SVU-International Journal of Engineering Sciences and Applications (2024) 5(2): 109-118
Print ISSN 2785-9967 | Online ISSN 2735-4571
DOI 10.21608/svusrc.2024.252828.1167

Finite Element Analysis for Cylindrical and Balling Bearings Under Static and Dynamic Loads A-review paper

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Abstract The ball bearing is a mechanical gearbox's most important component. It connects the roller to the inner and outer rings and hangs from the rotator to support the revolving parts. This technique allows for the transmission of both electricity and motion. In this paper, rolling bearings are commonly used to reduce rotational motion friction. The parts include rings, folding pieces, and cages. A ball bearing is made up of solid, spherical balls that rotate between two surfaces and reduce friction. A ball bearing's main functions are to support radial and axial loads and to lessen rotational friction. In this work, emphasis has been given to the design of bearings based on variables such as bore diameter, depth, and load ratings for both dynamic and static loads. A three-dimensional model of the ball bearing was created using CATIA. High-stress regions were identified, and design modifications were recommended if appropriate. because to determine bearing life, rotational speed and load parameters are also used.

Key word: Ball bearing, Static load, Dynamic load, Finite element.

1 Introduction

Electric motors, generators, pumps, compressors, turbines, and turbine blades typically employ conventional bearings. A sphere is made up of two spheres that revolve relative to one another.

Received: 3 December 2023/ Accepted: 24 February 2024

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The outer ring is upright, as the inner ring revolves at a speed. The transmission's main job is to maintain the rotating machine while supplying enough lubricant to isolate the moving parts and reduce friction. The change in the hydrodynamic film's capacity to lubricate causes a greater pressure of fluid to be produced during the race. The axis that revolves from the center is referred to as a rotating shaft. The dependability and safety of the entire mechanical system are directly impacted by the performance structure of the ball. Additionally, carrying the ball puts a vulnerable body region at risk for harm. Ball bearing failure makes up around 30% of machine failures, according to statistics. As a result, the stiffness, contact stress, and deformation of the soccer ball significantly impeded engineering research. Understanding the relationship between rotation and the inner or outer thread when learning about ball bearings can be challenging. It is a point contact with no load, and the contact area extends to the cabinet in the shape of an ellipse. The size of the applied load has an impact on the indirect contact problems of shape, size, contact pressure, and friction coefficient of the contact surface. The commercial FEM (Finite Element Analysis) program, ANSYS Workbench, is used in the research to construct its 3D finite element model, which uses the example of deep groove ball bearings. This offers a foundation for the analysis and calculation of contact stress and deformation, which supports the design and optimization of deep-seated structures.

2 Contact Bearing Rolling

The finite element technique is a useful tool for finding numerical solutions to a variety of design problems. The process is sufficiently flexible to accommodate any object with peculiar geometry, constraints, or overlapping requirements. The full specification of the finite element approach suits the testing requirements of today's complex buildings and structures, where closed-loop control of the balance conditions is frequently not possible. Additionally, it is a helpful planning tool that enables designers of clothing to create parametric structures by considering a variety of planning situations (such as different shapes, materials, loads, etc.) and analyzing them to determine which plan is ideal[1].

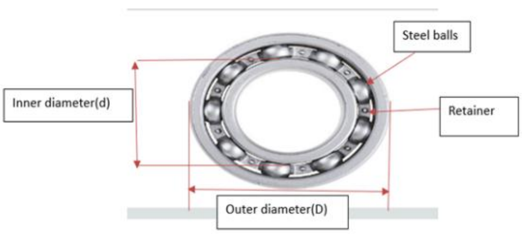

Fig. 1 show the details of ball bearing shape [1].

A bearing's inner ring load and the stresses observed on the outside ring are analyzed in connection to one another. Under various loading scenarios, a linear relationship is confirmed. To gather data on the bearing's outer ring's strain, a cylindrical rolling element bearing with 11 rollers underwent a finite element analysis in ANSYS. a bearing's inner ring is subjected to changing and static loads. The radial load placed on the inner ring and the strains accumulated on the outer ring are linearly related.

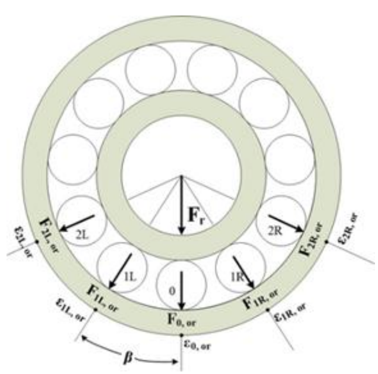

Fig. 2 shows the load distribution on a cylindrical roller bearing's rollers [1].

3 Literature review

Xin Wang, Xihui Liang, et al.(2022) mentioned in this study for examines and validates the linear relationship between the strain accumulated on the outer ring's exterior surface and the radial load applied to the bearing's inner ring. The outside wall of the outer ring is where the strain data are gathered. These spots are located in the middle of the straight lines that run parallel to the contact lines between the rollers and the inner wall of the outer ring on the outer wall of the outer ring. Under static radial load, sinusoid varying load with a low variation frequency (2 Hz), and sinusoid varying load with a high variation frequency (100 Hz), the linear coefficient k value is calculated in the simulation studies. [2].

Duo He,Yang Yang,Hongyang Xu,et al. They emphasized in their research that to diagnose machine faults, it is important to analyze the dynamic characteristics of the damaged bearing. There aren't many studies currently being done on numerical modeling of bearings with damaged rollers. This work uses the explicit finite element approach to create a nonlinear dynamic model of the cylindrical roller bearing with roller spalling faults in order to address this issue. The proposed model takes into account the flexibility of each component, internal friction, relative sliding, the finite size of the roller, and the contact force between the rollers and cage. The suggested dynamic model is then theoretically and experimentally confirmed. Based on the suggested numerical model, the bearing's vibration responses as well as the damaged roller and cage's sliding behavior are investigated

The findings indicate that when a roller defect occurs, increased roller to cage contact force, and increased roller to cage contact force. Additionally, the increased number of defective rollers and the increase in defect width will make the cage slide and the bearing vibrate more. [3], [4].

Firdous Zia, Gouraw Beohar , An integrated shaft bearing that is typical of its kind has been modeled, as well as its surroundings. The research was carried out utilizing the well-known finite element tool. The strains in a bearing system can be examined using ANSYS.. In order to examine the impact of integrated shaft bearing structural performance on bearing clearances and vice versa, we looked into it in this study.

Table 1 Results [5].

Condition of baring system	Equivalent Stress (MPa)	Total Deformation (mm)	Frictional Stress (MPa)	Contact Pressure (MPa)
Healthy	**0.6478**	**0.00139**	**0.0477**	**0.8258**
Shaft defect	**0.8202**	**0.00138**	**0.04591**	**0.9275**
Hub defect	**0.7966**	**0.00130**	**0.07691**	**0.7954**

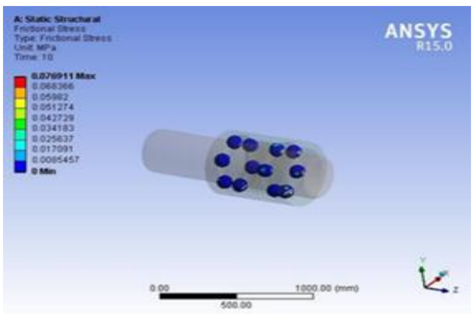

Fig. 3 Shows the results [5].

It can be seen from the structural analysis that the model is within safe design bounds. A healthy integral bearing is compared to a bearing with a shaft defect and a hub defect for the analysis. In contrast to frictional stress, which is lower, deformation, which is higher, and contact pressure, which is higher, equivalent stress is high for the bearing with a shaft defect. Thus, it can be seen that the bearing with the shaft flaw results in significant damage when the bearings are in operation. [5].

M. Raju1, S.Thiagarajan, D. Peter Pushpanathan, et al.(2021) In their research project, they used finite element analysis of a single-row deep groove ball bearing SKF6205 under radial and axial loads to evaluate the stress variation and displacement characteristics. Three criteria are used to evaluate the vibration analyses: static, modal, and harmonic analysis. The simulations demonstrate how the bearing's stress levels vary under various loads. These findings are applied to forecast the ball bearing's fatigue life, wear rate, and productivity under various stochastic scenarios. There has been an attempt in this work to choose the right of bearing's kind for a typical electrical motor with a medium speed. Deep-groove ball bearings of sizing and kind 6312 are the bearings that are employed. Solid works software was used to generate a three-dimensional model. Actual life is substantially higher than the calculated life of 284.94 x 103 hours; it is in the range of 106 cycles. Bearings are therefore secure for the specified load [6].

A. O. Köhn and F. de A. Silva, et al.(2020) They proposed Hertz's theory of contact surfaces as a means of studying the interaction between a sphere and a flat plate analytically. It was also suggested to use Inventor and Nastran in-CAD software to implement a numerical technique through a FEM model. Both methods yielded compressive normal stresses, and the surface of the bodies was where they were greatest. These tensions rapidly dropped until they were zero as the depth increased. Therefore, it may be inferred that the little area immediately surrounding the contact vertex is the only one impacted by contact stresses. Both methods produced satisfactory results. Shear stresses, which are the most important for the development of cracks, were obtained using both approaches, notwithstanding the divergence in results for the normal stress perpendicular to the contact plane. [7], [8].

A V BORGAONKAR, SYED, and colleagues (2020) So as to fully understand the topic, This paper has reviewed how different input parameters affect the RCF's life and tribological performance of coated rolling and sliding contact components. It has been discovered that both technical and financial considerations must go into the coating deposition process. In comparison to other procedures, the thermal spraying technique is the most affordable and offers better bonding strength, which lengthens the RCF's life. The impact of additional input factors has also been examined, and potential input parameter combinations that enhance the performance of coated contacting parts have been outlined. [9]. [10].

Linkai Niu, Hongrui Cao, et al. (2020) For rolling element bearings (REBs), a improved comprehension of a bearing's vibration characteristics is essential. The vibration reactions of a cylindrical roller bearing when a roller flaw travels across the outer and inner races are examined in the current work. The first step was to conduct an experiment, and the results were used to talk about the many impulses that are produced as a rolling flaw travels regarding a race. [11].

Y Siva krishna,Y Rajesh Kumar(2019) The rolling bearings typically employed to lower friction in rotary motion are discussed in this study. The component pieces are a cage, rolling elements, and bearing rings.

Hardened, spherical balls that spin between two surfaces to reduce friction make up a ball bearing. The primary purposes of a ball bearing are to support radial and axial loads as well as to reduce rotational friction. dependent on factors such as bore diameter, depth, and load ratings for both dynamic and static loads, The high stress areas were located, and if necessary, design modifications were suggested. On the basis of the rotational speed and load parameters, the bearing life was also determined. Results for the radial ball bearing under axial load and radial load applied conditions are described in terms of maximum displacement and maximum VonMises stress. The ball bearing's lifespan was also computed under conditions of applied axial and radial loads[12].

Mustafa Koç, Mehmet Bozca(2019) In this study, they used analytical and numerical methods to confirm the contact stress in rotary bearings. Hertizan contact theory is employed to provide an analytical solution. To achieve more precise findings for contact problems, it is necessary to compare the analytical solution provided by this theory with the numerical computations. As a result, the finite element method is also used to explore the same issues. Different types of contact configurations, such as a point or line of touch, are possible due to the geometry of the model under study. Line contact is the preferred contact type for cylindrical roller bearings, while point contact is the preferred contact type for ball bearings. Both of these two places of contact experience high stress. Depending on how much contact stress is there, the contact region will flex either elastically or plastically. Therefore, it is crucial to determine the stress at the contact area with greater accuracy. Von Misses equivalent stress is written as follows:

$$Vm = \frac{1}{\sqrt{2}}\sqrt{(\text{Б}_x - \text{Б}\mathbf{y})^2 + (\text{Б}\mathbf{y} - \text{Б}\mathbf{z})^2 + (\text{Б}\mathbf{z} - \text{Б}\mathbf{x})^2 + \mathbf{6}(\boldsymbol{\tau}\mathbf{xy}^2 + \boldsymbol{\tau}\mathbf{yz}^2 + \boldsymbol{\tau}\mathbf{xz}^2)^2} \quad (1)$$

where the judgment was reached The ANSYS workbench environment is used to simulate the numerical analysis of the rolling bearing contact problem. As a result, a 3D model is used to analyze the contact stresses for point and line contact types. Both of these problems are non-linear in ball bearing applications because the contact area has an elliptical geometry and the contact form is dependent on the applied force. Analytical theory makes numerous assumptions as a result. Reliability and load capacity of bearings are crucial. Because of this, rolling bearings are crucial machine components. A bearing's life calculation becomes even more crucial when done with great accuracy. Making it possible to align the bearing life with the machine's service life [13].

Zhang L, Xu H, and other,(2019) In this work, bearing with capable of adjustment Rounded clearance is suggested. A variable bearing's structure and operating principles are introduced. By altering the radial clearance, this movable bearing can modify its dynamic properties. In this research, the vibration response of the rotor system is investigated using a straightforward rotor-bearing finite element model. Reducing the radial clearance effectively lowers rotor vibration when the rotational speed is below the essential speed; this vibration suppression influence can reach 67%[14].

Ling Wanga, , and others (2019) One of the most frequently utilized parts of industrial machinery is the rolling bearing. The most likely mechanism of failure leading to subsurface-generated failures is rolling contact fatigue (RCF), provided it is properly installed, loaded, lubricated, and isolated from contamination. Many scientists have spent the last few decades researching how operating factors like pressure, temperature, and running time during RCF affect bearing failure and microstructural modifications like dark etching regions and white etching bands. This article seeks to give a general overview of these modifications, their characteristics, the processes by which they occur, and how they affect bearing failure[15].

The work provided here describes a novel method for estimating the operating lifespan of a bearing's rotating components as it relates to thrust ball bearings. The size development of an incline that was onto the raceway of a thrust ball bearing during cyclic loading is being looked at. The lifespan of elements can be mapped using FEM calculations. Initial comparisons are made between the numerical results and those obtained from experiments conducted under identical conditions.

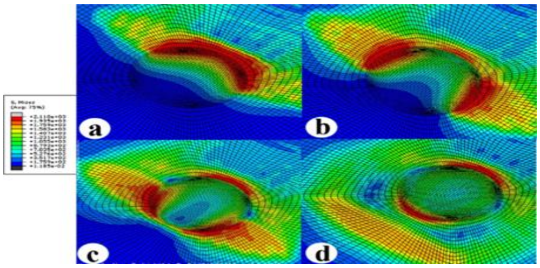

Fig. 4 Von Mises stress profile when the ball makes contact with the indent (a) at the beginning of contact, (b) during contact, and (c) when contact has ended [16]

Peter Šulka,Alžbeta Sapietová,etc al.(2017) The rolling ball bearing's contact pressure level, stress distribution, and displacement behavior have all been studied using finite element analysis. Acceptable to show an almost exact matching of findings and the proper setup of the specified The computational program's simulation ANSYS Workbench.

$$Бmax = 4.37 * ƐБ * \sqrt{\frac{Qmax}{de^{\wedge}2}} \quad (2)$$

$$Бmax = 40.4686 * (15450/36)^{0.5} = 366.62MPa$$

Max is the Hertz theory's the highest contact pressure [MPa], de is the rolling element's diameter [mm]. Finding similarities between findings from the analytical and FEM solutions through analysis. FEM = 3706.1 MPa and max = 3663.62 MPa The comparison of the analytical and numerical solutions demonstrates the accuracy of the MKP analysis's findings. [17].

Tengfei Xu, Lihua Yang, and others (2018) To suit the extreme load requirements in real engineering applications, single-row tapered roller bearings are typically joined into double-row bearings. The stability and operating safety of numerous equipment kinds are significantly affected by virtue of the qualities of a bearing with two rows of tapered rollers. To examine the bearing in the presence of coupled exterior forces and three degrees of freedom, a thorough analytical process has been created. [18], [19], [20], [21].

With the help of a discussion of Hertz contact theory and the performance variations in point contact pressure, they researched ball bearing design and evaluated the optimum material to be used for manufacturing bearing balls. To determine contact pressure, Hertzian contact stresses, and bearing ball deformation, a computer model was created. The findings of an experimental compressive test and a finite element model in ANSYS were used to further validate the numerical model. According to the findings of this study, steel ball bearing issues can be resolved entirely by using ceramic materials due to their low density, high wear resistance, electrical insulation to prevent electric arc damage, noiseless operation, low levels of discoloration, overheating, and corrosion[22].

Li F., Hu W., et al. (2017) By rolling the roller rather than a continuous contact pressure moving in the computational domain, explicit finite element analysis is used in order to calculate contact stresses that cycle in cylindrical roller bearings. Investigated are the links between contact stresses and fatigue damage, as well as how contact loading affects fatigue life. Crack initiation, crack propagation, and spalling are all simulated numerically. The outcomes are in line with those of the earlier experiments. A new damage evolution equation that include the non-proportional change of stress and is easily derivable from torsion fatigue testing data. [23].

Dr. Prabhat Kumar Sinha, Vimal Kumar Pal, and others, (2017), Axial and radial loads that cause friction, elevated temperatures, and vibration inside the bearings are supported and reduced by an integral shaft bearing. The temperature may rise above a predetermined threshold if the heat and vibration created inside the bearing cannot be adequately eliminated. Because of this, the system has been created and studied using the renowned finite element program ANSYS Workbench 14.0 [24],[25].

Alin Marian Pușcașu, Octavian Lupescu,and other (2017) The author's research uses the finite element approach to show how cylindrical roller bearings can be to improve structurally and functionally. This technique has a broad range of applications and is extensively used in structural fields like vibration, mechanical, and thermal analysis. The finite element method has many significant benefits. When a design is being conceptualized, the behavior of the structure under various media loads can be researched and modelled in real time. The model may then be revised prior to producing the final drawings for execution. after CAD model has been created, the design structure may be thoroughly analyzed using the FEM approach. Therefore, adopting FEM can reduce the amount of prototypes needed, saving time and money. The analysis of the outcomes produced the following finding: program for analyzing finite elements. The load disappeared from the discharge end of the rollers . Ansys' static structural analysis of The rollers and rings of the construction, extending the life of the bearing and altering loads distributed on the rollers. The rollers' edges can be seen to have spikes. The bearing life value is comparable to the sum listed in the S.C. Rulmenti S.A. Barlad catalog. [26]

Alin Marian Pușcașu, Octavian Lupescu (2017) In their paper, they demonstrated a static finite element analysis of an angular contact ball bearing. Finding the most significant influencing factors for the bearing's radial stiffness under an axial load is the major objective. All of the findings are founded on a single angular contact ball bearing with inner and outer groove radii of 11mm and a ball radius of about 22mm. Analyses are done on the variables that have the biggest impact on the radial reaction force from the housing to the outer ring. The curvature of the ball and the raceways of the inner and outer rings are the most significant factors that influence the response force. The response force increases by 27% for every 1.3% increase in ball diameter. Reaction force decreases by 9.3% for every 1.3% reduction in ball diameter. The resistance to touch and the overall response force are mostly impacted by mesh density in the contact zone. The second goal of the study is to streamline this angular contact ball bearing by using an arrangement in which the inner and outer rings are joined by a beam component, so minimizing the number of nodes and speed up computation. It is feasible to employ a "beam star" arrangement for this particular ball bearing, consisting of 12 circular beams with a 4.5mm radius. Even though it has a similar stiffness to a ball bearing.

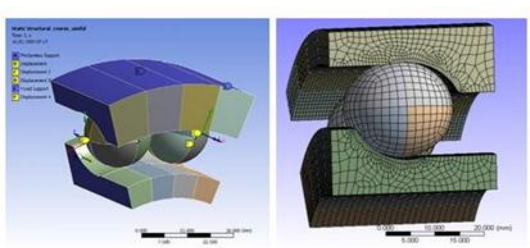

Fig. 5 Part model for the Mesh and Calculation [27].

So the mechanical system of rolling bearings has important physical and numerical influencing aspects that have been examined. A complete F.E. model with balls and a condensed F.E. model with balls as replacements by influences in a beam structure called a "beam star" were both built. Investigated are elements such mesh density, penetration, boundary condition, and ball and raceway curvature. The geometric curvature of such a ball and the raceways of the inner and outer rings are the most significant factors that influence the reaction force. The final reaction force can vary significantly (by an additional 27%) with a very minor change in ball diameter (raised by only 1.3%)[27].

J. Nam, H. S. Ryou & S. W. Cho,(2016) They conducted study on the heat distribution in rotating elements and the influence of rotation on that. For comparison, the analysis under consideration performs the rotation's impact. Therefore, you should take the rotational effects into account when determining the local temperature distribution in the bearing system. However, in cases of significant deformation, such as those involving rotating parts, the Lagrange technique for the study of the solid domain is inappropriate. Additionally, a bearing system problem that has numerous contact points is typically time-consuming. Due to the intricate boundary conditions and numerous contact points, it is difficult to obtain the convergent solution [28].

N. K. Arakere et al. (2016) New ball bearing steels are essential., extremely strong structural components utilized in a wide range the commercial applications. Because rolling contact fatigue (RCF) loading is confined, it is exceptional among structural materials. It is challenging to forecast the dependable bearing life in the gigacycle domain due to the complicated phenomena shown by RCF at length scales ranging from nanometer to millimeter. A thorough analysis of cycle-based fatigue loading that the volume of material influenced by RCF beneath the surface underwent is given. [29].

Zhigang Wang, et al. (2016) Preloads have a significant impact on the working efficiency and lifespan of the bearing in the wheel hub. As preload rises, the bearing's natural frequency rises as well, although the upward tendency tends to slow as the natural frequency rises. After conducting bearing swept-sine vibration tests with various preloads, the conclusion was reached. [30].

Agnieszka Chudzik and Bogdan Warda, (2016) They looked into how ring misalignment impacts a radial roller bearing's fatigue life. An approach that considered bearing geometrical characteristics like rolling generator profiles, bearing radial clearance, angular tilting of rings, and complex loads was utilized to predict fatigue life. The Boussines problem for the elastic half-space was numerically resolved for the elastic half-space using FEM to supply the necessary stress distributions for computing the anticipated fatigue life. The projected bearing life fatigue could be calculated using Lundberg and Palmgren's model. The results of the calculations were compared to the maximum ring tilt angles advised by roller bearing producers. [31], [32] .

An integral shaft bearing is preferred over a conventional one because it has a better specific load carrying capacity, prevents misalignment faults, and reduces the possibility of unfavorable bearing distortion. Integral shaft bearings are used to support radial and axial loads and lessen rotational friction, which raises the temperature and stresses throughout the bearing. The temperature may grow above a set threshold, which would cause the bearing to fail, if the heat generated cannot be properly evacuated from the bearing. The famous finite element tool has been used to model and examine a common integral shaft bearing and its environment in order to study the heat flow, temperature distribution, and stresses in a bearing system , They studied the structural and thermal properties of an integrated shaft bearing in order to analyze temperature distribution, thermal elongation brought on by friction, as well as its effect on bearing clearances and vice versa. We can infer that the design is secure given the observation that the equivalent (von Mises) stress maximum at the shaft is 189.1 MPa and the maximum allowable stress of the shaft material is 208 MPa. To study the stress and deformation of an integral shaft bearing, coupled thermal and structural analysis is crucial. Bearing life is 58172.302 hours when utilizing the analytical method, which also meets the design requirements.

So as to achieve stresses at various loading conditions in accordance with the forces and temperature applied to the component from the static analysis, FEM analysis is a very effective method. Today, it's customary to employ numerical methods, like the finite element method, to provide detailed information on structures or component parts] [33].

Analytical and numerical techniques are used in this article to evaluate the contact stress distribution of deep groove ball bearings. ABAQUS, a finite element program, calculates the bearing's 6004 ball and raceway's contact pressure distribution. Using Hertzian contact theory, MATLAB software derives an analytical method for validating the finite element model. Investigated is the effect of shaft misalignment at various angles, including 0.20, 0.40, 0.60, 0.80, and 10. It is discovered that the contact stress can be assessed using finite element analysis at any location close to the surface of contact. Additionally, It is determined that the shaft misalignment reduced the maximum contact stress and increased the contact area between the ball and raceway of the bearing [34].

M. Chandra Sekhar Reddy(2015) Since bearings are the principal heat-generating source in high-speed spindle units, the researchers made this claim. The internal temperature of the bearing is increased by bearing friction. The temperature may increase above a set threshold, which would cause the bearing to fail, if the heat generated cannot be properly evacuated from the bearing. In order to evaluate the heat flow in a bearing system, the finite element method has been utilized to model and analyze a typical ball bearing and its surroundings. Calculations based on heat generation have been made to determine the bearing's maximum temperature using the rotating speed as a parameter. The goal of this experiment is to ascertain how quickly rotational speeds affect the temperature of the bearing system. In this thesis, the temperature distribution of the bearing is examined using a steady state thermal stress simulation that is run at high speeds using the FEA approach. An analytical formulation supports the conclusion that the temperature increases steadily as the rotating speed increases. As rotating speed increases, the centrifugal displacement of the inner ring increases, causing increased touch distortion and stress. The dynamic stiffness of the variable preload bearing has been analyzed analytically, and the results show that as rotational speed increases, radial stiffness decreases. It was found that the inner ring's maximum temperature at 5000 rpm is 41.90 C˚, whereas the outer ring's maximum temperature is 40.750 C˚. The simulation also demonstrated that when the heat generated by the bearing grows, the temperature inside the bearing rises. The bearing's radial stiffness, which tends to decrease with rising speeds, has been demonstrated to be more affected by rotating speeds than by preload after researching the effects of bearing stiffness with relation to various bearing speeds. [35].

Zhang Yongqi,Tan Qingchang and other (2012) The Reynolds equation and the surface roughness are first used to generate a roller bearing finite element model. Then, by increasing the load and solving for the stress fields in the roller and raceway, the maximum stress and strain on the bearings is predicted. Using maximum stress and strain measurements, the impact of pre-tightening on the functioning characteristics of the bearings is finally investigated. The research given above leads to the following conclusions: 1: The mathematical model can faithfully replicate the lubrication of rolling bearings. 2: The finite element method's ability to compute contact stresses in rolling bearings depends on the size of the model grid. Near the contact region, the grid size is less than 50% of the elliptical contact's small axis. [36], [40].

4 Status of operation

The load it supports and the speed at which it operates determine the ball bearing's estimated life. The cube of the bearing load determines the lifetime under normal applied load conditions. The ball's maximum rated load is for 1 million spins at 60 Hz, or 4000 RPM, which equates to 6 operating hours of that kind of bearing, 80% have a lifetime of at least that, and 60% have a lifetime of at least five times longer.

5 Conclusion

Bearing rollers are capable of supporting heavy objects and axial loads in all directions. roller bearings are not strong enough to endure stringent and quick test conditions. These bearings are capable of supporting both axial and radial loads. They can only support axial loads going in one direction. Therefore, more research is needed on scaling. Although cylindrical bearings have similar stiffness to ball bearings, more research needs to be done on angular contact ball bearings with various geometric sizes and different types of bearings. The finite element analysis displays the locations of the stress concentrations as well as the maximum and minimum shear stresses in rolling bearings. These serve as the foundation for studying and predicting roller bearing failure.

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