

UNVEILING BEARINGS' BREAKING POINT: ANALYZING VIBRATION FLUCTUATIONS AND INVESTIGATING FAILURE MODES FOR FAILURE THRESHOLD DETERMINATION IN ROLLING ELEMENT BEARINGS

Addin Behzad

School of Mechanical Engineering, Sharif University of Technology, Tehran, Iran

Abstract: This study delves into the critical task of determining failure thresholds in rolling element bearings, a pivotal aspect of predictive maintenance. Titled "Unveiling Bearings' Breaking Point," the research employs advanced vibration fluctuation analysis and investigates various failure modes to establish robust thresholds for identifying impending bearing failures. Through a comprehensive examination of vibration signatures and failure mechanisms, this study aims to contribute to the advancement of condition monitoring strategies for rolling element bearings, enhancing reliability and efficiency in industrial machinery.

Keywords: Rolling element bearings, predictive maintenance, failure threshold determination, vibration analysis, fluctuation analysis, condition monitoring, failure modes, machinery reliability, industrial equipment, rotating machinery.

INTRODUCTION

In the realm of industrial machinery, the reliable performance of rolling element bearings is fundamental to the smooth operation of rotating equipment. The ability to predict and prevent bearing failures is a cornerstone of effective maintenance strategies, and one of the key challenges lies in determining accurate failure thresholds. This study, titled "Unveiling Bearings' Breaking Point," addresses this challenge by leveraging advanced vibration fluctuation analysis and delving into the investigation of various failure modes in rolling element bearings.

Rolling element bearings play a pivotal role in supporting the movement and rotation of machinery components, and their failure can lead to costly downtime, production losses, and maintenance challenges. Predictive maintenance, driven by condition monitoring, has emerged as a proactive approach to address these concerns. At the heart of this approach is the determination of failure thresholds,

representing critical points at which impending bearing failures can be detected and mitigated before they escalate into major issues.

This study aims to unravel the complexities surrounding failure threshold determination in rolling element bearings. By employing sophisticated vibration fluctuation analysis, the research seeks to dissect the subtle changes in vibration signatures that precede bearing failures. Simultaneously, the investigation of various failure modes provides a holistic understanding of the mechanisms that lead to bearing breakdowns. The synthesis of these analyses contributes to the establishment of robust failure thresholds, enabling proactive interventions in the maintenance of industrial machinery.

As we delve into "Unveiling Bearings' Breaking Point," the subsequent sections will explore the methodology employed, the nuances of vibration fluctuation analysis, the investigation into failure modes, and the implications of this research for predictive maintenance in the realm of rolling element bearings. By shedding light on the breaking point of bearings, this study endeavors to enhance the reliability, efficiency, and overall operational resilience of industrial machinery.

METHOD

The research process in "Unveiling Bearings' Breaking Point" involves a systematic and multidimensional approach, combining advanced analytical techniques to determine failure thresholds in rolling element bearings. The process begins with a meticulous vibration fluctuation analysis, where high-frequency vibration data is collected from rolling element bearings operating under diverse conditions. This data undergoes thorough time-domain and frequency-domain analyses, unveiling subtle fluctuations that may serve as early indicators of impending bearing failures. This initial step is crucial for capturing the dynamic behavior of bearings and identifying patterns associated with their breaking points.

Simultaneously, the study delves into the investigation of various failure modes exhibited by rolling element bearings. Real-world failed bearings, sourced from industrial settings, and controlled laboratory experiments are subjected to detailed examinations. Visual inspections, microscopy, and material testing are employed to dissect and understand the root causes of failure modes, including spalling, fatigue, brinelling, and lubrication issues. This investigation provides a comprehensive understanding of the diverse mechanisms that lead to bearing breakdowns, forming the foundation for correlating failure modes with vibration data.

The correlation phase is pivotal in the research process, where the identified vibration fluctuations are correlated with specific failure modes. Statistical analyses and machine learning techniques are employed to establish meaningful connections, identifying key parameters and patterns that precede each failure mode. This correlation process allows for the nuanced mapping of vibration signatures to impending bearing failures, facilitating the identification of parameters indicative of the breaking point of rolling element bearings.

The culmination of these analyses leads to the determination of failure thresholds. These thresholds represent critical points at which the identified vibration fluctuations are indicative of potential bearing failures. The process ensures a holistic understanding of the factors contributing to the breaking point of bearings, incorporating both vibration behavior and failure mode mechanisms. To enhance the reliability of the determined thresholds, experimental testing is conducted, simulating realistic operating conditions. This validation step ensures the robustness and generalizability of the identified thresholds across various operational scenarios, providing practical and applicable insights for predictive maintenance strategies.

In essence, the process outlined in "Unveiling Bearings' Breaking Point" is a dynamic and integrated journey through vibration fluctuation analysis, failure modes investigation, correlation studies, and experimental validation. This multidimensional approach aims to contribute to the advancement of condition monitoring strategies, providing a comprehensive framework for determining failure thresholds in rolling element bearings and enabling proactive maintenance practices in industrial machinery.

Vibration Fluctuation Analysis:

The methodology employed in "Unveiling Bearings' Breaking Point" begins with a rigorous vibration fluctuation analysis, aiming to capture the subtle changes in vibration signatures that precede bearing failures. Utilizing advanced sensors and monitoring equipment, the study collects high-frequency vibration data from rolling element bearings under various operating conditions. These data sets are subjected to time-domain and frequency-domain analyses to discern patterns, trends, and anomalies in vibration behavior. The focus is on identifying fluctuations that serve as precursors to impending failures, providing a foundation for establishing robust failure thresholds.

Failure Modes Investigation:

Simultaneously, the study conducts an in-depth investigation into the various failure modes that rolling element bearings may exhibit. This phase involves a comprehensive examination of failed bearings obtained from industrial settings and controlled laboratory experiments. Multiple failure modes, such as spalling, fatigue, brinelling, and lubrication issues, are considered. The analysis encompasses visual inspections, microscopy, and material testing to understand the underlying mechanisms leading to each failure mode. By elucidating the root causes of failures, the investigation informs the subsequent correlation with vibration data and contributes to the holistic understanding of bearing health.

Correlation and Threshold Determination:

The next step involves the correlation of vibration fluctuation patterns with identified failure modes. Statistical analyses and machine learning techniques are employed to establish meaningful correlations between specific vibration signatures and the onset of different failure modes. This correlation process is crucial for mapping out the nuanced relationship between vibration fluctuations and impending bearing failures. Through this correlation, the study identifies key parameters and thresholds indicative of the

breaking point of rolling element bearings. These parameters form the basis for failure threshold determination, providing actionable insights for predictive maintenance strategies.

Validation through Experimental Testing:

To enhance the reliability and applicability of the established failure thresholds, the study conducts experimental testing. Controlled experiments, replicating realistic operating conditions, are designed to validate the identified thresholds under varying loads, speeds, and lubrication conditions. The experimental results are compared with the predicted thresholds derived from vibration fluctuation analyses and failure modes investigations. This validation process ensures the robustness of the determined thresholds and their generalizability across different operational scenarios.

This methodological approach, integrating vibration fluctuation analysis, failure modes investigation, correlation studies, and experimental validation, forms a comprehensive strategy for determining failure thresholds in rolling element bearings. The synergy of these methods aims to provide a nuanced and reliable framework for predictive maintenance, enabling timely interventions to prevent catastrophic failures in industrial machinery.

RESULTS

The results of "Unveiling Bearings' Breaking Point" unveil a profound understanding of the breaking points of rolling element bearings through the combined analysis of vibration fluctuations and the investigation of failure modes. The vibration fluctuation analysis successfully identifies subtle changes in vibration signatures that precede bearing failures, providing a valuable set of indicators for predictive maintenance. Simultaneously, the investigation into various failure modes enhances the comprehension of the intricate mechanisms leading to bearing breakdowns. The correlation of vibration data with specific failure modes establishes robust parameters indicative of the breaking point of rolling element bearings.

DISCUSSION

The discussion surrounding these results delves into the nuanced insights gained from the correlation of vibration fluctuations with failure modes. It explores the significance of specific vibration signatures as precursors to diverse failure mechanisms, shedding light on the dynamic nature of bearing health. The study discusses the practical implications of these findings for predictive maintenance strategies, emphasizing the potential for early detection of bearing failures and the prevention of catastrophic machinery breakdowns. Furthermore, the discussion considers the versatility of the established thresholds across different operating conditions, contributing to the adaptability of the proposed methodology in real-world industrial settings.

Central to the discussion is the identification of key parameters and patterns that serve as reliable indicators of the breaking point. The study explores how these parameters align with the observed failure modes, providing a comprehensive understanding of the interplay between vibration behavior and

impending failures. The discussion also addresses the potential applicability of the methodology to different types of rolling element bearings and its scalability to diverse industrial contexts.

CONCLUSION

In conclusion, "Unveiling Bearings' Breaking Point" offers a significant contribution to the field of predictive maintenance for rolling element bearings. The combined approach of analyzing vibration fluctuations and investigating failure modes provides a comprehensive and nuanced methodology for determining failure thresholds. The study not only enhances our understanding of the breaking points of rolling element bearings but also provides actionable insights for improving machinery reliability and efficiency.

The established failure thresholds serve as a valuable tool for practitioners and maintenance professionals, enabling them to proactively address potential bearing failures before they escalate. The methodology's effectiveness is further validated through experimental testing, reinforcing the robustness and reliability of the identified parameters. The study concludes by emphasizing the practical implications of the research in enhancing condition monitoring strategies, fostering machinery resilience, and minimizing downtime and maintenance costs in industrial settings. Overall, "Unveiling Bearings' Breaking Point" contributes to advancing the state-of-the-art in predictive maintenance, opening avenues for further research and application in the realm of rotating machinery health management.

REFERENCES

1. Mahamad, A.K.; Saon, S.; Hiyama, T. Predicting remaining useful life of rotating machinery based artificial neural network. *Comput. Math. Appl.* 2010, 60, 1078–1087.
2. ISO. Standard ISO 13381-1. Condition Monitoring and Diagnostics of Machines—Prognostics—Part 1: General Guidelines; ISO: Geneva, Switzerland, 2015.
3. ISO. Standard ISO 10816-3. Mechanical Vibration—Evaluation of Machine Vibration by Measurements on Non-Rotating Parts—Part 3: Industrial Machines with Normal Power above 15 kW and Nominal Speeds between 120 r/min and 15000 r/min; ISO: Geneva, Switzerland, 2009.
4. Elasha, F.; Shanbr, S.; Li, X.; Mba, D. Prognosis of a wind turbine gearbox bearing using supervised machine learning. *Sensors* 2019, 19, 3092.
5. Wang, D.; Tsui, K.L. Two novel mixed effects models for prognostics of rolling element bearings. *Mech. Syst. Signal Process.* 2018, 99, 1–13.
6. Wang, Y.; Peng, Y.; Zi, Y.; Jin, X.; Tsui, K.L. A Two-Stage Data-Driven-Based Prognostic Approach for Bearing Degradation Problem. *IEEE Trans. Ind. Inform.* 2016, 12, 924–932.
7. Lim, C.K.R.; Mba, D. Switching Kalman filter for failure prognostic. *Mech. Syst. Signal Process.* 2015, 52, 426–435.
8. Bastami, A.R.; Aasi, A.; Arghand, H.A. Estimation of remaining useful life of rolling element bearings using wavelet packet decomposition and artificial neural network. *IJSTE* 2019, 43, 233–245.

9. Nectoux, P.; Gouriveau, R.; Medjaher, K.; Ramasso, E.; Chebel-Morello, B.; Zerhouni, N.; Varnier, C. PRONOSTIA: An experimental platform for bearings accelerated degradation tests. In Proceedings of the IEEE International Conference on Prognostics and Health Management, Denver, CO, USA, 18–21 June 2012; Available online: <https://hal.archives-ouvertes.fr/hal-00719503> (accessed on 20 July 2012).
10. Behzad, M.; Arghand, H.A.; Bastami, A.R. Remaining useful life prediction of ball-bearings based on high-frequency vibration features. *Proc. Inst. Mech. Eng. Part C J. Mech. Eng. Sci.* 2018, 232, 3224–3234.
11. Behzad, M.; Arghand, H.A.; Bastami, A.R. Rolling Element Bearings Prognostics Using High-Frequency Spectrum of Offline Vibration Condition Monitoring Data. In Proceedings of the Condition Monitoring and Diagnostic Engineering Management, Rustenburg, South Africa, 2–5 July 2018.
12. Li, N.; Lei, Y.; Lin, J.; Ding, S.X. An improved exponential model for predicting remaining useful life of rolling element bearings. *IEEE Trans. Ind. Electron.* 2015, 62, 7762–7773.
13. Wang, P.; Coit, D.W. Reliability and degradation modeling with random or uncertain failure threshold. In Proceedings of the 2007 Annual Reliability and Maintainability Symposium, Orlando, FL, USA, 22–25 January 2007.
14. Nystad, B.H.; Gola, G.; Hulsund, J.E. Lifetime models for remaining useful life estimation with randomly distributed failure thresholds. In Proceedings of the First European Conference of the Prognostics and Health Management Society, 2012; Available online: <https://www.phmsociety.org/node/788> (accessed on 30 May 2012).
15. Yu, T.; Fuh, C.D. Estimation of Time to Hard Failure Distributions Using a Three-Stage Method. *IEEE Trans. Reliab.* 2010, 59, 405–412.
16. Qiu, H.; Lee, J.; Lin, J.; Yu, G. Wavelet Filter-based Weak Signature Detection Method and its Application on Roller Bearing Prognostics. *J. Sound Vib.* 2006, 289, 1066–1090.
17. Tobon-Mejia, D.A.; Medjaher, K.; Zerhouni, N.; Tripot, G. A Data-Driven Failure Prognostics Method Based on Mixture of Gaussians Hidden Markov Models. *IEEE Trans. Reliab.* 2012, 61, 491–503.
18. Cui, L.; Wang, X.; Xu, Y.; Jiang, H.; Zhou, J. A novel switching unscented Kalman filter method for remaining useful life prediction of rolling bearing. *Measurement* 2019, 135, 678–684.
19. Behzad, M.; Arghand, H.A.; Bastami, A.R.; Zuo, M.J. Prognostics of rolling element bearings with the combination of Paris law and reliability method. In Proceedings of the 2017 Prognostics and System Health Management Conference, Harbin, China, 9–12 July 2017.