Tribology
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Lecture No. # 28
Rolling Element Bearings

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TRIBOLOGY

LECTURE 28: ROLLING ELEMENT BEARINGS

Welcome to 28th lecture of video course on tribology. Topic of today's presentation is rolling element bearings. These kinds of bearings are most commonly used. In other words, every industrial machine has some rolling element bearings.

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- "Rotation is *always* easier than linear motion". Low friction & moderate lubricant requirements are two important advantages of rolling bearings.

Reason being, they operate on the rolling motion and we always prefer rolling motion compared to linear motion. What we say rotation is always easier than linear motion, reason being low friction and moderate lubricant requirement.

We have studied what is the function of lubricant? What is the importance of lubricants, and we know to reduce the friction as well as wear, we require lubricant, in rolling element bearings, friction and wear are very low that is why we require low value or smaller quantity

of the lubricant. And in many times even, if there is a no lubricant bearing survive for some time. This is discontinuity of the lubricant bearing can survive. Depends on the rotating speed it can survive from few minutes to few hours to few days. This is the reason why we require rolling element bearings.

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- "Rotation is *always* easier than linear motion". Low friction & moderate lubricant requirements are two important advantages of rolling bearings.

- If you can buy it, don't make it!
- Bearing selection….

Another thing which is important for the rolling element bearing is standardization. These bearings are produced in mass. They have very good surfaces and they work with elasto-hydrodynamic lubrication mechanism. As these bearings are produced in mass, the cost is relatively lesser, and assembling and disassembling is much easier. And that is why we say if we can buy something; why to produce it.

When we know very well production is going to cost more than what we are buying, that is we say, if you can buy it do not make it. And that intimates us or that leads us to selection what we say the bearing selection, bearings need to be selected. We do not design the bearing so we do not design the rolling element bearing but, there is a problem.

If I say we do not design the bearing, there is a problem. Somebody must be designing it for us, mass producing it and selling in market. If you just select a bearing at some guidance and fit in the machine there is a possibility of the failure. Reason being we have not understood the all mechanism, all physics of the bearing.

So, if you want proper life of the bearing we should understand the concepts, without that there is a possibility bearing may function very well may not function at all. I remember one incident, we wanted to operate one machine at the high speed and all specifications were given to the manufacturer. To check, the fitting of the bearing; for his convenience

manufacturer tried to use some sort of the grease and that bearing failed in no time, because of the improper selection of the greases.

So, what we say that understanding bearing is important, understanding rolling element bearing is important, understanding the concepts related to rolling element bearings are important. And that is why we are going to discuss those in today and next lecture. How this rolling element bearing behave, work and operate.

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Failure of Four Row Cylindrical Roller Bearing

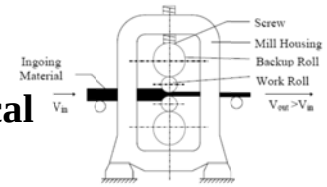


Fig. 1. Layout of a 4-high rolling mill stand.



And to start I am discussing about case study in which we did for one of the industry. What we call is the industry related to the rolling mill system. That figure shows, this is the rolling mill. Function is to reduce the thickness of sheet, say thickness may be initially around 10 mm and we want to reduce this thickness to 3 mm or 4 mm.

We required some sort of rollers and those rollers need to be supported on the bearing, for the perfect alignment and those bearing failed in no time. That is why we say that two large roller bearings when we are using the word large it was 865 mm; which is reasonably large.

And outer dimension of the bearing was one point one eight meter is pretty large. Those bearings both the two bearing were mounted and both the bearing failed. Now cost of the each bearing was very high, when we say in rupees it was more like 35 lacks rupees or more than 70000 dollars, one bearing and those bearing failed in no time expected life of those bearing was roughly 40000 hours or we say that five years.

And those one bearing failed in 105 hours, other bearing failed in 300 hundred hours and this is what we are saying when they were dismantled. In that much time actual operating time was slightly lower than this.

So, one bearing which was supposed to show 40000 hours of operation is showing the only 105 hours. Other bearing which was again supposed to show 40000 operating hours is showing only 300 hours. Survivability or reliability point of view if I consider they showed only the reliability of 0.5 or we say that 0.5 percent that means 0.5 divided by 101 percent or one divided by hundred so that is the reliability.

So, lower reliability there is a possibility that bearing fail because of the accessible load something went wrong in a machine, some spark and the load has suddenly increased to four to ten times and bearing failed. Second option is that bearing which was purchased was not in proper or its bearing was improper. Third option is a bearing was not mounted properly or fourth option is the bearing was not designed properly.

There are all the possibilities, when we try to investigate the value; we need to explore all options. And we did that I am not going in to detail of those investigations but, few slides are just trying to show that a silly mistake or lack of understanding many times get lot of problem.

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Failed Bearing



These are the figures of the failed bearings, you can see the bearing outer ring which failed. And these are the number of pieces we are able to see the number of cracks or which are the deep crack from one end of the outer ring to other end of the outer ring. A deep crack is more like a cutting by the knife in pieces.

So, we are cutting some fruits in a number of pieces. Interesting thing is that this value is happening only one-fourth of the ring, three-fourth of the ring is same, a single piece it has not fixed. When you see the closer of this when you magnify it you are able to see some kind of failure it is something like some corrosion happening here and which is also magnified and shown over here. There are some corrosion marks that indicate water plays its important role or there is an acid environment then it plays an important role we need to check whether bearing was operated in the water environment or acidic environment.

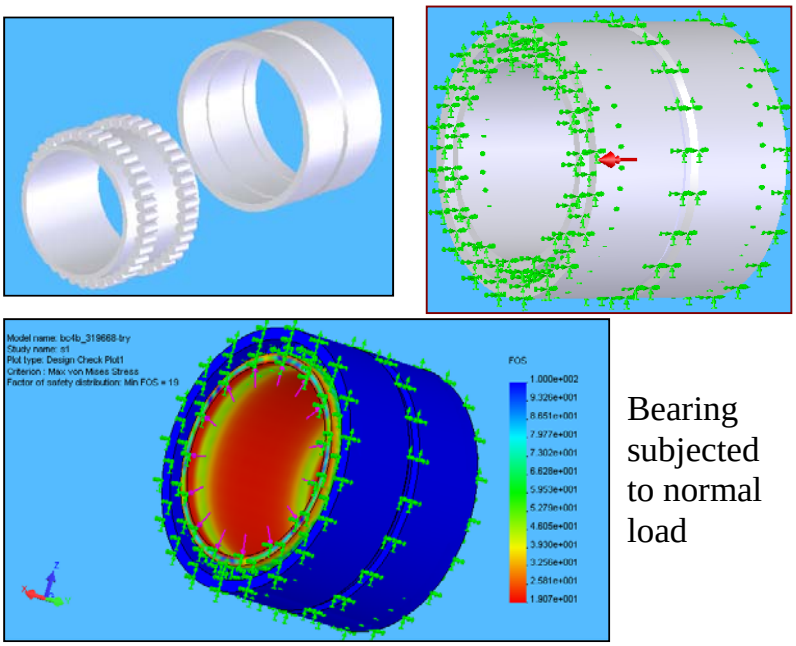
This is another failure near the hole and these holes are the taped holes, threading was done. There is a possibility there is some thread failed and because of that stress concentration increase and because of that there was a crack generated and once crack generated it lead to generation of number of other cracks, there is a possibility.

And there is a possibility of some sort of the fatigue failure. Of course when we see magnified figure of that we are able to see the beach marks and the beach mark is a significance of the fatigue failure. That means this bearing failed in point of fatigue under a corrosion, under the excess over load and because of the some sort of the hole where a stresses concentration increase significantly.

So when we are able to see the figures, we are able to guess number of things. Corrosion may be reason or hole which is causing the stresses or high stresses or raising stresses may be the failure cause or fatigue is another cause failure or the short cycle or low cycle fatigue.

And there is a possibility of very high load suddenly applied on the bearing. Of course, one kind of the failure will lead to other kind of failure there is always there but, we need to find out what was the root cause what was the main reason of this failure.

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Bearing subjected to normal load

So, what we did we could go higher with some sort of finite element study, generate a three dimensional model and that was our bearing which was under investigation was a four row cylindrical roller bearing.

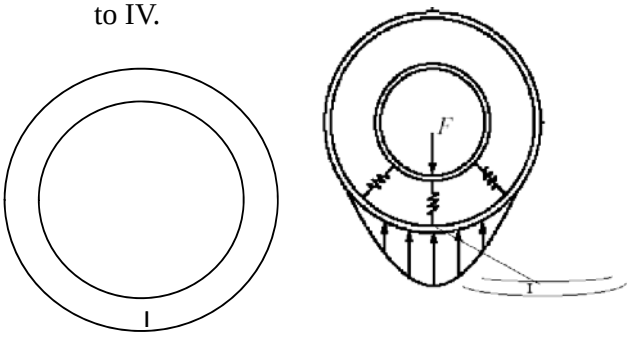
So, what we did we assumed that there is a cemetery of the mid plain we analyzed only half of the bearing, one side of the bearing and when we analyze that we are able to see their two roller rows. This is one roller row, there is another roller row, this is the outer ring and this is the inner ring.

We know bearing which is fixed in a rolling mill will be fixed at the boundary. And this inner ring will be rotating in this. So, we fix outer ring completely, no degree of freedom. So, there is no motion in rotational direction or we say there is no rotation, there is no linear transmission, completely frozen.

All six degree of freedom are been frozen. We did analysis, when we did analysis assuming all the cylinders, all the rolling elements are bearing the load, what we get? Stresses are very low in that situation and the factor of safety, is nineteen but, this bearing field and what we are able to see is the factor of safety is nineteen one nine is too high. We should not design any bearing for more than factor of safety, more than two point five or three that means something is wrong in investigation. We found some problem over here. What are the reasons of this kind of failure. When analysis shows that factor of safety is pretty high very high.

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- Constant direction load.
  - Quarter of the outer race is under load.
    - Outer ring with marking I to IV.



Then we found there was some clearance between the bearing elements, bearing was not pre-loaded and whenever there is clearance in a bearing. Only some portion of bearing will be loaded, it is not a complete bearing which is loaded. And something like that these are the inner ring, there is a outer ring and assuming there are rolling element in between that is spring connection shows the rolling element in between.

When the load is applied and there is a clearance between inner ring, outer ring or we say dimension of inner ring plus dimension of roller is still lesser than inner dimension of outer ring. Then there will be clearance, what will happen in this situation inner ring will slightly shift downwards. If it is shifting downward all the rollers, which are on the top will not be loaded at all. In addition because of clearance, there is a possibility of even extent of the load is lesser that 180 degree.

And then we did examination, we found only the one-fourth of the bearing is loaded. Three-fourth of the bearing is unloaded or we say that major load is been contributed by one-fourth of the ring and that is problem as well as advantage. What is the problem because this one-fourth, or quarter or say one-fourth of the ring is bearing the load. The load amount, the maximum value of the load is increasing but, second good point is that we can rotate this ring by 90 degree after certain duration. So, all four quarters can be subjected to the load at the fatigue loading.

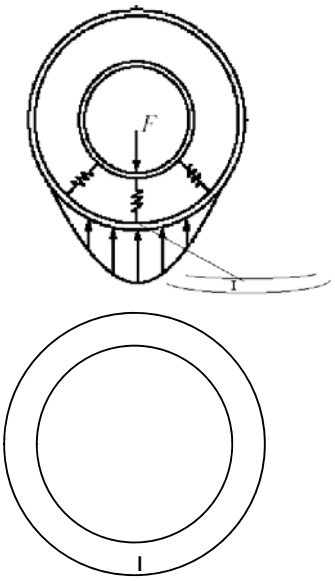
So, what will you say, one-fourth of the bearing will sustain few cycles, then next quarter will sustain few cycle, then next quarter will sustain few cycles. So, it would be that kind of rotation we can get good results. And that is happening in a rolling mill or we say that in

actual industry. What they do, they divide outer ring in to four zones they write zone 1 here and the zone 2 here, 180 degree phase zone 3 and 270 degree phase zone 4.

And this is the way they are assembled, initially they will arrange a zone 1 directly under load and after couple of months they will rotate by 90 degree. So, the second load zone can come into the picture. After second and third, after third there will be fourth and after fourth again there will be one.

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- **Constant direction load.**
  - Quarter of the outer race is under load.
    - Outer ring with marking I to IV.
- First time mounting
  - zone I along the direction of the load.
- After a period of approximately 1000 operating hours (≅ 2 months), outer ring is turned 90°.



So, there is some sort of load sharing, in terms of cycles. So, the first time mounting is directly done, load zone one is been kept along the direction of load and after some period, what industry was operating whether 1000 operating hours. They used to rotate by 90 degree.

So, whatever we are doing what we did in finite element modelling, we made a mistake, we assumed the bearing is completely loaded and that is why the factor of safety was very high. Now we know very well is only one-fourth of that ring is loaded.

So, I can simply say 19 divided by 4, factor of safety is decreased but, still the factor of safety is on a higher side. Still it is coming really the nearby the five. Then there is another reason, we say that even the one-fourth or we say, quarter of the ring is loaded but, only some percent will take maximum load and the remaining portion will not take that much load.

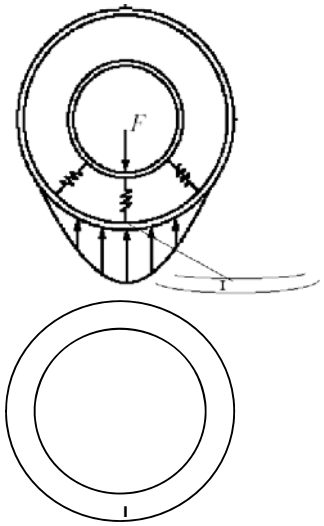
And this is a load distribution, maximum load at a point where load is applied, load is distributed which is to zero value near by the ninety degree or nearby the quarter of the ring.

That means there is a non-linear distribution of the load and it will not be distributed in the way we did in finite element analysis.

That means we need to modify that analysis, come out with the better results. And this is what good conclusion that after doing that finite element analysis. We understood we are doing some mistake that is why we need to modify it. Another word if I assume the bearing is a only the selection, then this kind of mistakes happen. When if you understand there is the clearance because of the clearance bearing will not be loaded completely will only one portion of the bearing, outer ring will be loaded, then I am able to understand the physics, I am able to modify. I realized my mistake and we did modification.

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- **Constant direction load.**
  - Quarter of the outer race is under load.
    - Outer ring with marking I to IV.
- First time mounting
  - zone I along the direction of the load.
- After a period of approximately 1000 operating hours (≅ 2 months), outer ring is turned 90°.



Conclusion: Rated bearing life = 4.* Life of one load zone. Expected life of each load zone = 10,000 operating hours

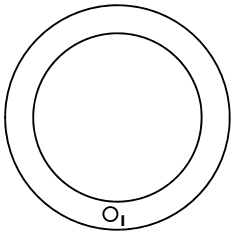
What we say, when we talk about the 40000 operating hours even it was a first slide on this lecture we say that this bearing was supposed to show a 40000 operating hours and the other things. If there are four quarter of this ring, bearing is supposed to show 10000 operating hours per quarter. It is not a 40000 directly.

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- Hole in line of maximum load.
- Four holes of 3/8” 10 UNC 3B of 45mm depth were drilled and tapped to facilitate the handling of outer race.







What we need to do analysis based on the 10000 operating hour not 40000 operating hours. Then second observation, what first we say that even the 19 divided by 4 factor of safety 5 decreed the factor of the safety is on a higher side. Second observation was when we are seeing the one quarter of the ring is sustained in the load. We arrange this one quarter and found there is a hole at the center and this load at this center or we say this hole was subjected to directly imposed load.

So, there is a problem, hole being in a line of maximum load is a problem. Even in an ordinary mechanical engineering or ordinary design you will not be doing this option. And when we did investigation what we found the four holes of this diameter depth 45 mm were drilled, as well as tapped to facilitate the handling because the bearing weight is very high. It cannot be transported from one place to other place by the manual labour.

So, they used cranes to lift this ring. We required some sort of arrangement and that is why they did it. In number of machineries or we say number of companies they use a magnetic attachment but in this company they were using this kind of chain arrangement to transport this ring from one place to other place and that has caused the problem.

When we did more study we found that holes can be tripped, there is no problem as such. So, from the designer point of view it is possible because we know that the one quarter and the two sides. I can drill a hole when the load will be much lower, compared to the maximum

load over here or we say the even whatever the load at this corner and be only the 30 to 40 percent compare to the load which is coming at the center. Even in this situation I can tap the hole, I can raise some factor 2 by 2 to the stress concentration may be 2 to 2.5 by this type of load is only 30 to 40 percent. We are saved or the ring is saved, bearing is not going to fail, we can design in such a manner.

The problem comes when bearing came out of the company they were only the marks one, two, three and four as a load marks or we say that there is a load zone marks but, when it was arranged for the manufacturing or we say the drilling hole and the tapping the hole, a person who was doing it. If I let this one marking, two marking, three and four is done for the hole.

There was a lack of understanding, that why this marking has been done for that person. So, he drilled the hole on the load zone itself or nearby that. A person who was assembling it he knew only one thing that there is a load zone one, load zone two, load zone three, load zone four, I need to assemble like that. So, there is a misunderstanding if we are not well educated then the problems come and that has happened over here.

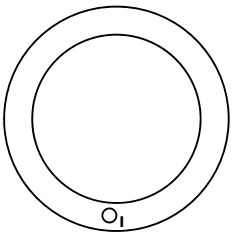
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- Hole in line of maximum load.
- Four holes of 3/8” 10 UNC 3B of 45mm depth were drilled and tapped to facilitate the handling of outer race.





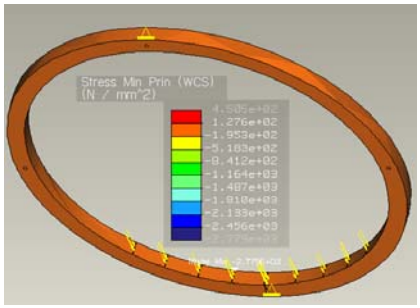


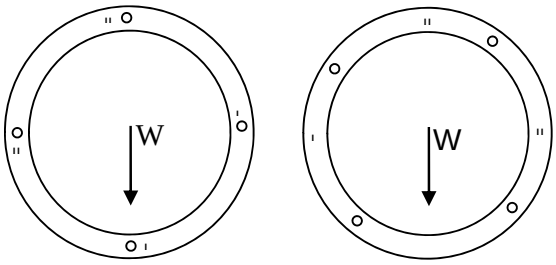


In the first crack, which is started it was the near the hole or we say whole was slightly away from the surface of the loads and that this stress concentration worked, crack was initiated or we say they started from the third profile itself and it has gone deeper. And once we know the

bearing was in two pieces after that they cannot sustain load it can turn out to be division based on the rollers, so that we did in a finite element analysis and figured out.

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(a) Earlier arrangement (b) New arrangement

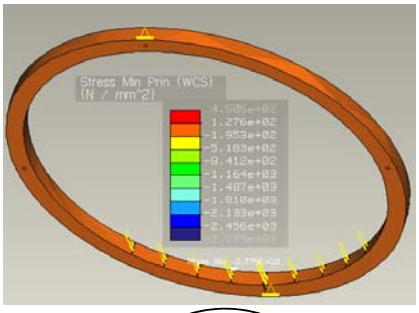
That if the load is applied like that and the hole is arranged in this manner. That is going to be cracked and that will be instantaneous crack. Dealing of survived 105 hours that was too much from that point of view bearing was supposed to fail instantaneously. Of course because of the rotation the load point was continuously changed or roller was continuously changing.

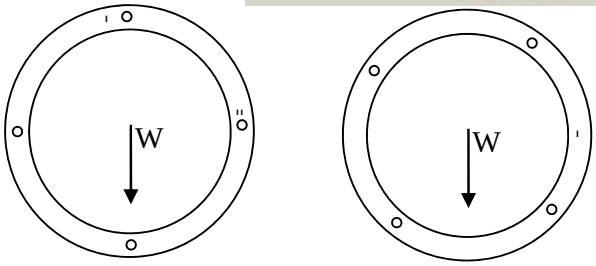
So, that was a stress high and then lower only that is why it was survived for the 100 hours; how was this kind of bearing arrangement is not supposed to survive that is why when we did in our investigation, we figured out of that is a load zone one and there should be hole instead of this arrangement hole and load zone one at the same place.

If we just tilt by 45 degree or we say the hole arrangement here, load zone arrangement here, then hole arrangement and the load zone arrangement in the such a manner that bearing should survive because what we are doing we are distributing the load. We say the more or less in such a manner every portion of bearing is loaded equally. That is permitted, that is reliable.

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- With new arrangement, no complaint was received.





(a) Earlier arrangement (b) New arrangement

And when we did that we found bearing was working well and there was no complaint at all. And that is what we say the just simple understanding of the bearing helps a lot. Company loss a lot of money in production because the bearing failure, mill will stop no fabrication, and then there is a problem of production loss as well as good will loss.

So, when we have some understanding about the bearing we can avoid this kind of failure and we do not know when this kind of knowledge will be required. So, we should always acquire a good knowledge related to the tribo systems and there is a possibility to avoid this kind of failure.

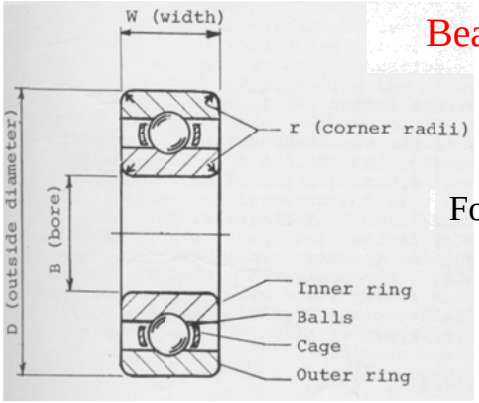
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Bearing Terminology

Four main components ?

That is why we start with the bearing topic, we say that there are some terminologies or there are few terms which are used for the rolling element bearing and we say whenever the rolling element bearing, we should understand there are four main components.

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Four main components are inner ring, rolling elements, cage and outer ring. When we are requiring this kind of inner ring and outer ring and there is a separation by some rolling element. So, there is a possibility the inner ring is rotating or there is a possibility outer ring is rotating, any arrangement is possible.

But what when we talk about the tribo system, we know there is a relative speed. If inner ring is rotating, there is a possibility outer ring will not rotate because we want isolation. We are not to transmit the motion which is happening at the short surface to the housing surface.

That is why, we use this kind of bearing this kind of isolation. We use fitting in such a manner this inner ring with a sharped goes with some sort of a transition fit or interference fit, outer ring also goes with the some sort of transition fit of the housing.

And the kind of rolling elements are arranged in a such a manner they do not collide with each other and that is why we require a cage. And we say the cage is used to separate the rolling elements. The rolling element starts colliding with the each other, they will interfere each other. Option they will reduce the rolling velocity or we say that rolling motion. They will increase unnecessary sliding just to avoid that we use this cage. And of course, these corners are always rounding. So that they should not be any stress concentration on this, stress concentration is reduced.

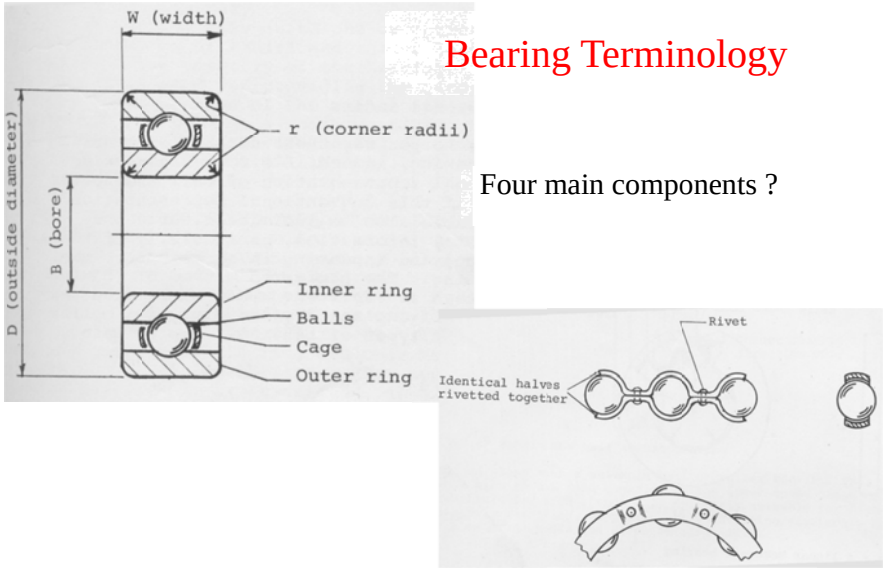
What else we have in this bearing is a width, larger the width of the bearing, more and more carrying capacity. For the same inner diameter we can change the outer diameter for this same B, same board diameter. We have a D, D1, D2, D3, D4, D5 and D2 will be greater than

D1, D3 will be greater than D2 but, as we are increasing this dimension the space restriction may come.

So, depends on the availability of the step we can choose any bearing. Lesser outer diameter more, outer diameter depends on the requirement, depends on the load requirement, depends on the space requirement. And the interesting thing is that all these kinds of bearings are available in a market.

As in my previous lecture, I mentioned about there are more than 2000 bearings. We have named the bearing, we get it. We named the dimension, we get it but, in discreet form not in continuous form. That is why we need to go ahead with standardisation. We need to find out what kind of bearings are available, what kind of class of the bearings are available and how they operate, how interact with the load.

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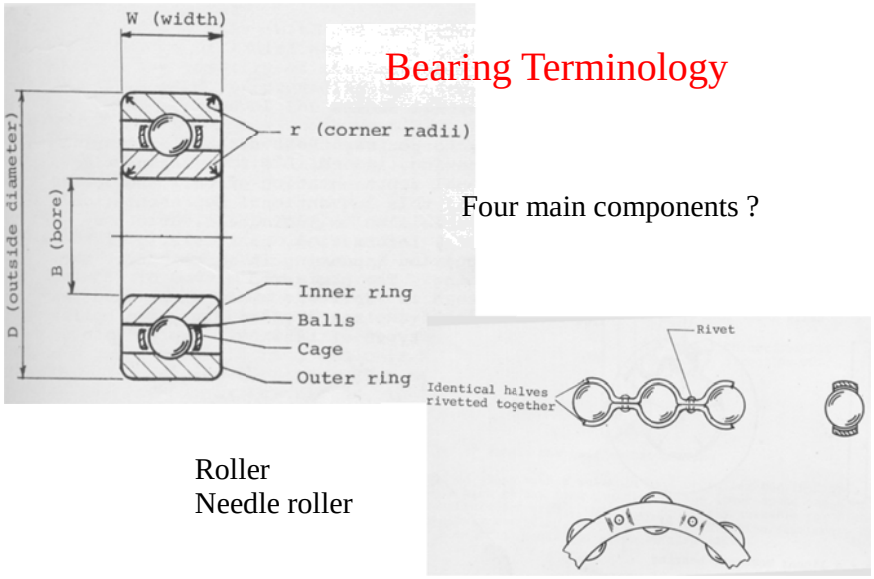


This diagram shows some sort of cages, are there cages or cage material are the more like a thin sheet metal formed in a shape in such a manner that they can guide the rolling elements. You can see there is a some sort of distance; one rolling element is not colliding without the rolling element.

And these cages are riveted, that means these cages are not going to rotate too much, it may be sliding to some speed and these are the three views of the cages with a rolling element. This is a side view that is clearly showed the cage is not over the complete rolling element. It is covering only some portion of the rolling element.

Similarly, in this case you are able to see the rolling elements are not completely covered. Only some portion for the guiding purpose is used. That is required to reduce the sliding between the rolling element and the cage but, depends on the requirement this cage material can be anything it can be polymer also, if the temperature or operating temperature is not going to be very high side or it can be some sort of a steel with a disulphide coating or graphite coating or some sought of a coating in that surface, so that there is a lesser friction lesser wear, more and more gliding on the surface.

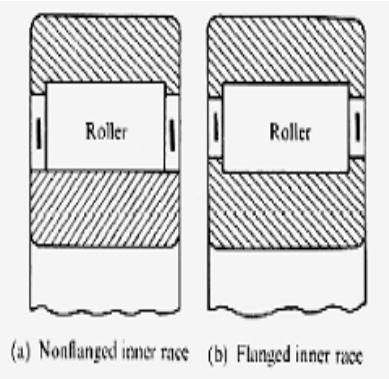
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Now, in this slide we have shown only the balls but, there is a possibility the balls can be replaced with a roller or we can think about the needle roller. We have seen the needles generally needle diameter is much lower than the length or we say the length l by d ratio in this kind of roller bearing will be roughly 10 plus, length will be minimum 10 times of the diameter. That is why we are using the word needle roller. They are used because of the space restriction diameter is much smaller. So, wherever the diameter restriction comes and we require larger load carrying capacity we can think about roller bearing.

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Cylindrical Roller Bearing



This slide shows two arrangements which is arrangement D, arrangement B for the cylindrical roller bearing. And it shows only the path view, you say that there is may be a central line away from this sketches or we say the only one half of the ring is been shown not when half is only the cut section you see the effect pass the cutting plain at the middle plain and remove and project, I will be getting this kind of a sketch.

What is the difference between this arrangement and difference between this. See that, in this arrangement in a ring is a flat, there is no groove arrangement. Of course, when I am using the word flat be confused it is a flat surface it is the curvature but, when we are showing on a sketch it is flat.

However, it will be the cylindrical piece, a hollow cylindrical piece. Inner ring is always a hollow cylindrical piece, outer ring is also a hollow cylindrical piece. As show over here from a center line to this dimension this is the hollow, nothing is there. They need to be fitted on the shaft or we say the shaft diameter will be up to this point after the bearing ring it stops over here on after the roller starts.

So, here in this case there is a no groove arrangement, while in this case there is a groove arrangement. We are cutting a groove in outer surface of inner ring. What is the advantage? In this case it can sustain the axial load, what we talk about the axial loads if the load is perpendicular to this x that will be radial load.

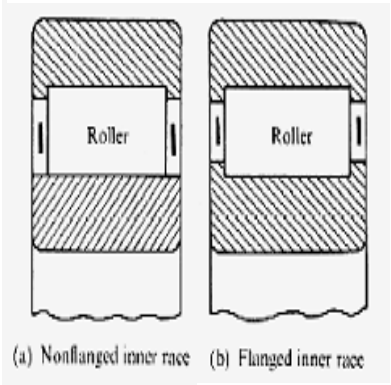
If any load is a parallel to the x, it will be axial load. When we are applying a load axially and if they there is no groove arrangement what will happen? This ring may get slide in one direction or to be moved out of the roller but, when we have this kind of arrangement. Even if we try to slide, this shoulder is going to restrict the motion. At least some portion or we say the some load; we cannot say that it will be infinite load you can sustain in finite load. Of

course, it depends on this strength of this shoulder and there is a possibility of plastic deformation or rupture of the shoulder if you apply axial load.

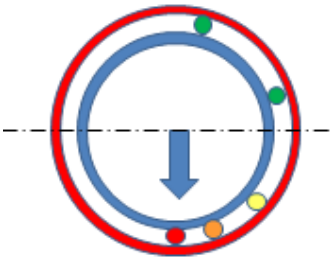
So, we need to know how much thrust force can be carried or it can be sustained by this roller bearing. It is interesting to note, when we studied in some common book you say the roller bearings are not meant for the thrust load but, this arrangement shows the roller bearings can be used for some thrust load, may be the 5 percent of the radial load, 10 percent of the radial load or some bus and depends on the kind of arrangement.

While in this case, outer ring is with a groove arrangement. There is a possibility of some alternative arrangement when there is a groove at the inner ring but, there is no groove at a outer ring. Depends on the requirement we can make we say that we can design this kind of a bearings and in market all 8 kinds of the bearings are available.

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50% of angular extent of load zone

$\psi_1 = \cos^{-1}(C_d / 2\delta_r)$;

δ_r = radial shift of ring

Deflection of rolling element under load

$W = K\delta^n$;

n = 1.5 for ball bearing,

n = 1.11 for roller bearing

And this is the projection of cage, what we say that there is a cage which is guiding the roller. See this arrangement there is a no cage in this, it's only the outer ring and there will be inner ring there is no cage. When there is no cage, what is the problem these rollers are going to collide with each other, they are in contact.

And you are able to see there are some pins coming out of this roller. These are the step shafts. They are larger dimension roller first and then pointed out or not pointed out because it is a smaller diameter way here just to fix in ring. That is why the ring arrangement which require act like pins.

So that, there is a free motion available but as there are number of rollers there will be more friction. And advantage is also there it can sustain much larger load. Smaller diameter will reduce the load sustainability, larger number of rollers will increase the sustainability but, larger loads, and larger rollers are also problem from the friction point of view.

That is why we say this kind of bearing show highest coefficient of friction and this highest coefficient of friction is reason for the small diameters. Sliding the speed will be or the slide into roller is rolling motion will be higher side or whether this ratio will be on higher side compared to the normal rollers here l by d is one or 0.5.

And there will be rubbing, of course, the surface is a perfect. Surface are good and they require slightly more lubricant for the n factor reduction in friction. So, there will be a rubbing that is why there is a lesser or smaller diameter. So, sliding to sliding rolling velocity ratio will be higher side that is why we have a higher coefficient of friction.

But they can sustain much larger load. To understand why they can sustain much larger loads? let us take a simple sketches, say this sketch is inner ring is a hollow ring, big cylinder, drill a hole in this or make a shape from the sheet metal in a such a manner or you do some sort of a molding and make this kind of ring. Then there is another ring so we say there is a inner ring there is outer ring. Then what is missing that is a rolling element. This is the rolling element between inner ring and outer ring. And there is a possibility of some clearance between inner ring rolling element and outer ring. When we apply load and if there is a one, only the one roller that is going to sustain highest load or we say the maximum load. What will be the load is been applied from the inner ring, whole load will get transferred to the roller and that load will be transferred to the outer ring and this roller is going to be subjected to the maximum load. Whatever if I am applying 1000 newton load, whole one thousand newton load is going to come on this roller or a ball whichever the rolling element which we are using. Suppose we are using the rolling roller in this case the whole one thousand newton load is going to come on this.

Now we say how to increase the number of rollers. Let us have one roller over here, what will happen this is a solid piece. When it is getting deflective when the load is applied it will not be only this much, this ring, this position of the ring is also subjected to the load.

And earlier there was no transmission route but, now when we are incorporating the roller there is a transmission route also coming over here. Of course we know very well this is along the line of direction or along the force direction so this portion will be subjected to the maximum load.

This roller will not be subjected to that high load. That is why is shown from red color to some sort of orange color. Orange is a lesser intensity compared to red. If I place one roller over here just this roller is going to subject to the load but, at the lesser magnitude. That is why red maximum load, orange slightly lesser than this red color roller and yellow will be lesser than red color as well as orange color roller.

As we move on, if I place now a green color or a some roller over here as I mentioned earlier if there is a clearance, slight clearance given then this lower portion will be subjected to the load but, top position will not be subjected to load. That is why we are showing with the green there is no load on this roller.

Similarly, on this side there will not be any load on this roller. Now I can say, if I want to find out what will be the angle? What will be the load angle? Otherwise what will be the half load angle? If I assume there is symmetry, if I draw a line here and may be some line over here. We say what is this angle? Of course, it will be from 0 to 90 degree, 90 degree when there is no clearance that is our understanding.

Now, to model this we can arrange using this relation, we say cos psi 1 is equal to C d, which is a diameter clearance divided by two into delta r and delta r is a radial shift of inner ring. No under load there will be a subject, there will be some sort of deformation as well as shifting of the ring and that need to be incorporated over here. So, C d is a clearance. If I keep zero clearance, no clearance at all, even in this situation this psi will be or psi 1 will be 90 degree because the cos psi 1 is a 0. That means psi 1 will be 90 degree.

Now, if we incorporate some clearance may be in micron also you may say 5 micron and the radial shift is by 2 micron or something like that. Then it will turn out to be more than this one which is not possible. Naturally this radial shift need to be more than this to reduce the value lesser than 1 and if that is done that means we can find out what will be the angular

extent of this load. Smaller clearance compared to this shift to delta r will be always compared to lesser clearance will be better from load arrangement point of view from the load sharing point of view.

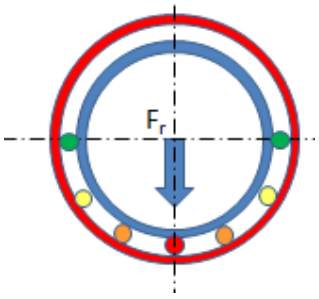
But what we explain here that is a increasing number of rollers. Now if I keep on increasing the rollers in this area, the more and more load sharing will happen by the rollers and the load maximum load which is coming in the any roller will be reduced.

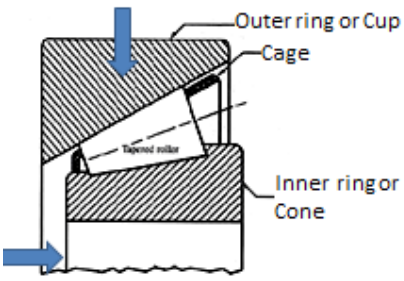
That can be explained by developing some relation but this understanding is helping us we can find out what is 50 percent zone of a load. That another half will be in this side there is symmetry.

For that purpose what we require a deflection curve. So, when we are applying a load on rolling element, they are going to be subjected to elastic deformation. It is a contact force and that can be simply represented in terms of deflection and whether that is a proportional constant k and this is a power n they are not linear, they are curvature that is why they will show non-linear behavior.

Linearity to some extent is been there in a roller bearing they have only curvature on one side in one direction. While ball bearing balls have a curvature in two dimension. That is why this n is more for balls lesser for the roller bearing. So, this n power x exponent is 1.5 for ball bearing, 1.11 is for the roller bearing. This is generally referred in number of books, we can see any book. And of course this is generally done by experimental base after doing experiment. They found that this is the relation by enlarge this relation when we do analytical expression or we want to find out load distribution.

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So, we can use this relation, there is another possibility or relation that this is sustaining maximum load by, this is sustaining lesser load and that is this kind of the load is in proportion to the deflection.

So, we can substitute that relation we say any time, load of the any roller depends on what is the extent from the center line. So, psi is 0 suppose then load will be maximum on that but, psi is maybe say 30 degree, then it will be Cos30 power depends on the roller or ball it will be 1.5 or 1.11.

Now, if we sum up because F_r which is a complete load applied on this rolling element bearing can be figured out can be calculated, can be estimated something like this. The W cos psi and of course there is a load on this and now we want to resolve in this know any company, any time load can be divided in a perpendicular direction. One will be along this axis; the other will be along this axis.

So, whatever the force comes along this axis will be added whatever force comes along this axis they will cancel each other. They will not finally, develop any overall load on this. The loads which are in this direction opposing this F_r only can be summed up. That is why we are saying W cos psi here into cos psi and depending the rolling element we can integrate from or we can sum up from psi is equal to minus psi. You say this is a minus psi, suppose to plus psi in this side or we can take anti clock wise or clock wise it does not matter.

Generally, we are assuming the symmetry on both the direction so arrangement is going to change whether we are going in clock wise direction or anti clock wise direction. This F_r will be same. Now when we develop the relation based on this, what we are going to get? Say F_r for the ball can come up with the number of rollers because we know that psi, this psi can figured but, two pi divided by number of rollers. So, numbers of rollers are going to be there in one way or another way in this expression.

When we develop the relation and approximate it, what we get F_r for the ball bearing is equal to Z, Z is a number of rollers or number of balls, for ball bearing is number of balls divided by 4.37 into maximum load on each element or any element. Of course, each element will be subjected to the max load because of the rotation in once one time the roller is here, next time in after rotation this red roller will come to this place so this orange roller will be in this place right.

So, each roller is going to be subjected to the maximum load and that is which other load on the ball bearing can be figured out by using this number of rollers. And for the roller bearing this is a relation that divided by 4.06 into W max, maximum roller over here.

Now, what is over all good thing about this, is that as number of element are increasing as the number of rolling elements are increasing load carrying capacity is for F_r which can be applied on this bearing is increasing continuously.

So, if I am using only this 10 rolling elements, load carrying capacity will be smaller. If I change to the 20 rollers of course depends on the space constraint or space is aligned to 20 balls or 20 rollers, if we accommodate those then the load capacity will be just double. And this is a reason why when we think about the rolling element bearing from one company and other company, we need to see the catalogue for the same dimensions there is a possibility of variable load carrying capacity. In one catalogue we can say that one rolling element bearing is showing some axial load in other catalogue can show 1.1 time or 1.05 times.

Unless they go with a perfect standardization for the rolling element, number of elements cage as well as the inner ring and the outer ring. Therefore, go ahead with the perfect standardization then there will be the same load carrying capacity. However there is a possibility of difference in the load carrying capacity.

So, we have talked about that roller bearing, talked about the needle roller bearing. To think about the taper roller bearing this taper we are able to see there is some sort of inclination or there is a some sort of cone formation. Inner ring and outer ring are also inclined they do not have a smooth or we say the surface parallel to the axis. Again this is the only one porting of bearing has been shown. What we are saying that is an inner ring particularly in the taper roller bearing is known as a cone, not inner ring is not a very common terminology for the taper roller bearing they use a cone and cup.

Outer ring is called as a cup there is a possibility of the groove in a cup as well as in a ring or they may avoid it they say provide it one side depend on the load, how the load is been applied on the bearings.

And there is a cage so that there is a possibility of operation between the rolling elements. We want this kind of bearing to be perfect and low friction and they show the intended function. they are fully complemented without cage then there is a possibility bearing showing very

good characteristics initially and suddenly all the rollers I mean three/four rollers. come closer or they started getting more separation because of the ware because of the scissor.

Then behavioral change if you want more consistent performance, cages are generally recommended. And this is showing a two direction now this kind of a bearing can sustain the real load which is a perpendicular to the axis of rotation, as well as it can be applied in one direction axial load parallel to the axis of rotation.

And when we apply load in this direction because of this shoulder you can sustain load. As well as because of this taper it can dissolve the forces accordingly and it can reduce overall force in magnitude.

These are the interesting bearing also we say that we talk about this term cylinder in a straight light profile but, when we merge which is a ball and roller we combine in a one way. Not in a other separate portion but, the curvature can be given to the rollers. When curvature is given to the rollers not in axial direction, but along the axis direction. Then what will happen this kind of bearing can show some sort of fluctuation in axis. It can sustain some fluctuation in axis, when there is a possibility of misalignment, one axis is continuously fluctuating, and load is not a stationary in that situation we can use this kind of bearings.

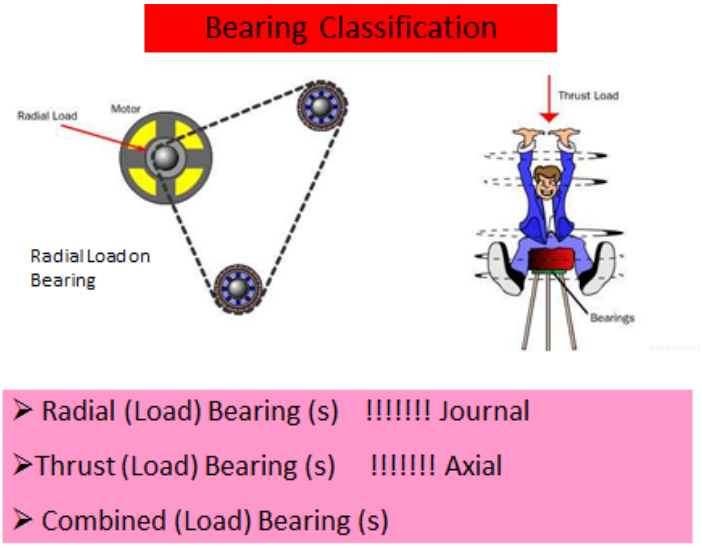
And what we call is the spherical roller bearing they have a spherical shape or we say the merging of ball profile with a roller profile or in some portion we say three-forth, one-forth of this side, one forth on this side can be profiled in a such a manner they are getting a spherical shape.

And made in a such a manner it can sustain there is the one simple sketch shown over here you can see if I pass one axis parallel and this axis is been misaligned. In this kind of situation two row roller bearing is been utilized.

Now, this chart can fluctuate because of this is spherical, there is a curvature shape over here and there is a curvature shape over here and the rollers are also curvature that this there is a possibility of giving or tolerating some misalignment in bearing.

So, whenever there is a misalignment you can recommend this kind of a arrangement or we say this self aligning bearing or a spherical roller bearing or some time we use housing which have this kind of curvature. It will be like a ball bearing but, housing is made in such a manner they can sustain some sort of a misalignment.

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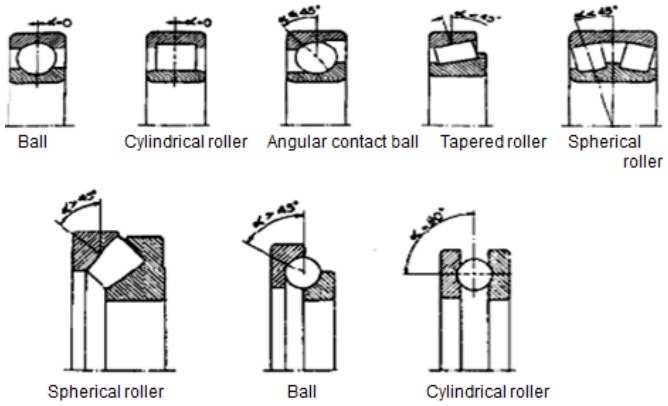


Now, we talk about the radial load we talk about the axial load that is why we say that bearing can be classified in two major categories. One is a radial roller bearing or radial ball bearing that is shown over here that the how the radial load is applied. This is the chain or may be any conveyor when is loaded, this bearing which is supporting this shaft or this is plain or what do we say this piston or we say this small axial whatever in that situation, radial load will be applied on the bearing.

Now, this simple cartoon shows that bearing is here and the load is getting transmitted for this guy and this is along the axis. We are saying that there is a spherical or maybe say any bearing at the ball bearing roller bearing and it is a curvature is given in such a manner there is more like a tire or a seat and when we apply a load there is a axis passing in between so this will be a thrust load.

That is why we see, bearing classification is a radial roller bearing which is often known as a journal bearing. Thrust bearing which often is known as a axial bearing or combined load bearing which what we call as a thrust bearing we call as a taper roller bearing in a previous slide that can be combined with this.

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Now, based on requirement the bearings are made with some angle between the race and the axis of rotation. You can see here the excess of rotation and this is the ring profile. Now, there is a no variation, the ring is also flat, this is flat, both are having a 0 angle and when we talk about the angle between a rolling element, and this also the 0; same thing in this cylindrical roller bearing. So, these bearings cannot sustain much extra thrust load. We say that wherever that this alpha is 0, thrust load carrying capacity will be negligible.

And wherever the thrust load carrying capacity will come, because of these shoulders, whatever the shoulders are made of over here, because of that only. Now, in this case this axis and this profile is having some inclination and we tried to produce something, we tried to show over here that if I arrange a ball and see the axis. Of course axis is will be average time but, wherever this contact and this contact is happening, this point cannot take and this point cannot take that is going to decide what is the angle of inclination.

And that shows us some angle as a 45 degree similarly, 45 degree from this axis. So, this is what we call this kind of bearing can sustain the thrust force as well as a radial force and what we know as this angular contact bearing. The ball bearing, spherical roller bearing, angular contact bearing here, contact point one here, one contact point here, we are joining this contact points and that line which is joining this contact point is making 45 degree angle with axis as well as a perpendicular axis.

In this case we are generally measuring the perpendicular with the axis so this is 45 degree and we can say the angular contact bearing can sustain axial as well as a radial load. Similarly, the taper roller bearing and now we said in previous slide, that the there was a cone there was a tapered angle along how on the surfaces of roller.

However, in this case we are able to see there is no taper roller, is the only the ring has a this taper or we say the cup and cone have some taper, but the roller does not have a taper. So, this kind of taper roller bearings are also possible and there we are able to see again is a some align the 45 degree over here which align this kind of bearing to sustain radial as well as a thrust force. Now, this is a spherical roller bearing again because of the change in this curvature, they are able to sustain thrust load and of course they are able to sustain the radial load also.

Coming to the major slide or in this case the major will be the load carried is radial some load will be carried as in thrust direction or along the axis direction. While in this category major load is a thrust load and we require some support to sustain the radial load.

So, in this case the spherical roller bearing you see the curvature is a spherical in nature. They are meant mainly for the thrust load along the axis, but to some extent if there is some sorts of radial force these rings can sustain that. Similarly, for this ball bearing the cylindrical roller bearing we are able to see the in cylindrical roller bearing in this and there is a 90 degree phase whatever the ball roller was shown here the roller is shown perpendicular to that, the other view of that.

So, that means in this ring arrangement it can sustain any load or maximum load along the axial direction. In this direction it cannot sustain the maximum load it can sustain only small portion because of restriction because of the constraint from the ring side.

Otherwise, there is no load carrying capacity along the radial direction. So, this is mainly for the thrust side from the axial load carrying capacity. Now, there is another one also if I say thrust load is applied in such a manner, it can sustain perpendicular to the axis and this kind of arrangement can be made to sustain major thrust load.

So, what do we say that there is a radial load perfect radial load in this case then combination, then major thrust load and this is complete thrust load. In this case these bearings are just sustaining only the thrust load no arrangement as such from radial load point of view, there is not much scope for the radial load. So, with this am completing present lecture, we will continue the rolling element bearing in our next lecture. Thanks, Thanks for your attention.