Int. J. Mech. Eng. & Rob. Res. 2014

International Journal of Mechanical Engineering and Robotics Research

ISSN 2278 – 0149 www.ijmerr.com
Vol. 3, No. 4, October 2014

Research Paper

ANALYSIS OF CONTACT PRESSURE DISTRIBUTION OF THE STRAIGHT AND CROWNING PROFILES OF TAPERED ROLLER BEARING

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Tapered roller bearings are the bearings that can take large axial forces (i.e., they are good thrust bearings) and also sustain large radial forces. Tapered roller bearings historically have been used in low speed applications. There has been a great deal of interest in recent years in evaluating the usage of tapered roller bearings at high speeds where ball bearings are normally used. The major benefit of using a tapered roller bearing is reduced size and weight. Tapered roller bearings have a significantly larger load capacity than ball bearings hence smaller bearing could be used to carry the same load. A rule of thumb is that a tapered roller bearing can carry two times the load of a similar size ball bearing. Basic tapered roller bearings consist of tapered rollers that are arranged between inner and outer rings having conical raceways. The inner and outer ring of a tapered roller bearing is commonly referred to as a cone and a cup respectively. When a tapered roller bearing is subjected to a radial load, the tapered rollers contact with mating raceways and compressive stresses at the roller ends tend to be substantially higher than those at the center of contact. This phenomenon of stress concentration is known as edge loading. In this bearing the radius of rollers are reduced in the order of micrometers to avoid edge loading. This modified geometry is called crowning. The fatigue life of a tapered roller bearing is heavily influenced by crowning profile of the roller. In the present study, the straight and crowning profiles of the roller of tapered roller bearing model is modeled by CATIA-V5 tool and meshing of the same is done by using HYPERMESH tool. The finite element analysis of contact pressure distribution is analyzed by using ABAQUS tool.

Keywords: Tapered roller bearing, Edge loading, Crowning, Contact pressure

INTRODUCTION

Tapered roller bearings historically have been used in low speed applications. There has been a great deal of interest in recent years in evaluating the usage of tapered roller bearings at high speeds where ball bearings are

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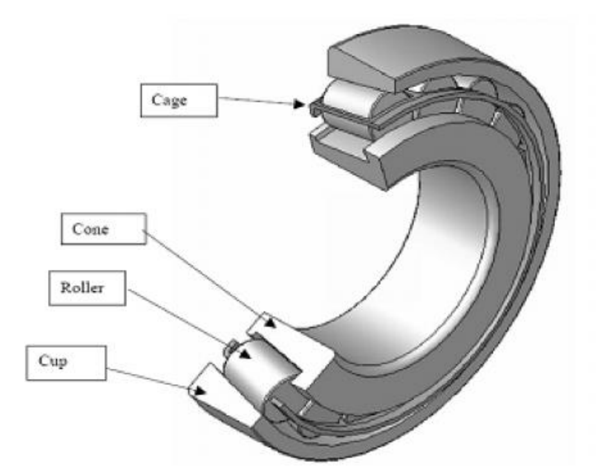
normally used. The major benefit of using a tapered roller bearing is reduced size and weight. Tapered roller bearings have a significantly larger load capacity than ball bearings so a much smaller bearing could be used to carry the same load. A rule of thumb is that a tapered roller bearing can carry two times the load of a similar size ball bearing.

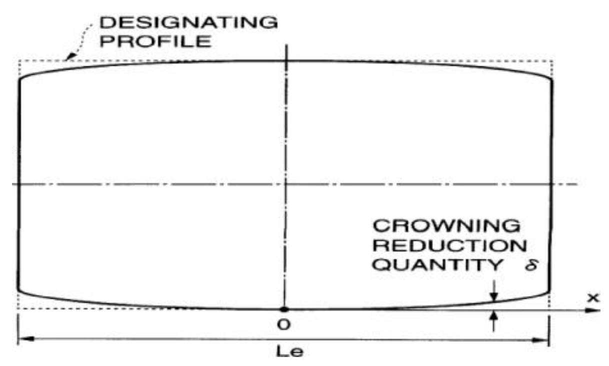
The term "tapered" refers to the shape of the rolling element within the bearing. Figure 1 illustrates a three dimensional view of a tapered roller bearing (Harris, 2001). The "tapered" shape of the cup, cone and roller can clearly be seen.

Figure 1: Tapered Roller Bearing



When a tapered roller bearing is subjected to a radial load, the tapered rollers contact with mating raceways and compressive stresses at the roller ends tend to be substantially higher than those at the center of contact. This phenomenon of stress concentration is known as edge loading. In this bearing the radius of rollers are reduced in the order of micrometers to avoid edge loading. This modified geometry is called crowning. The fatigue life of a tapered roller bearing is heavily influenced by crowning profile of the roller.

Figure 2: Roller Crowning



CROWNING

Crowning is a process of changing the straight profile of the roller by reducing its radius in microns to avoid edge loading and to have uniform pressure distribution. The simple crowning technique is used in the present project.

OBJECTIVE

The main objective of the present study is to determine the contact pressure distribution between the roller and the cone (inner race) along the axial direction when the bearing is subjected to radial load.

Case 1: Straight profile of the roller.

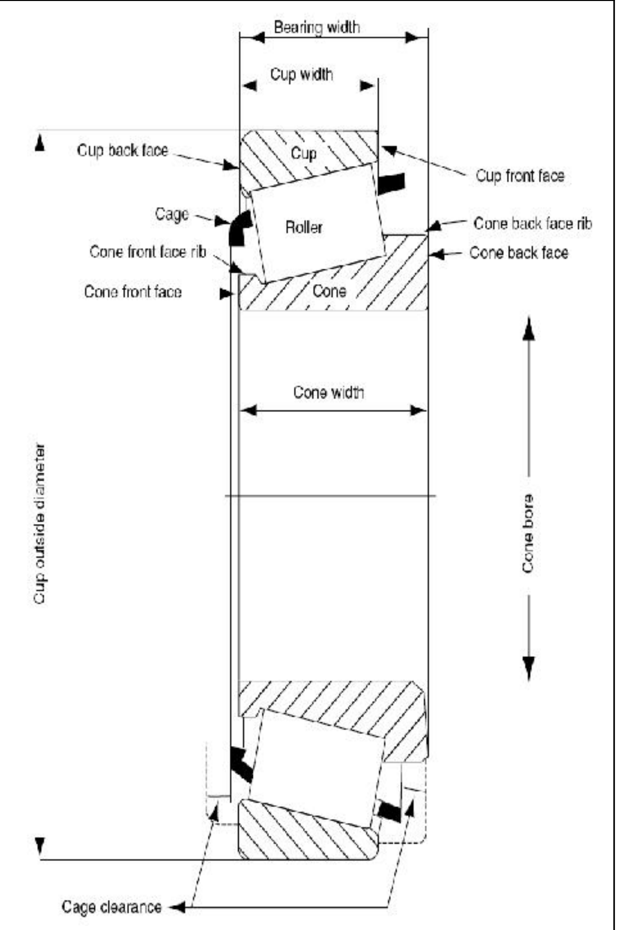
Case 2: Crowning profile of the roller.

Tapered roller bearing terminology:

Types of Contacts

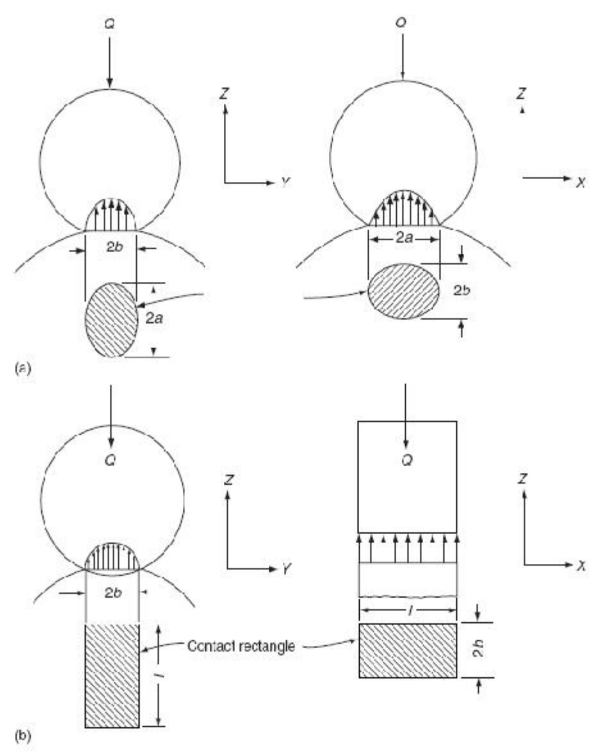
Rolling element bearings are typical mechanical components that operate under concentrated-contact conditions. Loads carried by rolling element bearings are transmitted through the discrete contacts between the rolling elements and the two raceways. Even under moderate bearing load, the stresses at the contact are quite high, being on the order of 1 to 4 GPa. Well-designed

Figure 3: Tapered Roller Bearing Terminologies



Source: Harris (2001)

Figure 4: Surface Compressive Stress Distribution (a) Point Contact; (b) Ideal Line Contact



bearings are, however, capable of carrying an appreciable amount of load. This is attributed to the fact that contact stress increases slowly with the applied load (to one third power for point contact and one half power for line contact) and that the material is in general compression. In rolling element bearings, point contact refers to the conjunction of two surfaces such that under no load, the initial contact is a single point. As load is applied, the contact develops into a finite area of a generally elliptical shape. Point contact exists between the rolling elements and raceways of ball bearings, and of roller bearings with high-crown on rollers and raceways. It also exists in roller bearings between the roller-ends and flanges. Line contact is the conjunction of two surfaces such that the initial contact under no load is a straight line. When loaded, the line spreads to form an elongated rectangle.

Basically, two hypothetical types of contact can be defined under conditions of zero loads. These are:

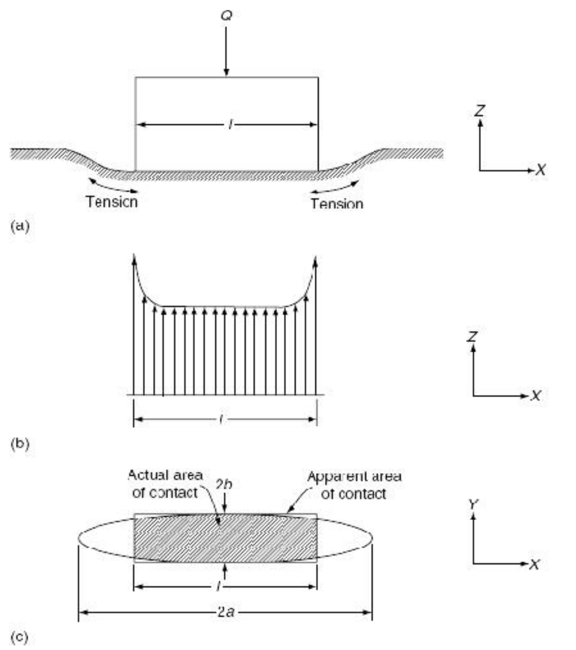
- Point contact, that is, two surfaces touch at a single point.
- Line contact, that is, two surfaces touch along a straight or curved line of zero width.

Obviously, after a load is applied to the contacting bodies the point expands to an ellipse and the line to a rectangle in ideal line contact, that is, the bodies have equal length.

Figure illustrates the surface compressive stress distribution that occurs in each case.

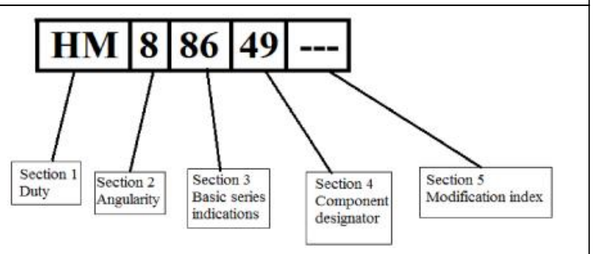
When a roller of finite length contacts a raceway of greater length, the axial stress distribution along the roller is altered, as that in Figure 4. Since the material in the raceway is in tension at the roller ends because of depression of the raceway outside of the roller ends, the roller end compressive stress tends to be higher than that in the center of contact. Figure 5 demonstrates this condition of edge loading.

Figure 5: Line Contact: (a) Roller Contacting a Surface of Infinite Length; (b) Roller–Raceway Compressive Stress Distribution; (c) Contact Ellipse



Bearing Part Number

Figure 6: Sections of Part Number



TRB Loading

Figure 7: Tapered Roller Bearing Loading

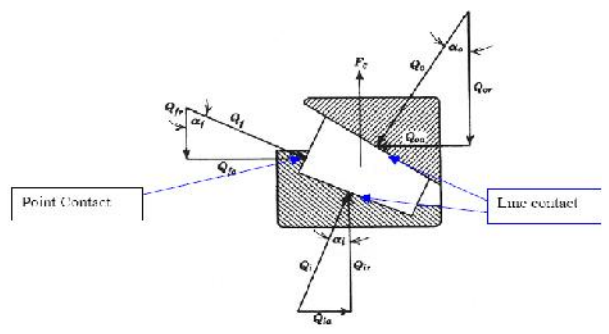


Table 1: Mechanical Properties of AISI 52100 Steel	
Mechanical Properties	
Density	7700-8030 kg/m^3
Poisson's Ratio	0.27-0.30
Elastic Modulus	190-210 GPa
Tensile Strength	2241 MPa
Yield Strength	2034 MPa

Mechanical Properties

The largest tonnage of bearing steels currently produced is the category of through-hardening steels. Through-hardening steels are classified as hypereutectoid-type steels when containing greater than 0.8% carbon by weight and essentially containing less than 5% by weight of total alloying elements. Assuming satisfactory material availability, the bearing producer selects the appropriate grade of steel, based on bearing size, geometry, dimensional characteristics, specific product performance requirements, manufacturing methods, and associated costs.

CAD MODELING AND MESHING

The different parts of TRB, i.e., cup, cone, roller is modeled by CATIA part drawing and meshed using hypermesh.

Figure 8: TRB Model

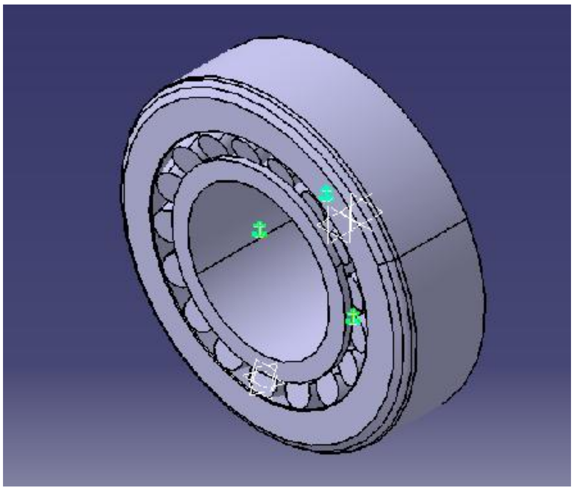
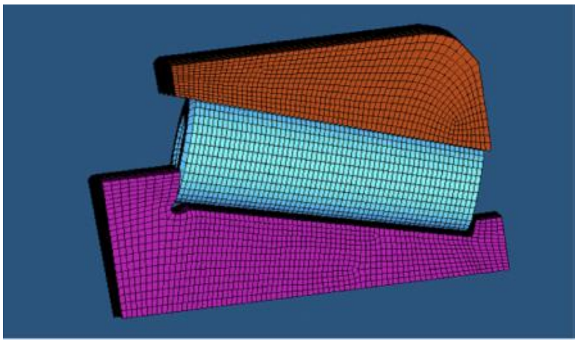


Figure 9: Sector of Meshed TRB Model



FINITE ELEMENT ANALYSIS

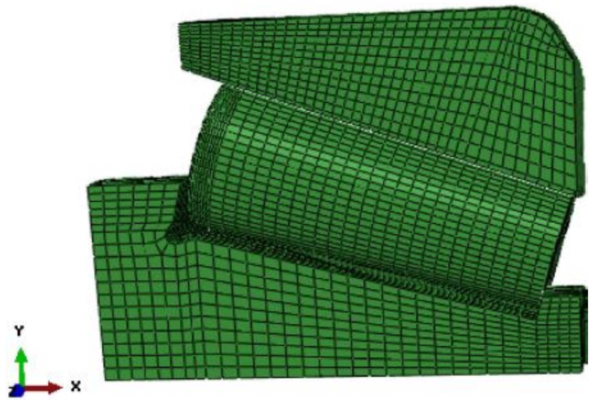
The stress and contact pressure distribution is analyzed by most accurate post processing tool called Abaqus. The following steps are used in Abaqus.

Step 1: The meshed roller, meshed sector of cone and cup is imported to Abaqus.

Step 2: In this step, the material properties is assigned for a material. The material used is AISI 52100 or SUJ2 and it is assumed to be solid, homogeneous and isotropic. The density is 7700 kg/m^3. The Young's modulus is 205 GPa and Poisson's ratio is 0.3. The yield strength of AISI 52100 materials is 2034 MPa.

Step 3: After assigning the material properties, the parts are assembled to make a single TRB model sector as shown in Figure 10.

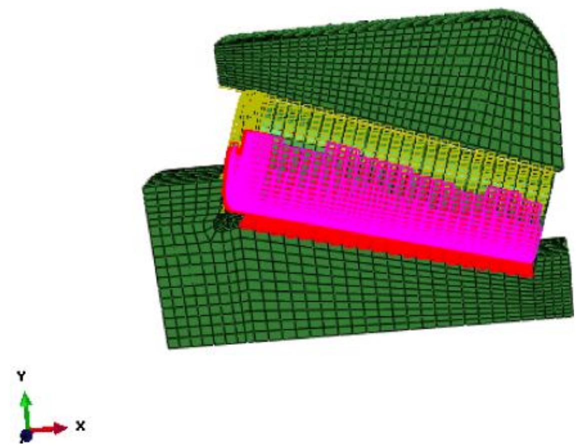
Figure 10: Assembled TRB Sector



Step 4: The next step in the analysis is to decide whether we are doing static or general analysis. In the present project, we are doing static analysis.

Step 5: The master and slave surfaces are selected and we will provide small sliding interaction with a co-efficient of friction of 0.08. The master surface acts as a load giver and has the coarse mesh. The slave surface acts as a load receiver and has the fine mesh.

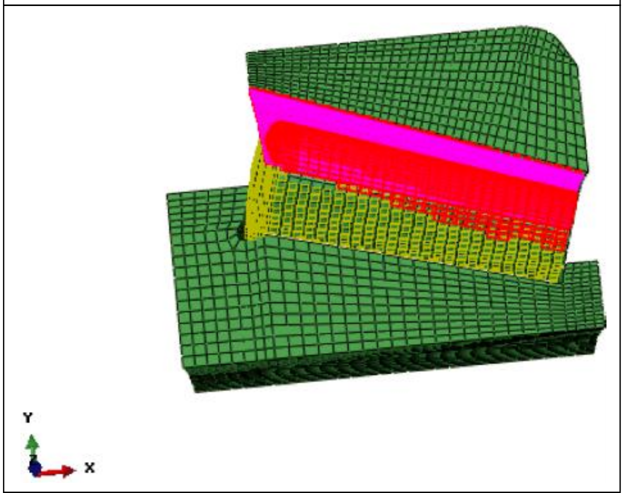
Figure 11: Interaction 1



Interaction 1: The cone inner race surface (red) acts as a master and roller surface(pink) acts as a slave as shown in Figure 11.

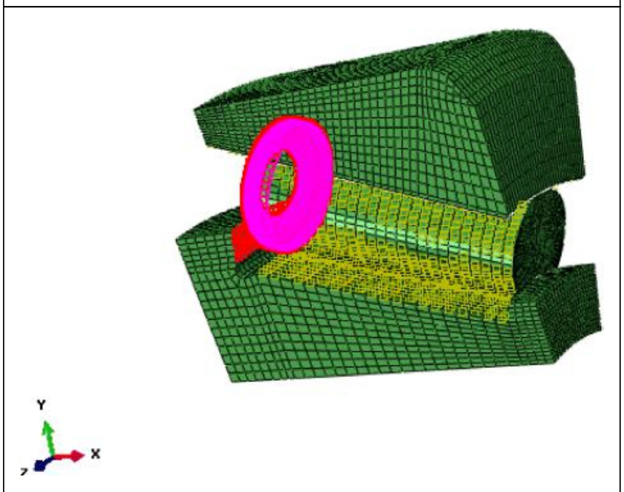
Interaction 2: The roller surface (red) acts as a master and cup inner race surface (pink) acts as a slave as shown in Figure 12.

Figure 12: Interaction 2



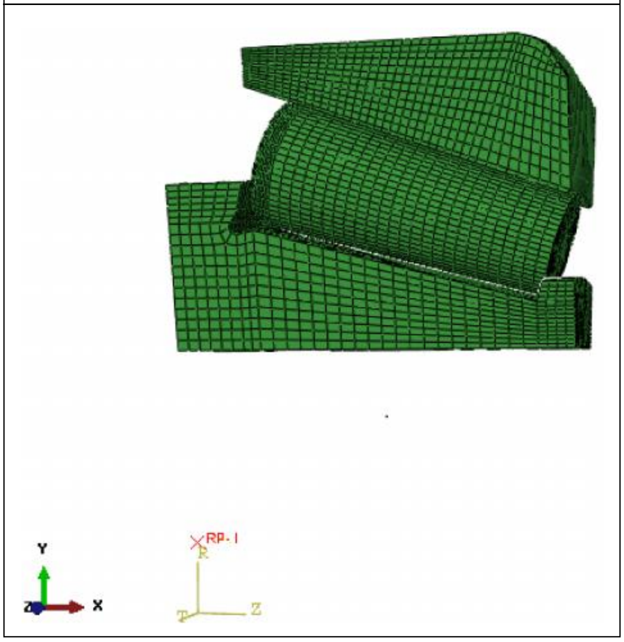
Interaction 3: The cone inner race surface (red) acts as a master and roller spherical end surface (pink) acts as a slave as shown in Figure 13.

Figure 13: Interaction 3



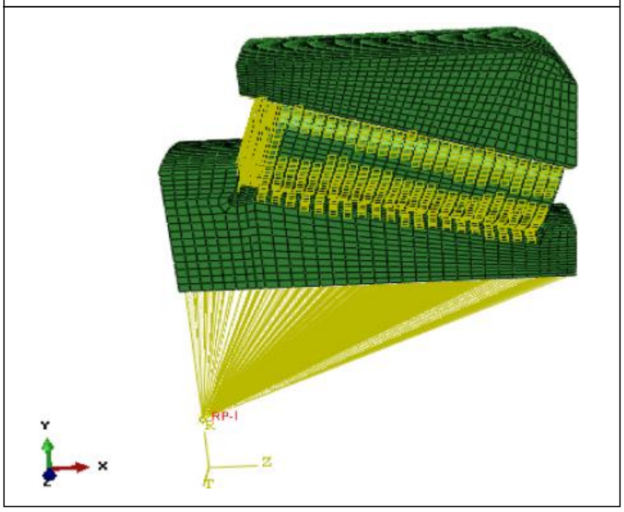
Step 6: The reference point is created with a coordinates (0, 4.6, 0) in (X, Y, Z) directions respectively. Since the radial load is applied, the load center value 4.6 mm is taken in Y direction as shown in Figure 14. The load center value is 4.6 mm for HM88649 bearing.

Figure 14: Reference Point



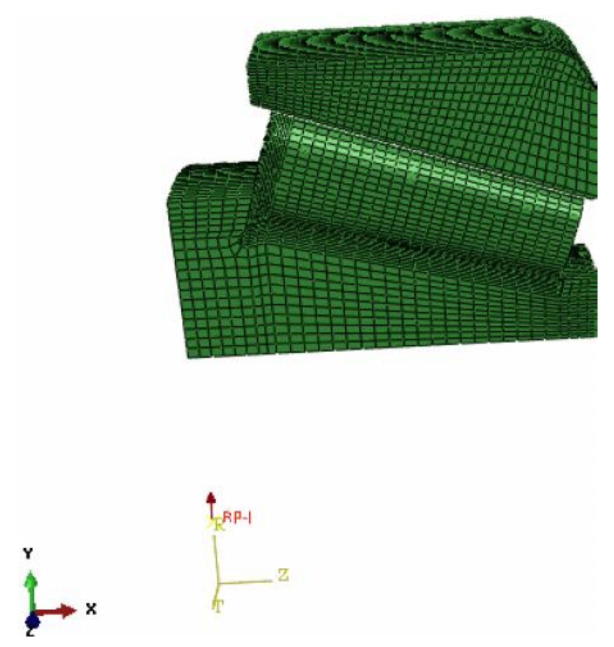
Step 7: Kinematic coupling is created between the reference point and cone outer race as shown in Figure 15. The load is distributed uniformly through kinematic coupling.

Figure 15: Kinematic Coupling



Step 8: A concentrated radial load of 5000 N is applied in Y direction at the reference point as shown in Figure16.

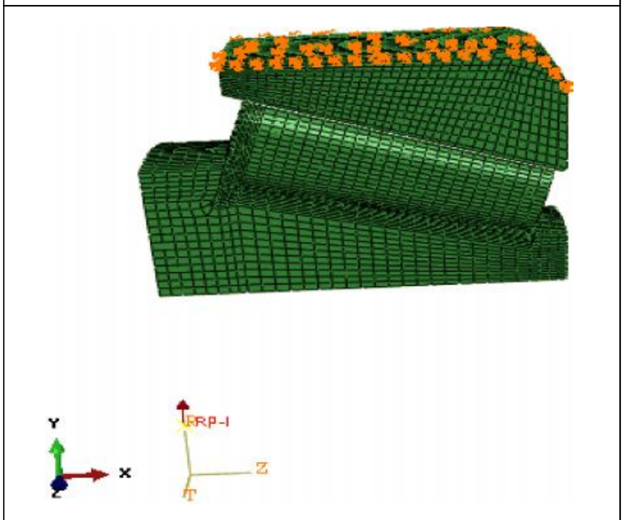
Figure 16: Radial Load Applied at Reference Point



Step 9: Boundary conditions

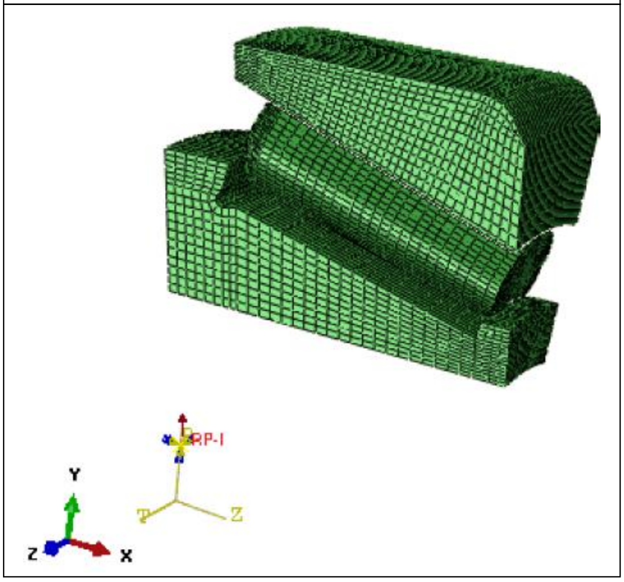
Boundary Condition 1: The cup outer raceway is constrained in X, Y and Z directions, i.e., displacements (U1, U2, U3) along these directions is zero as shown in Figure 17.

Figure 17: Boundary Condition 1



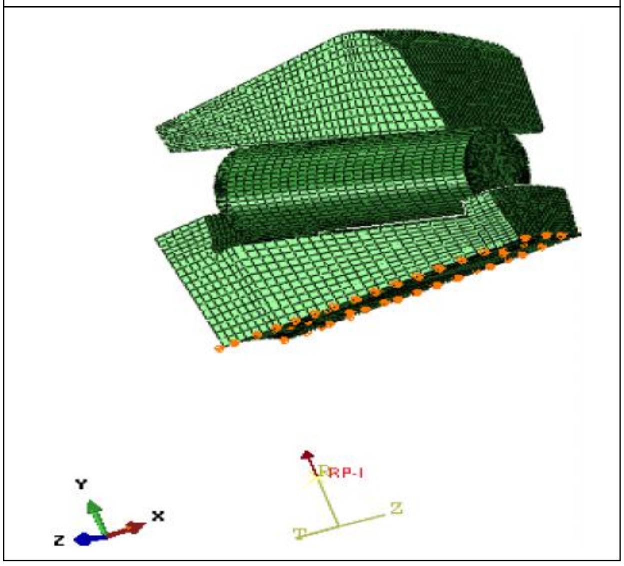
Boundary Condition 2: The reference point on which load is acting is constrained in all displacement and rotational directions, i.e., U1 = U2 = U3 = UR1 = UR2 = UR3 = 0 as shown in Figure 18.

Figure 18: Boundary Condition 2



Boundary Condition 3: The cone outer raceway is constrained in X direction, i.e.,

Figure 19: Boundary Condition 3



displacement (U1) along X direction is zero as shown in Figure 19.

Step 10: Finally the job is submitted for analysis and the results will be stored in ODB (output data base) file.

The above procedure is followed for both straight profile roller TRB model and crowned profile TRB model separately. The stresses, strains and contact pressure will be stored in output database file. We can also represent these results in the form of graphical representation.

RESULTS AND DISCUSSION

Contact Pressure Distribution

Under the application of radial load, the contact pressure at the roller ends is substantially higher than that of the center of contact. This leads to edge loading, which decreases the fatigue life of the bearing.

Case 1: Straight Profile Roller

The analysis will takes place in 10 increments. The given load is divided into 10 equal parts. The variation of load and contact pressure with respect to increments is shown in Figure 20.

Figure 20 shows that the contact pressure at the roller ends are more compare to other region. The Figure 21 clearly suggests that, there is an edge loading at the roller ends. This edge loading decreases the fatigue life of a bearing. The maximum contact pressure induced in the straight profile roller TRB is 1971 MPa.

Case 2: Crowned Profile Roller

The analysis will takes place in 10 increments. The given load is divided into 10 equal parts. The variation of load and contact pressure with respect to increments is shown in Figure 22.

Figure 22 shows that the contact pressure at the roller ends is same compare to other region. The Figure 23 clearly suggests that, there is no edge loading at the roller ends. This increases the fatigue life of a bearing. The maximum contact pressure induced in the straight profile roller TRB is 1866 MPa. This

Figure 20: Contact Pressure Distribution in Straight Profile Roller of a TRB

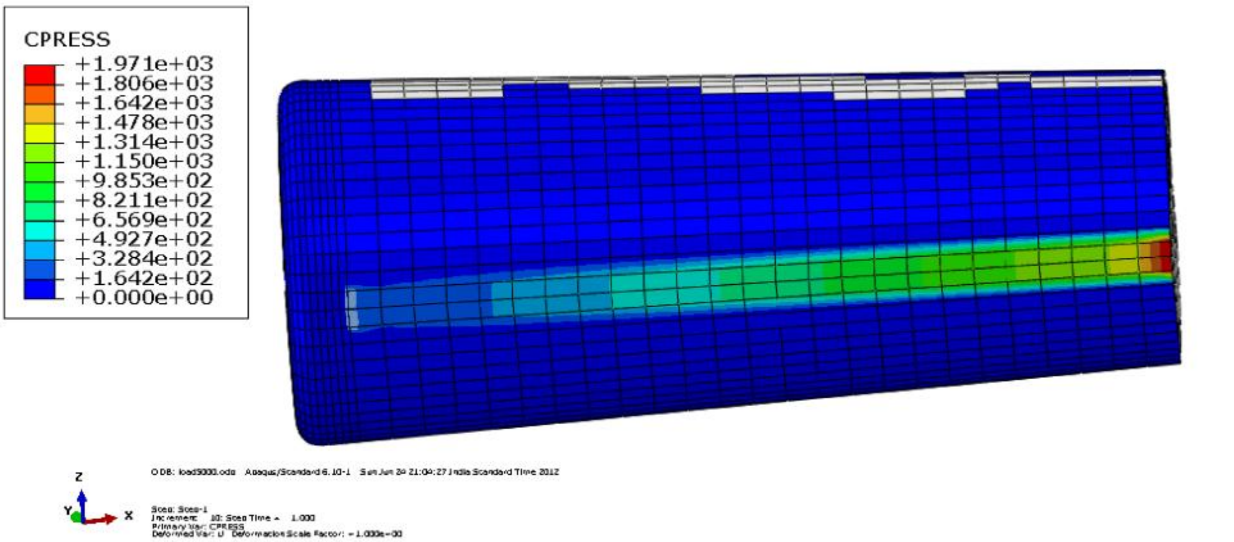


Figure 21: Shows the Contact Pressure Distribution in Straight Profile Roller of a TRB Along Roller Length in Axial Direction

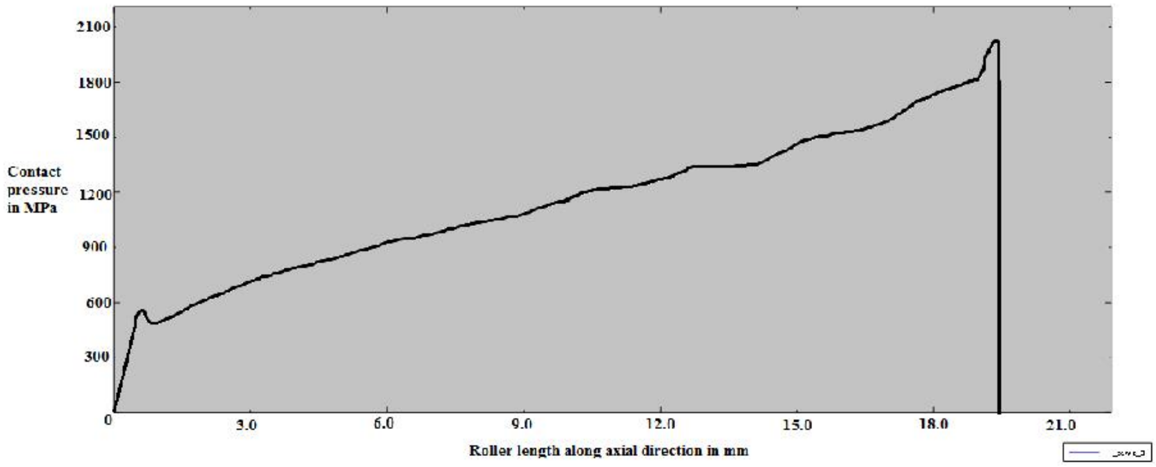


Figure 22: Contact Pressure Distribution in Crowned Profile Roller of a TRB

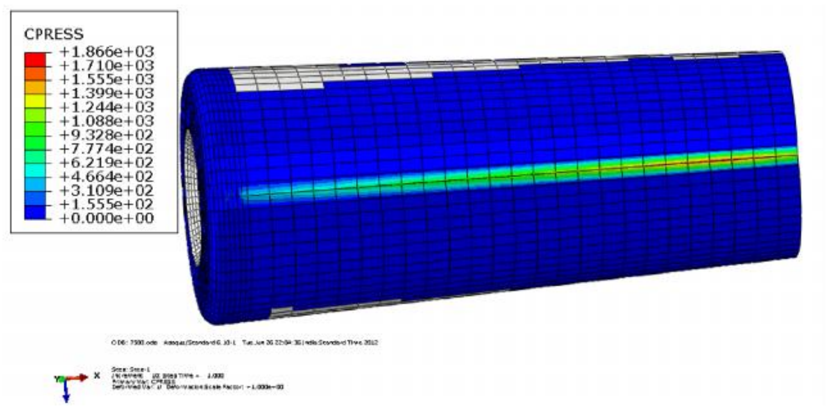
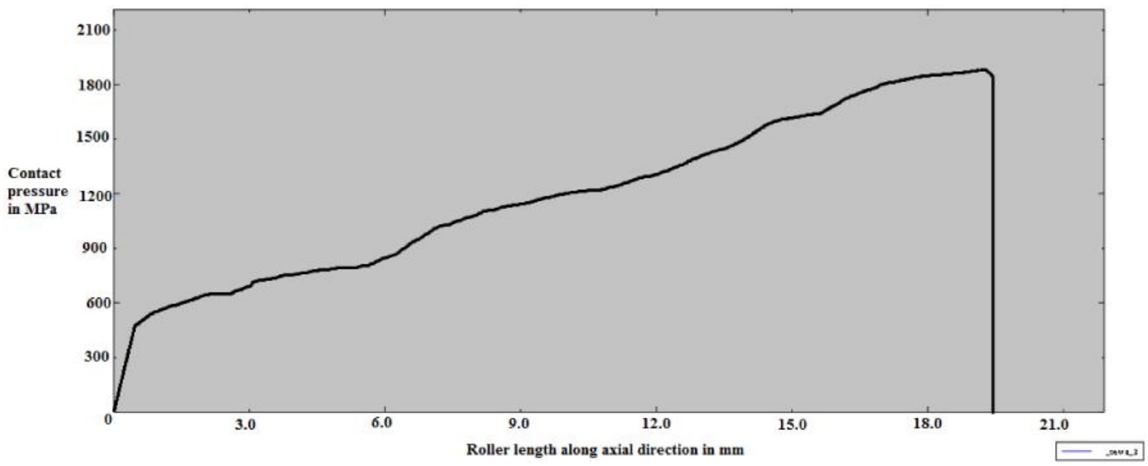


Figure 23: Shows the Contact Pressure Distribution in Straight Profile Roller of a TRB Along Roller Length in Axial Direction



clearly suggests that crowning of the roller is very useful in avoiding edge loading.

CONCLUSION

In the present study two types of tapered roller bearing models were analyzed, first the straight profile roller TRB and second the crowned profile roller TRB. The result shows that edge loading is minimized in crowned profile TRB. Crowning to a TRB roller results the line contact of roller-cone raceway into a point contact and minimizes the edge loading. The contact pressure distribution of crowned profile roller is uniform compare to the straight profile roller.

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