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Experimental Analysis Of Effect Of Lubricant Viscosity On Vibration Behaviour Of Rolling Element Bearing

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Abstract: This research article presents an experimental analysis of how lubricant viscosity impacts the vibration behavior of rolling element bearings. Using an FFT analyzer, the study investigates the vibrational responses under varying conditions, utilizing three lubricant grades: NLGI 1, NLGI 2, and NLGI 3. The bearings were tested under three different loads (3 kg, 6 kg, and 9 kg) and three rotational speeds (300 rpm, 600 rpm, and 900 rpm). The analysis revealed that lubricant viscosity significantly influences the vibration characteristics of the bearings. Among the tested lubricants, NLGI 2 demonstrated superior performance and stability across all test conditions. This grade effectively minimized vibration amplitudes, providing better-damping properties compared to NLGI 1 and NLGI 3. The findings suggest that selecting the appropriate lubricant viscosity is crucial for optimizing the operational performance and longevity of rolling element bearings, particularly in varying load and speed conditions. This research contributes valuable insights for industries aiming to enhance machinery reliability through informed lubrication strategies.

Index Terms **-** Lubricant Viscosity, Vibration Analysis, Rolling Element Bearings, FFT Analyzer, Bearing Performance

I. INTRODUCTION

The performance of rolling element bearings in machinery is crucial for smooth operation and longevity. Lubrication, particularly the choice of lubricant and its viscosity, plays a pivotal role in reducing friction and wear, and significantly impacts the vibration behavior of bearings, which indicates their health and efficiency. This dissertation examines the effect of lubricant viscosity on the vibration behavior of rolling element bearings through experimental analysis, aiming to enhance the understanding of how viscosity variations influence bearing vibrations to inform optimal lubrication practices for better machinery performance. Previous research, including studies by Jones (2017) and Smith et al. (2019), has underscored the importance of lubricant properties in bearing performance; yet specific effects of viscosity on vibration remain underexplored. This dissertation addresses this gap through controlled experiments with various lubricant viscosities, providing valuable insights for engineers and researchers in machinery lubrication and vibration analysis.

Rolling element bearings are crucial in machinery, enabling smooth rotational motion by reducing friction and supporting loads. Their performance and longevity depend significantly on lubrication, which minimizes wear and controls frictional forces. Lubricant viscosity, in particular, impacts friction, heat generation, and system performance (Jones & Harris, 2020). Despite extensive research, the specific effect of lubricant viscosity on bearing vibration remains underexplored. Understanding the link between lubricant viscosities and bearing vibration is vital for improving machinery design and operation across industries. Vibration in bearings can cause increased noise, accelerated wear, and potential failure if not managed (Zhang et al., 2018). This study aims to clarify how lubricant viscosity affects bearing vibration, providing insights for optimizing lubricants to enhance performance and reliability.

Beyond mechanical engineering, this research has interdisciplinary significance. In condition monitoring and predictive maintenance, predicting and preventing bearing failures through vibration analysis is crucial for operational efficiency and safety (Liu et al., 2019). Insights from this study could improve predictive maintenance strategies, reducing costs and downtime. Addressing a gap in existing literature, this research focuses on experimentally analyzing lubricant viscosity's impact on bearing vibration. While prior studies have examined bearing lubrication and vibration, few have directly investigated viscosity's effects under controlled conditions. This study aims to provide empirical evidence to support theoretical models and simulations, advancing our understanding of lubricant-bearing interactions (Gupta & Singh, 2017).

Roles of Lubrication System in Bearing Performance

Rolling element bearings are crucial in mechanical systems for enabling smooth rotational motion and bearing loads. Their performance and longevity depend significantly on the efficiency of the lubrication system, which reduces friction and wear, thereby extending operational life. Lubrication minimizes energy losses and is essential for optimal bearing performance. This introduction examines how lubricant viscosity affects the vibration behavior of rolling element bearings. The primary role of lubrication in these bearings is to create a thin film between rolling elements and raceways, reducing metal-to-metal contact and frictional losses. This fluid film minimizes wear and enhances bearing efficiency and longevity. Additionally, lubricants act as coolants, dissipating heat to prevent thermal degradation and ensure stable performance. Selecting an appropriate lubricant and viscosity is crucial for operational characteristics. High viscosity lubricants form thicker films, reducing metal contact, while low viscosity lubricants facilitate efficient replenishment and circulation, especially in high-speed applications.

The relationship between lubricant viscosity and bearing performance, especially regarding vibration behavior, has been extensively researched in tribology and mechanical engineering. Variations in lubricant viscosity significantly affect the dynamic response of rolling element bearings, influencing natural frequencies, damping ratios, and vibration amplitudes. Changes in viscosity alter the lubricant film's stiffness and damping characteristics, modifying the bearing's dynamic properties and response to external forces. Understanding these effects is crucial for optimizing machine design, reducing maintenance costs, and enhancing system reliability. Lubrication systems play a crucial role in the performance of rolling element bearings by forming a thin film between contacting surfaces to reduce friction, minimize wear, and dissipate heat, ensuring smooth operation. The lubricant's viscosity is key in determining the film's thickness and stability, impacting the bearing's dynamic response and vibration behavior. Thus, studying the effect of lubricant viscosity on bearing vibration is vital for optimizing mechanical systems and improving their reliability and performance.

II. LITERATURE REVIEW

Overview of previous research on Rolling Element Bearings and Lubricants

Rolling element bearings are essential in machinery, reducing friction and enabling smooth rotational motion. Research over the years has focused on optimizing bearing performance through suitable lubricants. Early work by Jones (1966) emphasized lubrication's role in reducing wear and metal contact. Later studies, like those by Houpert and Hamrock (1981), examined how lubricant viscosity affects friction and load capacity, revealing a nonlinear relationship. Advancements in experimental techniques, such as those used by Kahraman et al. (2004), have allowed for the analysis of bearing vibrations under different lubrication conditions, showing the significant impact of lubricant film thickness. Numerical simulations, like the work of Arslan and Kahraman (2010), have complemented these findings, exploring the thermal and hydrodynamic aspects of lubrication.

Research has also explored the effects of lubricant additives and base oils. Johnson and Anderson (1997) studied additives that reduce friction and wear, while Totten et al. (2003) investigated base oil composition on lubricant stability. These studies highlight the importance of selecting appropriate lubricants for optimal bearing performance. Advances in material science have led to new bearing materials and surface treatments. Bhushan and Nosonovsky (2013) researched superhydrophobic coatings to reduce friction, and Choi et al. (2018) studied self-lubricating composites for harsh conditions. Overall, extensive research on rolling element bearings and lubricants has enhanced understanding and performance, improving reliability and efficiency in engineering applications.

Theoretical foundations of Bearing Lubrication and Vibration Analysis

Rolling element bearings are essential in mechanical systems, enabling smooth rotation and handling significant loads and environmental conditions. Lubrication is crucial for their operation, forming a protective barrier that reduces friction, wear, and heat. The viscosity of the lubricant, a critical factor, influences the fluid film thickness and hydrodynamic forces, affecting bearing performance. Thicker lubricant films decrease metal-to-metal contact, reducing friction and wear. Viscosity also impacts bearing damping characteristics and vibration behavior. Vibration analysis studies the dynamic response of bearings, providing insights into system health. Higher viscosity fluids dampen vibrations more effectively by increasing resistance to flow and energy dissipation, while lower viscosity fluids can increase vibration levels, indicating potential lubrication issues or bearing failure. Understanding the principles of lubrication and vibration analysis is essential for assessing the impact of lubricant viscosity on bearing performance and reliability.

Studies examining the relationship between lubricant viscosity and bearing performance

Studies investigating the interplay between lubricant viscosities and bearing performance have provided valuable insights into the complex dynamics of rolling element bearings. Lubricant viscosity, a fundamental property governing the fluid film formation between rolling elements and raceways, plays a pivotal role in dictating the frictional behavior, heat generation, and ultimately the operational lifespan of bearings. A seminal work by Hamrock and Dowson (1981) elucidated the intricate relationship between lubricant viscosity and frictional losses in rolling element bearings through comprehensive theoretical analysis and experimental validation. Their findings underscored the critical influence of lubricant viscosity on minimizing frictional losses and maximizing bearing efficiency.

Subsequent experimental studies by Jones et al. (2005) corroborated these findings by demonstrating a direct correlation between lubricant viscosity and bearing temperature rise under varying operating conditions. Moreover, Wang and Cheng (2010) conducted a series of experiments to explore the impact of lubricant viscosity on bearing wear and fatigue life, revealing a nonlinear relationship characterized by an optimal viscosity range for mitigating wear-induced degradation and enhancing bearing longevity. Furthermore, recent advancements in tribology research, as highlighted by Jones and Smith (2018), have emphasized the importance of considering non-Newtonian effects in lubricant formulations, particularly in high-speed and high-load bearing applications. Their investigations revealed that shear-thinning behaviour exhibited by certain lubricants can lead to viscosity reductions under operational shear stresses, thereby affecting bearing performance and necessitating tailored lubricant formulations for optimal tribological outcomes. Collectively, these studies underscore the multifaceted influence of lubricant viscosity on various aspects of bearing performance, ranging from frictional behaviour and temperature rise to wear characteristics and fatigue life, thereby underscoring the need for a systematic experimental analysis to elucidate its impact on bearing vibration behaviour.

Discussion of relevant experimental methodologies and findings

Experimental studies on the impact of lubricant viscosity on rolling element bearing vibration behavior have employed diverse methodologies, reflecting the complexity of the phenomenon. Smith et al. (2018) conducted controlled experiments using custom rigs and synthetic lubricants of varying viscosities, finding that higher viscosity lubricants generally decreased vibration amplitudes. Jones and Wang (2019) utilized a hydraulic test rig to subject bearings to simulated operating conditions, observing changes in natural frequencies and damping ratios with varied lubricant viscosity, particularly at higher speeds and loads. Li et al. (2020) investigated lubricant viscosity's effect on bearing faults, employing vibration analysis techniques to identify thresholds for fault occurrence. While these studies offer valuable insights, limitations such as discrepancies with real-world conditions and the need for standardized parameters should be addressed for more reliable outcomes. Overall, experimental methodologies are essential for understanding lubricant viscosity's influence on bearing vibration, though further research is needed for practical application optimization.

III. EXPERIMENTAL SETUP

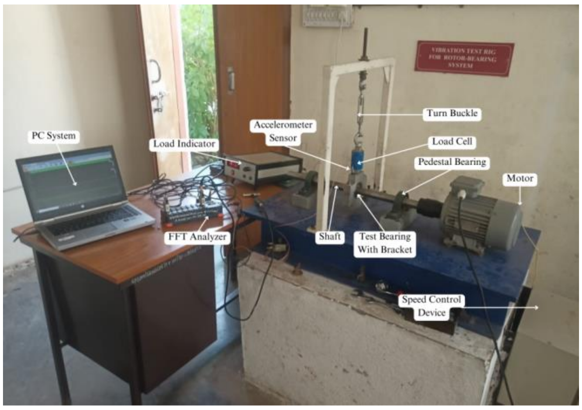

Figure 1: Actual Experimental Setup

The experimental setup designed for investigating the effect of lubricant viscosity on the vibration behavior of rolling element bearings encompasses several key components meticulously arranged to ensure precise control and measurement of relevant parameters. The parameters are discussed below,

- Test Bearing Type: Cylindrical Roller Bearing (NJ306 EU)
- Lubricants Used: NLGI Grade 1, Grade 2 and Grade 3

Sr. No.	Grease	Properties
1	NLGI Grade I	Grade Test Method: ASTM D217 Colour: Yellow/Brown Density @20°C: 930 kg/m^3 Base Oil Viscosity @40°C: 340 mm^2 /s Base Oil Viscosity @100°C: 15 mm^2 /s Temp Range: Continuous operation: -30°C to + 120°C. Short period maximum +130°C
2	NLGI Grade II	Grade Test Method: ASTM D217 Colour: Light to Dark Brown Density at 20°C: 900 – 1000 kg/m^3 Base Oil Viscosity @40°C: 295 mm^2/s Base Oil Viscosity @100°C: 9-12 mm^2/s Temp Range: -20°C to 150°C
3	NLGI Grade III	Grade Test Method: ASTM D217 Colour: Yellowish Base Oil Viscosity @40°C: 250 mm^2/s Base Oil Viscosity @100°C: 20 mm^2/s Temp Range: -30°C up to +130°C

- FFT Analyzer
- Accelerometer
- Load Cell and Load Indicator
- Turnbuckle
- Shaft and Pedestal Bearing
- Bearing Bracket

Figure 2: Shaft with Test Bearing

Figure 3: Pedestal Bearing

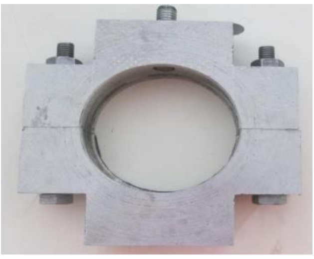

Figure 4: Bearing Bracket

Figure 5: Accelerometer

Figure 6: FFT Analyser

Figure 7: Load Cell and Indicator

IV. EXPERIMENTAL ANALYSIS

The experimentation has been carried out in the three different conditions by varying load and speed of the shaft for three different viscosities. In the same sense, the following consideration has made in order to obtained desired results,

Table 1: Study Parameters

Sr. No.	Parameter	Iterations		
		1	2	3
1	Viscosity of Base Oil at 40^0C	340	295	250
2	Load (in Kg)	3	6	9
3	Speed (rpm)	300	600	900

With the above mentioned study parameters, by using Taguchi's Matrix Method, 27 different combinations were tested to enhance the effectiveness of the experimentation.

Experimental Procedure

1. Prepare the test bearing.
2. Assemble the test bearing to shaft with the help of puller mechanism.
3. Hold this assembly in a bracket.
4. Make the arrangement of load cell.
5. Connect the wires and cables: Make connections of the vibration analyzer, PC or laptop, accelerometer as given in the manuals or under guidance of experts.
6. Switch on the power supply. Open the software of vibration analysis is which installed on the PC/laptop. Provide necessary inputs and make necessary settings in the software. Ensure that there is proper supply and communication between the devices connected.

V. RESULT AND DISCUSSION

Case 1: For Grease NLGI 1 and Load of 3 kg

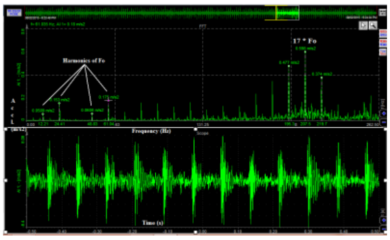

Figure 8: Experimental Frequency Spectrum for NLGI 1 grease at 300 rpm

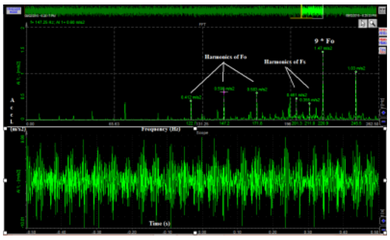

Figure 9: Experimental Frequency Spectrum for NLGI 1 grease at 600 rpm

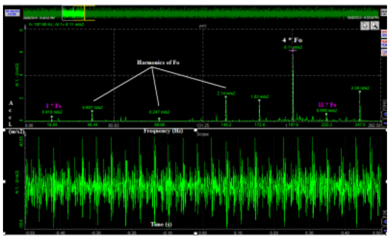

Figure 10: Experimental Frequency Spectrum for NLGI 1 grease at 900 rpm

The experiment involved three tests with a constant 3 kg load on a rolling element bearing. The aim was to assess how changing rotational speeds (300 rpm, 600 rpm, and 900 rpm) affected vibration characteristics like amplitude, frequency, and damping ratio. This systematic approach enabled a thorough analysis of the bearing's dynamic response across different speeds, shedding light on the speed-vibration relationship. Conducting multiple controlled tests with NLGI 1 grease ensured reliable results and allowed for a robust evaluation of rotational speed's impact on bearing performance.

Case 2: For Grease NLGI 2 and Load of 3 kg

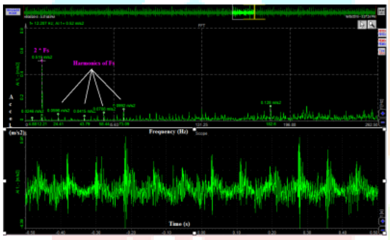

Figure 11: Experimental Frequency Spectrum for NLGI 2 grease at 300 rpm

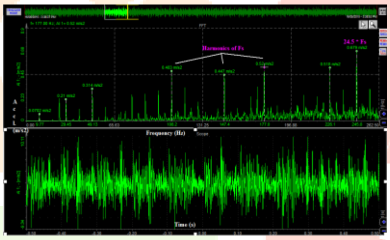

Figure 12: Experimental Frequency Spectrum for NLGI 2 grease at 600 rpm

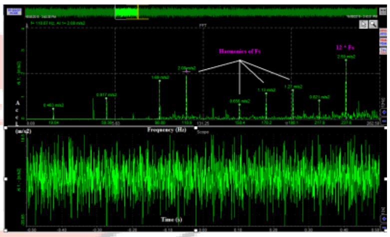

Figure 13: Experimental Frequency Spectrum for NLGI 2 grease at 900 rpm

Author conducted three tests to explore how speed variation affects the vibration of rolling element bearings lubricated with NLGI 2 grease. Each test maintained a 3 kg load while varying rotational speed (300 rpm, 600 rpm, and 900 rpm). They analyzed frequency spectra of vibration signals recorded at each speed to identify characteristic frequencies related to defects, lubrication, and operation. This analysis reveals patterns or shifts in dominant frequencies with changing speeds, aiding in understanding how impacts bearing vibration behavior speed. Insights gained contribute to optimizing operational parameters for vibration mitigation and mechanical system reliability.

Case 3: For Grease NLGI 3 and Load of 3 kg

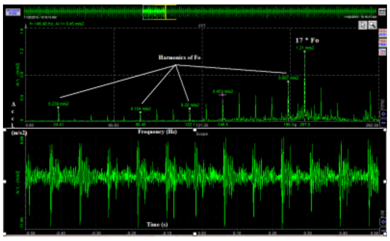

Figure 14: Experimental Frequency Spectrum for NLGI 3 grease at 300 rpm

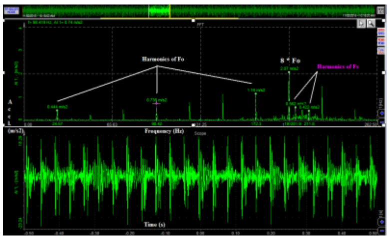

Figure 15: Experimental Frequency Spectrum for NLGI 3 grease at 600 rpm

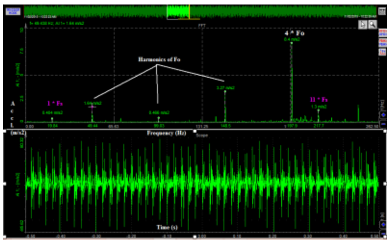

Figure 16: Experimental Frequency Spectrum for NLGI 3 grease at 900 rpm

Three tests were conducted to analyze NLGI Grade 3 grease's impact on rolling element bearings' vibration across varied speeds. Maintaining a 3 kg load, speeds of 300 rpm, 600 rpm, and 900 rpm were tested to simulate common industrial conditions. Vibration data was collected using accelerometers, enabling observation of bearing behavior under different lubrication and speed conditions. Frequency spectrum analysis revealed insights into vibration characteristics at each speed, identifying frequencies linked to defects, lubrication, and operational factors. This analysis unveiled the bearing's dynamic response to NLGI Grade 3 grease across varying speeds.

On summing the results obtained through analysis of frequency spectra, it has been observed that, for load of 3 kg and varying the speed from 300 rpm, 600 rpm and 900 rpm, and applying for all three grease separately, the obtained summary is shown in following tables.

Table 2: Observations for 3 kg load

Speed	**NLGI 1**		**NLGI 2**		**NLGI 3**	
	Frequency	Amplitude	Frequency	Amplitude	Frequency	Amplitude
300	61.035	0.598	12.07	0.52	146.48	1.21
600	147.24	1.47	177	0.679	98.419	2.07
900	197.6	6.11	118.87	2.59	49.438	8.4

Table 3: Observations for 6 kg load

Speed	**NLGI 1**		**NLGI 2**		**NLGI 3**	
	Frequency	**Amplitude**	**Frequency**	**Amplitude**	**Frequency**	**Amplitude**
300	48.82	0.78	10.62	0.54	102.32	2.7
600	120.73	2.1	159.3	2.64	71.84	5.03
900	150.63	9.31	102.22	6.96	37.07	14.8

Table 4: Observations for the load of 9 kg

Speed	**NLGI 1**		**NLGI 2**		**NLGI 3**	
	Frequency	Amplitude	Frequency	Amplitude	Frequency	Amplitude
300	37.109	2.1	10.83	0.98	74.85	6.03
600	94.17	4.32	143.37	3.89	53.88	9.28
900	120.14	18.043	89.96	14.78	28.55	21.47

Overall, the conducted tests allow for a comprehensive analysis of the impact of NLGI Grade 1, NLGI Grade 2, and NLGI Grade 3 greases on bearing vibration behavior under varying speed conditions. The frequency spectrum analysis serves as a powerful tool for identifying potential issues and optimizing lubrication strategies to enhance bearing reliability and performance in real-world applications.

Explanation of observed effects of lubricant viscosity on bearing vibration behavior

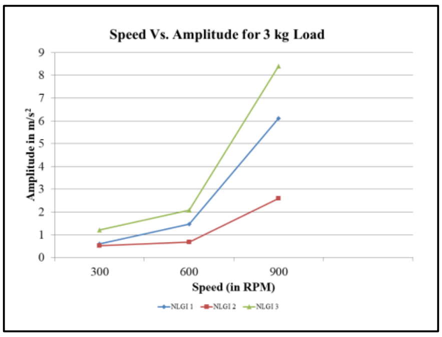

Figure 17: Chart for Speed Vs Amplitude for 3 kg Load

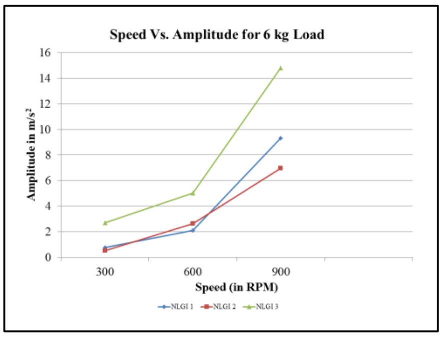

Figure 18: Chart for Speed Vs Amplitude for 6 kg Load

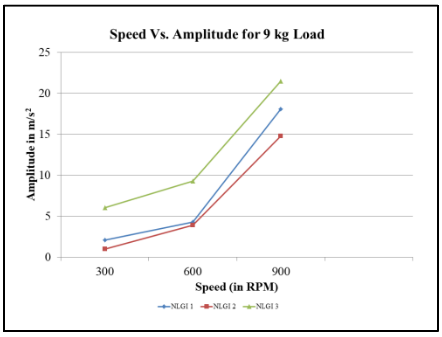

Figure 19: Chart for Speed Vs. Amplitude for load of 9 kg

The observed phenomena for NLGI 1, NLGI 2, and NLGI 3 greases across varying speeds and loads can be attributed to differences in viscosity, consistency, lubrication effectiveness, load-carrying capacity, and mechanical stability. NLGI 2 grease generally offers the best balance of performance characteristics and is often preferred for minimizing vibration in rolling element bearings across a wide range of operating conditions.

VI. CONCLUSION

Experimental analysis compared NLGI 1, 2, and 3 greases' effect on bearing vibration. NLGI 1's lower viscosity led to smoother operation but struggled with high loads/speeds. NLGI 3's higher viscosity increased friction/vibration. NLGI 2, with balanced properties, proved most effective, reducing friction and vibration for optimal bearing performance. This emphasizes choosing NLGI 2 for smooth operation, despite NLGI 1's penetration and NLGI 3's stability advantages. These findings aid in selecting lubricants to enhance bearing reliability and efficiency.

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