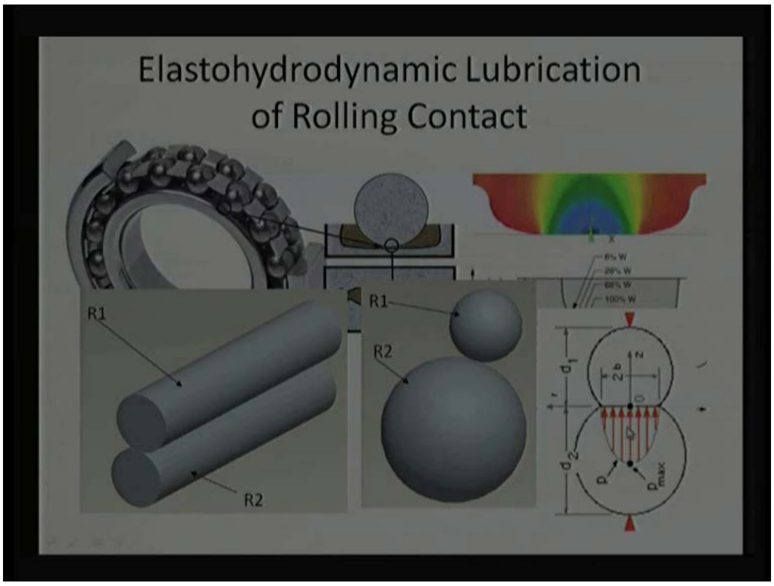

Now question comes, we are selecting lubricating oil; we are thinking about the grease. What should I do with this? We have selected this in the catalog; but that is only initial selection. It does not depend much on the load; it does not depend on what kind of material we are using. But we are selecting some lubricating oil. So, first we select that is an initial case and then we can go for detailed analysis. For detailed analysis, we know we require elasto hydrodynamic lubrication. Or we require how much deformation will occur the rolling elements and because of that deformation, what will happen at that viscosity?

Will there be a shear thickening effect or will there be piezo viscous effect? Under pressure, will the viscosity be thickened? That has been already covered in our basic subject. We are not going in that much detail. But we can use some sort of (( )) equations, which are more popular; because when we talk about the elasto hydrodynamic lubrication mechanisms, we require more and more experimental data. Just to elaborate this, I have kept few slides. We say, what is happening if I section some rolling elements? In this case particularly 2 row ball bearings, what we are getting? This is a cage; this is inner ring; this is outer ring and outer ring has been sectioned.

Now, any time there is a ball, lubricating oil and there is inner ring; they will be in contact. So, this is a magnified view of this or we say that this portion is not visible; that is why it has been magnified like that. Now, further we can magnify this portion and what we find there will be some sort of surface sharpness and there will be some sort of elastic deformation of the surface. And this lubricating oil is kept in between rolling element or we say the roller or ball and in the outer ring and inner ring. So, here we are talking about the outer ring and here here we are talking about inner ring here.

So, there is inner ring, there is a ball and this is grease or we say the lubricating oil. So, these two surfaces are completely separated. So, there will be some sort of hydrodynamic or elasto hydrodynamic lubrication depends what is the specific thickness. We have studied if specific film thickness is more than 3. Then there is a possibility of hydrodynamic (( )) hydrodynamic lubrication. But if this specific film thickness is lesser than 3, then we need to consider elastic deformation of the surfaces. And another thing is that wherever there is elastic deformation, ball will keep deforming. What will happen?

The contact area will continuously increase not contact area as such in mechanical contact. But area which is coming very closer and that area will increase. So, that is been shown here with this kind of sketch or figure. We say, the centre there will be maximum pressure; at outer side, this pressure will continuously decrease. And this is a complete contact patch, which we have studied in our previous lectures; that is equivalent to 2 into B; B 2 B is generally contact patch in one direction. Now, this shows that as the load is increasing, this flatness will increase; this much flatness with the some 6 percent of dynamic load carrying capacity.

Then when we come to the 25 percent, the flatness will increase. We will take about the 100 percent equal to… see this flatness has increased to drastic level. Naturally, after this we need to consider a larger deformation larger elastic deformation and we need to use sophisticated calculations or we say more like final element method to find out what will be the overall deformation of the surfaces. Now, we have studied the two kinds of geometries. One is the roller over roller or roller ball over ball and these two common geometries are used for the bearings. This may be used for the ball bearings; this may be used for the roller bearing and depends which kind of bearing which we are using, we can use a particular formula to find out what will be the minimum film thickness.

What is it? We are talking about this is what we have studied; that is elastic deformation and we use a Hudson theory; there is no lubricant in between. So, the film thickness will not be there. But this contact patch can be seen over here; the centre pressure will be maximum and the outside pressure is minimum and we want to study this with lubricating oil. If lubricating oil is also dragged at this interface, because of the high pressure what we are talking about pressure in giga Pascal that viscosity or we say that grease will get solidified there. And that is why it can share the load and that is why overall bearing can sustain very high load that what we can we cannot estimate with simple mechanical relations.

And what is our aim? To find out, what is the film thickness? Say if I assume this is a horizontal zero axis zero value; this is film thickness axis; as we go up, film thickness is going to increase. So, this may be the first low load; this is the film thickness. The gap between this line and this line; gap between this line and this line will going to give us film thickness of 25 percent of the (( )) and as the sea is increasing, that gap is not deceasing that fast. But elastic deformation of the zone is increasing. So, we need to know what will be the film thickness. Based on film thickness, we will be able to find out that the bearing is going to be safer side or not.

And the specific film thickness is always be greater than 1, then we are comfortable is greater than 3; we are much more comfortable in that. We talked about when the specific film thickness is the range of the 1 to 3, there is a possibility of mixed lubrication. When specific film thickness is between 3 and 5, then it will be elasto hydrodynamic lubrication. Ofcourse, there will be elastic deformation; there will be hydrodynamic lubrication mixed together; there will be elasto hydrodynamic lubrication and we are discussing about that elasto hydrodynamic lubrication mechanism.

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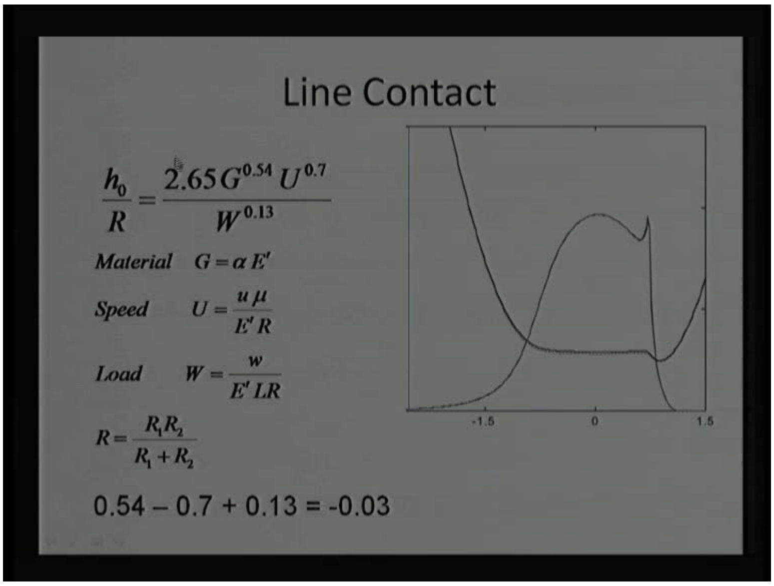

And if I see a close look of the pressure and film thickness profile, what we are getting? Get, I am assuming this 0 to 1 is B. So, minus B to plus B; that is the contact zone. If I do not use lubricant, metal and metal contact will happen. If I am using the lubricant, what is going to happen? Some additional zone will be generated, because the lubricant is getting pushed or we say the getting dragged at that contact area. And that is why this pressure generation will start from away away from minus B. So, this may 1. minus 1.5 1.5 B and still we are getting some pressure more than atmospheric pressure. Coming to the exit side, we may say 1 B is somewhere here and still slightly away from 1 B, there is a pressure generation.

But you can see the reduction in pressure is significant. While increase in pressure is gradual, reduction is pressure is very fast or we say immediate effect; that means, when ball or roller are subjected to the heavy load and the exit; there will be some sort of discontinuity certainly form high pressure to low pressure, liquid will come. So, there will be discontinuity in this and we are able to find some sort of peak over here; some sort of spike over here, which is not… It should not happen particularly. But it has it has been seen as the load increases. As the load increases, this value of the spike is going to decrease. But the lesser load lighter load, this spike value is more than even at this value; that shows clearly.

As the load is increasing, even this elasto hydrodynamic lubrication is turning out to be elastic deformation or elastic lubrication mechanism. Hydrodynamic action is going away or when the load is low, naturally peak will be on higher side; that is going to give us significance of hydrodynamic action. Or we say after quite close bounding between the two surfaces, suddenly space lot of space is available for the lubricating oil. That is why there is some sort of peak or jack comes and this peak is going to represent the jack. This film this line is showing the film thickness profile. See the film thickness; when the liquid lubricant has not been dragged in, there will be very large value.

And as it comes in the contact zone, this lubricant film thickness remains stationary for the longer duration. Reason being, that there is elastic deformation and separation is not going to change this value. However, the exit again this is going to thinner side; the pressure is higher side. Naturally, this will come to thinner side; this will be minimum film thickness; this is important to calculate. It is not the film thickness which is the centre, which is important. The minimum film thickness is important for us to find out what is the film thickness. For the line contact; that means, when we are talking about the cylinder cylindrical roller bearing or even the spherical roller bearing, cylindrical roller bearing is more dominating in this case.

Because there is a line contact that can be given on which is h 0, which is coming somewhere over here can be represented in terms of radius. Rolling element radius and this formula; this is coming from (( )) equation. We can solve individually elastic equation and hydrodynamic equation and bring some more balance about this. But that will be selectively tedious and that can be done when we have selected lubricating oil. We figure out here; everything is fine, then we can go for detailed analysis to find out what is the conservation or what is the overall available life to (( )) so, to the bearing. Now, it is involving three parameters; we say the G parameter, U parameter and W parameter. Remember, U parameter clearly indicates it is a speed parameter.

W parameter clearly indicates it is a load parameter; while G parameter is something different; it can be known or it can be termed as material parameter. So, we need to know what is this material parameter. You can see the G, which is material parameter is represented or given as a function of two parameters alpha and E prime; alpha is a piezo viscosity coefficient. If there is no piezo viscosity, this G will turn out to be zero and then we need to use hydrodynamic lubrication mechanism. But ofcourse, alpha value is already very low value; but we need to count to figure out what is elastic deformation and based on that we will be going to figure out what will be the film thickness. So, generally alpha value is very low and this E prime what do we say that reduced young's modulus or effective young's modulus.

It comes not only the young's modulus; but is also comes as the Poisson's ratio. Because when there is a deformation, load may be in one direction; but deformation will be in two directions. So, we need to know what is effective elastic modulus. G is equal to alpha into E prime and this G is a non dimensional number. We can see h 0 by R; this is non dimensional. Naturally, every parameter to the right hand side need to be non dimensional; otherwise, if there is dimension, this whole relation will change. Obviously, there for m case unit, we need to use one equation; for SI units, we have to use another equation; for British units a p p s and then we have to use another unit or another equation.

To avoid that kind of that kind of that kind of problems, we are generally representing this in terms of non dimensional numbers. So, alpha naturally will have a unit 1 by E. If E is represented in Newton per mm square or Newton per meter square, naturally alpha need to represent just opposite to that; the meter square per unit Newton or mm square per Newton. Coming to the speed parameter, again this is need to be a non dimensional number. There is a viscosity, mu; mu is a viscosity; u is velocity of contacting element; E prime, we already described over here and this is R is accounted; it is going to account the radius of the both contacting pairs. So, if I say radius of one element is R 1; radius of other element is R 2.

R can be figure out with a harmonic combination of this R 1 and R 2 or in another words, R is equal to R 1 into R 2 divided by R 1 plus R 2. So, this is a speed parameter. Coming to the load parameter, this is applied load; now here given load may be different than this load. Reason being, in rolling element there are maybe say 10 balls, 8 balls, 14 balls, 16 balls; as the numbers of balls are increasing, this w will decrease. Reason being, that those many rollers or those many balls are sharing the load, but we are not sharing equally. That is why we use a relation, which we are draw it in earlier classes; that with increasing number of rolling element, w will decrease.

So, we need to find out what is the maximum value of w on any one roller pair roller and ring pair or balls and ring pair. So, once we know G, once we know U, once we know W and other relevant parameter we can figure out what will be the film thickness in cylindrical roller bearing. Now, interesting thing first thing is that W power is just 0.13; that means, applied load is not to be very sensitive towards the film thickness. It will be increasing sensitivity towards the stress. But this is not going to affect much to the film thickness. Reason being, there is elastic deformation and the flatness continuously increases.

That is why we say we showed in earlier one slide; the flatness is increasing; the contact zone is increasing; 2 B zone is increasing; but not film thickness. It is having some sensitivity. But that sensitivity is much lower; when compared to one, it is turning out to be 0.13. Now, we see other sensitivity material parameter sensitivity is more than 0.5 here and then in case of the U, this power is more than 0.7 or we say 0.7. Now, if I think about the young's modulus, generally we say the softer material will be subjected to more deformation and there is more deformation, film thickness will increase. But if I compare all these three parameters, G involves E prime that is 0.54; U involves E prime, but in the reverse side in denominator; it will turn out to be minus 7.

And W, W also involves E prime, but again in this case it is happening in the reverse 1 by E; that means, W is already in denominator. So, E will turn out to be in numerator; that is why it is written 0.13. Now 0.57 and sorry in this case 0.54 plus 0.13 is turning out to be 0.67. If I reduce from 0.7, it is turning out to be 0.03 negative sign. This clearly says young's modulus does not have much effect on a film thickness. So, generally we visualize or we imagine that if there is a softer material, it will be subjecting larger film thickness or lower material is going to give much better going to give much better performance. It does not happens we say that if I leave in this (( )) equation, it does not happen to that extent.

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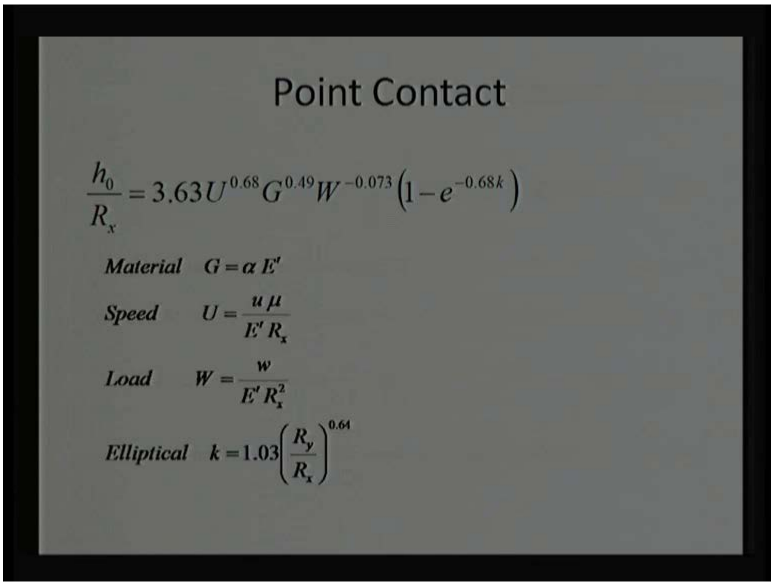

Now, we talk about the point contact. Say in point contact, sensitivity of each parameter is reduced. In earlier line contact, sensitivity which is U power was 0.7; here the power is turning out to be 0.68. So, slight decrease in the power of U. Similarly, G in case of the line contact, it was 0.54; well here it is turning out to be 0.49; the sensitivity slightly reduced. Coming to the W, in (( )) W in case of the line contact was equal to the 0.13; say W power minus minus 0.13; however, this again is decreasing. So, sensitivity discontinuously decreases for all the parameters and in addition to that, there is one parameter what we call as electricity parameter.

Reason being, in ball bearing even though ball has a is a perfect sphere, but inner ring and outer ring which we use with the balls they do not have a radius same radius in both the directions. In rolling directions, they will be having different radius; in perpendicular direction or along the axial direction, they will be having different radius. So, there will be some sort of ellipse formation and that electricity parameter is defined with k. So, this material parameter remains same, which we have defined in line contact case. The speed parameter is also same expect initially we use only R; while here we are using R x.

R x is representing the effective radius in rolling direction. Similarly, in the load in previous slide we show the E prime R into l; we know there is no l available for this pair; usually we have to use R x for the instead of l. So, it will turn out to be R x square. Again we are using radius in rolling direction effective radius in rolling direction not in axial direction and this is elliptical parameter, which is giving a mirror of electricity. This says that R x R y divided by R x and what is R y is effective radius in axial direction. So, we can calculate this radius effectively. Let us consider one example to elaborate whatever we have studied in rolling element bearing.

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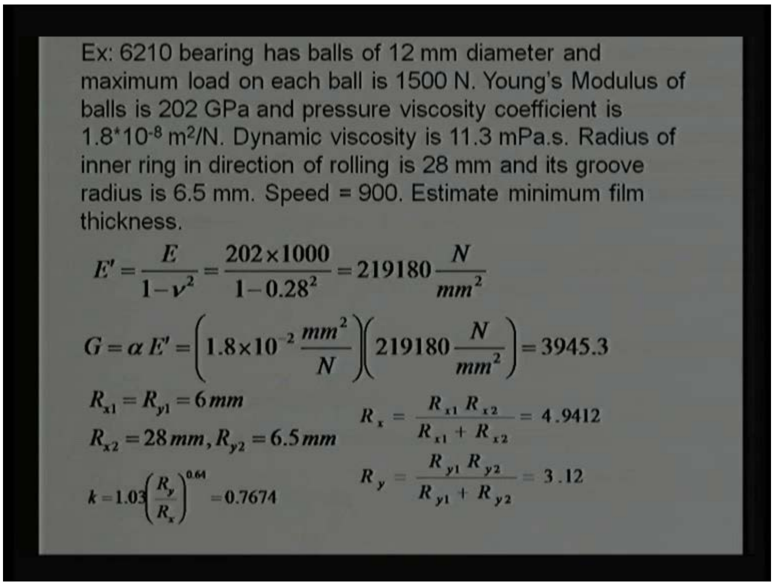

We are saying that in this case, we are choosing 621 bearing; 6 is strength for the deep groove ball bearing; 2 is the series of the bearing and 10 is the bore diameter series. One bore diameter means this 10 in to 5 is a 50 mm of the bore; small d value is the 50 mm and we are saying that it is a ball bearing and it has a ball diameter of 12 mm and a maximum load on each ball is been calculated 1500 Newton. If these values are not given to us, then applied load will be given to us and number of balls included in that bearing will be given to us. Based on the applied load and number of balls and number of rows, we can figure out what will be the maximum load on each ball.

So, that is when in this case, it is already given; we need not to calculate that. Say in each ball, it is turning out to be 1500 Newton. Young's modulus for the balls as well as inner ring and outer ring is somewhere 202 giga Pascal. Pressure viscosity coefficient that is alpha, it is given over here; 1.8 10 is to minus 8 meter square per unit Newton. And as I mentioned this value is much smaller; wherever there is pressure in mega Pascal, then only this alpha value is need to be accounted. However, there is no need of such. Dynamic viscosity is 11.3 milli Pascal second. Radius of the inner row we are defining also in direction of the rolling is 28 mm, in direction of the rolling is given as 28 mm even the bore diameter in this case is 50 mm.

Naturally, there will be some sort of thickness and then radius which is coming into contact the rolling element, which is need to be small slightly greater than 50 mm. Obviously, slightly greater than 25 mm, because we are talking about the radius. So, minimum 3 mm thickness; we are keeping the thickness of the inner ring. And its groove radius is 6.5 mm that is axial direction, which is retaining the ball in space; that is a 6.5 mm. Operating speed is 900 RPM. So, this 900 is represented in RPM. What we need to do? We need to find out minimum film thickness for these given parameters. So, we can start we say, we need to find out first what is E prime?

What is effective young's modulus? Young's modulus where we can use both the material; but in this case, material is the same. That is why we are using the reduced formula; that is given as the E divide by 1 minus nu square and nu is generally for the bearing is still is represented as the 0.28. So, we use those values what we figure out this; instead of 202 giga Pascal, it is turning out to be 219180 Newton per mm square or if I think about the giga Pascal, it will turn out to be 219 giga Pascal. Now, second one is the G parameter, which depends on E parameter and alpha is given in this situation; that is 1.8 10 is to minus 8 meter square per unit Newton and what we have calculated E prime in Newton per mm square.

So, naturally we need to convert this alpha in mm square per unit min per unit Newton. So, that is what given mm square per unit Newton and this 10 is to minus 6 has been used over here. So, 1.8 into 10 is to minus 2 into 219180. So, this mm square mm square will be cancelled out; N and N will be cancelled out. So, this will turn out to be non dimensional number. As I mentioned, we need to assume these are the non dimensional numbers and this value is a non dimensional number will turn out to be 3945.3. Ofcourse, we can we can simplify it. We can we say that we should avoid any decimal numbers. However, it has been calculated with the calculators. So, we are just writing this number.

Now, to find out other parameters, we require R x and R y and R x 1, the radius of the ball either in x direction or y direction will remain same; that is the 12 mm divide by 2. Coming to the bearing inner ring, what we say R x 2 is equal to 28 mm, which is given over here and R y 2 is given as 6.5 mm. Now, I can utilize R x 2 and R x R x 1 and R x 2 to figure out what will be R; that is the harmonic combination of these two. Similarly, I can figure out what will be the R y; that will be the harmonic combination of R 1 and R 2. So, we do that; say R x is equal to harmonic combination of R x 1 and R x 2; that is turning out to be 4.94. Naturally, this is a smaller value compared to R x 1 and R 2; that is the harmonic combination.

We can find out harmonic summation, then we need to find lesser value than any of individual value. Coming to R y that is shown as R y 1 R y 2 divided by R y 1 plus R y 2 and when we substitute this value 6 mm and 6.5 mm, naturally we need to find out the value, which is lesser than this and that is turning out to be 3.12. If this value is lesser than 6 mm is lesser than 6.5 mm, we say that it is one of the check to find out whether we have done right calculation or wrong calculations. Based on this R x R x and R y, we can find out what will be the electricity parameter; that depends on the ratio R y by R x and that is coming out to be 0.7675 or we say 0.77 as electricity parameter.

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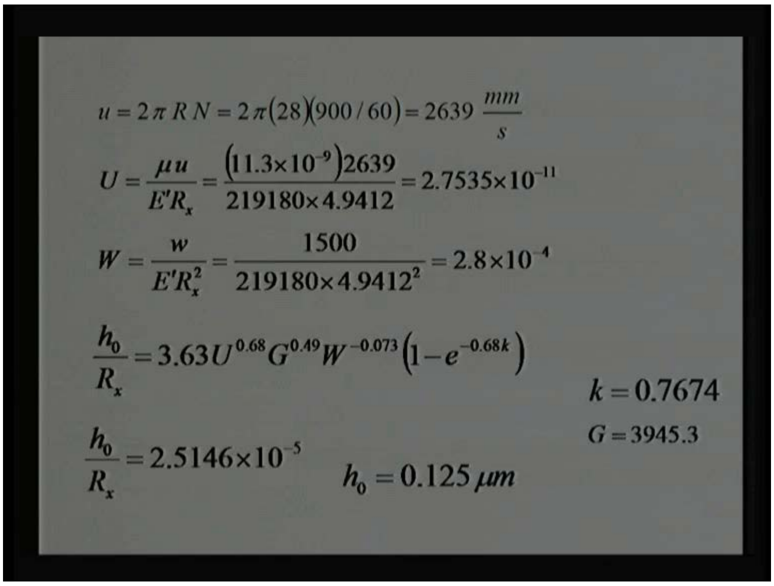

Continue with this occasion, we need to find out what is the u; because we need the velocity parameter and to find out the velocity parameter, we need to find out what is the rotational velocity. Inner ring is rotating at 900 RPM and we can choose a bore diameter also. But inner ring outer surface say inner ring larger diameter will be rotating at much faster speed; not much faster faster speed compared to the bore diameter; that is why R is taking that value. So, instead of 25 mm, we are use 28 mm which is been given to us and that is giving the value as a 2.6 meter per second. So, based on the available values, we can figure out what is the U; that is function of viscosity; function of velocity; function of effective young's modulus; function of radius.

Substituting all these values, what we find this U number as very, very low value; that is turning out to be 2.7 10 is to minus 11. Last parameter in this sequence is W and that w is applied load divided by E prime R x square. And when we substitute this value, this is turning out to be slightly more than the U parameter and this is a 2.8 10 is to minus 4 and we know U parameter has more effect more sensitivity compared to the W. So, we can find out what is the film thickness. This is the 3.63; this is the formula, which we are directly using U power 0.68 is already known to us. We can directly substitute this value of the U. G, there is a material parameter power 0.49. W is having low sensitivity and power is negative of 0.073.

Electricity parameter already we have calculated k and thus value of k was and thus value of k was 0.77 or 0.7674. G value was 3945. We can see the G has a maximum effect compared to viscosity; compared to velocity; compared to over here. The G value is very high compared to any of this. When you substitute, figure out. What we get? This ratio; this ratio is 2.5 10 is to minus 5 and this is a non dimensional number. If R x is been represented in mm, h 0 will come in mm. If R x is represented in micron, then h 0 will be in micron and that will turn out to be something like this 0.125 microns; that is a reasonably small value.

We know the surface roughness for the rolling element will be somewhere in some micron may be lesser than we say 1 micron or may be nano meter. So, we know very well these are super finished surfaces and that is why this kind of… Even the film thickness is lower, we can find out a specific film thickness, which may turn out to be more than 3 or nearby 3. So, it can give a satisfactory operation. If we find the film thickness is really lesser than specific film thickness is lesser than desirable limit like 3, then we should change the viscosity. We increase the viscosity of lubricating oil; that is going to affect the result; that is going to change the film thickness; that is going to increase the film thickness.

So, viscosity is going to be playing a very important role, because operational parameter cannot be changed. If we find h 0 is lesser than desirable limit, then in those situations we need to change the viscosity, we need to increase the viscosity of that lubricating oil. So, with this I am trying to close the topic on rolling element bearing. In next lecture, we will be starting gears, which are very important elements or we say that important Tribo pairs. Most widely used and commonly used, because commonly filled because of the surface fitting. Thank you for your attention.