# Contact Analysis of Frictional Motion between Fiber Reinforced Polymer (FRP) Races and Cylindrical Roller Bearing

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**Abstract:** ***The purpose of bearing is to constraint relative motion between moving parts to only desired motion. The design of the bearing provide for free linear movement of the moving part or for free rotation around a fixed axis or it may prevent a motion by controlling the vectors of normal forces that bear on the moving parts. Cylindrical roller bearing carry heavy radial loads. These are suited for low coefficient of friction and less frictional loss in high speed application. Due to this reason cylindrical bearing generates more noise. Optimization of noise depends on materials suited for bearing, design calculation of cylindrical bearing and radial force acting on it. Fiber-reinforced polymer (FRP), is a composite material made of a polymer matrix reinforced with fibers. The fibers are usually glass, carbon, or aramid, although other fibers such as paper or wood or asbestos have been sometimes used. Fibers play major role in self lubrication and noise reduction in cylindrical bearing. Optimization of contact pressure between FRP and cylindrical bearing is used for noise reduction. This works deals with design of cylindrical bearing based on radial force acting on bearing. Also estimate the life of cylindrical bearing. To evaluate the deflections and stresses developed on cylindrical bearing using different types of materials (i.e, Steel, HM Carbon/ Epoxy, HS Carbon/Epoxy) in FEA Analysis. The project also includes the determination of the influence of fiber and matrix material combinations, frictional coefficient and fiber ply orientation on the contact pressure distribution and contact area between the FRP and cylindrical bearings. Sliding contact between FRP and cylindrical bearing done using FEM software. Also, NX CAD software is used for designing of cylindrical bearing and Contact Analysis was done in Ansys11.0 software.***

**Keywords:** FEM, FEA, Static Analysis, Nodes, Elements, Yield Strength, Deflection, Stress

## 1. Introduction

Bearings are components designed to connect machine parts. Bearings transmit motion and forces. They are usually mounted on axles or shafts and inserted in housings. If a bearing transmits rotary motion, it is called a rotary bearing. Linear bearings are used for longitudinal motion. The type of friction involved distinguishes plain bearings from rolling bearings.

Rolling bearings are classified into two types.
1.Ball bearings and 2. Roller bearings.

- Ball bearing: Deep groove ball bearings, Angular contact ball bearings , Four point contact ball bearings, Self-aligning ball bearings.
- Roller bearings: Cylindrical roller bearings Needle roller bearings Tapered roller bearings Spherical roller bearings.

## 2. Objective

Cylindrical roller bearing carry heavy radial loads. These are suited for low coefficient of friction and less frictional loss in high speed application. Due to this reason cylindrical bearing generates more noise. Optimization of noise depend on materials suited for bearing, design calculation of cylindrical bearing and radial force acting on it. Fiber-reinforced polymer(FRP), is a composite material made of a polymer matrix reinforced with fibers. The fibers are usually glass, carbon, or aramid, although other fibers such as paper or wood or asbestos have been sometimes used. Fibers play major role in self lubrication and noise reduction in cylindrical bearing. Optimization of contact pressure between FRP and cylindrical bearing is used for noise reduction. This works deals with design of cylindrical bearing based on radial force acting on bearing. Also estimate the life of cylindrical bearing. The project also includes the determination of the influence of fiber and matrix material combinations, frictional coefficient and fiber ply orientation on the contact pressure distribution and contact area between the FRP and cylindrical bearings. Sliding contact between FRP and cylindrical bearing done using FEM software. Also, NX CAD software is used for designing of cylindrical bearing and Contact Analysis was done in Ansys11.0

## 3. Life Estimation of Cylindrical Bearing

### 3.1 Cylindrical Bearing Rating Life Equation

**Input**:
Cylindrical roller bearing with oil lubrication
Diameter of inner races(d) = 85 mm
Diameter of outer races (D)= 150 mm
Based on diameter values, Bearing number is NUP217
Dynamic radial load rating (Cr)= 121 kN
Basic static load rating (C0r)= 140 kN
Radial load (Fr)= 10kN
Equivalent static bearing load (P0r)= Fr= 10kN
Shaft speed (N)= 1000 rpm

**Output**:
Bearing rating life equation (L10)

$$= \left(\frac{Cr}{P0r}\right)^{\frac{10}{3}} * 10^6\ revolutions$$

= 4067.09 million revolutions
Operating hours(L10h)

$$= \frac{\left(\frac{Cr}{Por}\right)^{\frac{10}{3}} * 10^6}{60 * N}$$

= 13556.979 hours

## 4. Finite Element Analysis of Cylindrical Bearing

### 4.1 Static Analysis of Cylindrical Bearing for Stainless Steel Alloy Material

A static analysis can however include steady inertia loads and time varying loads that can be approximated as static equivalent loads. The 3d model of the cylindrical bearing is created in NX-CAD and converted into parasolid. The parasolid file is imported into ANSYS and finite element analysis is carried out using ANSYS software.

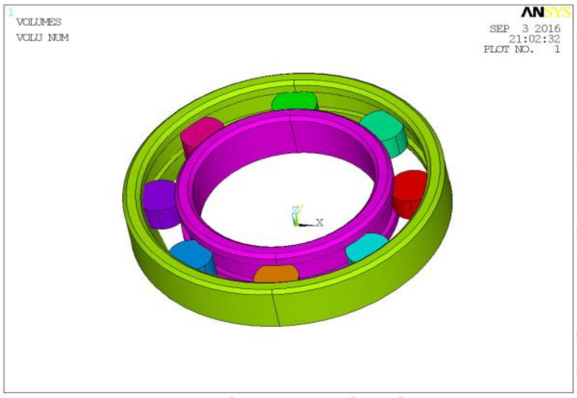


**Figure 1:** Geometric model of the cylindrical bearing

**Material used for cylindrical bearing is Stainless steel alloy:**

- Young's Modulus: 200 GPa
- Poisson's Ratio: 0.3
- Density: 7850 Kg/m3
- Yield strength: 300 MPa

Element Types used:

- Name of the Element: SOLID 92
- Number of Nodes: 10
- DOF: UX, UY & UZ

**SOLID92 Element Description**

SOLID92 has a quadratic displacement behavior and is well suited to model irregular meshes (such as produced from various CAD/CAM systems). The element is defined by ten nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The element also has plasticity, creep, swelling, stress stiffening, large deflection, and large strain capabilities.

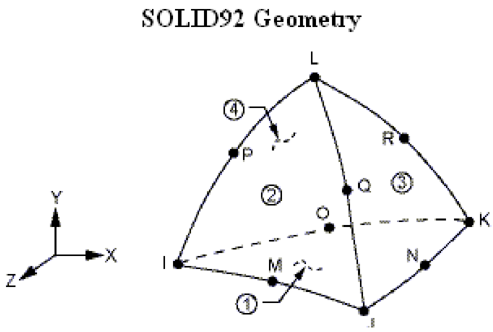


**Figure 2:** Solid 92 Geometry

**SOLID92 Input Data**

The geometry, node locations, and the coordinate system for this element are shown in Figure "SOLID92 Geometry". Beside the nodes, the element input data includes the orthotropic material properties. Orthotropic material directions correspond to the element coordinate directions. The element coordinate system orientation is as described in Coordinate Systems.

Element loads are described in Node and Element Loads. Pressures may be input as surface loads on the element faces as shown by the circled numbers on Figure "SOLID92 Geometry".


**Figure 3:** Meshed model of cylindrical bearing

**Boundary Conditions**

- A radial force of 10000 N is applied on centre of cylindrical bearing.
- The sides of cylindrical bearing are constrained in all dof.

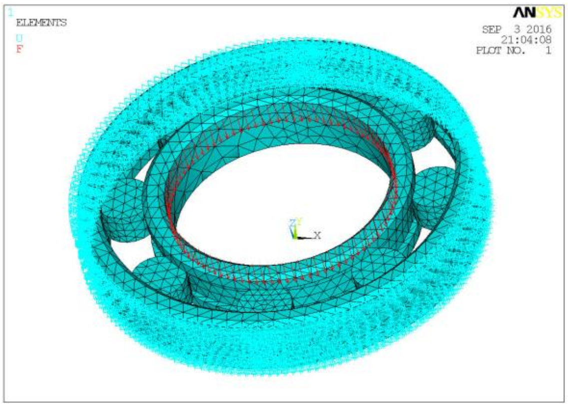


**Figure 4:** Applied boundary conditions of cylindrical bearing

**Deflections:**

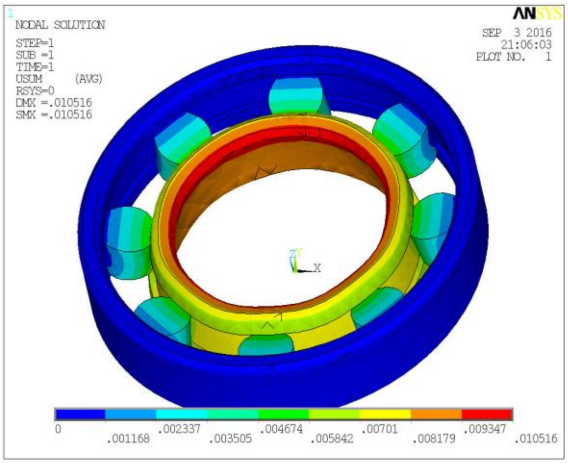


**Figure 5:** Resultant displacement of cylindrical bearing

**Stresses**

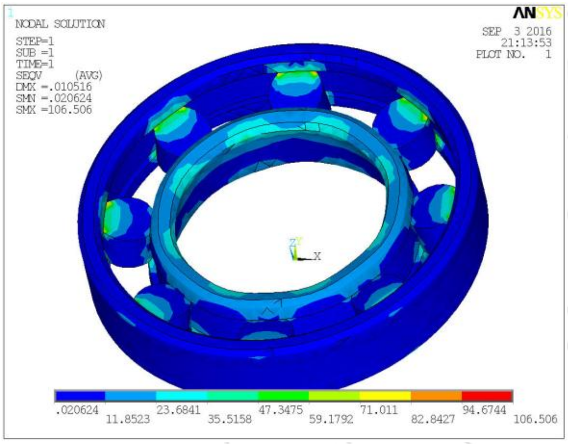


**Figure 6:** Von mises Stress formed on cylindrical bearing

From static analysis results for steel material, The Resultant Displacement found on cylindrical bearing is **0.0105 mm.** The Von misses stress formed on cylindrical bearing is **106.506Mpa**. The Yield strength of steel material is **300 MPa**. The Von mises stress of cylindrical bearing was **64.5%** less than the yield strength of the material. Hence the cylindrical bearing was safe in design for static conditions.

### 4.2 Static Analysis of Cylindrical Bearing for Composite Material

#### 4.2.1 Material used for cylindrical bearing is composite materials (hm carbon/epoxy)

- Longitudinal Modulus ($E_z$): 190 GPa
- Transverse Modulus ($E_y$): 7.7 GPa
- Shear modulus ($G_{xy}$ ): 4.2 GPa
- Shear modulus ($G_{yz}$ ): 4.2 GPa
- Shear modulus ($G_{xz}$ ): 4.2 GPa
- Poisson's Ratio: 0.3
- Density: 1600 $Kg/m^3$
- Ply orientation: -45$^o$, 0$^o$, 0$^o$, 45$^o$
- Yield strength: 800 MPa

Ply-angle/ ply orientation:

Angle-ply or axially biased composite laminates are an important class of laminates because they combine good properties in the axial and shear directions. The Ply- angle architecture, which offered one of the best combinations of axial and shear properties, had a much lower experimental compressive strength than that predicted using the maximum stress or maximum strain failure criteria.

Element Types used:

Name of the Element: SOLID 185
Number of Nodes: 20
DOF: UX, UY & UZ

**SOLID 185:**

SOLID185 is used for 3-D modeling of solid structures. It is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The element has plasticity, hyper elasticity, stress stiffening, creep, large deflection, and large strain capabilities. It also has mixed formulation capability for simulating deformations of nearly incompressible elasto plastic materials, and fully incompressible hyper elastic materials.

SOLID185 Structural Solid is suitable for modeling general 3-D solid structures. It allows for prism and tetrahedral degenerations when used in irregular regions.

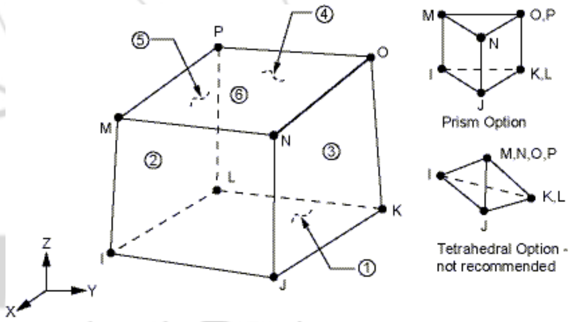


**Figure 7:** SOLID 185 Geometry

**Boundary Conditions**

- A radial force of 10000 N is applied on centre of cylindrical bearing.
- The sides of cylindrical bearing are constrained in all dof.

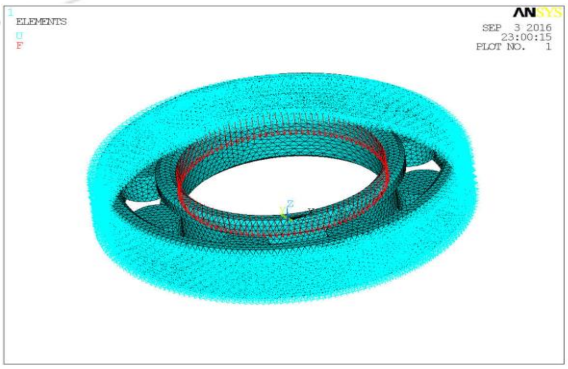


**Figure 8:** Applied boundary conditions of cylindrical bearing

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**Deflections:**

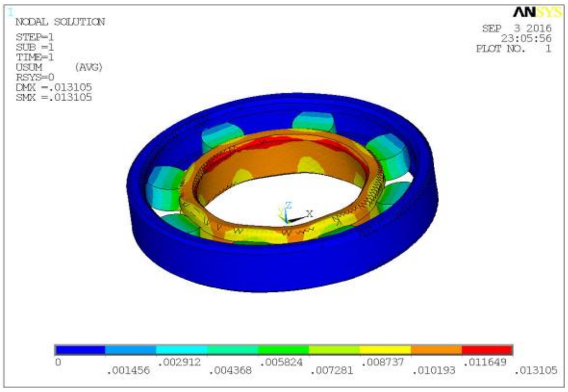


**Figure 9:** Resultant displacement of cylindrical bearing

**STRESS:**

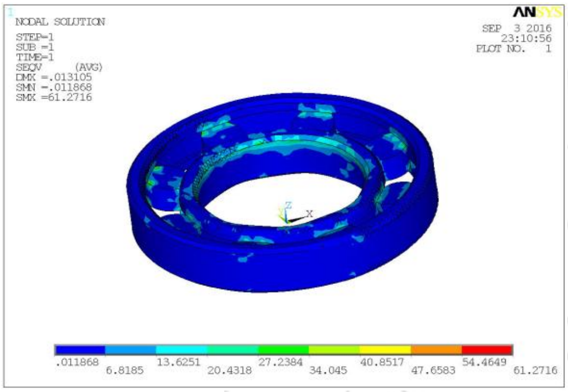


**Figure 10:** Von mises Stress formed on cylindrical bearing

From static analysis results for HM Carbon/epoxy, the resultant displacement found on cylindrical bearing is **0.0131 mm**. The Von misses stress formed on cylindrical bearing is **61.2716MPa**. The yield strength of HM Carbon/Epoxy material is **800 MPa**. The Von mises stress of cylindrical bearing was **92.34%** less than the yield strength of the material. Hence the cylindrical bearing was safe in design for static conditions.

**4.2.2 Material used for cylindrical bearing is composite materials (HS Carbon/Epoxy):**

- Longitudinal Modulus ($E_z$): 134 GPa
- Transverse Modulus ($E_y$): 70 GPa
- Shear modulus ($G_{xy}$ ): 5 GPa
- Shear modulus ($G_{yz}$ ): 5 GPa
- Shear modulus ($G_{xz}$ ): 5 GPa
- Poisson's Ratio: 0.11
- Density: 1600 Kg/m$^3$

Ply orientation: -45$^o$, 0$^o$, 0$^o$, 45$^o$
Yield strength: 300 MPa
Element Types used:
Name of the Element: SOLID 46
Number of Nodes: 10
DOF: UX, UY & UZ

**Boundary Conditions:**

- A radial force of 10000 N is applied on centre of cylindrical bearing.
- The sides of cylindrical bearing are constrained in all dof.

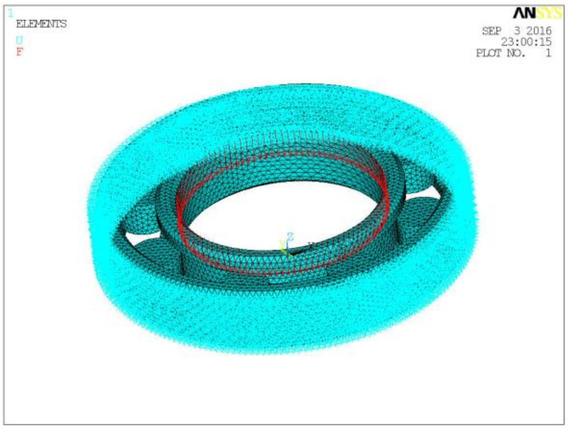


**Figure 11:** Applied boundary conditions of cylindrical bearing

**Deflections**

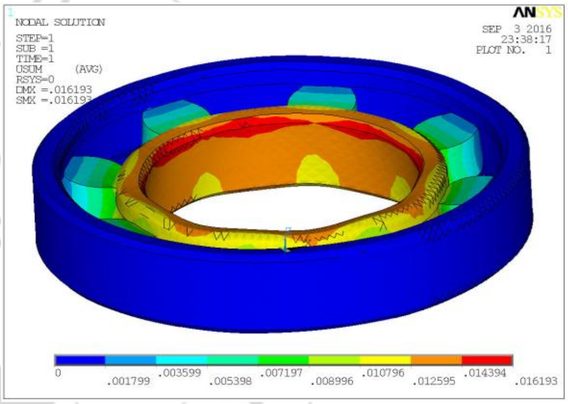


**Figure 12:** Resultant displacement of cylindrical bearing

**STRESS**

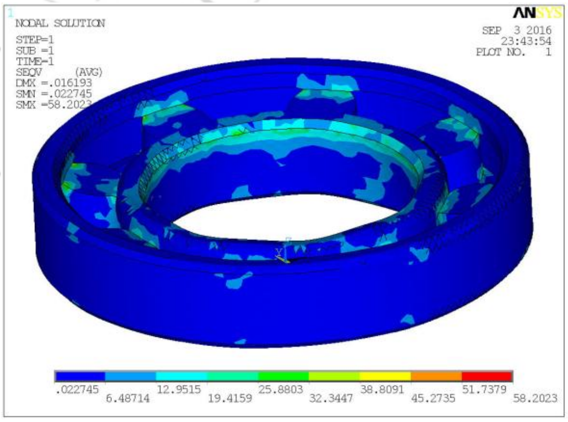


**Figure 13:** Von mises Stress formed on cylindrical bearing

From static analysis results for HS Carbon/epoxy, the resultant displacement found on cylindrical bearing is 0.0161 mm. The Von misses stress formed on cylindrical bearing is 58.202MPa. The yield strength of HS Carbon/Epoxy material is 800 MPa. The Von mises stress of cylindrical bearing was 92.72 % less than the yield strength of the material. Hence the cylindrical bearing was safe in design for static conditions.

## 5. Contact Analysis of Cylindrical Bearing

### 5.1 Contact Analysis of Cylindrical Bearing Using Steel Material

Material Properties:
Young's Modulus: 200 GPa
Poisson's Ratio: 0.3
Density: 7850 Kg/m3
Yield strength: 300 MPa

Element Types used:
Name of the Element: SOLID 92
Number of Nodes: 10
DOF: UX, UY & UZ


**Figure 14:** Boundary conditions applied to cylindrical bearing

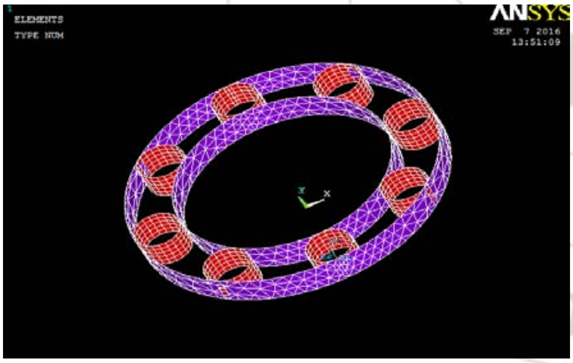


**Figure 15:** Contact region between rollers and races

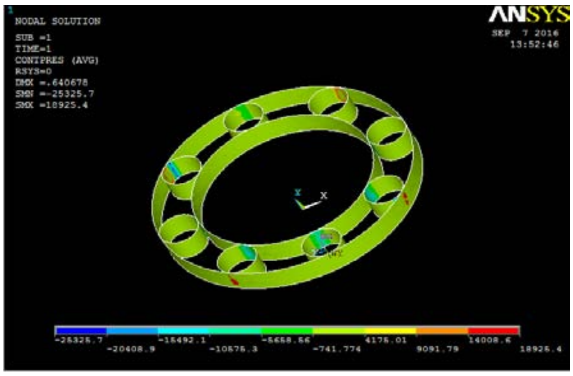


**Figure 16:** Contact pressure formed on cylindrical bearing

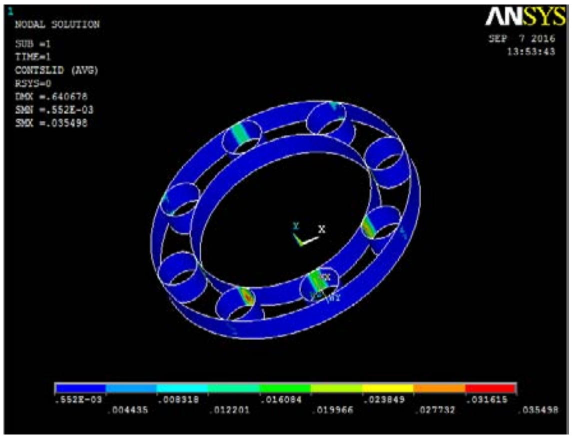


**Figure 17:** Contact sliding distance between rollers and races

### 5.2 Contact Analysis of Cylindrical bearing Using HS Carbon/Epoxy Material


**Figure 18:** Boundary conditions applied to cylindrical bearing

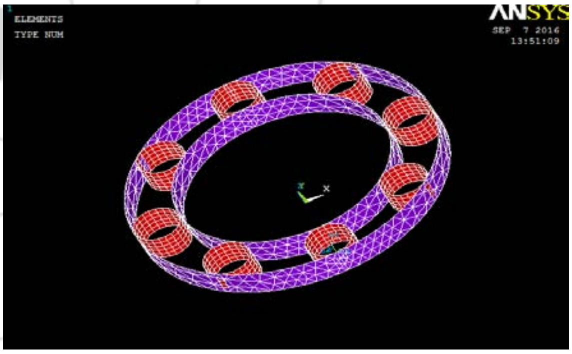


**Figure 19:** Contact region between rollers and races

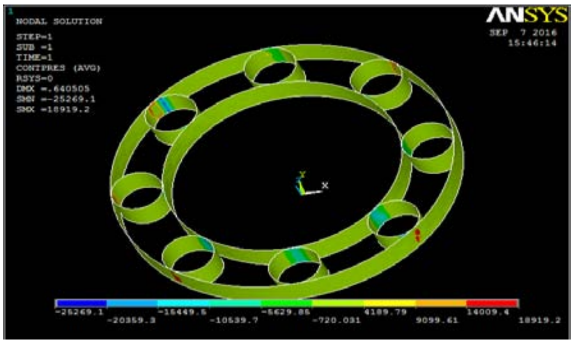


**Figure 20:** Contact pressure formed on cylindrical bearing

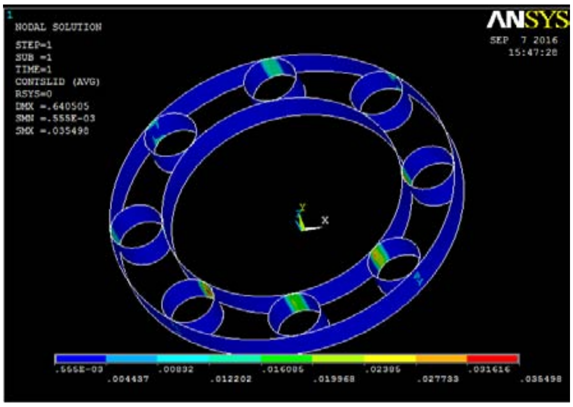

**Figure 21:** Contact sliding distance between rollers and races

### 5.3 Contact Analysis of Cylindrical Bearing Using Hm Carbon/Epoxy Material

**Figure 21:** Boundary conditions applied to cylindrical bearing

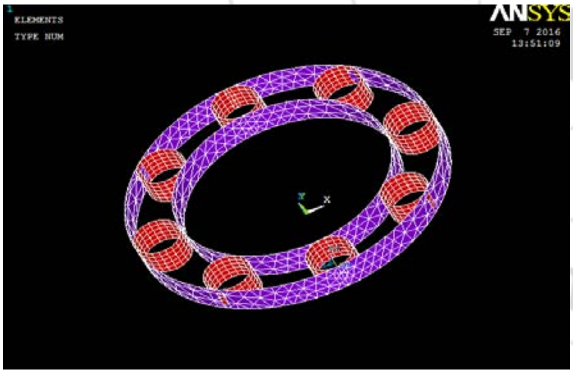

**Figure 22:** Contact region between rollers and races

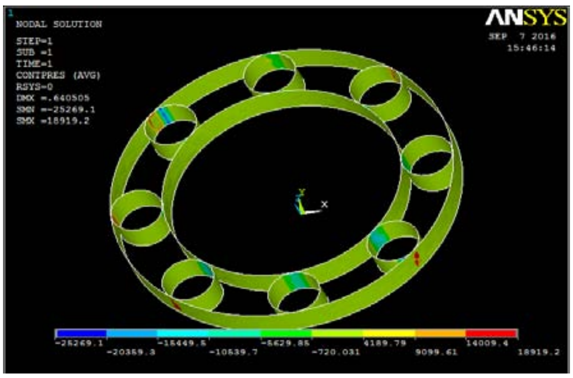

**Figure 23:** Contact pressure formed on cylindrical bearing

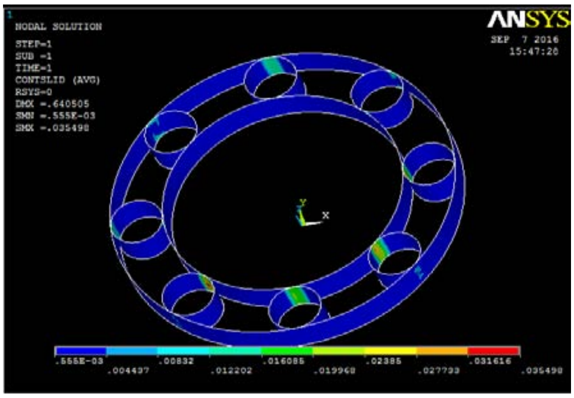

**Figure 24:** Contact sliding distance between rollers and races

## 6. Results

Results absorbed from static and contact analysis of cylindrical roller by using different materials are given below.

| | Steel Material | HM Carbon/ EPOXY | HS Carbon/ EPOXY |
|---|---|---|---|
| Deflection | 0.0105 mm | 0.0131 mm | 0.0161 mm |
| Von mises stress | 106.506 MPa | 61.271 MPa | 58.202 MPa |
| Ply angle | - | $-45^0,0^0,0^0,45^0$ | $-45^0,0^0,0^0,45^0$ |
| Friction coefficient | 0.33 | 0.11 | 0.1 |
| Sliding Contact distance | 0.03549 mm | 0.03548 mm | 0.03548 mm |
| Contact Pressure | 18925.4 Pa | 18919.19 Pa | 18919.19 Pa |

## 7. Conclusion

From the results in both static analysis and contact analysis of cylindrical bearing by using different types of materials, HS Carbon/Epoxy material have less ratio of von mises strength to yield strength and also have less contact pressure values comparing to steel and HM Carbon/Epoxy materials. Design of cylindrical bearing was under safe conditions when it should be made by HS Carbon/Epoxy.

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