

Investigation of Lubrication Effects on Gear and Bearing Dynamic Operational Performance

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ABSTRACT

This study examines how lubrication properties particularly viscosity and film thickness affect the dynamic performance of gears and bearings through a MATLAB-based simulation. The gear and bearing assemblies were represented as single-degree-of-freedom (SDOF) systems with lubrication-dependent damping. In the simulations, viscosity (η) was varied between 0.01 and 0.1 Pa·s, while film thickness (h_f) ranged from 1×10^{-6} to 1×10^{-5} m. Dynamic responses, including peak vibration, RMS vibration, and load distribution, were evaluated using 3D surface and contour plots. The results show that increasing viscosity reduces peak gear vibration from 0.98 m to 0.55 m and peak bearing vibration from 0.51 m to 0.30 m equivalent to a reduction of about 44% and 41%, respectively. Load analysis further reveals that gear and bearing loads decrease by nearly an order of magnitude with greater film thickness, underscoring the importance of lubrication in reducing mechanical stress. Contour plots identified vibration hotspots under conditions of low viscosity and thin films, highlighting regions most vulnerable to wear and failure. The analysis results provide practical guidance for selecting lubricants and optimizing mechanical system performance. They also address a key gap in the literature by quantifying how the combined effects of viscosity and film thickness influence the dynamic behaviour of gear-bearing systems, an area that has received limited attention in prior research.

Keywords: Gear system, Bearing System, Viscosity, Lubrication, Dynamic Performance.

INTRODUCTION

Gears and bearings play a central role in mechanical and industrial systems, serving as the backbone for power transmission and load-bearing operations. The performance of these components is closely tied to the overall reliability, efficiency, and lifespan of machines [1], [2]. When lubrication is insufficient or improperly applied, it can lead to increased vibration, elevated mechanical stresses, and accelerated wear. These issues often result in premature failures, which not only reduce the service life of machinery but also contribute to higher maintenance costs and unexpected downtime [3]. Lubrication serves a crucial role in ensuring the smooth functioning of mechanical components by acting as a protective barrier between contacting surfaces. It not only minimizes friction and wear but also aids in dissipating the heat generated during operation. Two fundamental properties that determine the effectiveness of lubrication are viscosity and film thickness. When lubricants have low viscosity or when the lubricant film is too thin, the surfaces may come into direct contact [4]. This metal-to-metal interaction generates high dynamic loads, increases vibration, and accelerates component wear [5]. On the other hand, lubricants with excessively high viscosity or overly thick films can create additional fluid drag, lowering system efficiency and, in some cases, even influencing the resonance characteristics of machinery [6].

Dynamic loading in gears and bearings is primarily generated by the interaction of gear meshing forces, variations in bearing stiffness, and fluctuations in rotational speed. These loads give rise to vibration responses, which are commonly analyzed using parameters such as peak displacement, root mean square (RMS) vibration, and frequency spectra. Such vibration characteristics are widely used as indicators of machine health and overall

operational efficiency, offering valuable insights for condition monitoring and maintenance planning [1], [7]. Among the many influencing factors, lubrication plays a particularly important role. By altering the damping properties and the transmission of loads through the contact surfaces, lubrication directly shapes the vibration response of gears and bearings. However, despite the recognized importance of this relationship, the quantitative influence of lubrication on dynamic responses remains insufficiently addressed in existing research, leaving a gap for further investigation.

Mathematical modelling and simulation have become powerful tools for understanding the dynamic behaviour of mechanical systems under different lubrication conditions. In particular, single-degree-of-freedom (SDOF) models for gears and bearings that integrate lubrication-dependent damping provide valuable insights into how viscosity and film thickness influence both vibration and load distribution [8], [9]. Such models enable researchers and engineers to capture complex system responses that would be difficult to observe experimentally. Additionally, advanced visualization techniques enhance the interpretation of these simulations by pinpointing vibration hotspots and regions of critical load, which are essential for improving design reliability and implementing predictive maintenance strategies [10], [11].

Although lubrication in gears and bearings has been widely studied, much of the existing research tends to focus on either vibration characteristics or tribological performance in isolation. Vibration-based studies have provided insights into fault detection and dynamic responses [7], while tribological research has advanced understanding of friction, wear, and surface interactions under different lubrication modes [1], [5]. However, relatively few investigations have examined the combined, quantitative influence of lubricant viscosity and film thickness on both vibration behaviour and load distribution. This gap in knowledge makes it challenging to optimize lubrication strategies that balance dynamic performance with operational safety, especially in modern machinery operating under high-speed or high-load conditions [6]. This study aims to evaluate how lubrication viscosity and film thickness influences the dynamic behaviour of gears and bearings. By using MATLAB-based simulation and visualization tools, the goal is to identify the optimal lubrication parameters that can reduce vibration and mechanical stress, ultimately improving system reliability and performance.

MATERIALS AND METHODS

This study focuses on mechanical components; spur gear, rolling element bearing and lubricants. The study makes use of a MATLAB-based dynamic simulation framework that models the behaviour of gears and bearings using single-degree-of-freedom (SDOF) vibration systems, with damping effects influenced by lubrication. To gain a comprehensive understanding of system behaviour, both time-domain and frequency-domain analyses were carried out, allowing the vibration responses and load distributions to be quantified and compared.

System Mathematical Modelling

Gear Dynamics Model

The gear system was modelled as a single degree of freedom (SDOF) rotational system subjected to external torque and lubrication dependent damping [3]. The governing differential equation is:

$$J\ddot{\theta}(t) + C_{gear}\dot{\theta}(t) + k_{gear}\theta(t) = T_{input}(t) \tag{1}$$

Where:

J = Gear moment of inertia ($kg \cdot m^2$)

$C_{gear} = C_0 + \eta$ = Damping coefficient including lubrication viscosity ($Pa \cdot s$)

k_{gear} = Gear Stiffness ($N \cdot m/rad$)

$\theta(t)$ = angular displacement (rad)

$$T_{input}(t) = \text{Applied torque } (N - m)$$

Natural Frequency and Damping Ratio:

$$\omega_n = \sqrt{\frac{k_{gear}}{J}}, \zeta = \frac{C_{gear}}{2\sqrt{k_{gear}J}} \tag{2}$$

Vibration Response of the gear:

$$\theta(t) = \theta_0 e^{-\zeta\omega_n t} \sin(\omega_t t) \tag{3}$$

This shows how lubrication viscosity increases damping, reducing gear vibration amplitude.

Bearing Dynamic Model

The bearing was modelled as a linear SDOF translational system subjected to transmitted gear loads:

$$[2] m_b \ddot{x}(t) + C_b \dot{x}(t) + k_b x(t) = F_{load}(t) \tag{4}$$

Where:

m_b = Bearing mass (kg)

$C_b = C_b + \eta$ = Damping coefficient including lubrication effects

k_b = Bearing Stiffness (N/m)

$x(t)$ = Linear displacement

$F_{load}(t)$ = Dynamic Load from Gear (N)

Natural Frequency and damping Ratio:

$$\omega_{n,b} = \sqrt{\frac{k_b}{m_b}}, \zeta_b = \frac{C_b}{2\sqrt{k_b m_b}} \tag{5}$$

Vibration Response of the Bearing

$$x(t) = x_0 e^{-\zeta_b \omega_{n,b} t} \sin(\omega_{n,b} t) \tag{6}$$

Lubrication increases damping reducing oscillations and minimizing bearing fatigue (7)

Lubrication Effects on Damping

The dynamic load transmitted through gears and bearing depends on lubrication film thickness and viscosity:

$$F_{gear} = K_g \frac{\eta}{h_f}; F_{bearing} = K_b \frac{\eta}{h_f} \tag{8}$$

Where:

K_g, K_b = are proportionality constant depending on gear speed, geometry and bearing properties

η = lubrication viscosity

h_f = lubrication film thickness

This simple model captures the inverse relationship between film thickness and transmitted load [6].

Vibration Parameters

This study evaluates peak and RMS vibration amplitudes:

Peak Vibration

$$V_{peak} = \max\{\theta(t) \text{ or } x(t)\} \quad (9)$$

RMS Vibration

$$V_{RMS} = \sqrt{\frac{1}{T} \int_0^T \theta^2(t) dt} \quad \text{or} \quad \sqrt{\frac{1}{T} \int_0^T x^2(t) dt} \quad (10)$$

These parameters quantify dynamic behaviour as a function of lubrication variable

RESULTS AND DISCUSSIONS

The table identified as Table 1 below highlight the parameters deployed for the simulation analysis

Table 1: Simulation Analysis Parameters

Parameters	Values/Units
Gear speed	1000 rpm
Number of gear teeth	30
Gear module	0.01 m
Gear inertia	0.01 kg·m ²
Bearing stiffness	1×10 ⁶ N/m
Bearing damping	50 N·s/m
Bearing mass	2 kg
Lubricant viscosity range	0.01 – 0.1 Pa·s
Lubrication film thickness range	1×10 ⁻⁶ – 1×10 ⁻⁵ m
Time vector	0 – 5 (1000 points) s

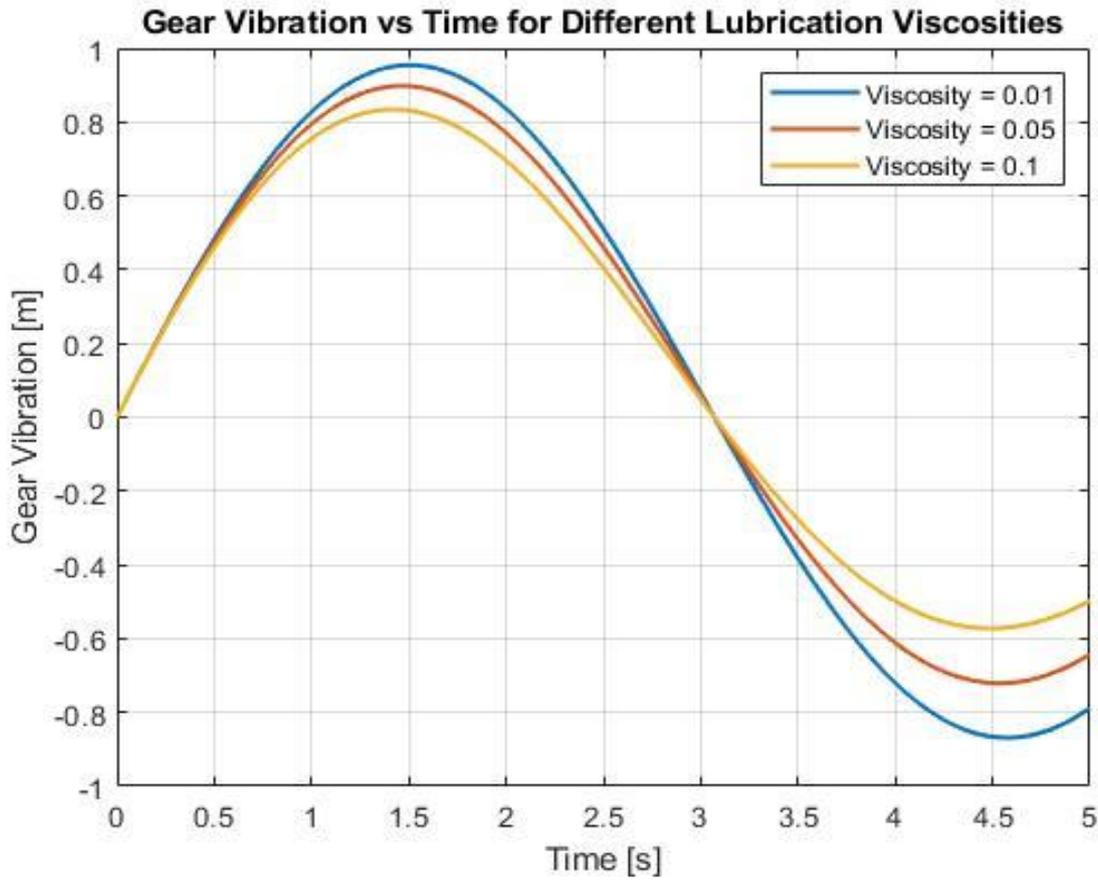


Figure 1: Gear Vibration against Time for Different Lubrication Viscosity

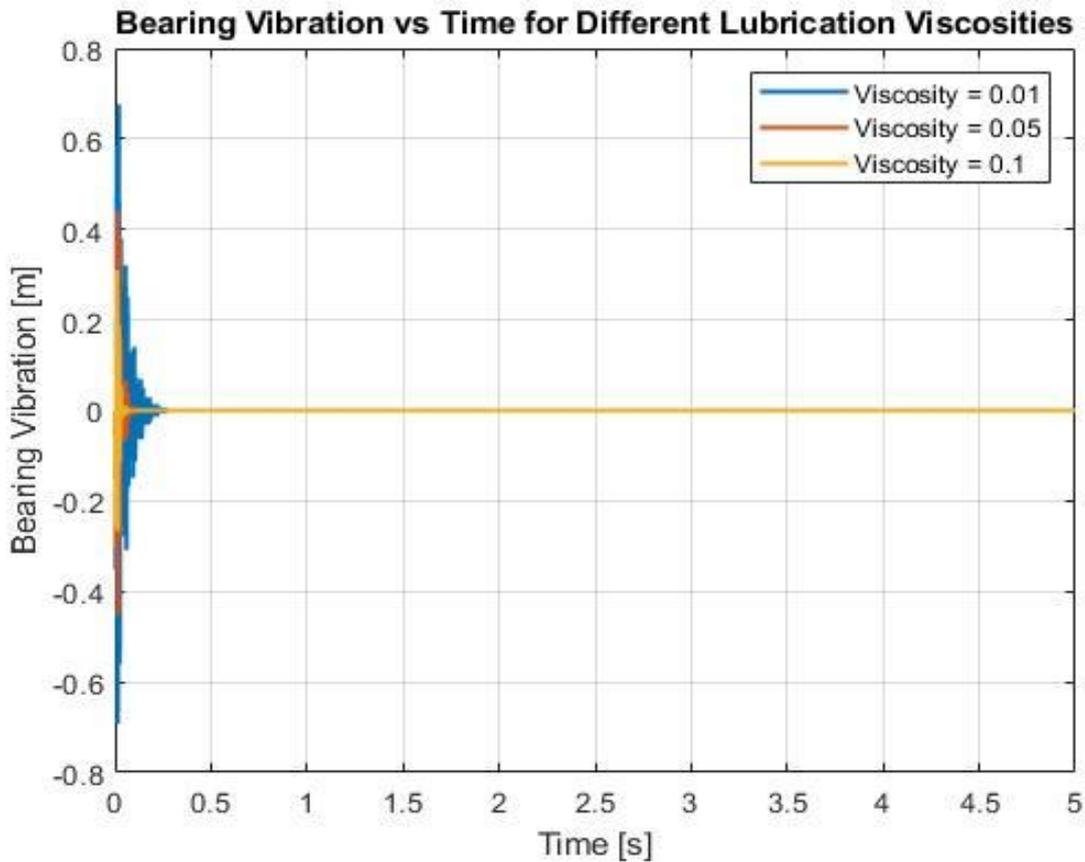


Figure 2: Bearing Vibration against Time for Different Lubrication Viscosity

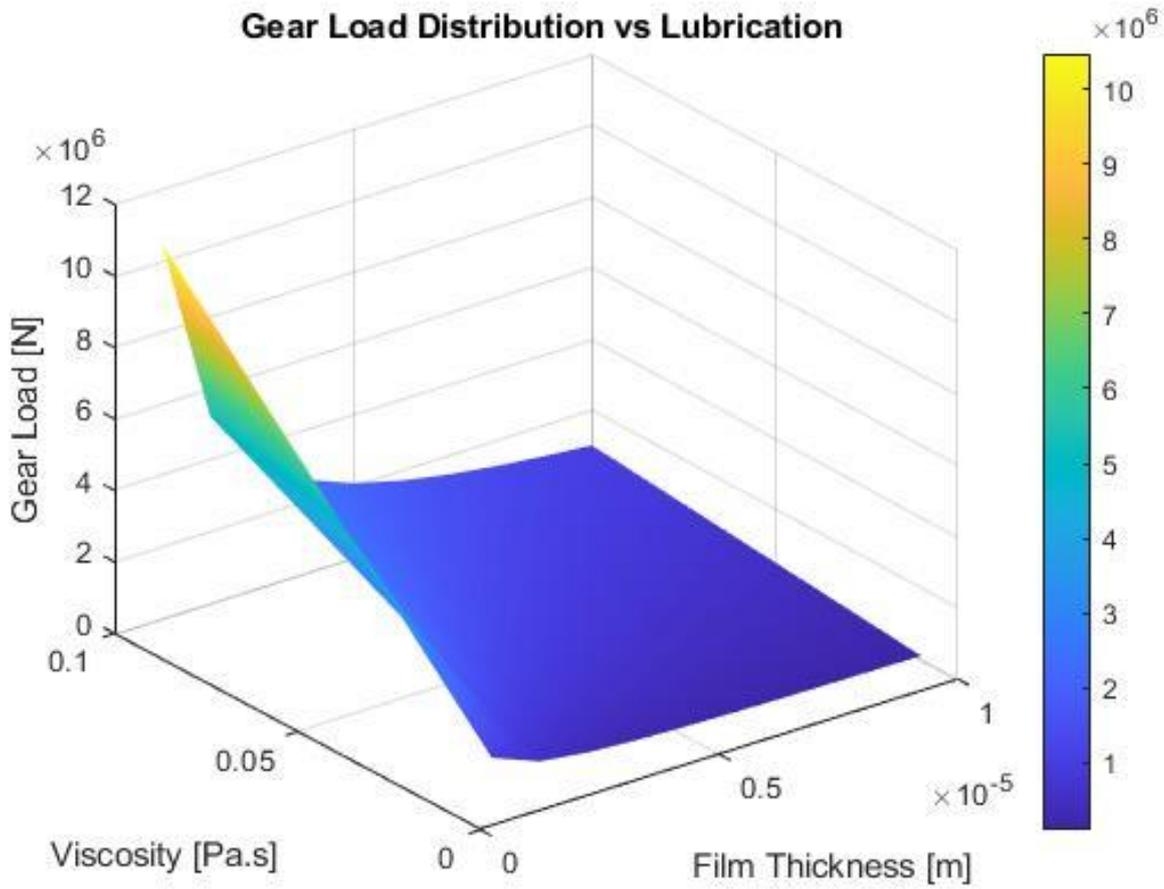


Figure 3: Gear Load Distribution against Lubrication

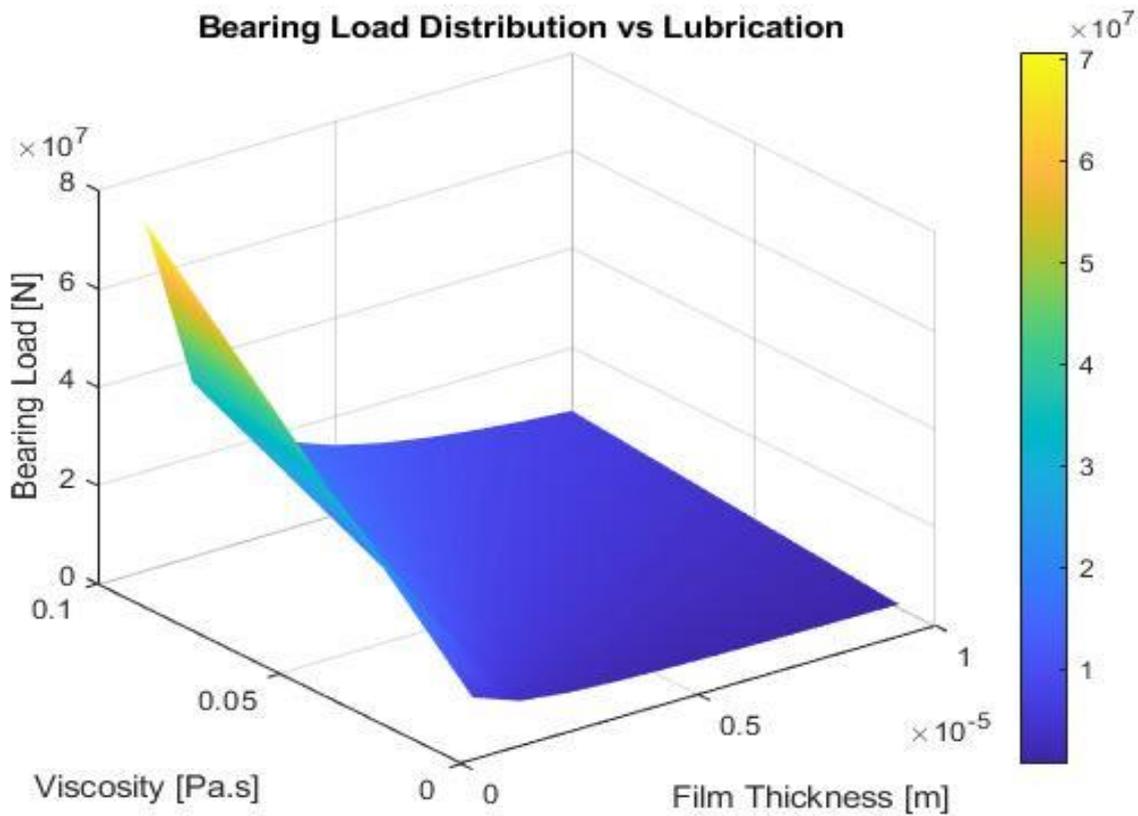


Figure 4: Bearing Load Distribution against Lubrication

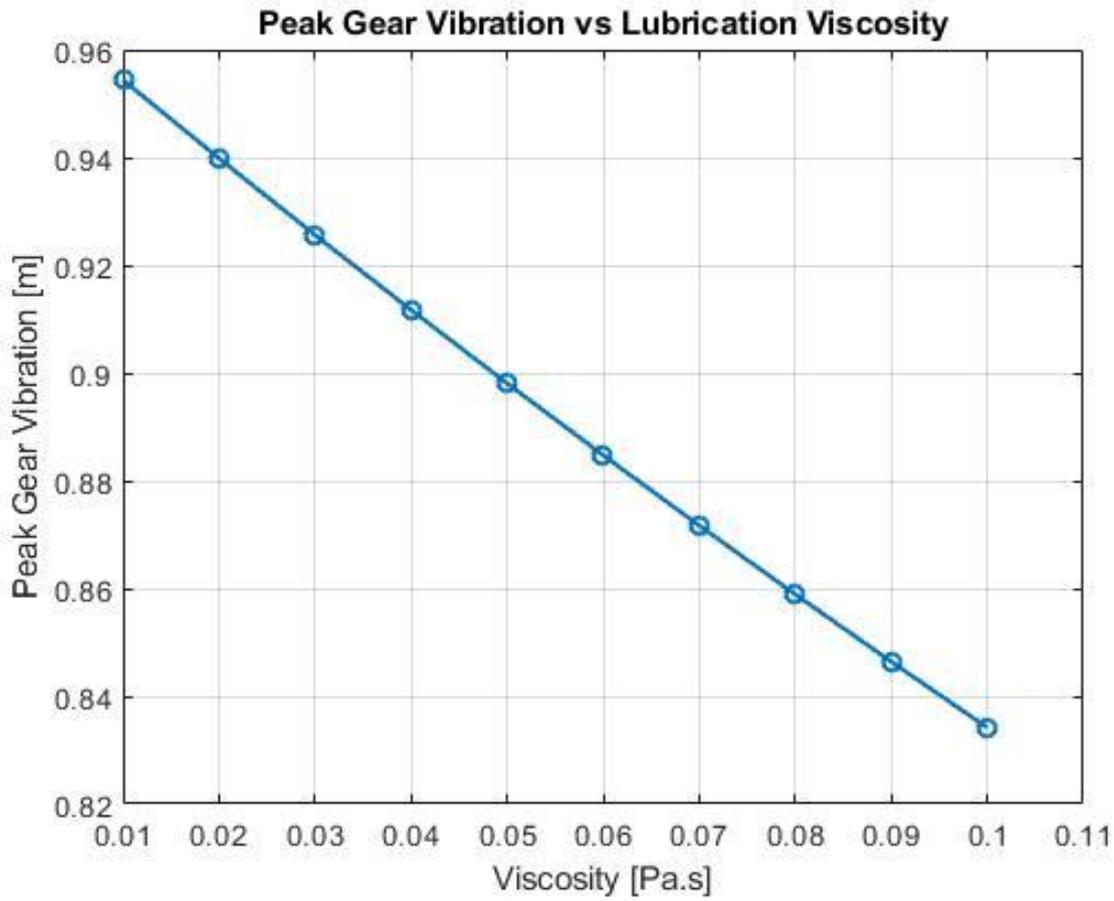


Figure 5: Peak Gear Vibration against Lubrication Viscosity

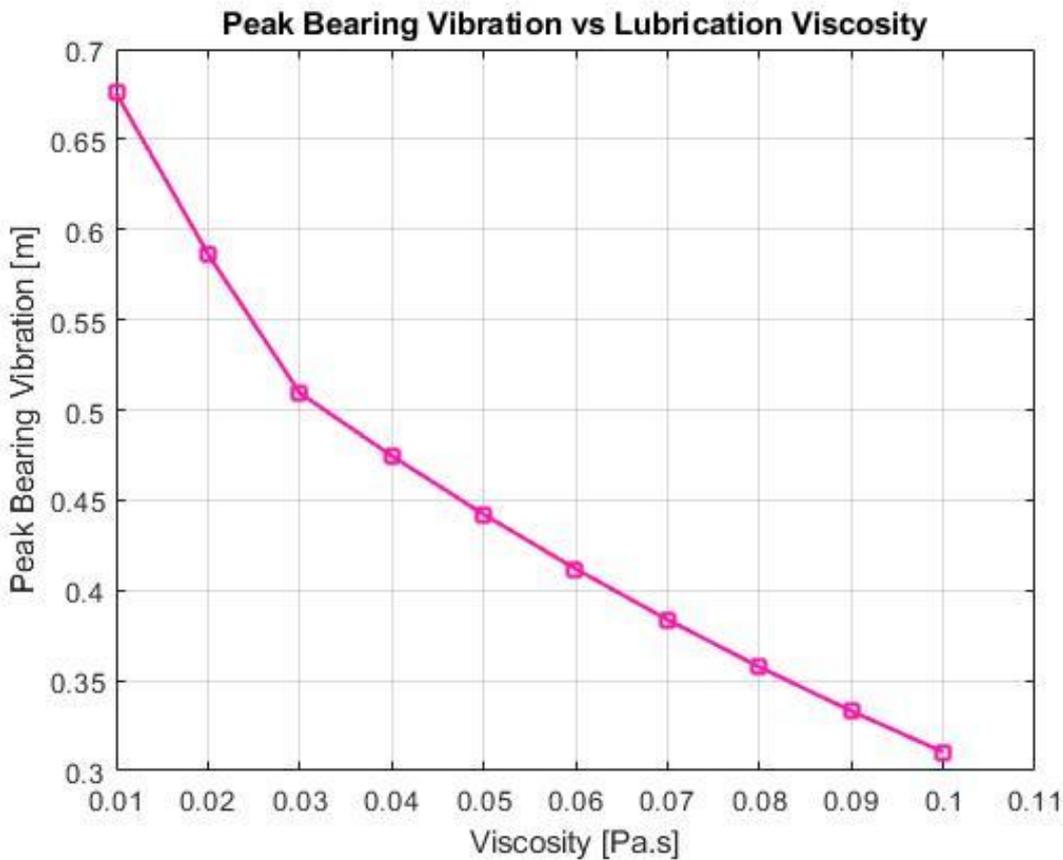


Figure 6: Peak Bearing Vibration against Lubrication

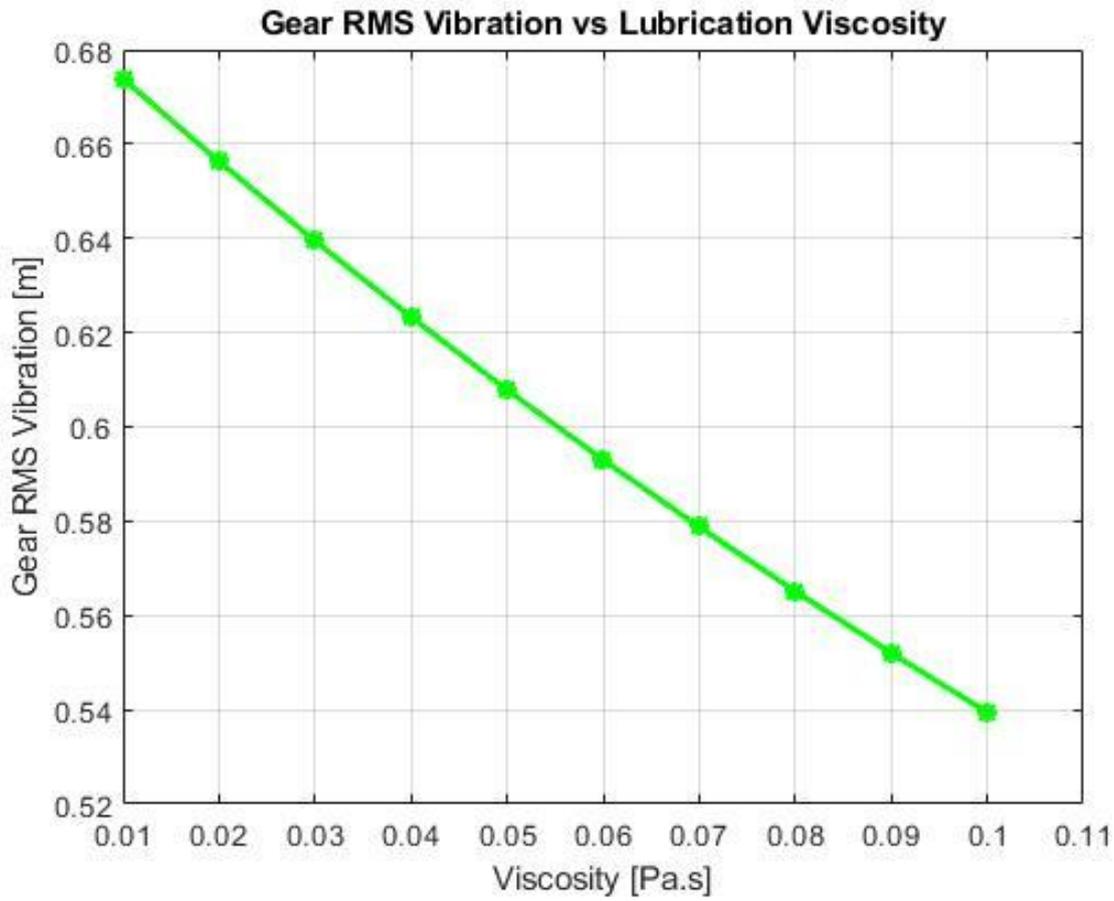


Figure 7: Gear RMS Vibration against Lubrication Viscosity

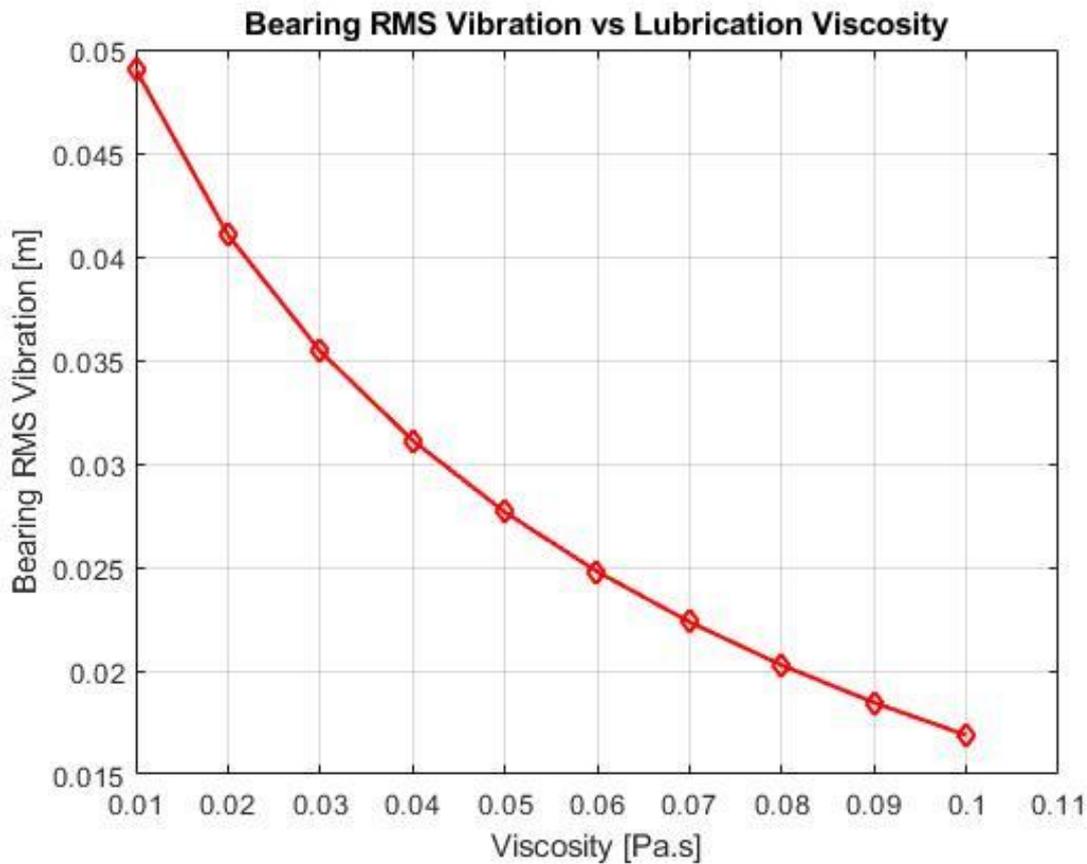


Figure 8: Bearing RMS Vibration against Lubrication Viscosity

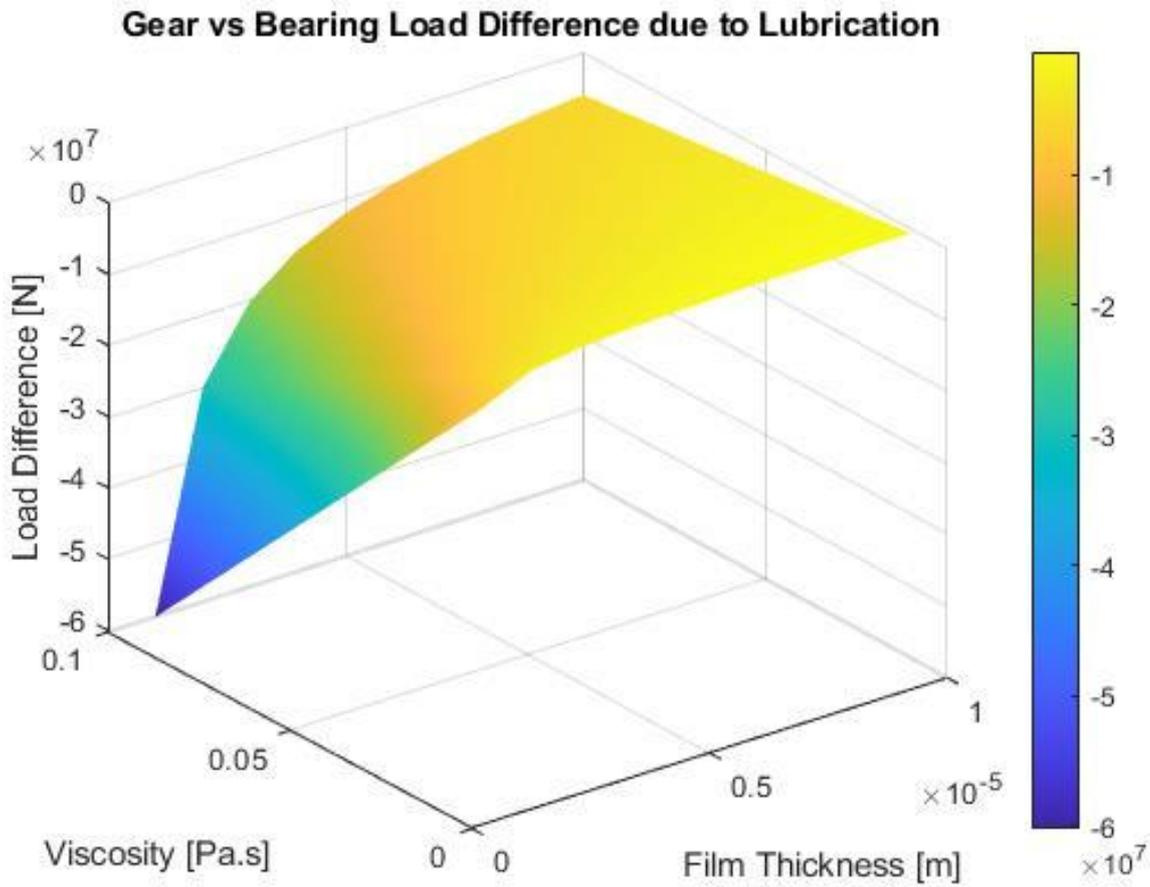


Figure 9: Gear against Bearing Load Distribution due to Lubrication

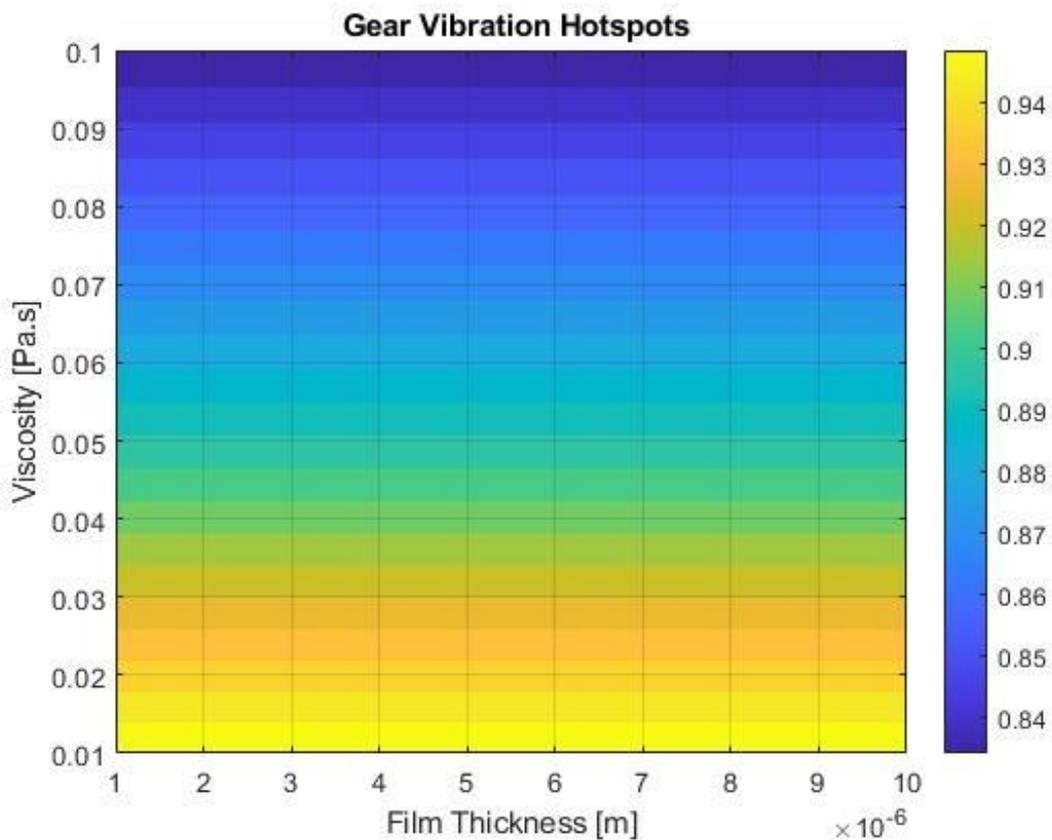


Figure 10: Gear Vibration Hotspots

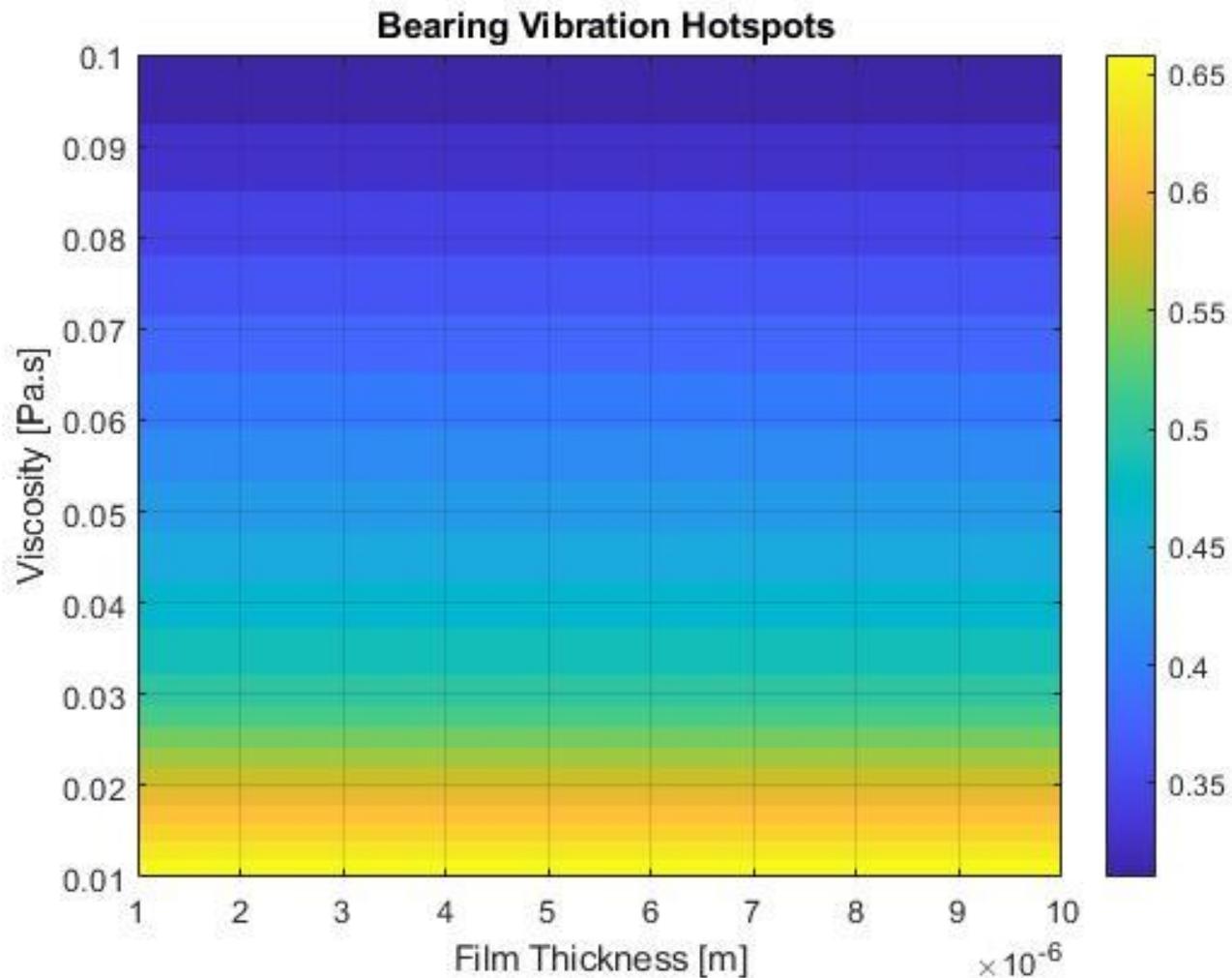


Figure 11: Bearing Vibration Hotspots

Evidently, from the Figure 1, it can be construed that the gear vibration response is a damped sinusoid. As lubrication viscosity increases, the damping ratio increases, reducing vibration amplitude over time. Higher viscosity lubricants significantly reduce gear vibration amplitude, improving dynamic stability. Figure 2 demonstrate bearing vibration response, from the result higher viscosity reduces oscillations but at slightly slower decay compared to gear vibration due to the bearing damping ratio. Therefore, higher lubrication viscosity helps Bearings, excessive vibration mitigation, enhances operational longevity. In Figure 3 Gear load is remarked to increase as film thickness decreases, for a given viscosity. Load is more sensitive to thin lubrication films due to reduced fluid separation. Proper lubrication film thickness is critical: too thin increases gear load dramatically, risking wear. Figure 4 shows also for gears that thinner films result in higher dynamic loads. Bearings show slightly lower absolute load values due to lower stiffness compared to gears.

Maintaining adequate film thickness prevents overloading and potential bearing failure. Figure 5 indicates that Peak vibration decreases monotonically with increasing viscosity. It proves that viscosity is a key variable in controlling peak gear vibrations. In addition, in Figure 6, peak bearing vibration shows a similar decreasing trend. Lubrication designers must consider bearing damping benefits; optimal viscosity reduces peak vibration and mechanical stress. For Figure 7, RMS vibration provides a measure of overall energy in the vibration signal. Energy in gear vibration is significantly reduced with higher viscosity, indicating smoother operational dynamics. Also, in Figure 8, RMS vibration of bearing shows similar trend, slightly lower than gears due to damping and mass differences. This indicates bearings' vibration energy is effectively mitigated with proper lubrication, reducing wear and noise.\

In Figure 9, difference between gear and bearing loads shows relative stress. Maximum load difference occurs at low film thickness and high viscosity. Lubrication optimization reduces extreme load differences, preventing gear-bearing mismatch failures. While for Figure 10, the observed contours show regions of high vibration

amplitude at low film thickness and low viscosity. This helps to identify operating regions where gears are most vulnerable to vibration; design lubrication can target these hotspots. And, for Figure 11, Peak vibrations occur in low viscosity, thin film regions. Bearings are highly sensitive to inadequate lubrication; contour plots provide clear visual guidance for preventive maintenance and lubricant selection.

CONCLUSION

This study offers valuable quantitative insights for choosing the right lubrication, highlighting how optimizing both viscosity and film thickness can significantly improve the lifespan of gears and bearings while ensuring safer operation. Choosing the right lubricant viscosity and ensuring sufficient film thickness are vital to minimizing vibrations and loads in gears and bearings. Using contour and 3D plots, the study provides practical insights that support design improvements and help plan effective preventive maintenance strategies.

REFERENCES

1. Harris, T. A. & Kotzalas, M. N. (2007). *Rolling Bearing Analysis*, 5th ed., CRC Press, Boca Raton, FL, USA.
2. Randall, R. B. & Antoni, J. (2011). Rolling element bearing diagnostics: A tutorial, *Mechanical Systems and Signal Processing*, vol. 25, no. 2, pp. 485–520.
3. Hamrock, B. J., Schmid, S. R. & Jacobson, B. O. (2004). *Fundamentals of Fluid Film Lubrication*, 2nd ed., Marcel Dekker, New York, NY, USA
4. Cameron, A. (2013). *Basic Lubrication Theory*, 3rd ed., Ellis Horwood, Chichester, U.K.
5. Hamrock, B. J., Schmid, S. R. & Jacobson, B. O. (2004). *Fundamentals of Fluid Film Lubrication*, 2nd ed., Marcel Dekker, New York, NY, USA.
6. Stachowiak, G. W. & Batchelor, A. W. (2013). *Engineering Tribology*, 4th ed., Butterworth-Heinemann, Oxford, U.K.
7. Randall, R. B. & Antoni, J. (2011). Rolling element bearing diagnostics: A tutorial, *Mechanical Systems and Signal Processing*, vol. 25, no. 2, pp. 485–520.
8. Gupta, A. K. & Singh, R. (2020). Effect of lubricant properties on gear dynamics: A single-degree-of-freedom model approach, *Mechanism and Machine Theory*, vol. 145, pp. 103–118.
9. Zhang, Y., Zhu, J. & Houser, L. (2021). Dynamic modeling of bearing systems with lubrication effects under variable operating conditions, *Tribology International*, vol. 152, pp. 106–118.
10. Li, H., Wu, X. & Noor, M. (2021). Visualization of vibration characteristics in gear systems for predictive maintenance, *Journal of Vibration and Control*, vol. 27, no. 11-12, pp. 1394–1408.
11. Kumar, P., Bhosale, S. & Reddy, D. (2022). Advanced simulation and visualization methods for tribodynamics in rotating machinery, *Mechanical Systems and Signal Processing*, vol. 170, p. 108–193.