Design And Analysis Of Contact Between Fiber Reinforced Polymer (Frp) Races And Cylindrical Roller Bearing Due To Frictional Motion

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Abstract- *The purpose of the bearing is to constraint relative motion between moving parts to only desired motion. The design of bearing provides free linear movement of the moving part or free rotation around a fixed axis, or it may prevent a motion by controlling the vectors of regular forces that bear on the moving parts. Cylindrical roller bearing carries heavy radial loads. These are more suitable for low coefficient of friction and less frictional loss in the high-speed application. By this reason, more noise is generated by the cylindrical bearing. The materials which suit for bearing will result in Optimization of noise, design calculation of cylindrical bearing and the radial force acting on it. Fiber-Reinforced Polymer is a composite material made of a polymer matrix reinforced with fibres. The fibres are usually glass, carbon, or aramid, although other fibres such as paper or wood or asbestos have sometimes used. Fibers play a significant role in self-lubrication and noise reduction in the cylindrical bearing. Optimization of contact pressure between the Polymer and cylindrical bearing is used for noise reduction.*

This works deals with the design of cylindrical bearing based on radial force acting on bearing. Also, estimate the life of the cylindrical bearing. To evaluate the stresses and deflections developed on cylindrical bearing using different types of materials (i.e., Steel, HM Carbon/ Epoxy, HS Carbon/Epoxy) in Finite Element Analysis. The project includes the determination of the influence of fibre and matrix material combinations, frictional coefficient and fibre ply orientation on the contact pressure distribution and the contact area between the FRP and cylindrical bearings. Sliding contact between FRP and cylindrical bearing did by using FEM software. Also, NX CAD software is used for designing of cylindrical bearing, and Contact Analysis was done in Ansys11.0 software.

I. INTRODUCTION

1. BEARING

Bearings are components which are designed to connect machine parts. Bearings transmit forces and motion, are usually mounted on axles or shafts and inserted in housings. If a bearing transmits rotary motion, it is called a rotary bearing. For longitudinal motion, linear bearings are used. Plain bearings from rolling bearings are distinguished by the type of friction involved.

These components are with a sliding layer between two parts. This sliding layer may be a solid layer that is fixed to the bearing, such as bronze layers or plastic. Otherwise, a lubricating film separates the surfaces. Rolling bearings are bearings designed with two components which tend to move in opposite directions. These parts are the inner and outer ring, and they are separated by rolling elements. While the mechanism is going on, the rolling elements tend to roll between the two rings. This is observed on the surfaces of hardened steel called raceways. The generated friction is significantly lower compared to plain bearings. Rolling elements are the most important parts of a bearing because they carry most of the loads. Rolling elements come in different shapes: balls, cylindrical rollers, needle rollers, tapered rollers or spherical rollers. The names of many bearing types are based on the kind of rolling element used, such as "needle roller bearing" or "ball bearing". In modern designing of bearings, a cage is used to provide even spacing for the rolling elements. This prevents them from contacting each other. Cages can be made from sheet steel, plastic or brass. Additional components may be seals or sealing shields. The lubricant is another important part of a bearing. Rolling bearings are lubricated with oil or grease to extend operating life. The seal keeps the lubricant in the bearing and prevents dirt and moisture from entering.

COMPOSITE MATERIALS

A composite material is a mixture of two or more materials – often ones that have very different properties. The two materials work together to give the unique composite properties. The biggest advantage of modern composite materials is that they are light in weight as well as strong. By choosing a suitable combination of matrix and reinforcement material, a new material can be introduced which exactly meets the requirements of a particular application. Composites also provide design flexibility because many of them can be moulded into complex shapes. The downside is often the cost. The end product is considerably more efficient; the raw materials are often expensive. Composite material a combination of a matrix and reinforcement, which when combined gives properties superior to the properties of the individual components. In the case of a composite, the reinforcement is the fibres and is used to fortify the matrix regarding stiffness and strength. The reinforcement fibres can be cut, aligned, placed in different ways to affect the properties of the resulting composite. The matrix, normally a form of resin, keeps the reinforcement in the desired orientation. It protects the reinforcement from chemical and environmental attack, and it bonds the reinforcement so that applied loads can be effectively transferred.

TYPE OF COMPOSITES

The term ‘composite' can be used for a multitude of materials. Composites UK uses the term composite, or reinforced polymers to encompass:

1) Carbon fibre-reinforced polymers (CFRP)
2) Glass fibre- reinforced polymers (GFRP)
3) Aramid products (e.g. Kevlar)
4) Bio-derived polymers (or bio-composites)

II. LITERATURE REVIEW

Prasanna Subbarao Bhamidipati has written a title on "FEA ANALYSIS OF NOVEL DESIGN OF CYLINDRICAL ROLLER BEARING" and explained that When a bearing is properly designed, manufactured, installed, and maintained, then the natural cause of bearing failure is typically the fatigue life of its rolling elements and races. The environment within the bearing operates and also determines the bearing life. The contact stresses developed in the rolling elements and races of a typical bearing is cyclic. This, in turn, will result in a potential fatigue failure of these elements. The fatigue life a bearing is influenced by the operating speed, load conditions, bearing material, clearance of the mating parts, contact surface geometry, and the environment in which the bearing operates.

R. J. Kleckner J. Pirvics have published a paper on "HIGH-SPEED CYLINDRICAL RO LLER BEARING ANALYS IS". This paper presents that Engine shaft speeds will be increased, to derive greater compressor efficiency. Increased speeds, 1j.owever, accentuate centrifugal effects. Dominance in Raceway loading is transformed from inner to outer rings. Failure to maintain loaded contact on the inner ring across this spectrum of operating speeds results in the increased hazard of roller skidding, unnecessary heat generation and unstable performance. Combined with increased shaft diameters, required by system stiffnE1ss, increased speed raises questions beyond the limits of currently available bearing design analysis.

B. Ramu, V. V. R. Murthy has published a project entitled "Contact Analysis of Cylindrical Roller Bearing Using Different Roller Profiles". According to this, to carry heavy radial loads cylindrical roller bearings are designed, but due to misalignment and edge loading, it is affecting the life of the bearing. So the designing of cylindrical roller bearings, the profile of the roller plays an important role. Stress analysis is done based on two-dimensional models of the roller and raceways. The roller profiles analyzed are flat, circular and logarithmic, which is loaded against two flat raceways.

Gautam Mukhopadhyay, S. Bhattacharya has published a journal on “Failure Analysis of a Cylindrical Roller Bearing from a Rolling Mill". According to this project, premature failure of a cylindrical roller bearing of a gearbox input shaft from a hot strip mill has been investigated. The pins of the cylindrical rollers of the bearing broke from the welded joints at their ends on the cage ring. Investigations were performed on the failed the welded joint and roller pin. The investigation includes visual observation, chemical analysis, and characterization of macro- and micro-structures, measurement of hardness profile, fractography, and energy dispersive spectroscopy (EDS).

III. PROBLEM DEFINITION AND METHODOLOGY

PROBLEM DEFINITION

Cylindrical roller bearing carries heavy radial loads. These rollers are suited for low coefficient of friction and less frictional loss in the high-speed application. Due to this, it results in more noise is generated by this cylindrical bearing. Optimization of noise depends on materials suited for bearing, design calculation of cylindrical bearing and radial force acting on it. FRP is a composite material that is made of a polymer matrix reinforced with fibres. The fibres are usually carbon, glass, or aramid, although other fibres such as paper or wood or asbestos have sometimes been used. Fibers play a significant role in self-lubrication and noise reduction in the cylindrical bearing. Noise reduction is achieved by

Optimization of contact pressure between FRP and cylindrical bearing.

This works deals with the design of cylindrical bearing based on radial force acting on bearing. Also, estimate the life of the cylindrical bearing. The project also includes the determination of the influence of fibre and matrix material combinations, frictional coefficient and fibre ply orientation on the contact pressure distribution and the contact area between the FRP and cylindrical bearings. Sliding contact between FRP and cylindrical bearing did use FEM software. Also, NX CAD software is used for designing of cylindrical bearing, and Contact Analysis is carried out in Ansys11.0 software.

METHODOLOGY

Modeling of cylindrical roller bearing will pass through NX CAD software based on radial force acting on it. Life rating of cylindrical roller bearing will be calculated. Designed cylindrical roller bearing was imported in Ansys11.0 software.

Finite element analysis of cylindrical roller bearing passes through Ansys11.0 software with conventional steel material and also with different composite materials like HM carbon/Epoxy, HS Carbon/Epoxy for the radial load.

A static and contact analysis of cylindrical roller bearing is done with the help of Ansys11.0 software for different composite materials with different layer orientation to calculate deflections, stresses and contact pressure of the front cylindrical roller bearing. Results obtained from the analysis are compared, and the best material is proposed based on the ratio of resultant (Von Mises) strength to yield strength and contact pressure.

IV. LIFE ESTIMATION OF CYLINDRICAL BEARING 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) = CrP0r103*106 revolutions
= 4067.09 million revolutions
Operating hours (L10h) = CrP0r103*10660*N
= 12100010000103*10660*5000
= 13556.979 hours

V. MODELING OF CYLINDRICAL BEARING

2D sketch and 3D model of cylindrical bearing are done by using Unigraphics software-based on the input. Below image shows 3D modelling of the cylindrical bearing.

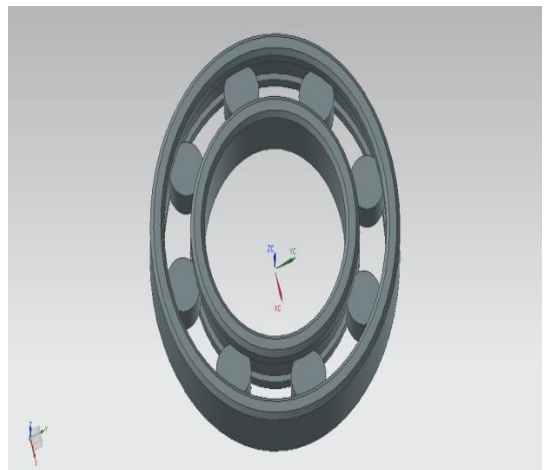

Figure 1. 3D model of cylindrical bearing

VI. FINITE ELEMENT ANALYSIS OF CYLINDRICAL BEARING

DESCRIPTION

Finite Element Modelling (FEM) and Finite Element Analysis (FEA) are two most popular mechanical engineering applications offered by existing CAE systems. This is attributed that the FEM is perhaps the most popular numerical technique for solving engineering problems. The method is general enough to handle any complex shape of geometry (problem domain), any material properties, any boundary conditions and any loading conditions. The generality of the FEM fits the analysis requirements of today's complex engineering systems, and designs, where closed form solutions are governing equilibrium equations, are not available. Besides it is an efficient design tool by which designers can perform parametric design studying various cases (different shapes, material loads etc.) analyzing them and choosing the optimum design.

FINITE ELEMENT METHOD

The FEM is numerical analysis technique for obtaining approximate solutions to wide variety of engineering problems. The methods originated in the aerospace industry as a tool to study stresses in complicated airframe structures. It grew out of what was called the matrix analysis method used in aircraft design. The method has gained popularity among both researchers and practitioners and after so many developments codes are developed for a wide variety of problems.

Structural analysis of cylindrical bearing

The structural analysis comprises the set of physical laws and mathematics required to study and predicts the behaviour of structures. The subjects of structural analysis are engineering artifacts whose integrity is judged largely based upon their ability to withstand loads; they commonly include buildings, bridges, aircraft, and ships. The structural analysis incorporates the fields of mechanics and dynamics as well as the many failure theories. From a theoretical perspective, the primary goal of the structural analysis is the computation of deformations, internal forces, and stresses. In practice, structural analysis can be viewed more abstractly as a method to drive the engineering design process or prove the soundness of a design without dependence on directly testing it.

METHODS OF PERFORMING STRUCTURAL ANALYSIS

To perform an accurate analysis, a structural engineer must determine such information as structural loads, geometry, support conditions, and materials properties. The results of such an analysis typically include support reactions, stresses and displacements. This information is then compared to criteria that indicate the conditions of failure. The advanced structural analysis may examine dynamic response, stability and nonlinear behavior.

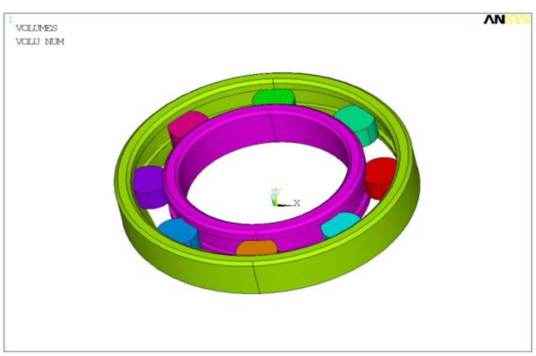

Figure 2. Geometric model of the cylindrical bearing

MATERIAL PROPERTIES

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

Figure 3. Meshed model of cylindrical bearing

RESULTS

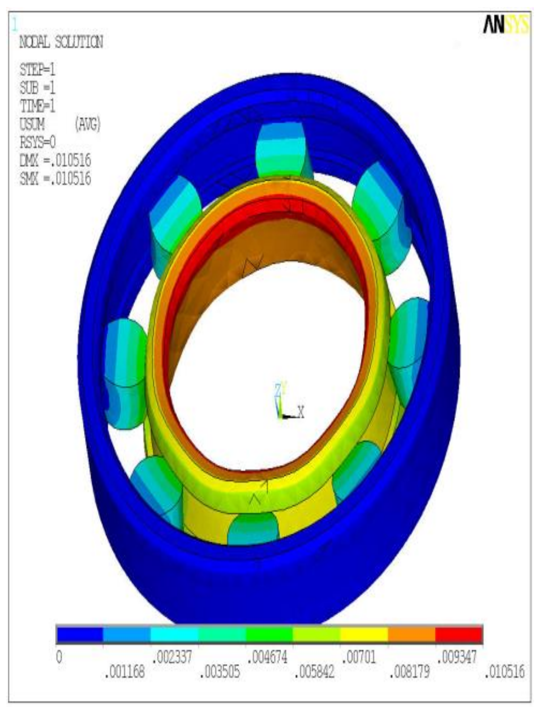

Figure 4. Resultant displacement of cylindrical bearing

Stress

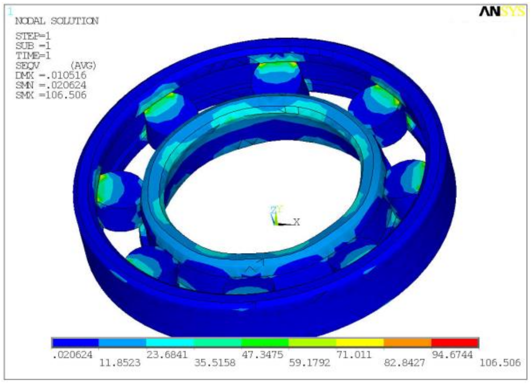

Figure 5. Von Mises Stress formed on cylindrical bearing

From static analysis results for 'steel material', the resultant displacement found on the cylindrical bearing is 0.0105 mm. The Von misses stress formed on the cylindrical bearing is 106.506 Mpa. The yield strength of steel is 300 MPa. The Von Mises stress of cylindrical bearing is 64.5 % less when compared to yield strength of the material. Hence the cylindrical bearing is safe in design for static conditions.

STATIC ANALYSIS OF COMPOSITE MATERIALS USED FOR CYLINDRICAL BEARING

Material used for cylindrical bearing is made of composite (hm carbon/epoxy)

Longitudinal Modulus (EZ)	190 GPa
Transverse Modulus (EY)	7.7 GPa
Shear modulus (Gxy)	4.2 GPa
Shear modulus (Gyz)	4.2 GPa
Shear modulus (Gxz)	4.2 GPa
Poisson's Ratio	0.3
Density	1600 Kg/m3
Ply orientation	-45o, 0o, 0o, 45o
Yield strength	800 Mpa

Ply-angle/ ply orientation

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

Element Types used

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

Figure 6. Shows the meshed model of cylindrical bearing

RESULTS

DEFLECTIONS

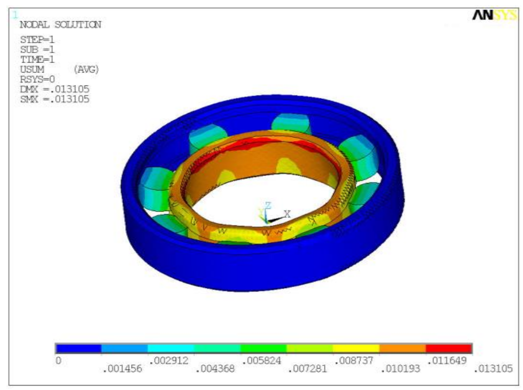

Figure 7. Resultant displacement of the cylindrical bearing Stress

Stress

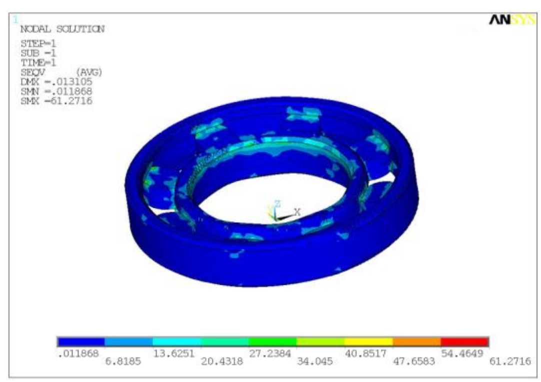

Figure 8. Von Misses Stress formed on cylindrical bearing

From static analysis 'results for HM Carbon/epoxy', the resultant displacement found on the cylindrical bearing is 0.0131 mm. The Von misses stress formed on the cylindrical bearing is 61.2716MPa. The yield strength of HM

Carbon/Epoxy material is 800 MPa. The Von Mises stress of cylindrical bearing is 92.34 % less when compared to yield strength of the considering material. Hence the cylindrical bearing is safe concerning design for static conditions.

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

Longitudinal Modulus (EZ)	134 GPa
Transverse Modulus (EY)	70 GPa
Shear modulus (Gxy)	5 GPa
Shear modulus (Gyz)	5 GPa
Shear modulus (Gxz)	5 GPa
Poisson's Ratio	0.11
Density:	1600 Kg/m3
Ply orientation	-45o, 0o, 0o, 45o
Yield strength	300 MPa

Element Types used

Name of the Element: SOLID 46
Number of Nodes: 10
DOF: UX, UY & UZ

Figure 9. Shows the meshed model of cylindrical bearing

RESULTS

DEFLECTIONS

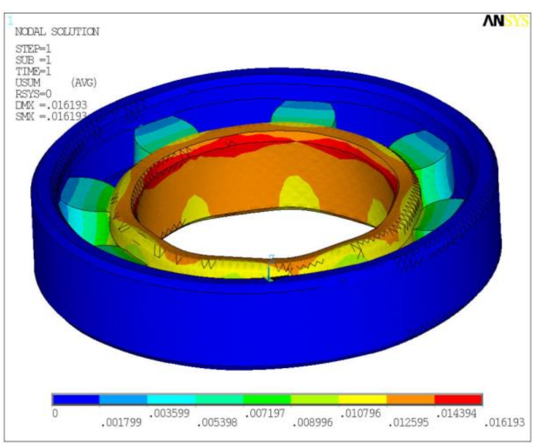

Figure 10. Resultant displacement of the cylindrical bearing Stresses

STRESS

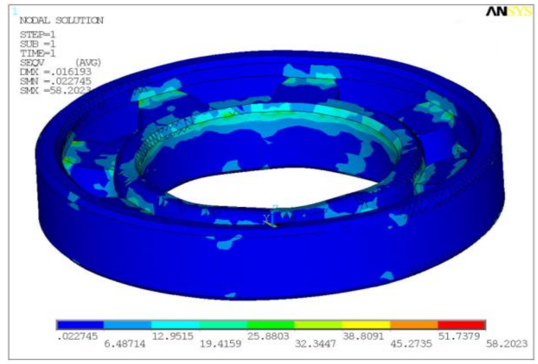

Figure 11. Von Mises Stress formed on cylindrical bearing

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

VII. CONTACT ANALYSIS OF CYLINDRICAL BEARING

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

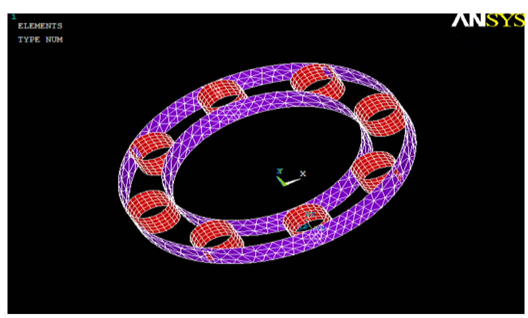

Figure 12. Contact region between rollers and races

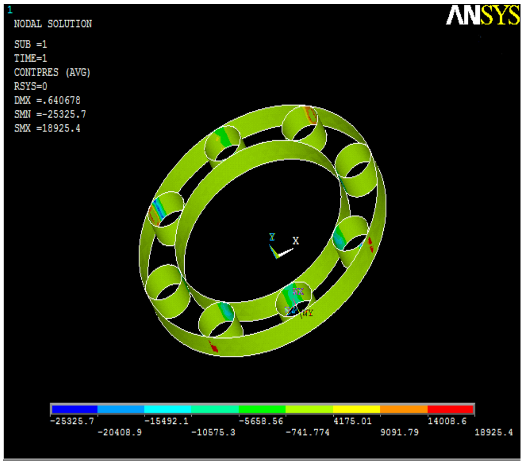

Figure 13. Contact pressure formed on cylindrical bearing

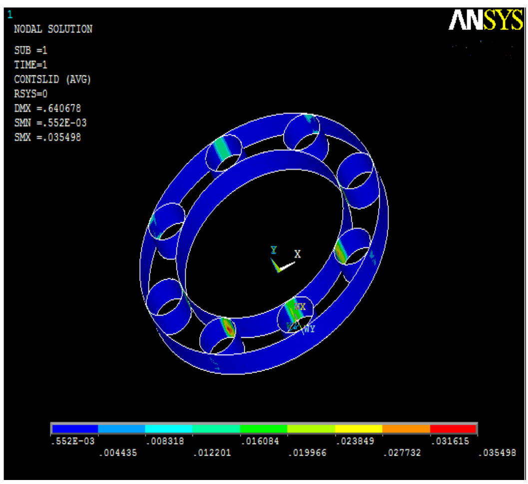

Figure 14. Contact sliding distance between rollers and races

CONTACT ANALYSIS OF CYLINDRICAL BEARING USING HS CARBON/EPOXY MATERIAL

Material Properties

Longitudinal Modulus (EZ)	134 GPa
Transverse Modulus (EY)	70 GPa
Shear modulus (Gxy)	5 GPa
Shear modulus (Gyz)	5 GPa
Shear modulus (Gxz)	5 GPa
Poisson's Ratio	0.11
Density	1600 Kg/m3
Ply orientation	-45o, 0o, 0o, 45o
Yield strength	300 MPa

Element Types used

Name of the Element	SOLID 186
Number of Nodes	20
DOF	UX, UY & UZ

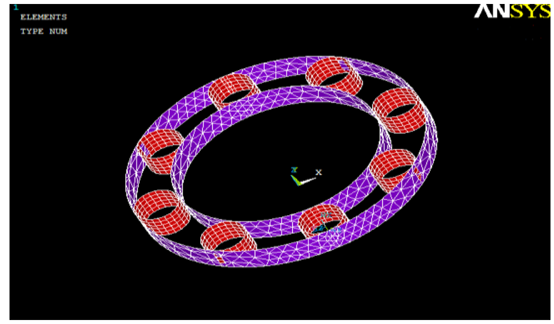

Figure 15. Contact region between rollers and races

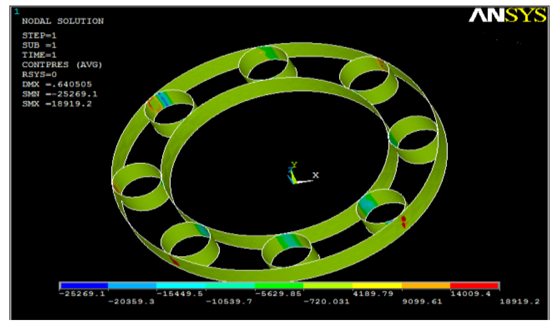

Figure 16. Contact pressure formed on cylindrical bearing

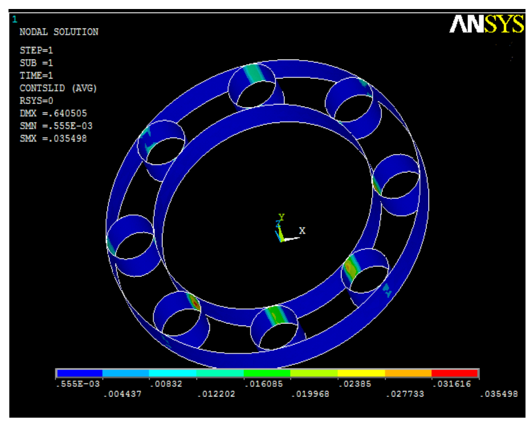

Figure 17. Contact sliding distance between rollers and races

CONTACT ANALYSIS OF CYLINDRICAL BEARING USING HM CARBON/EPOXY MATERIAL

Material Properties

Longitudinal Modulus (EZ)	190 GPa
Transverse Modulus (EY)	7.7 GPa
Shear modulus (Gxy)	4.2 GPa
Shear modulus (Gyz)	4.2 GPa
Shear modulus (Gxz)	4.2 GPa
Poisson's Ratio	0.3
Density	1600 Kg/m3
Ply orientation	-45o, 0o, 0o, 45o
Yield strength	800 Mpa

Element Types used

Name of the Element	SOLID 186
Number of Nodes	20
DOF	UX, UY & UZ

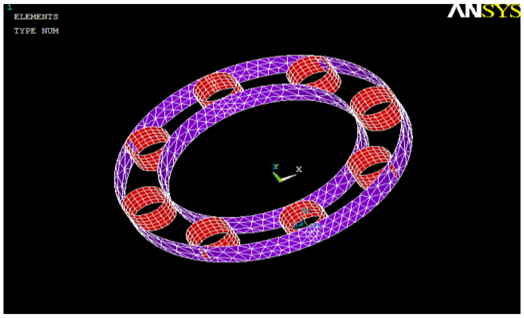

Figure 18. Contact region between rollers and races

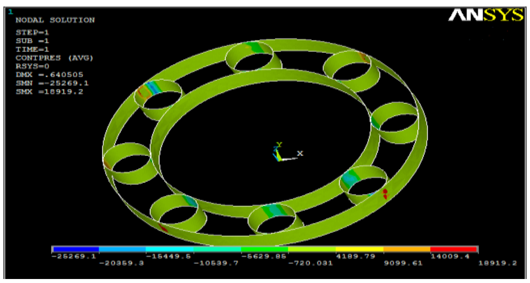

Figure 19. Contact pressure formed on cylindrical bearing

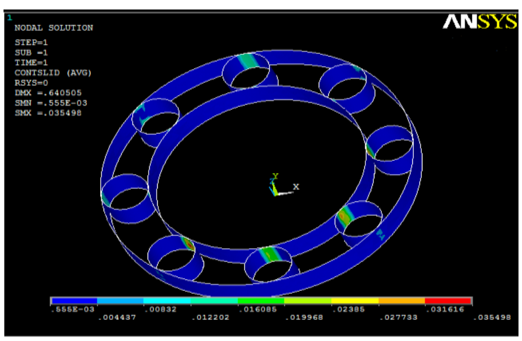

Figure 20. Contact sliding distance between rollers and races

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

Table 1.

	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

VIII. RESULTS AND CONCLUSION

From the results of both static analysis and contact analysis of cylindrical bearing by using different materials, HS Carbon/Epoxy material has less ratio of Von Mises strength to yield strength, and they have less contact pressure values comparing to steel and HM Carbon/Epoxy materials.

The design of cylindrical bearing was under safe conditions when it should be made by HS Carbon/Epoxy.

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