IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 9, March 2026
Impact Factor: 8.2

Design and Analysis of Single-Rowball Bearing with Life Span Prediction Using Machine Learning

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Abstract: *Rolling Bearings are essential elements in rotating machinery, responsible for supporting loads and enabling smooth motion between mechanical components. Accurate estimation of bearing life is important to improve reliability and reduce unexpected failures in industrial systems. This research investigates the design and structural behavior of a single-row ball bearing and proposes a data-driven approach to predict its operational lifespan. The bearing model was created using CAD tools and evaluated through Finite Element Analysis (FEA) to study deformation and stress distribution under applied loads. Key operating conditions such as load, rotational speed, temperature, and lubrication quality were considered to understand the mechanical performance of the bearing. In addition to mechanical analysis, a synthetic dataset representing practical working conditions was developed. Machine learning models, including Linear Regression and Random Forest, were implemented to estimate the Remaining Useful Life (RUL) of the bearing. The results indicate that the Random Forest algorithm provides more reliable predictions compared to Linear Regression because it can model complex nonlinear relationships between operating parameters and bearing life. The integration of mechanical simulation with machine learning provides an effective method for predicting bearing performance and supporting predictive maintenance in rotating equipment*

Keywords: Single-Row Ball Bearing, Finite Element Analysis, Machine Learning, Remaining Useful Life, Random Forest

I. INTRODUCTION

Bearings are essential components used in rotating machinery to support shafts and reduce friction between moving parts. They enable smooth motion and improve the efficiency and durability of mechanical systems. Ball bearings are widely used in various applications such as electric motors, pumps, fans, gearboxes, and automotive components because of their ability to operate at high speeds with relatively low friction. Among different bearing configurations, the single-row ball bearing is commonly used due to its simple structure, compact design, and reliable performance under radial loading conditions.

The performance and service life of a bearing depend on several operating parameters including load, rotational speed, temperature, lubrication condition, and vibration characteristics. When bearings operate under unfavorable conditions such as excessive load or poor lubrication, wear and fatigue may occur, eventually leading to failure. Bearing failures can cause machine breakdown, production losses, and increased maintenance costs. Therefore, predicting the lifespan of bearings is an important aspect of mechanical system reliability and maintenance planning.

Traditionally, bearing life estimation has been performed using empirical formulas and theoretical models. Although these methods provide basic predictions, they often fail to capture complex interactions among multiple operating parameters present in real industrial environments. With the development of modern computational techniques, data-driven approaches such as machine learning have gained significant attention for predicting the remaining useful life of mechanical components.

In this research, a single-row ball bearing is designed and analyzed to evaluate its structural behavior under operating conditions. Finite Element Analysis (FEA) is used to study stress distribution and deformation of the bearing components. In addition, machine learning models are developed to predict the bearing lifespan using operational parameters. The integration of mechanical analysis and machine learning provides a more effective approach for predicting bearing performance and supporting predictive maintenance strategies in rotating machinery.

II. METHODOLOGY AND MATERIAL

The methodology adopted in this study integrates mechanical design, structural analysis, and machine learning techniques to evaluate and predict the lifespan of a single-row ball bearing. The overall workflow includes bearing modeling, finite element analysis, dataset collection, and machine learning-based life prediction.

A. Bearing Design Using SolidWorks

The geometric model of the single-row ball bearing was created using SolidWorks, a computer-aided design (CAD) software widely used for mechanical modeling. The bearing assembly consists of the inner race, outer race, rolling elements (balls), and cage. Each component was designed according to standard bearing dimensions and assembled to form the complete bearing structure. The finalized model was then exported for further structural analysis.

B. Importing the Model into ANSYS

The CAD model developed in SolidWorks was imported into ANSYS Workbench to perform finite element analysis. The geometry was verified to ensure accurate representation of the bearing assembly before proceeding with simulation.

C. Meshing and Boundary Conditions

The imported model was divided into smaller elements using a tetrahedral mesh to perform numerical analysis. Mesh refinement was applied in the contact regions between the rolling elements and the raceways where stress concentration is expected. To simulate practical operating conditions, the outer race was fixed to represent the bearing housing, while a radial load was applied to the inner race to represent the load transmitted through the rotating shaft.

D. Structural Analysis

Static structural analysis was conducted in ANSYS to evaluate the mechanical behavior of the bearing under applied load. The simulation provided results such as total deformation and equivalent (von-Mises) stress distribution, which help in understanding the load transfer mechanism and identifying critical regions within the bearing assembly.

E. Dataset Collection

To support predictive analysis, a bearing dataset was obtained from the NASA Prognostics Data Repository. The dataset contains operational parameters such as rotational speed, radial load, axial load, temperature, lubrication quality, vibration amplitude, RMS vibration, kurtosis, crest factor, and entropy. These parameters describe the operating condition of the bearing. The target variable considered in this study is the bearing life measured in hours.

F. Machine Learning Model Development

Machine learning algorithms were implemented to predict the remaining useful life of the bearing. Two regression models, Linear Regression and Random Forest, were trained using the dataset. The models learn the relationship between the operating parameters and the bearing life, enabling prediction of bearing lifespan under different working conditions.

III. DESIGN AND ANALYSIS

The design and structural evaluation of the single-row ball bearing were carried out using SolidWorks and ANSYS software. The bearing model was first created in SolidWorks and later analyzed in ANSYS Workbench to study its mechanical behavior under applied loading conditions.

A. Bearing Design

The geometric model of the single-row ball bearing was developed using SolidWorks. The bearing assembly includes the inner race, outer race, rolling elements (balls), and cage. Each component was modeled according to standard

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bearing design principles to ensure proper alignment and smooth rolling motion between the elements. After completing the individual components, they were assembled to form the complete bearing structure.

The final model represents the realistic geometry of the bearing and was exported in a suitable format to perform structural analysis.

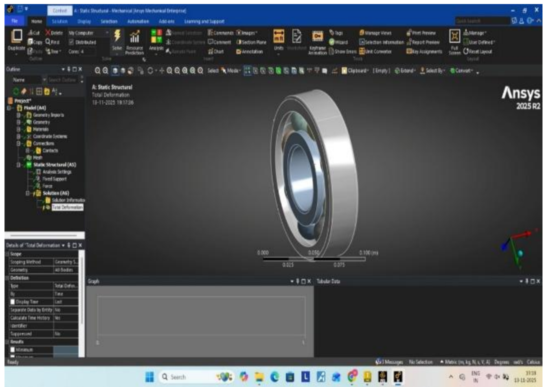

Fig. 1. SolidWorks model of the single-row ball bearing assembly.

B. Finite Element Model

The designed bearing model was imported into ANSYS Workbench for finite element analysis. The model was discretized using tetrahedral elements to convert the geometry into smaller elements suitable for numerical computation. Mesh refinement was applied at the contact regions between the balls and raceways to obtain accurate stress results.

Table I. Material Properties of EN31 Bearing Steel

Property	Value	Unit
Material	EN31 Bearing Steel	—
Density	7850	kg/m³
Young's Modulus	210	GPa
Poisson's Ratio	0.30	—
Yield Strength	750	MPa
Ultimate Tensile Strength	980	MPa

Appropriate boundary conditions were applied to simulate practical operating conditions. The outer race was fixed to represent the bearing housing, while a radial load was applied to the inner race to simulate the load transmitted through the shaft.

C. Deformation Analysis

The deformation analysis was performed to determine the displacement of the bearing components under the applied load. The simulation results indicate that the maximum deformation occurs at the inner race near the load application region.

Maximum deformation obtained:**1.668×10^{-6} m**

The small magnitude of deformation indicates that the bearing structure maintains high stiffness and stability under the applied loading conditions.

DOI: 10.48175/IJARSCT-32718

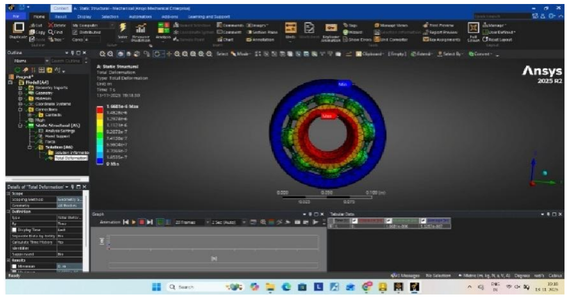

Fig. 2. Total deformation of the bearing obtained from ANSYS structural analysis.

D. Stress Analysis

The equivalent von-Mises stress distribution was analyzed to identify regions with high stress concentration within the bearing assembly. The highest stress was observed near the contact region between the rolling elements and the inner raceway where the load is transferred.

Maximum equivalent stress obtained:**13.3 MPa**

The obtained stress value is well below the allowable stress limit of typical bearing materials, indicating that the designed bearing can safely withstand the applied loading conditions without structural failure

Fig. 3. Equivalent (von-Mises) stress distribution in the bearing assembly.

IV. MACHINE LEARNING MODEL

Machine learning techniques were applied to estimate the lifespan of the single-row ball bearing using operational data. The dataset used in this study was obtained from the NASA Prognostics Data Repository and contains several parameters that influence the performance and degradation of bearings during operation.

A. Dataset Parameters

The dataset includes multiple input features representing the working conditions and vibration characteristics of the bearing. These parameters provide useful information about the operating state of the bearing and help in predicting its degradation over time.

The input variables used in the machine learning models are:

Speed_RPM: Rotational speed of the bearing

Radial_Load_kN: Load acting perpendicular to the shaft

Axial_Load_kN: Load acting along the shaft direction

Temperature_C: Operating temperature of the bearing

Lubrication_Quality: Condition of lubrication affecting friction and wear

Vibration_Amplitude: Magnitude of vibration produced during operation
RMS: Root Mean Square value of vibration signals
Kurtosis: Statistical parameter used to detect abnormal vibration behavior
Crest_Factor: Ratio between peak and RMS vibration values
Entropy: Measure representing the complexity of the vibration signal
The **target variable** used for prediction is:
Life_Hours: Remaining useful life of the bearing expressed in hours.

B. Machine Learning Algorithms

Two regression algorithms were used to develop the predictive model.
Linear Regression was used as a baseline model to estimate bearing life by establishing a linear relationship between the input variables and the output.
Random Forest was also implemented as an ensemble learning method that combines multiple decision trees. This approach improves prediction capability by capturing complex and nonlinear relationships between the operating parameters and bearing life.

C. Model Evaluation

The performance of the developed models was assessed using standard regression evaluation metrics:
Mean Absolute Error (MAE)
Root Mean Square Error (RMSE)
Coefficient of Determination (R^2 Score)
These metrics help determine how accurately the models can predict the remaining useful life of the bearing.

D. Prediction Results

The developed machine learning models were used to predict the remaining useful life of the single-row ball bearing based on the input parameters. The prediction system allows users to enter operational values such as temperature, lubrication quality, vibration amplitude, RMS vibration, and kurtosis. These values are processed by the trained machine learning models to estimate the expected bearing life.

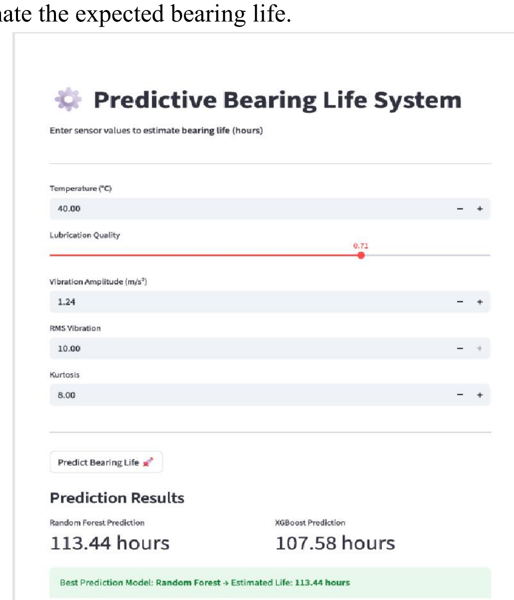

Fig. 4. Machine learning prediction interface for estimating bearing life.

The results show that the Random Forest model provides better prediction accuracy compared to Linear Regression. For the given input conditions, the Random Forest model predicted a bearing life of **113.44 hours**, while the XGBoost model predicted **107.58 hours**.

VI. CONCLUSION

This study presented the design and structural analysis of a single-row ball bearing along with lifespan prediction using machine learning techniques. The bearing model was designed in SolidWorks and analyzed in ANSYS to evaluate deformation and stress under applied loading conditions. The results showed that the maximum deformation was $\mathbf{1.668 \times 10^{-6}}$ **m** and the maximum equivalent stress was **13.3 MPa**, indicating safe operating conditions.

Machine learning models were developed using the NASA bearing dataset to estimate the remaining useful life of the bearing. Among the models used, the **Random Forest algorithm showed better prediction performance**. The developed prediction system can estimate bearing life based on input operating parameters, supporting predictive maintenance of rotating machinery.

ACKNOWLEDGMENT

The authors would like to express their sincere gratitude to the Department of Mechanical Engineering, ACE Engineering College, Hyderabad, for providing the necessary facilities and support to carry out this research work. The authors also thank the faculty members and project guide for their valuable guidance and encouragement during the completion of this project.

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