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Fatigue Analysis of Bearing

Ms. Shelke A. A.
Department of Mechanical Engineering
JCOE Kuran Pune 410511

Prof. Galhe D.S.
Department of Mechanical Engineering
JCOE Kuran Pune 410511

Abstract

The development of the technology of rolling bearings has as one of its objectives constitute a set of mechanical components that combine mechanical strength and stiffness, designed to support the loads, speeds and life specified for a particular application. This work aims to discuss the application of the finite element method in the analysis of fatigue failure in rolling bearings, evaluating the influence of some construction and operational parameters in the stress distribution, such as geometry of contact surfaces, applied load, rotation, and properties of materials in contact. Specifically, we investigated the relationship between the stresses caused by cyclic loading in fatigue life of these bearings. The analysis of the life of rolling bearings was performed using the commercial software, based on the finite element method in a virtual environment. Expected that the results obtained in this study will be useful in developing methods for predicting fatigue failure in rolling bearings.
Keywords- Rolling Bearings, Fatigue, Finite Element Method

I. INTRODUCTION

Bearings are one of the important machine elements used in many applications, which include rotating component. This supports another moving machine element permitting the relative motion between the rolling-element bearings consist of balls or rollers positioned between raceways. Depending on the bearing design specification, the loads acting on the bearing may be angular, axial, or radial. Ball and roller bearing appear to be relatively simple mechanisms but their internal operations are relative complex. At extreme operating condition of heavy loading, very high speed, and very high or low operating temperature leads to early bearing failure. When design requirements not met that leads to excessive deflection, vibration, high frictional torque and temperature. Mostly the ball and roller bearing failures are caused by interference of the lubricant supply to the bearing or inadequate delivery of the lubricating oil to the raceway contact.

Ball and roller bearings commonly referred to as bearings are frequently used in simple and complex machinery e.g., bicycles, gas turbines, transmissions, dental drills, etc. They are used to allow rotary motion and support significant load. Before the 1940s, their design and application in machinery were more of an art than a science and little was known about their operation. However, since the 1940s, due to ever increasing demand for bearings, usage has required better knowledge and understanding of bearing operation i.e, elasto hydrodynamic lubrication, dynamics, rolling contact fatigue. This deals with the bearing rolling contact fatigue empirical and analytical models developed and proposed over the past few decades. It has been proposed that if a ball or a rolling element bearing is properly loaded, lubricated, installed, and kept free of foreign contaminants, then the main mode of failure is material fatigue. Historically, it has also been postulated that a rotating bearing has a limited life because of probability of subsurface initiated fatigue spall. The localized contact stresses in ball and rolling element bearings are extremely high as compared with stresses acting on rotating structural components e.g., shafts. Neglecting the lubrication effects, stress in bearing contacts is governed by the Hertzian theory, where the pressures are in the order of a few giga pascal. RCF results in metallic particles flaking from the surface of the ball and rolling elements or raceways. When the bearing is properly lubricated this phenomenon commences as a crack below the surface and propagates to the surface causing a pit or a spall in the bearing raceway. The high level of cleanliness of bearing steels in current bearing technology is one factor in minimizing the probability of fatigue spalls. A second important factor is the micro plastic deformation behavior of bearing steel under the action of RCF.

Ball bearings can be divided into three categories, i.e. radial contact, angular contact, and thrust. Radial-contact ball bearings are designed to support radial loads. Angular contact bearing designed to support combination of radial and axial loads. Thrust bearings designed to support axial loads. Roller bearings have higher load capacities than ball bearings for a given size and are usually used in moderate speed heavy-duty applications. The preliminary types of roller bearings are cylindrical, needle, tapered, and spherical roller bearing. The service life of bearings is expressed either as a period of time or as the total number of rotations before the occurrence of failures in the inner ring, outer ring or in rolling element (ball or roller) because of rolling fatigue, due to repeated stress. Rated life of bearing expressed as the period at which equipment or machine element fails under specified condition of use given by its manufacturer. The service life of bearing differs from rated life, where bearing failure may cause by poor lubrication, misalignment, and mounting damage before its actual life.

Contact Fatigue is a surface-pitting-type failure commonly found in ball or roller bearings. This type of failure can also be found in gears, cams, valves, rails, and gear couplings. Contact fatigue has been identified in metal alloys (both ferrous and nonferrous) and in ceramics and cermets. Contact fatigue differs from classic structural fatigue (bending or torsional) in that it results from a contact or Hertzian stress state. This localized stress state results when curved surfaces are in contact under a normal load. Generally, one surface moves over the other in a rolling motion as in a ball rolling over a race in a ball bearing. The contact geometry and the motion of the rolling elements produces an alternating subsurface shear stress. Subsurface plastic strain builds up with increasing cycles until a crack is generated. The crack then propagates until a pit is formed. Once surface pitting has initiated, the bearing becomes noisy and rough running. If allowed to continue, fracture of the rolling element and catastrophic failure occurs. Fractured races can result from fatigue spalling and high hoop stresses. Rolling contact components have a fatigue life (number of cycles to develop a noticeable fatigue spall). However, unlike structural fatigue, contact fatigue has no endurance limit. If one compares the fatigue lives of cyclic torsion with rolling contact, the latter are seven orders of magnitude greater. Rolling contact life involves ten to hundreds of millions of cycles.

II. LITERATURE REVIEW

A. History

This review provides the knowledge about fatigue analysis, fatigue life of bearings.

W.A. Glaeser and S.J. Shaffer [1996],gives the contact fatigue is a surface-pitting-type failure commonly found in ball or roller bearings. This type of failure can also be found in gears, cams, valves, rails, and gear couplings. Contact fatigue has been identified in metal alloys (both ferrous and nonferrous) and in ceramics and cermets. Contact fatigue differs from classic structural fatigue (bending or torsional) in that it results from a contact or Hertzian stress state. This localized stress state results when curved surfaces are in contact under a normal load. Generally, one surface moves over the other in a rolling motion as in a ball rolling over a race in a ball bearing. The contact geometry and the motion of the rolling elements produces an alternating subsurface shear stress. Subsurface plastic strain builds up with increasing cycles until a crack is generated. The crack then propagates until a pit is formed. Once surface pitting has initiated, the bearing becomes noisy and rough running. If allowed to continue, fracture of the rolling element and catastrophic failure occurs. & concluded that, as power systems become lighter and more compact, bearings, gears, and other rolling elements will have to operate at higher speeds. Although even at this time not all is understood about the mechanisms of contact fatigue, advances in improved reliability and component life are being made. Research and testing continue to try to narrow the life scatter and increase the predicted life of rolling contact parts [1].

R.K. Upadhyay , L.A. Kumaraswamidhas, Md.Sikandar Azam [2013] focused on,review case study of Rolling Contact Fatigue (RCF) occurs due to the result of cyclic stress developed during operation and mechanism that involve in fretting failure of rolling element bearing. As bearing raceways of non-rotating rolling element bearings exposed to vibration or sliding oscillation false Brinelling occurs. Bearing surface due to false Brinelling tends to damage within a short period, due to cavities created on the bearing raceway. Recommendation towards enhancement of bearing life is also suggested & concluded that, In order to prevent fretting (false brinelling) in bearings of standby equipment, it is necessary to provide continuous slow rotation of shafts during operation while nearby machines is running. Increment in the angle of oscillation to secure roller overlap in order to drag fresh lubricant into the area, if the surfaces can be separated by lubricant, fretting of the metal cannot occur. When the load is supported by lubricating film it can separate two surfaces from contacting each other with minimum friction. Recommendation towards use of larger bearing of higher capacity to reduce contact loads. It is also recommended that increase the hardness of the elements as much as possible [2].

Farshid Sadeghi [2009] proposed that, Ball and rolling element bearings are perhaps the most widely used components in industrial machinery. They are used to support load and allow relative motion inherent in the mechanism to take place. Subsurface originated spalling has been recognized as one of the main modes of failure for rolling contact fatigue (RCF) of bearings. In the past few decades a significant number of investigators have attempted to determine the physical mechanisms involved in rolling contact fatigue of bearings and proposed models to predict their fatigue lives. In this work, some of the most widely used RCF models are reviewed and discussed, and their limitations are addressed. The work also presents the modeling approaches recently proposed by the authors to develop life models and better understanding of the RCF & concluded that, RCF is the most unavoidable mode of failure of ball and rolling element bearings. There are two most dominant mechanisms for RCF, i.e., the subsurface originated spalling and surface originated pitting. In this paper, a review of the most acceptable empirical and research models, existing in literature, developed for investigating the rolling contact fatigue caused by subsurface originated spalling was provided.

J Halme and P Andersson [2010] gives that, Rolling bearing operation is affected by friction, wear and lubrication mechanisms, fluid dynamics and lubricant rheology, material properties, and contact mechanics. Changes in rolling surfaces occur due to plastic deformation, rolling contact wear, and rolling contact fatigue. Wear particles can be formed and mixed into the lubricant. Increased levels of vibrations due to surface degradation can be monitored by sensors. Rolling contact wear and rolling contact fatigue during rolling bearing operation can be diagnosed by combining measured and interpreted condition monitoring data with theory, and conclusions drawn thereof can support a continuous prognosis for the remaining bearing life. In the present work, connections between bearing diagnostics and tribological mechanisms are outlined. and conluded that, Friction, wear, and lubrication mechanisms acting at the rolling and sliding contacts are central issues for the operation of rolling contact bearings, and considered in rating life calculations for bearings at specific operational conditions. During bearing operation, rolling surface roughening and wear particle formation may eventually occur as a consequence of rolling contact wear and rolling contact fatigue, unless the operational conditions are mild enough to limit the surface alterations to polishing. Rolling contact fatigue, in particular, causes changes in the bearing kinematics by rolling surface roughening and wear particle formation, which in turn increase the bearing vibrations. The vibrations and the wear particle formation can be monitored during the operation of the bearing. Useful methods for vibration-based condition monitoring of rolling bearings are the vibration acceleration high-frequency techniques, the SPM, the envelope analysis, and the AE analysis for obtaining an early warning. For the detection of a severe bearing defect, the most useful methods are the spectrum analysis of the vibration velocity amplitudes at nominal bearing frequencies, the determination of the RMS value of the vibration velocity, and the analysis of the statistical parameters of the vibration acceleration such as the Kurtosis and RMS values. Condition monitoring measurements can be combined with a theoretical rating life estimate, in order to give an updated and more reliable prognosis for the remaining operational lifetime of the bearing.[4]

Prabhat Singh[2014], compares the total deformation of thrust ball bearing & contact stress b/w ball & raceways & its effect on fatigue life of thrust ball bearing. The 3-Dimensional Modeling has been done through modeling software Pro-e wildfire-5.0. The parts assembly is also done in Pro-e wildfire-5.0 & analysis has been done through ANSYS- 14. An analytical method is good, less expensive and gives the best results. Analytical results give good agreement with the experimental data. The thrust ball bearings are subjected to various, thrust & dynamic loads, which simulated easily through Pro-E software & analysis because experimentally calculation is very complicated. The general theory used for calculating the Fatigue life of Bearing is basic life rating theory. The material taken for the Bearing is AISI8720H. In this study we have used various analysis codes and got a good result through these codes. Comparison of the simulation results with the previous research work result shows good qualitative agreement, both in shape & magnitude of wear profile. The analytical result is equivalent the simulation result. The total deformation of bearing is compared for 3 different loads and the difference between result is varies from 0.01 μm to 0.5 μm. It has also been shown that the changes due to wear causes high pressure peaks at the contact area, which explains that bearings fail at the contact area under working conditions [5].

III. General Theory for Bearing Fatigue Life Analysis

A. Fatigue Life

ASTM defines fatigue life, Nf, as the number of stress cycles of a specified character that a specimen sustains before failure of a specified nature occurs. For some materials, notably steel and titanium, there is a theoretical value for stress amplitude below which the material will not fail for any number of cycles, called a fatigue limit, endurance limit, or fatigue strength. Engineers have used any of three methods to determine the fatigue life of a material: the stress-life method, the strain-life method, and the linear-elastic fracture mechanics method. One method to predict fatigue life of materials is the Uniform Material Law (UML). UML was developed for fatigue life prediction of aluminum and titanium alloys by the end of 20th century and extended to high-strength steels and cast iron.

B. Characteristics of Fatigue

1) Fracture of an aluminum crank arm. Dark area of striations: slow crack growth. Bright granular area: sudden fracture.
2) In metal alloys, when there are no macroscopic or microscopic discontinuities, the process starts with dislocation movements, which eventually form persistent slip bands that become the nucleus of short cracks.
3) Macroscopic and microscopic discontinuities as well as component design features which cause stress concentrations (holes, keyways, sharp changes of direction etc.) are common locations at which the fatigue process begins.
4) Fatigue is a process that has a degree of randomness (stochastic), often showing considerable scatter even in well controlled environments.
5) Fatigue is usually associated with tensile stresses but fatigue cracks have been reported due to compressive loads.
6) The greater the applied stress range, the shorter the life.
7) Fatigue life scatter tends to increase for longer fatigue lives.
8) Damage is cumulative. Materials do not recover when rested.
9) Fatigue life is influenced by a variety of factors, such as temperature, surface finish, metallurgical microstructure, presence of oxidizing or inert chemicals, residual stresses, scuffing contact (fretting), etc.
10) Some materials (e.g., some steel and titanium alloys) exhibit a theoretical fatigue limit below which continued loading does not lead to fatigue failure.
11) High cycle fatigue strength (about 104 to 108 cycles) can be described by stress-based parameters. A load-controlled servo-hydraulic test rig is commonly used in these tests, with frequencies of around 20–50 Hz. Other sorts of machines—like resonant magnetic machines—can also be used, to achieve frequencies up to 250 Hz.
12) Low cycle fatigue (loading that typically causes failure in less than 104 cycles) is associated with localized plastic behavior in metals; thus, a strain-based parameter should be used for fatigue life prediction in metals. Testing is conducted with constant strain amplitudes typically at 0.01–5 Hz.

C. Bearing Fatigue Life Calculation

The fatigue life of the bearing can be estimated by “Lundberg & Palmgren theory”,

L=(C/P) ^n

Where

L10=rated fatigue life with a statistical reliability of 90%

P=bearing equivalent load

C=basic radial dynamic load rating (Get from Individual bearing selection charts)

There are generally two factors used in thrust ball bearing:

1) The Bearing Fatigue Life Criterion

Under ideal conditions the repeated stresses developed in the contact areas b/w the ball & raceways eventually can result in the fatigue of the material. In most applications the fatigue life is the maximum useful life of a Bearing.

2) Static Loading Criterion

A static load is load acting on a non-rotating bearing. The permissible static load is dependent upon the permissible magnitude of permanent deformation. Depending on requirements for smoothness of operation, friction, higher or lower static load limits may be tolerated.

3) Basic Life Rating

The Basic Life Rating (L10) is defined in specification JIS B1518 "Dynamic load ratings and rating life for ball bearings" as follows:

The Basic Life Rating is the life obtained with 90% reliability, when an individual bearing or an identical group of bearings are manufactured with common materials, common manufacturing processes and quality, and operate under the same conventional conditions. L10 Life is the accumulated rotation where 90% of survive without material flaking when they are operated under fixed conditions, of a population of bearings.
The calculation formula for the Basic Life Rating is the following.

$$L_{10} = \left(\frac{C_r}{P_r}\right)^3$$

L10: Basic Life Rating in millions of revolutions
Cr: Basic Dynamic Load Rating
Pr: Equivalent Dynamic Radial Load Factor
There is a relationship between the Basic Life Rating (revolutions) and Basic Life (time).

$$L_{10} = \left(\frac{10^6}{60 \cdot n}\right) \times \left(\frac{C_r}{P_r}\right)^3 \quad (h)$$

n: Rotation Speed (min)
h: Time (hours)

IV. SIMULATION & ANALYSIS WITH SOFTWARE

Computational 3 dim simulation & analysis indicates the numerical solution of differential governing equations of bearings, with the help of computers. Computational 3 dim simulation & analysis also provides the convenience of being able to switch off specific terms of governing equations. This permits the testing of theoretical models and, inverting the connection, suggesting new paths for theoretical explorations. Computational 3 dim simulation & analysis provides five major advantages compared with various experimental, thrust & dynamic loads:

1) Lead time in design and development is significantly reduced.
2) It can simulate flow conditions not reproducible in experimental model test.
3) It provides more detailed and comprehensive information.
4) It is increasingly more cost-effective than real time testing.

V. CONCLUSION

We have found the contact deformation in different loads & compared the result by using finite element method & software analysis gives the good result of Fatigue life of Bearing. This research shows the stress developed & deformation in Thrust Bearing is less as compared to Experimental result in same force conditions, material properties, thickness and boundary condition. In this paper The Basic Life Rating theory is used to calculate the load, but more accurate result is obtained experimentally in finite element analysis.

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