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Development of an Electro Tribological Instrument to Examine the Deterioration of the Robot- Bearing

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ABSTRACT: The increasing electrification of robotic systems poses significant tribological challenges, particularly for bearing components. This study investigates the impact of direct current (DC) on the wear behaviour and tribological characteristics of robotic bearing systems. Experiments were conducted using a Ball-on-Disc tribometer under various DC current levels, lubrication conditions, and loading parameters. Results indicate that DC current significantly influences electrical impedance, friction coefficient, and wear scar diameter. Increased current intensity reduces impedance due to diminished lubricant viscosity and enhanced metal-to-metal contact. Friction initially decreases at moderate currents due to electrostatic repulsion but increases at higher currents due to electrostatic breakdown. Wear scar analysis reveals a decrease in scar diameter with increasing current, attributed to oxide layer formation. While load was found to be a significant factor influencing wear loss, the effects of sliding speed and current on wear and friction were less pronounced. These findings provide crucial insights into the tribological mechanisms in electrified robotic systems and highlight the need for optimized load and lubrication conditions to improve component durability.

KEYWORDS: Robotic Bearings, Electro-Tribology, Electrical Impedance, DOE Optimization

I. INTRODUCTION

The integration of advanced energy technologies, such as robotics and automation, has led to specific tribological challenges, especially in bearing performance and reliability [1, 2, 3]. Bearings, as critical components in robotic joints, are responsible for a significant portion of system failures—estimated at around 60%—often due to wear and electrical discharge damage (EDD). The increased use of Variable Frequency Drives (VFDs) in robotic actuators has amplified the incidence of premature bearing failures caused by stray electric currents [4].

The historical issue of bearing damage from electrical currents dates back to the 1920s with the discovery of "fluting" marks on ssssssssscoated bearings, initially helped mitigate these effects [6]. However, high-frequency Pulse Width Modulation (PWM) inverters, now widely used in robotic systems, have introduced new challenges. Rapid voltage fluctuations cause substantial voltage differentials between the motor shaft and casing, rendering traditional solutions less effective [7]. In robotic systems, the interaction between high-speed rotating shafts and bearings increases susceptibility to stray currents, posing risks to component longevity [8, 9].

Recent advancements in tribology tools, including DC-enabled tribometers, have enabled precise measurements of friction, wear, and electrical impedance in robotic bearings under various current levels. Understanding the effects of DC currents on tribological behavior is essential to improving bearing life and optimizing performance. Research shows that electrical factors affect lubricant film thickness and tribological performance, highlighting the importance of studying these interactions [10, 11].

This study focuses on examining the impact of DC currents on wear and friction under different lubrication and load conditions. By measuring impedance alongside wear and friction, we aim to gain insights into the effects of electrical stress on bearing surfaces. Developing an electrified bearing test methodology is essential for advancing modern robotic applications where electrical influences on bearing health and performance are increasingly relevant.

II. EXPERIMENTATION

To investigate the influence of electrified environments on the friction and wear behaviour of ball bearings, a standard Ball-on-disc tribometer conforming to ASTM G99 was employed. The tribological pair was insulated using a carbon bush on the disc and fiber material on the ball holder to prevent electrical interference [12]. Experiments were conducted under both dry and lubricated conditions. This insulation was implemented to mitigate potential damage to the test apparatus caused by stray currents generated during electrified pin-on-disc testing. 100Cr6 bearing steel balls were paired with En31 discs and subjected to the parameters illustrated in Table 1. A Schneider servo motor controls disc speed, and all testing was performed under ambient conditions [13].

To simulate the potential exposure of electric vehicle bearings to stray currents, a ball-on-disc arrangement was electrified using a Testronix 36C DC power supply. Given that electric vehicle bearings may experience stray currents ranging from 0.2A to 1.4A, this study investigated current intensities from 50mA to 1.5A [14]. As outlined in Table 1, experiments were conducted at three discrete current levels: 50 mA, 750 mA, and 1500 mA [15].

Fig No 1: Electrified Ball on Disc Setup

III. RESULTS AND DISCUSSION:

A. Effect of current on the electrical Impedance:

This section explores the influence of DC current on the electrical impedance of the tribological system. Both transmission and mineral oils exhibited a decreasing trend in impedance with increasing current intensity Fig No 2. This behaviour can be attributed to the heating effect of the current, which reduces lubricant viscosity and consequently its load-bearing capacity. This leads to increased metal-to-metal contact between the tribological surfaces, resulting in a lower overall impedance. Interestingly, even under dry conditions (without lubrication), a similar decrease in impedance was observed with increasing current Fig No 2. The electrical impedance values displayed minimal variation throughout the 600-second test duration for all tested conditions (transmission oil, mineral oil, and dry). This suggests a relatively stable electrical response within the parameters explored.

Detailed Impedance Measurements:

Mineral Oil: At 50mA, the initial impedance was 27 ± 6 ohms, indicating minimal variation. As current intensity increased to 750mA and 1.5A, the impedance values progressively decreased to 0.75 ± 0.15 ohms and 0.3 ± 0.15 ohms, respectively. This trend signifies a weakening of the lubricant film with increasing current.

Table No 1 Selected Process Parameter for testing of the Electrical impedance, Wear loss and COF

Sl No	**Parameters**	**Level 1**	**Level 2**	**Level 3**
1	Sliding Speed	100 m/s	1000 m/s	2000 m/s
2	Current	50 mA	750 mA	1500 mA
3	Load	10 N	30 N	..
4	Condition	Dry	Lubricated	

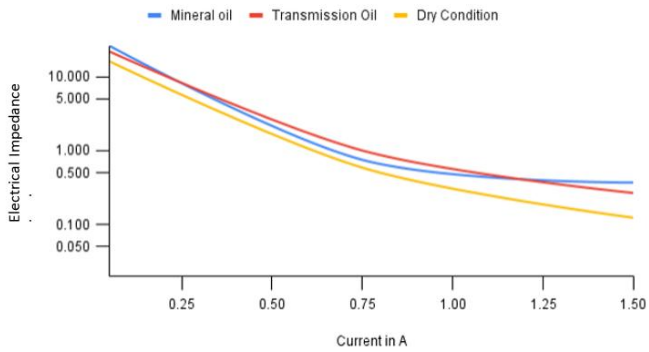

Fig No 2 Electrical Impedance variation of the Transmission Oil, Mineral Oil and Dry Condition With respect to the current

Transmission Oil: Similar to mineral oil, transmission oil displayed a decreasing impedance trend with increasing current. At 50mA, the initial impedance was 21.5 ± 2.5 ohms. This value dropped to 0.9 ± 0.2 ohms at 750mA and further decreased to 0.25 ± 0.1 ohms at 1.5A, suggesting a similar breakdown of the lubricant film.

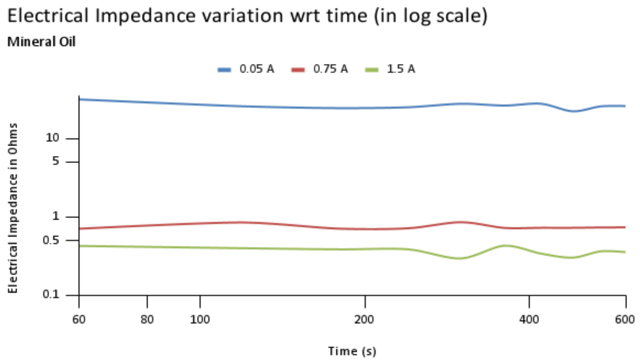

Fig No 3 Electrical Impedance variation for different current intensities with respect to time in Mineral oil Lubricated condition

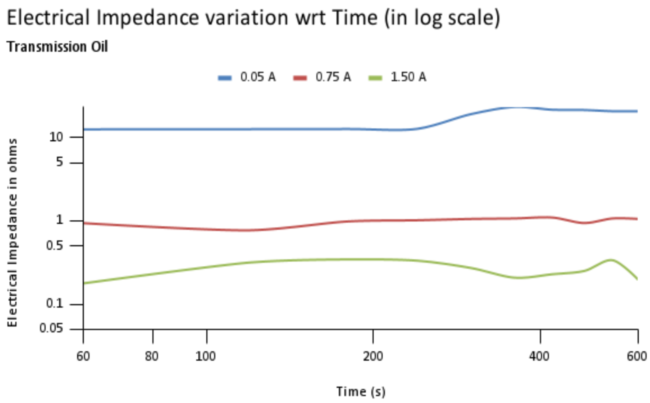

Fig No 4 Electrical Impedance variation for different current intensities with respect to time in Transmission oil Lubricated condition

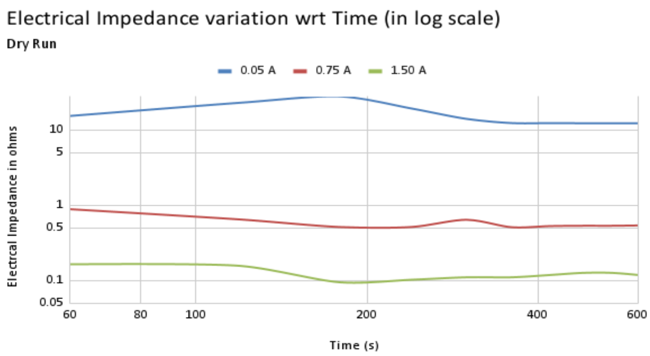

Fig No 5 Electrical Impedance variation for different current intensities with respect to time in Dry Condition

Dry Condition: Under dry conditions, the initial impedance at 50mA was 9.5 ± 2 ohms. This value reflects the electrical resistance offered by a potential oxide layer formed due to wear debris [16]. This oxide layer could explain the observed decrease in the coefficient of friction for the 50mA dry run compared to the completely dry condition, as depicted in Fig No 6. Notably, increasing the current to 750mA and 1.5A further reduced the impedance to 0.7 ± 0.2 ohms and 0.125 ± 0.05 ohms, respectively. This convergence of impedance values across lubricated and dry conditions suggests a potential breakdown of the lubricant film at higher currents, leading to increased metal-to-metal contact. This phenomenon can be a valuable indicator for monitoring lubricant film integrity in electrified robotic bearings.

In conclusion, the analysis reveals a significant influence of DC current on the electrical impedance of the tribological system. The observed decrease in impedance with increasing current points towards a weakening of the lubricant film and a transition towards metal-to-metal contact. This information provides valuable insights into the lubrication behaviour of robotic bearings in electrified environments.

B. Effect of current on friction coefficient and wear scar:

Friction and wear coefficients are primary parameters in tribology. This study investigated the influence of varying current levels on these parameters. Initially, tribo-pairs were tested without applied current. Friction coefficients were measured as 0.07, 0.13, and 0.49 for mineral oil, transmission oil, and dry conditions, respectively, with reference to Fig. 5: Friction Coefficient with respect to the Current under dry and Lubricated (Transmission oil and mineral oil) Condition. Corresponding wear scar diameters were 0.57, 0.30 mm, and 0.79 mm for the mineral oil, transmission oil, and dry conditions, respectively.

Subsequently, wear scar diameters were determined for current levels of 50 mA, 750 mA, and 1500 mA, and the results are presented in Fig No 7. With reference to Fig No 6, It is observe that the average frictional force in dry conditions increases to 5.44 N from 4.89 N upon the application of 50 mA of current, and at 750 mA, the mean frictional force decreases to 2.94 N. This decrease in frictional force is attributed to the electrostatic repulsion experienced by the tribo-pairs due to the accumulation of similar charges on both tribo-surfaces. Further, the mean frictional force increases to 5.21 N on applying 1.5 A of current to the tribo-pairs, accounting for electrostatic breakdown, which reduces the repulsion and increases the frictional force. This trend is observed across all lubricated scenarios depending on the lubricant nature.

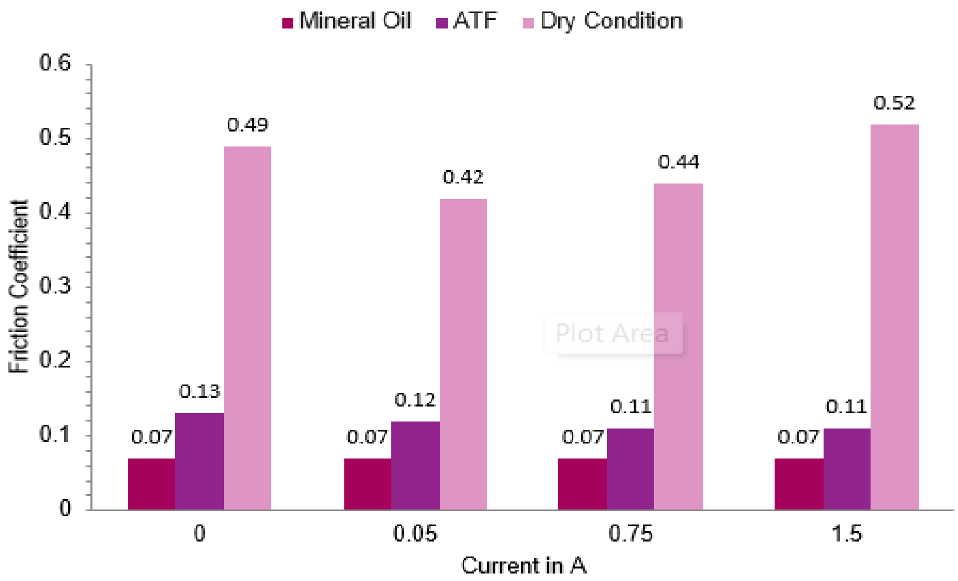

Fig No 6 Friction Coefficient Variation with respect to the Current

Wear scar diameter decreases to 0.49 mm from 0.79 mm (wear scar at 0 A) under dry conditions upon the application of current, as shown in Fig No 7. This phenomenon is due to the oxide layer formation between the tribo-pairs, which reduces friction and wear scar size [16].

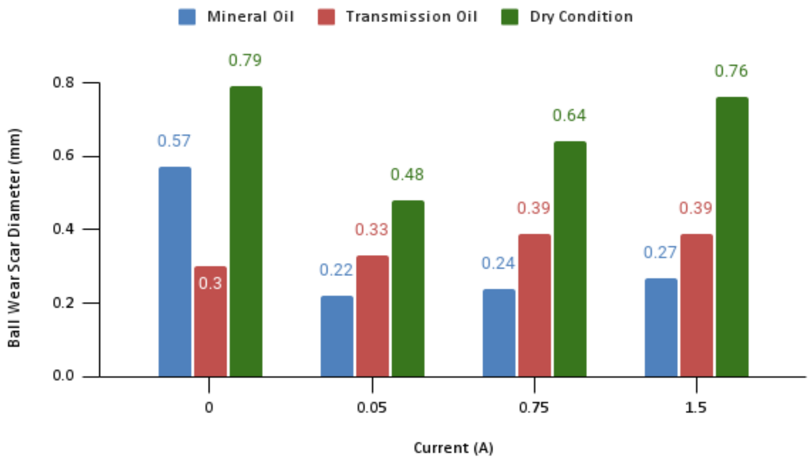

Fig No 7 Ball wear Scar Diameter variation with respect to the current

IV. CONCLUSION

This study investigated the impact of various experimental parameters, including sliding speed, current, load, and lubrication condition, on the electrical impedance, coefficient of friction (COF), and wear loss of a tribological system. The analysis revealed that while load exhibited a significant influence on wear loss, the other parameters, including sliding speed, current, and lubrication condition, had limited impact on the measured tribological properties within the tested range. Electrical impedance remained relatively stable across different conditions, suggesting a lack of significant sensitivity to the tested parameters. Similarly, the COF was found to be largely unaffected by variations in sliding speed, current, and load. However, a potential influence of load on COF cannot be entirely ruled out, as indicated by a marginally significant p-value. The significant impact of load on wear loss highlights its critical role in determining the tribological performance of the system. While the interaction between sliding speed and current showed a trend towards significance, further investigation is required to confirm its true influence. To gain deeper insights into the complex interplay between these factors, future research should consider expanding the parameter range, employing advanced statistical modeling techniques, and exploring alternative experimental designs. This comprehensive approach will enable a more accurate assessment of the tribological behavior and the identification of potential synergistic effects between the various parameters.

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