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Fault Diagnosis of Rotor-Bearing System for Misalignment.

Miss. Riza Patel[1], Miss. Devyani Patil[2], Mr. Shivam Mohite[3], Mr. Mayuresh Deshmukhe[4], Mr. Sourabh Dhage[5], Mr. Girish. B. Pawar[6]

[1-5] Student, [6]Guide

Affiliated to Shivaji University, Kolhapur, Department of Mechanical Engineering, Annasaheb Dange College Of Engineering, Ashta, Sangli, Maharashtra, India

A B S T R A C T

This study investigates the impact of shaft misalignment on rotor-bearing systems using Fast Fourier Transform (FFT) analysis. Misalignment is a major cause of excessive vibrations and machinery failure. The experiment evaluated three misalignment levels—0 mm (aligned), 0.25 mm (moderate), and 0.75 mm (severe)—at rotational speeds of 720, 1000, and 1440 RPM. Aligned systems showed a dominant 1X frequency with low harmonics, while moderate and severe misalignment introduced 2X and higher-order harmonics, indicating mechanical stress. The Z-axis was most sensitive, with a peak vibration of 855 mm/s² at 1000 RPM for 0.25 mm misalignment. Results confirm FFT as an effective tool for early fault detection and severity assessment. This aids predictive maintenance by linking vibration patterns to misalignment levels, reducing downtime and improving system reliability. The study also suggests future integration of machine learning for real-time diagnostics and fault classification in industrial applications.

Introduction

Rotor-bearing systems are critical parts of a variety of rotating machinery, including turbines, compressors, pumps, and electric motors. The reliability and performance of these systems significantly influence the operational efficiency and safety of industrial equipment. One of the most common and detrimental faults in rotor-bearing systems is misalignment, which occurs when the rotational centreline's of coupled shafts do not coincide. Misalignment can be categorized into two main types angular and parallel (offset) misalignment. Probably the most frequent reason why machinery malfunctions is misalignment. Despite the significance of alignment, little is known about its vibration spectra. Due in large part to the observed significant variability in the character of machinery vibration, even when seemingly identical alignment states exist, experience has shown that diagnosing misalignment through vibration analysis can be very challenging. The most common cause of machine vibration is misalignment. The first step in decreasing needless vibration, lowering maintenance expenses, and improving machine performance is comprehending and putting the principles of rotating shaft parameters into practice. In the industry, misaligned machines account for 30% of machine downtime. Additionally, extensive experimental research has been conducted on rotating machinery to address issues such as misalignment (both parallel and angular), imbalance, bearing clearance, rotor rub, mechanical looseness, and crack at the shaft's mid-span. Combinations of flaws, such as angular and parallel misalignment, as well as rotor cracks and imbalances, have also been reported. Building on these investigations, current trends emphasize the integration of advanced monitoring techniques such as machine learning algorithms and real-time sensor networks to detect and differentiate complex fault combinations in rotor-bearing systems. These technologies enable early fault detection and offer predictive maintenance capabilities, thereby reducing the risk of sudden breakdowns. Researchers are also exploring non-invasive diagnostic tools that minimize downtime while providing accurate insights into system health. As the demand for higher efficiency and reliability grows across industries, a thorough understanding of fault interactions, especially under varying operating conditions, becomes increasingly vital for developing robust, fault-tolerant rotating machinery systems. Recent advancements in diagnostic technologies have allowed for more precise identification of fault patterns, even when multiple issues occur simultaneously. Engineers are now leveraging high-resolution spectral analysis and multi-sensor data fusion to gain deeper insights into vibration behaviour under different misalignment severities. With these approaches, it is possible to track subtle shifts in frequency responses that were previously overlooked. Furthermore, integrating cloud-based systems facilitates continuous remote monitoring, ensuring that real-time feedback is available without interrupting operations. This shift toward proactive strategies not only extends machine lifespan but also supports efficient planning for component replacements and scheduled overhauls, ultimately minimizing unplanned production losses.

Problem Statement

Rotor-bearing systems are essential in industrial machinery, where misalignment can lead to inefficiency, excessive wear, vibration, and system failure. Early detection of misalignment is crucial to avoid costly downtimes, production delays, and safety risks. However, current diagnostic methods often lack reliability, sensitivity, or real-time applicability. This project aims to develop a reliable and cost-effective fault identification system for early detection and diagnosis of misalignment in rotor-bearing systems, improving machine reliability, reducing downtime, and extending operational life.

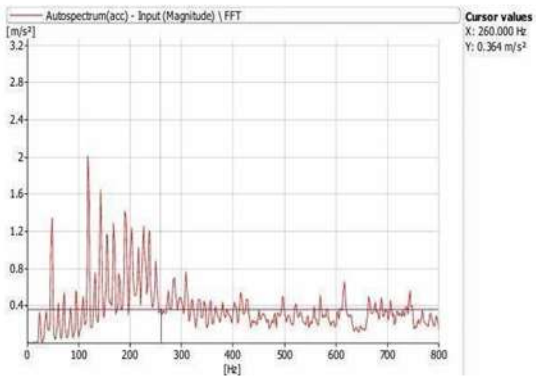
Experimental Setup

The experimental setup consists of a motor-driven shaft mounted on tapered roller bearings, supported by a mild steel frame. A flexible coupling was used to introduce misalignment levels (0 mm, 0.25 mm, 0.75 mm). Accelerometers were mounted on bearing housings to measure vibrations at different speeds (720, 1000, 1440 RPM). A dimmer and VSD controlled the motor, and data was analysed using FFT. This setup simulates real misalignment conditions for diagnostic analysis.

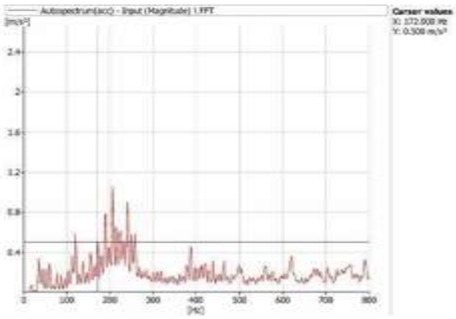
Experiment Procedure

The experiment investigates the effect of parallel shaft misalignment on rotor-bearing vibrations. The setup includes a motor-driven shaft supported on bearings and coupled via a flexible coupling. Accelerometers mounted on the bearings capture vibration data, which is analyzed using FFT to interpret frequency responses. Baseline data is first recorded under perfect alignment using dial indicators, with the motor running at controlled speeds (1000–1500 RPM). The FFT spectrum shows a dominant 1× frequency and minimal harmonics, representing healthy conditions. Next, a 0.25 mm parallel misalignment is introduced. The system is re-run and analyzed, showing increased vibration at 1× and the appearance of 2× harmonics—indicative of misalignment. A further increase to 0.75 mm misalignment results in stronger 1×, 2×, and new 3× harmonics, reflecting higher mechanical stress. All spectra are compared based on harmonic amplitudes and sideband formation. This growing frequency content with misalignment confirms the effectiveness of FFT in early fault detection, vital for predictive maintenance

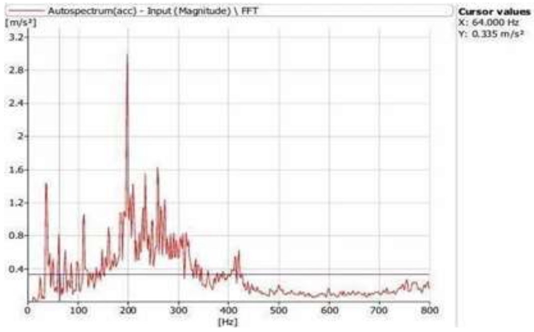
Results



The FFT graph shows vibration data with acceleration (m/s²) plotted against frequency (Hz), highlighting peaks below 300 Hz. A notable peak at 260 Hz with 0.364 m/s² suggests possible faults like misalignment or imbalance. Such spectra help identify mechanical issues for predictive maintenance.



The spectrum at 1000 RPM with 0 mm misalignment shows a peak at 172 Hz with 0.500 m/s², indicating normal operation. No unusual spikes or noise are present, confirming proper alignment and healthy rotor-bearing conditions. This serves as a reference for fault-free performance.



The FFT graph at 720 RPM with ideal alignment shows a primary peak at 64 Hz with 0.335 m/s². The spectrum remains flat with no higher-order peaks, indicating stable, balanced operation. This serves as a benchmark for low-speed, fault-free machine performance.

Conclusion

The shaft misalignment under vibration analysis, particularly FFT techniques, of rotor-bearing systems was the aim of this project. Misalignment in rotating machinery is a generic and malevolent fault that produces excessive vibration and, thus, premature failure of bearings and degraded performance of systems. This project set up three conditions for evaluating the degree of misalignment: a condition of perfect alignment at 0 mm, moderate misalignment at 0.5 mm, and a condition of severe misalignment at 0.75 mm.

Under each case, vibration data were recorded by sensors located close to the bearings. The time- domain signals were transformed into the frequency domain using FFT analysis. This enabled us to observe the dominant frequency components and detect characteristic alterations correlating with the different severities of misalignment.

Key Observations:

In a condition of no misalignment, 0mm in its realization, the frequency spectrum had a very prominent peak at the speed of rotation (1X) without a very high harmonic content. The whole system has a low overall vibration amplitude and proves that an independent system in health.

Misalignment through 0.5mm is such that vibration increases in amplitude, particularly at the 1X and 2X frequencies. These harmonics are known as angular and parallel misalignment indicators; the system is showing moderate instability.

When misalignment exceeded **0.75 mm**, the vibration spectrum showed a notable rise in amplitude at the **1X and 2X harmonics**, with some instances of elevated higher-order harmonics as well. This suggested increased mechanical imbalance and higher stress on the rotor-bearing assembly. The findings demonstrate that **shaft misalignment directly influences rotor dynamic v**ibration amplitude and harmonic content with increasing misalignment aligns with theoretical expectations and previous studies on rotating machinery diagnostics.

Conclusion Summary:

- FFT analysis successfully identified variations in vibration patterns due to different levels of misalignment.
- 1X and 2X frequency components were found to be reliable indicators of misalignment severity.
- The methodology used can serve as a predictive maintenance tool for early detection of shaft misalignment in industrial applications.
- Early fault detection using vibration analysis can help reduce unplanned downtime, improve machine reliability, and extend the lifespan of rotating equipment.

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