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Operating characteristics of bearings with magnetic nanoparticles doped lubricant

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Abstract:

The main aim of the presented research was to investigate the operational characteristics of a bearing when alternative lubricants were used for comparison with a standard lubricant, including that containing magnetic nanoparticles. The bearing was subjected to varying operating conditions, differing in terms of mechanical load status. The monitoring of the bearing operation parameters primarily focused on monitoring the velocity and acceleration of vibrations, as well as the operating temperature of the bearing. The bearing with lubricant doped by magnetic nanoparticles exhibited reduced vibration velocity and acceleration values both under no load conditions and when subjected to a mechanical load. The operating temperature slightly increased during testing in the case of the bearing with nanoparticles compared to the bearing using the original lubricant.

Keywords: lubricant, magnetic nanoparticles, bearing, vibration

1. Introduction

The doping of nanoparticles as additives in lubricants can enhance their performance in various applications, such as the automotive industry, aerospace industry, heavy machinery and mining sector, producing so-called magnetic lubricants, or fluids [1-3]. Nanoparticles have the potential to improve wear resistance, reduce friction, and enhance lubrication properties. The advantageous properties of magnetic lubricants find numerous applications, and it is likely that their utilization within electromechanical devices is also promising [4]. Magnetic fluids are used in hydrodynamic bearings where they provide enhanced capacity and vibration damping [5]. Additionally, they reduce fluid leakage serving as a sealing mechanism [6].

Sealing with magnetic fluids offers significant advantages over seals made of solid materials. In comparison to conventional seals, like rubber parts on a shaft, magnetic fluid seals do not involve any friction between solid components, thereby eliminating the generation of particles from worn seals [7]. Magnetic seals can be utilized in dynamic applications, where, for example, a rotating shaft is sealed. In static applications, they seal mutually immobile components or parts [8].

The production of magnetic solutions typically involves a physicochemical process based on prolonged mechanical grinding of ferromagnetic particles, most commonly magnetite or ferrite, in the presence of a suitable surfactant. Subsequently, coarser particles are separated via centrifugation, a method known as wet grinding. However, this technique suffers from the drawback of being time-consuming, taking approximately 1,000 hours. To address this limitation, a faster and simpler method based on co-precipitation of metal salts in an aqueous solution is utilized [9, 10]. The size of the magnetic particles significantly influences the properties of magnetic fluids, necessitating the use of different magnetic fluids with distinct particle sizes in various industrial applications. For instance, larger particles that act as pure dipoles are required for optical applications, while small superparamagnetic particles are needed for NMR imaging.

The stability of a magnetic fluid depends on maintaining consistent chemical and physical properties throughout its volume. Achieving stability relies on a dynamic balance of several factors influencing the uniform dispersion of magnetic particles throughout the lubricant. These factors include the impact of thermal movement, magnetic moment, and stabilizing components [11, 12].

Thermal movement of molecules counteracts their spontaneous aggregation. However, at room temperature, it is often insufficient to compensate for dipole interactions, leading to particle aggregation. To prevent particles from approaching a critical distance, stabilizing additives are introduced. As the position of magnetic particles in the liquid is not fixed but subject to Brownian motion, interactions of their magnetic moments become enhanced, resulting in particle attraction and spontaneous aggregation, which is an undesirable phenomenon for magnetic lubricant stability. The aggregation is limited by the closest distance at which particles can approach each other. The potential energy decreases as the distance decreases, reaching its minimum value when particles come into contact. A surfactant, being an amphiphilic molecule with polar and non-polar parts, plays here a vital role. In a non-polar environment, the presence of a surfactant enhances the solubility of magnetic particles and stabilizes them. The surfactant forms a monomolecular layer on the particle's surface, with its polar part oriented towards the particle and its non-polar part interacting with the non-polar solvent. In a polar environment, a second layer is required, with the non-polar part oriented towards the non-polar part of the first layer and the polar part interacting with the carrier liquid. This arrangement effectively increases the minimum distance at which two coated particles can approach each other, preventing particle aggregation [13]. The surfactant's monomolecular and bipolar bilayer acts as a spherical barrier in the interaction of the magnetic moments of the particles and hinders particle aggregation. The bipolar double layer carries a group of charges on its surface, contributing to the electrostatic repulsion of the coated particles.

Whereas the usage of ferrofluids in hydrodynamic bearings offers several advantages, including increased bearing capacity and vibration damping, reduced fluid leakage, and the bearing functioning as a seal [14, 15] the primary objective of the presented research is to investigate the operational

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characteristics including vibration and temperature of the common type of bearing when employing a lubricant containing magnetic nanoparticles as an alternative to the standard lubricant.

2. Experimental materials and methods

The lubricant containing nano-additives was synthesized at the IEP SAS in Kosice, comprising three primary constituents. The first component is a commercially available lubricant, SKF LGWA 2/0.2. The second component consists of magnetite nanoparticles coated with a layer of oleic acid, which constitutes the third component of the magnetic lubricant.

The preparation of the magnetic lubricant involved a three-step process (Fig. 1). Within the initial step, magnetic nanoparticles were synthesized using the chemical co-precipitation method. A solution containing ferrous Fe^{2+} ($FeSO_4.7H_2O$) and ferrous Fe^{3+} ions ($FeCl_3.6H_2O$) in a molar ratio of 1:2 was heated to 80°C. Addition of ammonium hydroxide to this solution led to the precipitation of iron ions and the formation of magnetite nanoparticles.

The second step involved the coating of the precipitated nanoparticles with oleic acid surfactant at a temperature of 82°C. Chemisorption of oleic acid molecules occurred on the nanoparticle surfaces, creating a spatial barrier between the particles, with a thickness of approximately 4 nm. The coated nanoparticles underwent multiple washing steps with distilled water and acetone to eliminate unreacted salts and unbound oleic acid residues. During washing, magnetic decantation with the use of a magnet was employed to separate and retain the magnetic nanoparticles, while the non-magnetic residue was removed by pouring out.

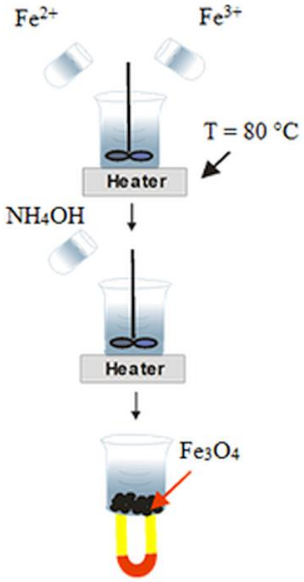

Fig. 1. Principle of magnetic nanoparticles synthesis by chemical co-precipitation

In the third preparation step, the pure SKF LGWA 2/0.2 lubricant was mixed with the coated nanoparticles. The two components were mixed in a 1:1 ratio at a temperature of 70°C until a homogeneous nanocomposite was achieved [2, 16].

To assess the performance of the lubricants, SKF 6205 ETN9 bearings were chosen [17]. Experiments were conducted at the laboratory stand (Fig. 2) of the Centre for Testing and Monitoring of Technical Systems at the Faculty of Manufacturing Technologies, Technical University of Kosice [18, 19]. The bearing was mounted using a steel intermediate piece to the output shaft of the SIEMENS 1LA7090-2AA10-Z electric motor with a power of 1.5 kW/50 Hz and a maximum rotational speed of 3000 rpm.

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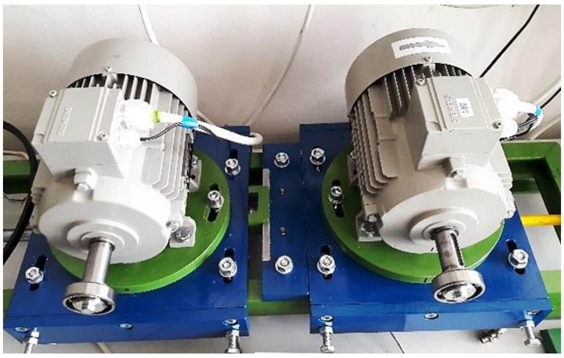

Fig. 2. Test bearings mounted on the experimental stand

Three types of bearings were subjected to testing. The first set of bearings consisted of those with the original lubricant applied during the manufacturing process. For the second set of bearings, a magnetic lubricant weighing 1.5 g was used. Prior to the application of the magnetic lubricant, the original bearings underwent a dismantling process to remove the bearing cage, followed by a degreasing bath to eliminate the original lubricant [20]. Subsequently, the magnetic lubricant was applied to the bearings, and after reassembling the bearing cage, the bearings were securely affixed to the test stand, ready for testing.

3. Experimental results

The bearing lubricated with the manufacturer's standard lubricant was assessed under the following conditions: without load and with a 30 kg load at a constant speed of 3000 rpm. When measured without the load, the CMMS Checker device recorded effective value of vibration velocity values of approximately 20 mm/s on both stands. The vibration acceleration in the unloaded bearings averaged around 6.8 g. Upon loading the bearings, the vibration velocity values decreased by an average of 64.5%. The vibration acceleration with a loaded bearing on the M1 engine decreased by 46.9%. However, for the M2 engine, the vibration acceleration increased by 0.6 g. The vibration velocity observed was likely due to the slightly unbalanced output shaft of the electric motor, which diminished after applying a 30 kg weight load on both stands.

A comparison of the bearings containing original and magnetic lubricant showed distinct behaviours of velocity and acceleration of vibrations as depicted in Table 1. The measured average vibration velocity for unloaded bearings was 47.5% lower for the bearing with magnetic lubricant than for the bearing with the original lubricant. As for vibration acceleration values, the bearing with magnetic lubricant exhibited lower values by 81.25% compared to the bearing with the original lubricant.

Table 1. Comparison of the vibrations of the bearing with original lubricant, with SKF LGWA 2/0.2 lubricant and the LGWA 2/0.2 lubricant doped with magnetic nanoparticles

	Velocity [mm/s]	Acceleration [g]
Original lubricant from the manufacturer without load	20.4	6.4
Original lubricant from the manufacturer with load 30 kg	7.8	3.4
SKF LGWA 2/0.2 lubricant without load	17.4	7.5
SKF LGWA 2/0.2 lubricant with load 30 kg	6.9	1
Magnetic lubricant without load	9.5	1.2
Magnetic lubricant with load 30 kg	4	1.6

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Regarding the operating temperature, on the bearing with magnetic lubricant an average temperature of 33.1°C was detected, which represented an increase of 6.7°C when compared to the bearing with the original lubricant. During the measurement, the average temperature of the bearing with the original lubricant was 26.4°C. This rise in temperature can be attributed to the presence of magnetite nanoparticles in the magnetic lubricant. It is plausible that the rotation of the bearing causes the magnetite nanoparticles in the lubricant to rub against each other, leading to a slight temperature increase [21].

The measurements conducted on bearings with a load of 30 kg demonstrated a more significant reduction in both vibration velocity and acceleration compared to unloaded bearings. Specifically, the measured values of velocity and acceleration of vibrations for the loaded bearing with magnetic lubricant were 51.3% lower than those for the bearing with the original lubricant. During testing, the operating temperature of the loaded bearings with magnetic lubricant averaged at 31.4°C, while the temperature of the loaded bearings with the original lubricant was on average 4°C lower, reaching 27.2°C.

The comparison between bearings with SKF LGWA 2/0.2 and magnetic lubricant, under both no-load and loaded conditions, revealed notable differences. In the case of unloaded bearings, the bearing with magnetic lubricant exhibited values up to 45.4% lower than the bearing with SKF LGWA 2/0.2 lubricant. The operating temperature of the bearing with magnetic lubricant during no-load testing reached an average value of 31.1°C, while the bearings with SKF LGWA 2/0.2 lubricant had an average operating temperature of 30.0°C without load.

After testing both bearings with a 30 kg load and evaluating the average values, the bearing with magnetic lubricant displayed measured vibration velocity values 37.5% lower than the bearing with LGWA lubricant. In this scenario, the bearing with SKF LGWA 2/0.2 lubricant exhibited acceleration values 37.5% lower than the bearing with magnetic lubricant. Following the loading, the operating temperature of the bearing with magnetic lubricant averaged at 32.1°C, whereas the bearing with SKF LGWA 2/0.2 lubricant maintained an average temperature of 30.5°C.

After an hour's operation of the bearings under load, the measured average values of the vibration speed were unchanged. The average values of the vibration acceleration of the bearing with magnetic lubricant were reduced by 0.5 g, which is a difference of 17.9%. The operating temperature of loaded bearings with magnetic lubricant was on average 37.2°C after one hour of operation. The temperature of the bearing with SKF LGWA 2/0.2 lubricant was 32.4°C after one hour of operation.

The measured average values after a 10-hour test operation do not differ much from each other. The bearing with SKF LGWA 2/0.2 lubricant gives vibration velocity values of 4.2 mm/s and the bearing with magnetic lubricant gives 4.6 mm/s, a difference of 8.7%. Regarding average vibration acceleration values, the bearing with magnetic lubricant has values 33.4% higher than the bearing with LGWA 2/0.2 lubricant. The operating temperature after 10 hours of operation reached an average temperature of 35.7°C for the bearing with magnetic lubricant. A lower temperature was measured on the bearing with SKF LGWA 2/0.2 lubricant at an average level of 29.8°C.

4. Conclusion

The objective of this study was to develop a lubricant containing magnetic particles from a readily available standard lubricant and apply it to a rolling ball bearing. The commercial lubricant SKF LGWA 2/0.2 and the ball bearing 6205 ETN9 were chosen for testing purposes. The magnetic lubricant was created by incorporating magnetite nanoparticles into the SKF LGWA 2/0.2 lubricant for research purposes.

The bearings were subjected to a load of 30 kg and tested with three different lubricants. The first test involved bearings with the standard lubricant provided by the manufacturer. The second test utilized SKF LGWA 2/0.2 lubricant, while in the third variant, the bearing was treated with the lubricant containing magnetite nanoparticles. The CMMS Checker diagnostic tool and an infrared digital thermometer were employed to obtain measurements of the loaded and unloaded bearings.

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The tests were conducted after 10 minutes of operation, during which the improved properties of the bearing with the magnetic lubricant were evident. Further testing was performed after one hour and 10 hours of operation. The results indicated that after these intervals, only minimal differences were observed between the measured values.

In all scenarios, the bearing with the magnetic lubricant exhibited lower measured values of vibration velocity and acceleration, both before and after loading. The operating temperature during testing showed a slight increase for the bearing with the doped lubricant in comparison to bearings with the original lubricant. On average, the temperature rose by approximately 5°C. This increase in temperature can be attributed to the presence of magnetic nanoparticles in the lubricant, which undergo friction with each other during rotation. The reduction in velocity and acceleration of vibrations can be attributed to the magnetic lubricant's higher density, which effectively dampens vibrations.

Acknowledgments

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