Tribology

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Lecture No. # 33

Bearing Clearance

Hello and welcome to 33 rd lecture of video course on Tribology. Today's topic is bearing clearance. In previous lecture, we studied we understood various sources of friction on an ideal condition. Even though there is a friction loss, temperature rise will not be significant; well within limit. So, bearing operation will be stable, but there is a possibility. If there is no clearance in the bearing, bearing is pre loaded or we say there is some sort of interference. Or in other words, there is a negative clearance between the rolling components, then there is a possibility of high temperature rise; that is we are going to explore today, we are going to discuss about those issues. So, bearing clearance is important from those points of view.

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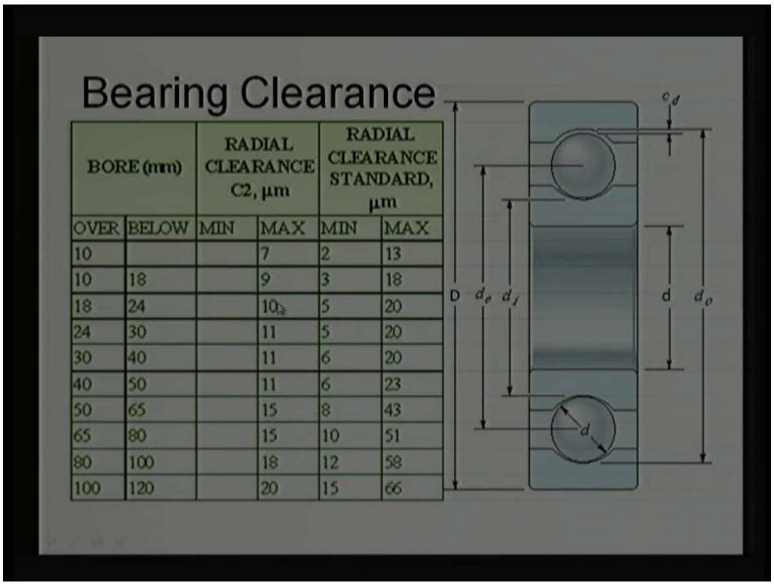

How to define bearing clearance? This is a bearing clearance can be shown by this diagram by sketch. This is a inner ring, inner ring is hollow; so, this portion is hollow portion. This is a rolling element ball; it can be roller also. But in this case we are using ball. So, there are two balls and this is outer ring; outer ring again is a hollow. So, that is why the cross section is shown over here this portion, and this portion and they are connected with plank. As usual they are two dimension (( )); this is a d is a bore diameter is the same as a shaft diameter. If I forget or we say they do not govern the tolerance, and capital D is the outer diameter of bearing. Capital D and small d generally both are defined in bearing catalogs.

What else is there? There is something like c d; this is diameterial clearance. How to get it? Say, in outer ring we were if we assume the axis of this bearing is horizontal, actually gravity force will be acting vertical downward direction. Outer ring is stationary; is supported; ball is getting support from outer ring by getting contact or when it comes in a contact. Inner ring is getting supported or we say gets support from the ball like touching the ball surface. Same thing in the opposite diameterial opposite side, there is another ball which get supports from the inner ring. Now, the ironic contact outer ring in contact with the ball; ball in contact with the inner ring; inner ring when you contact with the ball; but outer ring is completely stationary. Is not it fixed?

So, there is some separation and that makes a diameterial clearance. If I divide by 2, it will be radial clearance and often in bearing catalog, radial clearance is defined something like this. See, in this case bearing clearance table is given; first column says the bore diameter and gives the range. It is generally 0 to 10 millimeter, 10 to 18 millimeter, 18 to 24 millimeter. There is another called radial clearance C 2 and we have standard clearance. If nothing is been mentioned about the reduced clearance or half side clearance, then it will be standard clearance. See, when the bearing is lesser than 10 millimeter standard clearance or radial clearance is 2 to 13 micron there is a margin of 11 microns.

There is a variation of 11 microns. Same thing when you go for high diameter. Let us take an example of 30 millimeter, 30 millimeter to 40 millimeter; that means, this is 06 series and 08 series in between there will be 07series also. What we are getting? Minimum clearance minimum standard clearance as a 6 microns; maximum standard clearance is 20 microns. Now, there is some gap the 14 micron; there is a possibility of variation in the clearance variation in clearance for the different bearings in the same group. When you go for higher site 10 to 100 to 120 millimeter bore diameter, what we are getting is 15 to 66 micron clearance; this gap is increasing significantly.

Now, we have another table or we are able to see this column also; that is called a C 2 clearance, where the minimum clearance is 0; maximum clearance is 0 here it is 7 micron. That means, for the bearing having bore diameter of lesser than 10 millimeter, this clearance will be 7 micron or lesser than that; minimum value here is 0; so, 0 to 7 micron. Coming to the second category or second range 10 to 18 millimeter, what we are getting 0 to 9 micron. See in this case available range is relatively smaller compared to this range. So, these bearings can be used for more precise operations for instruments, where we require exact position of the shaft and there we require lesser tolerance or we say the permissible tolerance will be lesser side.

We do not want to change the bearing performance or bearing performance should not be changed because of manufacturing processes. We want more reliable performance and more and more reliability comes whenever there is a lesser and lesser available range, because if I want to if I want to install 10 bearing and a 2 bearing something say there is a clearance is 3 micron and 2 bearings clearance is 11 micron. Actually, performance from the 2 to 11 micron will be very, very different; because of the clearance of the available noise level will be different and there is a preload or installation procedure; there is something wrong in that. Then bearing performance will change. How? That is going to be we are going to discuss in next few slides.

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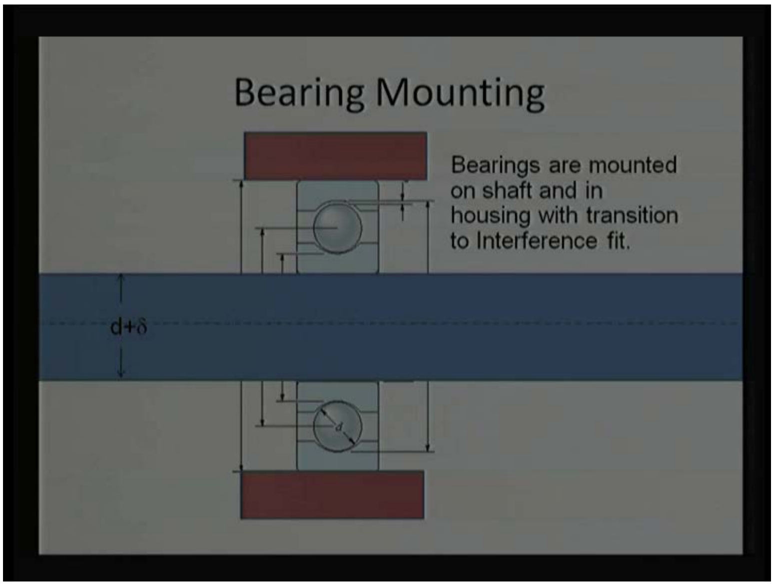

So, let us take this is the bearing clear mounting. Now, bearing need to be mounted on a shaft. So, there is a shaft. We say there is a axis may be we are assuming the geometry axis; geometric axis or the bearing and geometric axis of the shaft, they are matching, they are aligned, they are on the same line, there is no difference, there is no eccentricity, but as bearing is going to rotate with the shaft. And if we do not have any firm connection between inner ring and the shaft, there will be possibility of the slip and we do not want that.

Because if there is a slip, bearing is not going to fulfill this intended function; in addition, there will be some sort of heat generation and that we are going to lose some energy there. That is not desirable from the product point of view. So, there is some sort of interference rate in between these two. Now, if there is interference in it, what is going to happen? There will be some sort of push or this this ring inner ring will get deformed or geometry of the dimension over here will increase by some value; it may be any delta value. So, there will be change in the geometry after the installation; obviously, the change in the dimension of the inner ring after installation.

When the shaft is pushed in bearing or bearing is pushed over the shaft, there will be some change in the dimension of inner ring and that is on a positive side, the dimension will increase in the value. If there is increase in the dimension because of this push made, there will be reduction in c d available space for c d; obviously, the radial clearance or diametric clearance will reduce. Now, there is another one; this outer ring needs to be fitted with the housing. Housing is a stationary and we want this bearing outer ring to be stationary. Then we require some sort of the fit. Generally, we do not recommend the interference fit for this process.

We require a transition fit; is not there; there is some clearance and some interference way. We can say there is some sort of surface roughness and then mix itself is some fit in that. So, that is important. Now, if there is some sort of fit and there is some sort of disturbance in outer ring, again there is a possibility of some change in outer ring over here. Some dimension will decrease. I would say outer ring inner dimension will decrease. If that is this ring is going to decrease; obviously, it comes down this ring ring is going go up. What will happen? Available space will reduce and that is going to reduce the diameterial clearance.

And there is a possibility of negative clearance also; that will generate interference fit within the balls, inner ring and outer ring; will create a more difficulty in rotation; will cause more friction and we should avoid that as far as possible. How to avoid that? That is always a big question. How to mount it properly? That is always a big question. However, we can say or we can conclude from side, the bearings are mounted on a shaft and housing with the transition to interference fit; transition fit. (( )) We recommended for the housing and outer ring and interference fit between the shaft and inner ring. To keep that kind of interference in the transition fit, we said we know the bore diameter of the bearing is d.

(( )) Assuming that there is no variation; there is no tolerance in that bearing. There is a manufacture with precision and there is no tolerance on there is no available tolerance on the bore of bearing. But there is a possibility, we should account if we have knowledge of that. For time being, we are taking this diameter of the shaft as a d plus delta; that may be 1 micron, 2 micron, 10 micron, 20 micron depends on what kind of interference fit we will need. And when this larger diameter is pushed in a bearing bore diameter d, there will be some sort of deformation; there will be contact pressure and that contact pressure is going to keep shaft and inner ring in tact together.

But it is going to cause some deflection of inner ring and that is going to cause some reduction in the clearance available clearance. Similarly, if you go for the transition fit of the housing, we can keep D as it is plus delta 1. This D is outer diameter of ring and that is what we say in this case plus whatever thickness of what we are seeing the two times of thickness of the housing plus we keep this one as delta 1. This is may be much lesser than what we are keeping over here. But there we are keeping this D as a diameter outer diameter of the bearing plus two times the thickness of housing.

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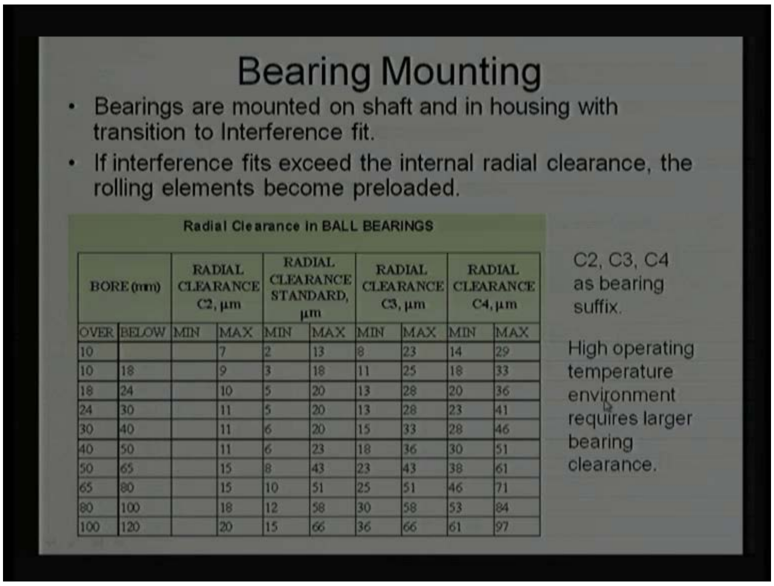

BORE (mm)		RADIAL CLEARANCE C2, µm		RADIAL CLEARANCE STANDARD, µm		RADIAL CLEARANCE C3, µm		RADIAL CLEARANCE C4, µm	
OVER	BELOW	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
10			7	2	13	8	23	14	29
10	18		9	3	18	11	25	18	33
18	24		10	5	20	13	28	20	36
24	30		11	5	20	13	28	23	41
30	40		11	6	20	15	33	28	46
40	50		11	6	23	18	36	30	51
50	65		15	8	43	23	43	38	61
65	80		15	10	51	25	51	46	71
80	100		18	12	58	30	58	53	84
100	120		20	15	66	36	66	61	97

Now, what we covered is the bearings are mounted on a shaft and housing with a transition to interference fit. And if interference fit exceeds the internal radial clearance, whatever we are doing if that is going to causes reduction in the radial clearance versus the mounting. And we are going to mount or we are going to do some sort of manufacturing processes or we are going to fit it by some assembly procedures. If that interference fit exceeds the internal radial clearance, there is a possibility of preloading of rolling element bearing. (( )) This will cause some sort of deflection and that is showing or that is going to show, there is a preload on the bearing.

And if there is preload on the bearing, actually friction loss will increase; temperature rise will be on a higher side. Whenever there is a situation like we require higher clearance or lesser clearance, then we can follow these external tables available in the catalog. Say, we have studied this radial clearance standard size, then we talked something about C 2 clearance which is lesser than this clearance. But there is a possibility to choose higher clearance like C 3 clearance. C 3 clearance will be always larger than C 0 clearance; obviously, the C standard clearance. Same way in the similar way, C 4 clearance which is on a higher side; it will be having higher clearance compared to C standard or compared to C 3 clearance.

So, it is in a range lowest clearance; you say moderate clearance, high clearance and highest clearance in this case or it can be made as a C 5 clearance also for the particular (( )) some companies. Whether operating range is very high or temperature range is very high and we need to account the expansion of the shaft expansion of the inner ring, expansion of rolling element and expansion of outer ring. There will be non uniform and we need to find out because of the temperature increase; because of the expansion of the dimension of individual elements, how much clearance we need to keep? Or in another word, what we are discussing? At room temperature, clearance is very high; maybe say C 4 clearance.

When we operate or we are fit a bearing and we start operation on that or bearing is supporting the shaft, then that time running clearance will be lesser than what we are providing the initial clearance; that is because of the temperature. What we are mentioning? Like in this case 2 to 13 micron is the clearance, while C 4 clearance is 14 to 29 micron. See if I take a mean value if I take a mean value of this, we may say 12; 2 plus 13 divided by 2 will be 7.5 micron. While in this case 14 plus 29, 43 divided by 2 is 21.5 micron; so, 7.5 micron into 21.5 micron. This we when we assemble initially at the room temperature, this will be high clearance in 21.5 micron. The average clearance is the mean clearance.

When when we operate at that temperature because of thermal expansion, it may come back to the 7.5 micron clearance which is a desirable. So, whenever there is a high temperature application, we need to choose higher clearance as C 3 clearance and C 4 clearance. Generally, these are defined with a suffix whatever bearing number, we say 6214 suffix with a C 3 or suffix with a C 2 or suffix with C 4. If there is no suffix, then it is standard clearance. So, what we say high temperature high operating temperature environment requires a larger bearing clearance. Is it clear? Because of the expansion, we need to account those and clearance will reduce with operating temperature. So, we need to account those.

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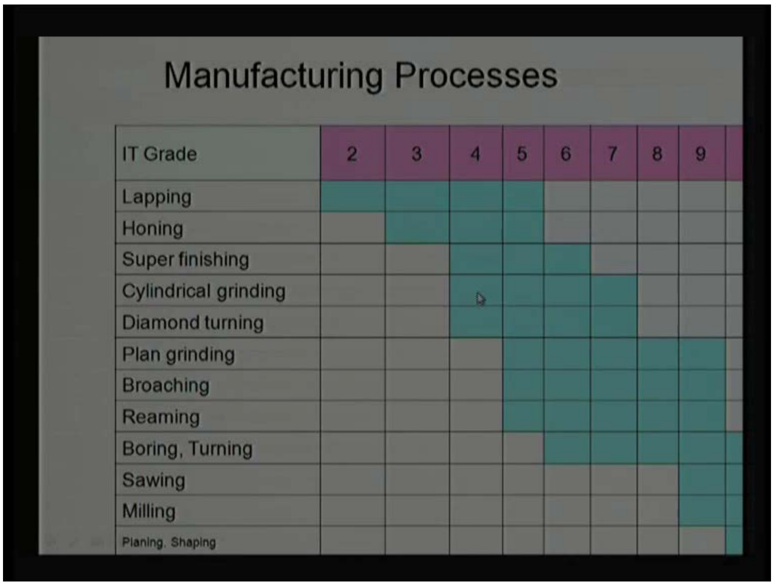

Now, we were talking about the clearance and we were talking about some sort of delta variation and some tolerances naturally. We need to consider, what are the manufacturing processes or do we recover, if a design some bearing or we say that we select as a bearing for the some design component. Design component may be the shaft with housing, then what kind of manufacturing should be recommended or if we know the manufacturing processes, we will be able to understand what kind of clearances will be there or final clearance after mounting what kind of clearance will be there, whether those are fine or not or they are appropriate or not.

So, generally manufacturing processes are defined with IT grade. We say that is a tolerance grade; tolerance grade 1, 2, 3, 4, 5, 6 up to 16. As the tolerance grade increases, allowable tolerance tolerance is increasing or we say that IT 16 will have a larger tolerance range compared to IT 1 grade. Next one is the manufacturing processes; because at this tolerance range itself depends on the manufacturing processes, take an example of lapping is good operation super finish operation and still this is giving us some range IT grade 2 to 5; it is not giving exact value. So, we are in some sort of variable limit; we say that dimensions are dimensions will be variable.

Coming to the another operation of honing, which is the… In this case, we are not including IT 2 grade; because it cannot give as good surface or tolerance as lapping; that is why, it is coming in the range of 3 to 5. Talking about the super finish, other operations slandering cylindrical grinding is another operation, what we are getting when we are going for the grinding or good operation or manufacturing operation, still we are getting a range from IT 4 to IT 7. We are not getting only IT, it is in range depends on operating parameter; what kind of what kind of tolerance we are going to get that will affect.

When we talk about the simple operation like a turning operation or milling operation, still we are getting on the worser side IT grade 6 to IT grade 9. In this case of IT grade 10 also included while milling, starting itself is IT 9. Actually, when we talk about IT grades, we need to know what is the tolerance limit for that. So, we should refer some table. We have we know the IT grade or we say we know the manufacturing processes, we will be knowing from that angle or from that point of view, what is IT grade for that manufacturing process. Once we know IT grade, we need to refer to the dimensional table and see what is the tolerance limit.

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	Nominal Sizes (mm)										
over	1	3	6	10	18	30	50	80	120	180	250
inc.	3	6	10	18	30	50	80	120	180	250	315
IT Grade	International tolerance grade of industrial processes.										
1	0.8	1	1	1.2	1.5	1.5	2	2.5	3.5	4.5	6
2	1.2	1.5	1.5	2	2.5	2.5	3	4	5	7	8
3	2	2.5	2.5	3	4	4	5	6	8	10	12
4	3	4	4	5	6	7	8	10	12	14	16
5	4	5	6	8	9	11	13	15	18	20	23
6	6	8	9	11	13	16	19	22	25	29	32
7	10	12	15	18	21	25	30	35	40	46	52
8	14	18	22	27	33	39	46	54	63	72	81
9	25	30	36	43	52	62	74	87	100	115	130
10	40	48	58	70	84	100	120	140	160	185	210
11	60	75	90	110	130	160	190	220	250	290	320

For that purpose, we can refer this kind of table. You say this generally grades or IT grades also depend on the dimension. Like in this case, first case dimension is more than 1 millimeter and lesser than 3 millimeter or 3 millimeter; for that case, IT grade is IT grade 1 gives a 0.8 micron variation in dimension. Well for higher cases, you can see this range is also increasing; these values are also increasing. Or we talk about the 30 to 50 millimeter, may be say is the bore diameter or we say the shaft diameter 30 to 50, what we are going to get? Tolerance, we may 1.5 micron, when we are choosing IT 1. When we go for higher side like IT 6, what we are getting is 16 micron variation. And if the bearing clearance is only 16 micron; if we choose this manufacturing process of 16 micron, then what will happen?

There is a possibility of variation. If the 16 micron on negative side, there will be clearance will be just (( )) and when the clearance on this 16 is a positive side, there will not be any clearance. If we go for worser process, not worser process; process is always good, but kind of the tolerance range which we can get from the manufacturing process is more on that side. So, the IT grade 9 or IT grade 8 in this case 16 micron, this is turning on to be 39 micron. In generally, bearing will not have that much clearance. We choose the kind of surfaces, actually bearings are going to subject to the interference fit and whenever there is a interference fit, there is a possibility of extra preload on the surface and extra frictional force on the surface.

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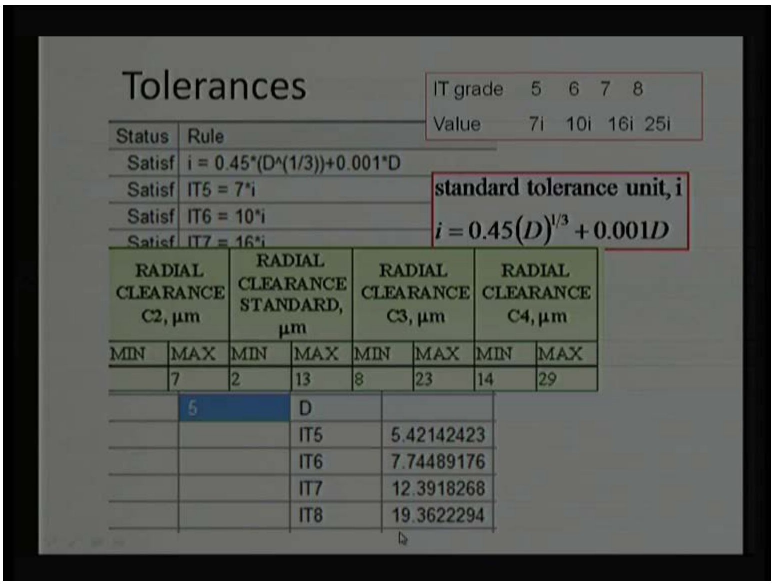

There is another way to calculate IT grades tolerance limit; what we say instead of just referring the table, we can go ahead with this one you say. If we know what is the IT grade and this is generally recommended for the bearing IT grade 5, IT grade 6, IT grade 7, IT grade 8; that value in micron can be calculated by this relation. Say for 5 it is IT 5, it is 7 i; for IT grade 6, it is 10 i; IT grade 8, it is a 25 i. So, question comes, what is i? This is again some sort of unit gives and it depends on the dimensions or depends on the diameter of the surface, which we really require or we say that we are trying to find the tolerance for that kind of surface.

So, D is the diameter you say; suppose this is a shaft shaft diameter and we want to find out what will be the tolerance limit on the shaft surface. So, this is a given i as a 0.45 D cube root of D plus some 0.001 or 0.1 percent D. Once we know diameter, we can calculate what will be the IT 5 tolerance limit; what will be the IT grade 6 tolerance limit; what will be the IT grade 7 tolerance; what will be the IT grade 8 tolerance. Let us take some examples simple examples say the shaft diameter is just 5 millimeter. It can be 10 millimeter also; it can be 15 millimeter also; it can be 20 mm.

But present case, what we are doing is we are choosing i this diameter as only 5 mm. And we use this (( )) the way it is been defined; i is been defined over here and we know IT 5 is 7 into i; IT 6 is 10 into i; IT 7 is 16 into i and IT 8 is 25 into i. Now, if we use that, what we are going to get in micron IT 5 is a 0.5 micron; that is a lowest value. IT 8 is we are going to get 19 micron for 5 millimeter and that is going to; this is compatible with the table or the only thing in this case is helps as a mathematical calculation. And we try to find out what will be the exact tolerance on the surface for different manufacturing processes.

Now, what we discuss about these grades and again showing the table over here; we will say that radial clearance for lesser than 10 mm. Even for the C 2 clearance is the 0 to 7 micron; for radial clearance, for C 0 or standard clearance is a C lesser than bearing diameter is lesser than 10 millimeter is between 2 to 13 micron. If I take a mean value, that comes to 7.5 micron; ofcourse this is the radial clearance and we are talking about this is the diameter; so, 7.5 micron. If I assume that and I go ahead with this IT grade 19 for 5 millimeter, what we are going to get may be say this is diameterial clearance. So, radial diameterial variation radial variation will be around 9.5 or 9.6.

We compare 7.5 with 9.5. We are not going to get a very good result; it will cause negative clearance and that too because of the shaft. We are not considering the housing fitting. Actually, we cannot choose this kind of manufacturing process; because the manufacturing process is which is providing IT 8 grade surface. Actually, we need to go with the (( )) super finish operation will come. We need to come down to 5 or 6 grade, where we are getting lesser variation in this case say the 7. … We say the 8 micron roughly; 8 micron divided by 2 is 4 micron; 4 micron can be adjustable for the mean value of 7.5 micron; that is, still some clearance is kept and bearing will work satisfactorily.

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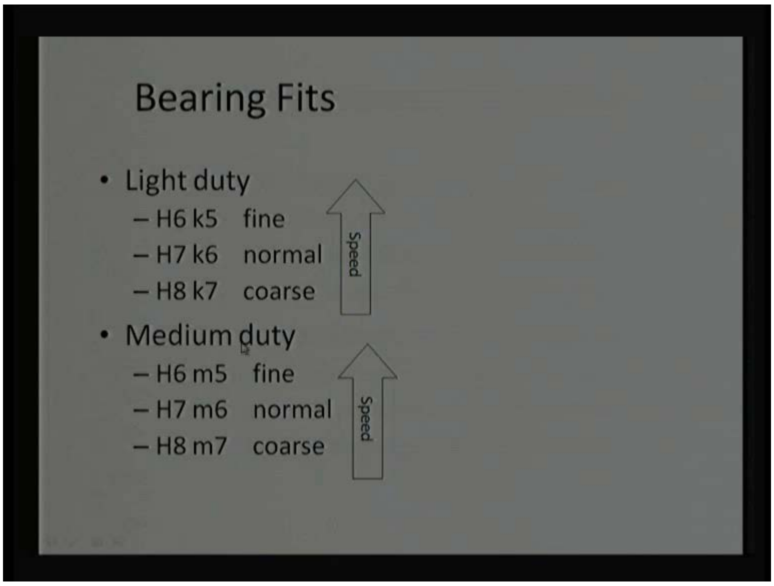

Now, we were discussing about the fit, which we should be providing form manufacturing or we say bearing surfaces and what we get a standard bearing fit, which are available in the catalog or in number of books. One is called the light duty fit; other one is called a medium duty fit. When we talk about the light duty; that means, it is having a lesser load; medium duty means higher load. And of course, this fit also depends on the speed, because the shaft is going to rotate and inner ring is going to get mounted on that. If the (( )) this speed is the higher side, actually we have to go for higher fit or we say that closer fit or we say that we need to keep larger interference for high speed application compared to the low speed application.

And that is why is given light duty coarse operation is H8 k7; for normal operation is H7 k6; fine case it is H6 k5. Now, if the load is increasing, what we are going to do? We are going to go for the better fit; much closer fit for the same kind of the speed, which we say speed is same and this case for medium duty medium duty fine cases, which is having very close we say speed is very high. It will be H6 m5 and for the coarse case, it will be H8 m7. What is the common in these two is housing tolerance will be same. H is for housing case or we say that capital letter is generally for the bore. So, bore fit will remain same for the light duty as well as heavy duty also medium duty.

When we talk about shaft fit that is changing in this case k5, k6, k7; here m5, m6, m7; 5 is again IT grade; IT grade 5, IT grade 6, IT grade 7; in this case m5, which has closer fit compared to this. Or we say that if we use this, there will be more interference between the shaft and inner ring compared to this one. And which is also desirable for the larger load, there will be larger friction force and then there will be possibility of the sharing of the junction. So, here the m5, m6, and m7 is m IT grade 5, IT grade 6, IT grade 7. Question comes, what is this k and what is this m and how do we define it? Again this comes from standard tables or standard figures.

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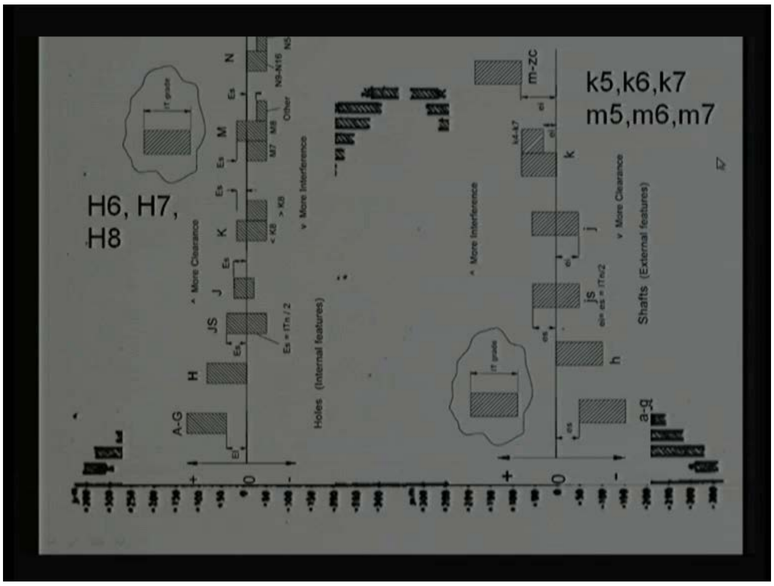

One of the standard figures generally we see in number of hand book is something like this. This picture is not very clear; but I will what I will do? I will try to super impose with the some relevant features; this is like this. This is housing or the capital letter domain; we can see here. This side is the negative; that means we are going to reduce the dimension. If the dimension of the bearing bore is a 50 millimeter and we choose IT grade of the fit this this side, usually dimension will be lesser than 50 millimeter; we say 50 minus some micron dimension. So, there will be a causing; if we put directly on a shaft of the 50 millimeter that will cause interference. So, this this side is going to generate some interference on the shaft.

Coming to this side, what we are going to get is the clearance. You can see A to G, there is some definite clearance initially; it may be 30 to 40 microns. While coming to the H, there is a no change. It is just touching the surface or we say the base deviation is almost 0. While (( )) deviation is more, say IT 1 grade will come somewhere here; IT 16 will come somewhere here. As we are moving this side, IT grade is going to increase. You keep IT 5; so, it will be somewhere here. As this is a line between the clearance and interference, there will be some sort of overlap in this domain and what we say that because of surface roughness, there will be some sort of transition fit.

As far we say, H as a transition fit; while this JS as a closer fit and what we have seen in the previous slide, it was H. So, H5 may be will come somewhere; here H6 will come somewhere; here H7 comes somewhere here; because this complete range is IT grade. That is what we are showing 1 to 16 grade has been given on this. We need to chose proper dimension and that can be figure out from this. This is 0; this is 50 micron and somewhere may be 20 to 25 micron will be there; that is up to IT grade. Or we say there will be a variation; even though we are talking about the 50 millimeter diameter of the bearing bore, actual diameter of the manufacturing will be slightly more than that.

It will be 50 plus may be say 20 micron or may be 15 to 20 micron. So, that is going to give some sort of clearance and we know that because of surface roughness, some sort of irregularities on surfaces that will cause a transition fit. And generally housing and outer ring, we prefer transition fit that was discussed or described in previous slide; previous to previous slide. So, this is for the housing. Similar, super imposition can be done for the shaft. Again there is a clearance or there is a 0 line and this is on the negative side; this is on the positive side. What is the meaning of positive side? We say that if the shaft diameter is at 50 millimeter and I am choosing some range or we say some grade such a manner that shaft comes this side; that is on the positive side.

Now, for 50 millimeter bore, if I have a shaft diameter 50 plus some delta that is going to cause some interference; that is why, we say this complete domain is interference domain. This is a clearance domain. Similarly, in this case where shaft diameter is lesser than 50 millimeter or we say that I am just choosing the 50 as a number; it not necessary only 50, it can be 100, it can be 150, it can be 5; it can be 10 also depends. Now, in this case particularly what we are showing if it is going this side, then shaft diameter is reduced from 50 millimeter and that is going to generate some sort of clearance. Naturally, we will not be choosing this side; we need to choose only this side.

And that is why, when we talk about the k fit and m fit, this k is always in this direction and m is always in this direction. That is why you say H6, H7, and H8 can give some sort of transition fit. There is a clearance between outer ring and housing. But still we are using the word transition fit; because we do not know the exact value. There is a change in surface roughness. There will be change in surface profile also; that is going to cause some sort of transition fit. Similarly, what we talk about the shaft is the k5, k6, k7; k5, k6, k7 will come somewhere here in this range naturally. So, what we are going to get we say this somewhere here 5 to 7 is somewhere here.

So, what we are going to get is interference fit between the bearing bore and the shaft and we want to increase because of the heavy load. We want to increase that interference; that is why, we have to give initial deviation and this is 50; this initial deviation is 30 micron. So, it will be 50.03 plus whatever the IT grade we are suggesting. Better IT grade will start from here; lower IT grade will start form here or we say higher IT grade will start from here. So, this is demonstrating or this is illustrating us how to choose proper surfaces if we know what kind of interference fit we need to keep it to the shaft and bearing bore or bearing bore diameter or the inner ring diameter. Then we can choose proper fit and generally it has been recommended H6 k5, H7 k6, H8 k7; these kind of fits for the bearing for that depend on the application.

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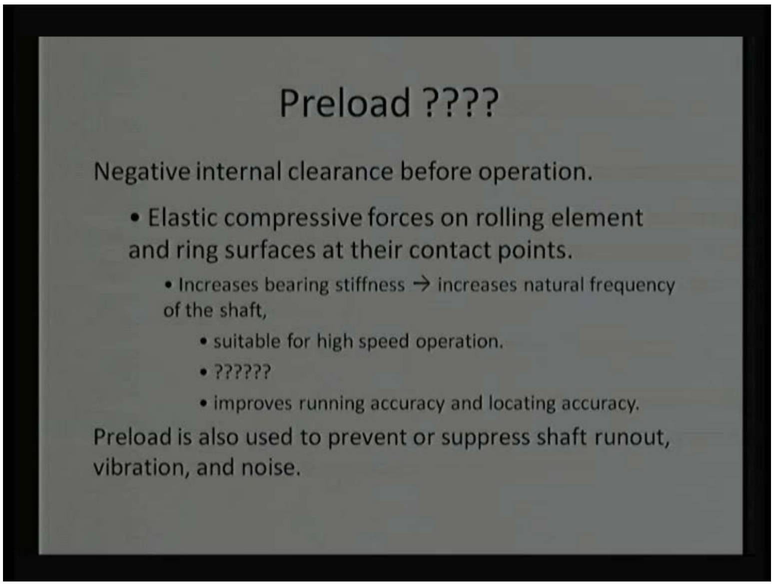

Now, what we are coming to the negative part of this clearance or we say the negative clearance or we say that negative clearance before operation. If it starts, it is going to cause some sort of elastic force on the ring surfaces or we say between ring and rolling element surfaces. There will be the contact, and there will be some sort of deformation of the bearing surfaces. What will happen? It has merits as well as the demerits. It is generally required if there is a high speed application was shown in a previous slide also for high speed, we require closer tolerance, we require more and more interference fit.

But this is also negative. If we go for more interference fit, the high tolerance even for the same frictional force heat generation will increase.

If there is a high heat generation and that is going to increase the temperature, there is a possibility of instable operation; because high temperature is going to reduce the viscosity of the lubricant. The reduction in viscosity is going to increase the friction coefficient friction; increase in coefficient friction is going to increase energy loss; increase in energy loss is going to cause more temperature and again high temperature is going to reduce the viscosity. So, there will be chain reaction; there will be a catastrophic and there is a possibility of bearing may be say few hour operation. Another positive point about this negative clearance is the increase in stiffness. Naturally, if the shaft some shaft is the hunting or natural frequency is the lower and we want to increase the stiffness.

Naturally, we can increase; obviously, decrease clearance or bring some sort of negative clearance. There will be more and more stiffness in the system and natural frequency of the system will increase and that may reduce the vibration problem. So, there is a there are good features about that. But what we are talking if it is not done properly; if it is not done intentionally, it is not done with a complete sign. There is a possibility of high friction and this is another advantage is been mentioned. Preload is also used to prevent or suppress shaft run outs or we are talking about the 49 or 50 millimeter diameter. So, there will be some sort of run outs on the surface also, vibration and the noise. So, these are the positive features. But there are negative features also.

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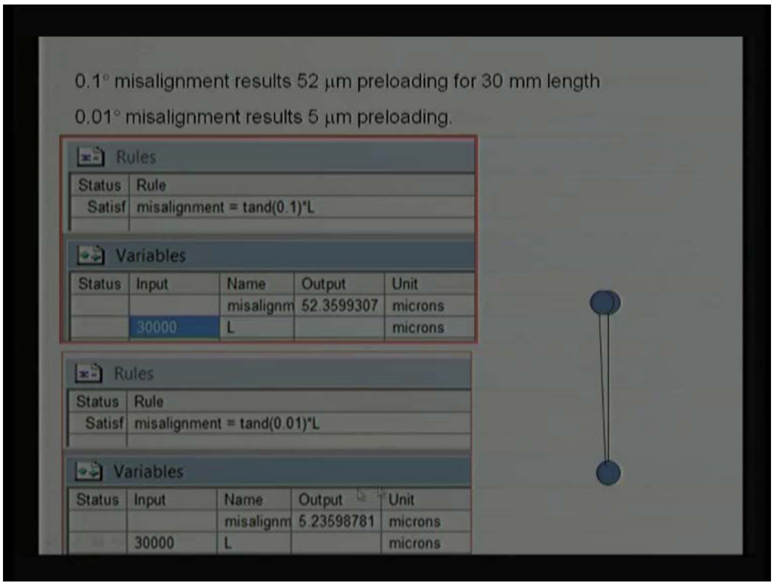

Of this tolerance in addition to that, there is a possibility of misalignment. Misalignment (( )) makes a good grade shaft or we say IT grade. We keep even the 5 and we try to maintain within a tolerance of bearing. We say over all variation in the shaft geometry and the bearing geometry are within the limit and it is not going to kill or we say eat away all the clearance of the bearing; even in that situation, we need to be more careful about the bearing length. To demonstrate that what do we say that? Assume that this is the one bearing end and this is another bearing end and they are connected with a straight line. We need to keep a perfect alignment of the bearing or we say it should be powered to the shaft surface.

Or we say that it should be powered to the aligned to the bearing axis as well as shaft axis; but there is a possibility of some change. Some when we push it, there is a possibility of some variation. Let us say this one. If I am assuming this point or this point is the constant and there is some misalignment in this, which cannot be ruled out. When we assemble the component, there will be always a possibility of some sort of misalignment; because the shafts are manufactured the different machines and bearings are manufactured or we say, we are buying those are manufactured from the different machines and there will be some variation in axis.

These are not necessary it will be 100 percent correct; 99 percent chances are there will be some variation. Now, if this degree is angle of inclination even is a 0.1 degree, what we are going to get? For 30 millimeter length, we are going to get a preload of 52 microns; this is substantially high. Shaft length 30 millimeter is very ordinary or we say that bearing bore diameter or bearing length of 30 millimeter is very ordinary length. And what we are talking about 0.1 degree, it is very difficult to quantify also; it is very difficult to measure also. And that gives 52 micron preload or says 52 micron deflection from the one surface, if it is more than clearance.

Now, if I think about even the 0.01 percent is still it is going to give us a 5 micron preloading; 5 micron deflection. Naturally, we need to keep clearance. Whenever we assembling, we need to keep this clearance; it has more than this. We know these are the operations. We choose a proper clearance. External clearance will be there and then we need to find out the mean clearance is of this order or not if it is not of this order. Naturally, we should choose or say we think about some other bearing. Now, this is what?

How it has been calculated is a simple relation has been used; a misalignment, a deflection, as a tan d of 0.1 degree and this is tan d says that it will be it is not necessary we have to give 0.1 degree in a radian. We can directly give in degree itself and the length of the… This we say bearing length and this is what bearing length is 30 millimeter or 30000 microns and we are getting microns in 52 microns in this case. Now, if we are reducing it to the… From 0.1 to 0.01 what we are getting is still 5.2 microns. So, that is the substantial and we need to account whenever there is a possibility of this kind of problems.

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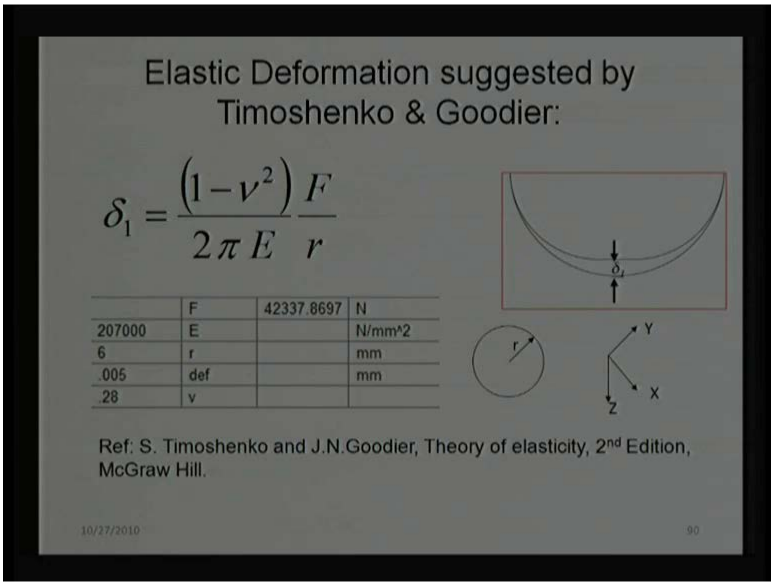

Now, what is the where is the problem with this kind of interference what we are talking about the 5 micron preloading 52 micron preloading? Is there any relation really with the force? Yes, there is a relation. We have discussed this slide in one of our lubrication mechanism points. We say that this assuming the shafts assuming the ball in perfect shape initially. Now, if you deflect by delta 1, you punch the surface of a ball. So, that gets deflected by delta 1; delta 1 may be 1 micron, 2 micron, 5 micron, 10 micron depends on the softness and depends on the stiffness of the surface and depends on the load, which is applied on the ball.

Then in that case, what we this deflection versus force can be given by this relation, which has been mentioned as the reference of this equation is been referred is given over here. We have discussed this equation earlier in lubrication mechanism class of a lecture. Now, here E is young's modulus generally for the steel or the material which we are using for the bearing generally is very high is known like 207 giga pascal. And nu is a poisson ratio nu varying from 0.23 to 0.3 for our case of most of the bearing material. It is kept as a 0.28.

Our radius is initially the radius of the ball which we it is getting deform or which is subjected to deformation. So, what we get? Say, I am keeping r as a 6 millimeter; 6 millimeter ball is a relatively bigger size. It can be lesser also for a 6 millimeter ball. And if I am assuming this deformation is only 5 micron 5 micron deformation, which is not very unusual thing it is the most often, happens and it is generally more than that. nu as a 0.28, which was mentioned and E as 207 giga pascal and if we are keeping in newton per millimeter square, it will turn out to be 207000. What we are getting force as a 42000 newton, which is very very high force just by deflecting 5 5 micron.

If there is interference fit and interference fit, which is directly imparted to the ball is causing interference between the ball and inner ring. I am assuming time in the inner ring is a flat surface in this case; because generally they have a larger radius; that is going to cause 42000 newton substantially high value. And if we consider this 42000 newton in friction loss is naturally coefficient of friction will be higher side and temperature rise will be there. So, let us take (( )) example we consider or we discussed in the previous lecture. We will just repeat that example with some addition of 5 micron as deflection or interference.

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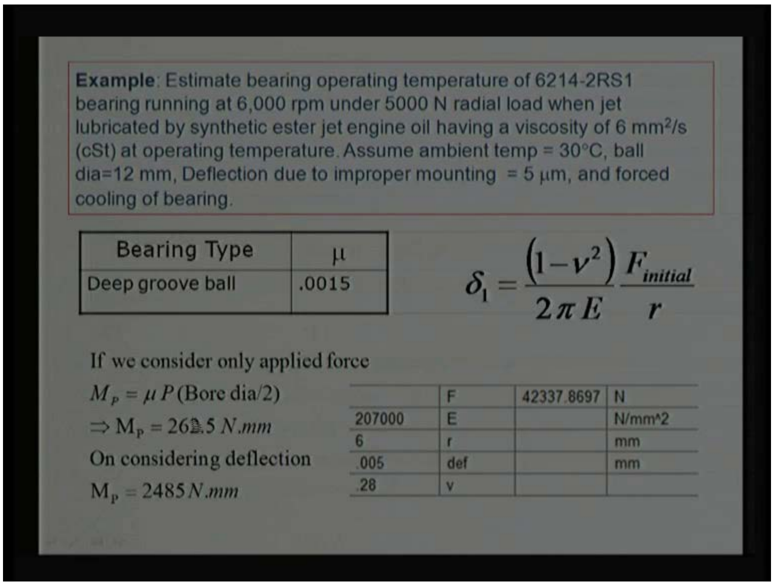

So, this is the table or this is the complete same slide. So, estimate bearing operating temperature; bearing number is defined 6214. This is the deep groove ball bearing; second is the diameterial series; 14 is the bore diameter. We say 14 into 5 is a bore diameter; 2RS1 is something like it has both the sides (( )) is running at a 6000 rpm with a operating load of 5000 newton. Having some sort of lubrication mechanism, which has lubricant has a viscosity of 6 millimeter per millimeter square per second and that is the room temperature. Now, assume ambient temperature is 30 degree; we are talking about this viscosity at this temperature.

Ball diameter in previous slide, we took radius as 6 millimeter. In this case, we are talking about the 12 millimeter diameter. Deflection due to improper mounting may be we are not able to keep perfect alignment. So, there is the defection of the negative clearance is going to cause going to bearing surfaces together may be indicating deflected 5 micron or the ball itself is getting deflected by 5 micron. And there is a force cooling of the bearing, we already discussed for the force cooling. Cooling factor comes out to be 2.5; for natural cooling, it will be 1; for the close side case, where there is no heat dissipation; proper heat dissipation that will turn out to be 0.5.

Now, we are choosing a deep groove ball bearing. Naturally, we need to choose what will be the coefficient of friction in ideal condition; ideal condition is still I am saying because of the load. Now, that coefficient of friction is 0.0015. However in real case, this coefficient of friction will be on higher side wherever there is a misalignment. Now, using this relation without considering the preload because of the defection, what we get? M p is the movement due to the load is something like a 262.5 newton millimeter, which is the same what we have done in our earlier example which was discussed in the previous lecture.

Now, think about the preload. What is the preload in this case? It is given as 5 micron over here; delta 1 is a 5 micron. Here E may be can treated as young's modulus 207 giga pascal and r is given over a 6 millimeter; ball diameter is a 12 mm. So, r will be 6 millimeter in this is situation, what we are going to get. See E is been given as 207000; unit is newton per millimeter square; radius is 6 millimeter; deflection is 0. Deflection is 5 micron and nu, poisson ratio is 0.28. What we are getting F as 4233.337. It takes something which is the 42338 newton. This is the same thing which we have shown in we will seen in the previous slide.

Now, if I implement this, if I use this as a preload or we say that pre instead of writing P, write P plus this F. Then what we are going to get? Movement due to load as the 2485 newton millimeter; what is the… We are keeping in units; but you can see is almost 10 times jump 262.5. Here it is coming at 2485, almost 10 times jump in movement term. Apply load is not affecting that much compared to this one; that can also be say that this applied load is only 5000 newton. This is turning out to be 42000 newton is naturally 8.5 times; 8.5 5 times plus 1. It will be 9.5 times just I am saying is almost 10 times lesser or 9.5 times.

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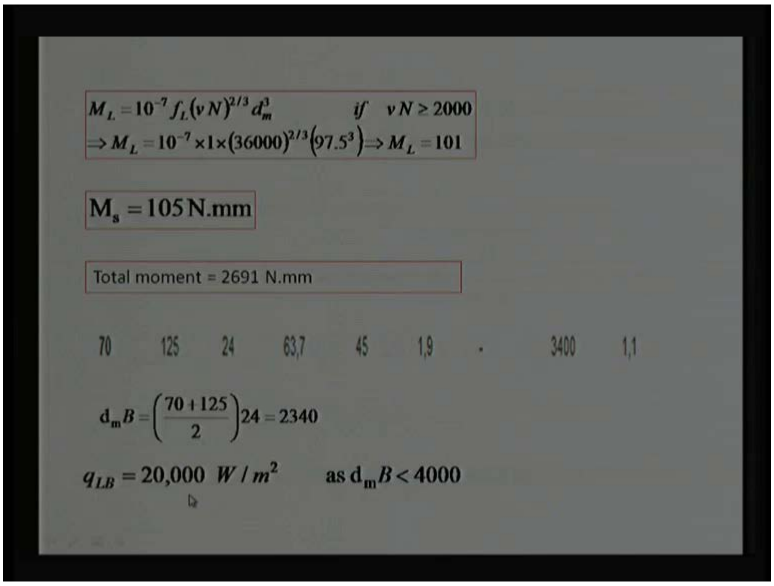

Now, other relation in time mean, we are keeping same. Even though we know the preloading sliding will increase and that is going to cause additional losses. For time being, we are choosing sliding is same; we need to get some number first. So, M L because of the viscosity because of the sliding and viscosity sharing can be given by this relation and then it is turning out to be 101; this is the same thing which we got in previous lecture example. But in actual case, there will be more sliding and this answer will get amplified. But at a time we do not want to consider all the factors together it will not give the impression what is happening. So, for the independent point of view, just for preload which is affecting the force, how much variation will occurs?

We are trying to discuss this one; we are emphasizing on that. Same thing, if I consider seals, this is 2RS is a seal unit. We are using a 105 newton millimeter; again in this was the loss in ideal cases. If the bearing shaft is getting deflected by 5 micron or more than that, then finally the shaft is bearing ball and race is getting deflected of 5 micron. You mean in that in those situations, seal will also get deflected and that will also cause more friction and that will increase this value; that will increase I am say may be 2 times, may be 3 times of this. It does not matter as we are just trying to understand only the load component. So, we are keeping M L same; M S same; only M P is changed. If I sum up all together, what we are going to get? 2691, the major component is because of the load dependent component.

Even though it is affecting seal, it is going to affect the sliding. But still what you know for time being, we are not considering those. I have just focusing only one component that is giving us 2691 newton millimeter as a total total friction movement. Now, to find out what will be the temperature rise, we need to find out the we need to find out the value and parameter; outer diameter is in this case is 125; length is 24 mm. So, what we calculate generally d m is the mean diameter into B and we found that is a 2340, which is lesser than 4000. So, we can choose it density as a 20000 watt per meter square in the same units. This is clear to us which is the same which we have discussed in the previous.

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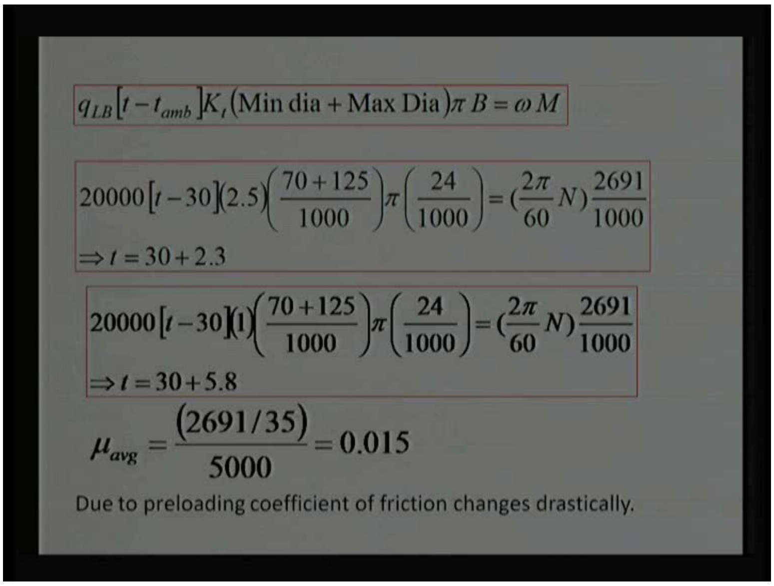

Now, the energy equation, energy generated and energy dissipated; this is given energy generated and heat generated and heat dissipated. Here the length is B and this is the minimum diameter and maximum diameter. We are trying to find out the whole surface area. What is the pi B into minimum dia; pi B into maximum Dia? This is giving outer diameter, where the heat dissipation can happen because of that. Similarly, inner diameter periphery also heat dissipation happens because of that; that is why it has been summed. It is not kept as a average value. This K t is a factor which is giving gets some value as the 0.5, 1, 2, 2.5; 2.5 is generally come in this way.

There is a sufficient cooling or heat circulation system is there. When there is a complete natural layer and it is an open system, K t will be 1 and when it is environment is such a manner, see circulation is not sufficient is not proper, then K t will turn out to be 0.5. This is 20000 which we discussed in the previous slide and this is a change in temperature. If I am know that ambient temperature, I can find out what will be the operating temperature. Omega is speed of operation or rotational speed of the shaft and this is the total movement. So, when we do that, what we are getting is 30 is ambient temperature. We are getting 2.3 degree centigrade temperature rise because of this section.

Earlier we got about 0.38 or lesser than that temperature rise. And so, there is a significant variation in temperature rise. Here it is coming; 2.3 is coming because of sufficient cooling or cooling is sufficient on the surface. But if it does not happen, the cooling is not sufficient. Then we can use instead of to 2.5, 1 value and what we find the temperature rise is by 5.8 degree and this temperature rise is just because of load component and not consider lubrication component or we say the sliding component. We are not considered seal component and has been realized ordinary slightly change in the mounting increases the temperature from 1 to 10 degree.

I mean the main times more than 10 degree; that is major problem in the temperature rise is more than 10 degree, we should replace a bearing or we should open it and try to remounted bearing. Otherwise, there is a possibility of catastrophic failure of bearing or associate components. And if I try to find out the average cost of friction, what we do the whatever the movement we got divided by bore diameter of that and not diameter radius bore radius of that and whatever the initial or applied load. So, this is a movement. This is the applied load what we are going to get here is the catastrophic friction as a 0.015.

Keep in the mind. We selected coefficient of friction form the table as 0.0015. So, this coefficient of friction is 10 times compared to that coefficient of friction, which we initially considered based on the bearing selection (( )) here. This coefficient of friction is increasing by 10 times; that is why we say that due to preloading coefficient of friction changes drastically. In actual case, seal will play major role because of deformation moreover contact force and that will shear the force shear the seal as well as cause damage of seal as well as cause more friction.

But this says clearly that coefficient of friction is heavily affected sometime from industry point of view. We believe that know, this coefficient of friction is still is not very high just a 0.015, who cares about this. This is a very low coefficient of friction. If I compare with the sliding coefficient of bearing, coefficient of friction will be more than 0.1 or 0.2. If I think about the drive bearing totally, then coefficient of friction will be 0.3. So, why do we think about this? Even though this rolling element bearing is giving very local coefficient of friction, I should select this coefficient of friction itself.

I do not have to worry and I can see this as anti-friction bearing; this is the why the name is popular we say that the rolling element bearings or anti-friction bearings effective coefficient of friction is lesser. But there will be frictional losses, there will be heat generation, and if there is an improper mounting, they will fail in low time. It will not take much longer time to fail that bearing. We will continue rolling element bearing, we will be talking about how to lubricate that bearing; what are the lubrication mechanisms in our next lecture. Thank you for your attention.