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Research Status of Wear Prediction of Spherical Friction Pair

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ABSTRACT

Spherical friction pairs are widely used in mechanical equipment, and predicting the wear of spherical friction pairs can help evaluate and predict bearing life. At present, when using the finite element analysis method to calculate the wear of spherical friction pairs, it is still necessary to simulate under idealized conditions, and the limitations of calculation amount and time need to be considered. The accuracy of the prediction method is measured by experimental means to measure the wear amount, which can be characterized by measuring the mass, volume, or wear thickness of the material under grinding. Based on the wear test methods used and the characteristics of the tested materials, suitable wear characterization parameters and measurement methods can be selected. This article also analyzes the influence of friction pair materials and service conditions on the wear of spherical friction pairs. Finally, the article looks forward to the development trend of predicting the wear of spherical friction pairs.

KEYWORDS

Spherical Friction Pair; Wear Amount; Influence Factor.

1. INTRODUCTION

Spherical friction pairs are commonly found in mechanical devices such as spherical sliding bearings and joints [1]. Spherical friction pairs have the advantages of withstanding large loads and torques, and have low friction coefficients and wear rates. In order to reduce friction and wear, spherical friction pairs usually require the addition of lubricant between the inner ring of the outer sphere and the outer ring of the inner sphere. Common lubrication methods include lubricating oil, grease, and solid lubricant [2]. Spherical friction pairs operating in high temperature, high speed, and heavy load environments often experience equipment failure due to wear and tear. The wear of spherical friction pairs is the main form of failure of spherical friction pairs. Wear will cause the clearance between the inner and outer rings of the bearing to expand, and at the same time, the friction coefficient will increase [3]. Regarding the manifestation of bearing wear failure, the most commonly used method is to determine the failure state of spherical friction pairs based on changes in wear amount [4]. Predicting the wear amount of spherical friction pairs is crucial for evaluating and predicting the life, performance, and reliability of bearings [5]. Therefore, it is crucial to conduct research on the wear of spherical friction pairs in order to improve the performance of bearings and extend their service life.

2. PREDICTION METHOD

There is a close relationship between the distribution of contact stress and the wear of spherical friction pairs [6,7]. Contact stress refers to the stress distribution caused by the load on the contact surface, while wear refers to the amount of material lost due to friction and wear during the contact process. The prerequisite for ensuring the strength verification and wear life prediction of bearings is to understand the distribution of contact stress. During the contact process, the distribution of contact stress plays an important role in the wear amount of spherical friction pairs [8,9]. For example, in areas with concentrated contact stress, local peeling or wear may occur, while in areas with uniform contact stress distribution, the wear amount is relatively small. Therefore, understanding the distribution of contact stress is crucial for studying and predicting wear levels.

By using numerical calculation methods such as finite element analysis, the distribution of contact stress can be obtained [10], and its relationship with the wear of spherical friction pairs can be further analyzed. As Shen et al. [14] combined the classic Archard wear model with finite element software, researchers used the Archard model to analyze the dynamic wear process [11]. Dynamic wear is simulated by discretizing the wear process into multiple wear steps, that is, the stress distribution on the contact surface is obtained through finite element analysis, and then combined with numerical simulation methods to discretize the wear process into multiple wear simulation steps. The total wear amount is calculated using the Euler integral formula. Researchers have found a deviation of approximately 10% between the maximum wear depth calculated by Abaqus and the actual measurement results. Subsequently, Luo et al. [12] proposed the concept of wear step size in further research to improve the wear model of self-lubricating joint bearings, and corrected the distortion of the internal mesh of the model by introducing wear step size. By calculating the improved model, it was found that the wear in the middle area of the joint bearing was the highest, while the wear in the boundary area gradually decreased, with a relative error of about 6.38%. In the above study, with the aim of simplifying calculations, the researchers simplified the wear model into a two-dimensional form. However, in order to obtain results that are closer to the actual values, other researchers used a three-dimensional finite element model. Lu Jianjun [13] established a three-dimensional self-lubricating joint bearing model and simulated the bearing motion under various swing modes. He used finite element analysis software to study the combined wear of bearings within a complete cycle, and estimated the life of bearings based on the maximum allowable combined wear of bearing friction pairs, or the life ratio under different working conditions.

In summary, when using the finite element analysis method to calculate the wear of spherical friction pairs, it is still necessary to simulate under idealized conditions and consider the limitations of calculation amount and time. With the advancement of computer technology, it is believed that these problems can be gradually solved to improve the accuracy and reliability of simulation calculation results.

3. EXPERIMENTAL VERIFICATION OF PREDICTED WEAR AMOUNT

Experimental verification is an effective offline verification method for measuring wear, which can effectively verify the accuracy of the method for predicting wear of spherical friction pairs. The amount of wear can be characterized by measuring the mass, volume, or wear thickness of the ground material. According to the wear test method used and the characteristics of the tested material, suitable wear characterization parameters and measurement methods can be selected.

3.1. Weighing Verification Method

The common method for measuring the wear of spherical friction pairs is the weighing method. This method determines the amount of wear by measuring the mass of the specimen before and after wear, and calculating the difference between the two. However, this method is only applicable to small and medium-sized specimens, and its accuracy may be affected in the presence of difficult to remove oil stains.

3.2. Measurement Diameter Verification Method

The diameter measurement method is used to measure the distribution of wear on friction pairs. Spherical friction pairs are different during the wear process, and these different distributions may cause deformation of the spherical friction pair. By measuring the diameter, the mass of the deformed part can be obtained, thereby determining the wear amount of the spherical friction pair. However, if this calculation method includes size changes caused by deformation, it will not achieve high accuracy, so the diameter measurement method is not suitable for experiments that require high testing accuracy.

3.3. Verification Method for Debris Analysis

During the wear process of spherical friction pairs, debris will be generated. Collecting and analyzing these debris before weighing can determine the wear amount of spherical friction pairs. However, the wear amount obtained by the debris analysis method is the total wear amount of the friction pair, and the wear amount of different parts of the friction pair cannot be obtained.

4. FACTORS AFFECTING THE PREDICTION OF FRICTION PAIR WEAR

The wear behavior of spherical friction pairs is extremely complex, and their wear amount is influenced by various factors, which can be mainly summarized as follows: firstly, material factors, including material hardness, wear resistance, lubrication, etc. These characteristics directly affect the wear behavior of friction pairs; Secondly, the working conditions, including speed, load, friction temperature, etc., have a significant impact on the wear of the friction pair during operation. Therefore, the factors affecting the wear of spherical friction pairs summarized in this article mainly include the above two aspects.

4.1. The Influence of Friction Pair Materials on Predicting Wear Amount

Generally speaking, for the materials of spherical friction pairs, research is mainly focused on the materials of the ring and liner. When the outer ring or liner of a bearing comes into contact with the inner ring and undergoes relative sliding, materials of different structures will exhibit their unique wear characteristics. Therefore, in improving the wear life of joint bearings, it is important to choose appropriate materials based on the wear characteristics of different friction pairs.

Dhananjay et al. [14] proposed a self-lubricating joint bearing, whose inner ring is made of ceramic material with high strength, high hardness, and excellent anti friction and anti-wear performance. The friction pair composed of ceramics and self-lubricating pads exhibits excellent performance, significantly reducing the degree of bearing wear.

At present, self-lubricating joint bearings widely use self-lubricating pad materials and self-lubricating coating materials. Self lubricating lining materials are represented by high polymer materials, such as PTFE fabrics. Researchers have focused on different modification methods in improving self-lubricating joint bearings. Yu et al. [15] investigated the effect of octaethylene cage silsesquioxane OvPOSS modification on PMB/PTFE composites, as shown in Figure 1. It can be clearly seen from the figure that the modified composite coating exhibits better performance under UV and atomic oxygen irradiation, especially in terms of atomic oxygen irradiation performance. After modification, the composite coating can form a protective layer similar to SiO_2 after being irradiated by atomic oxygen, effectively preventing internal material erosion and greatly improving the wear life of the coating.

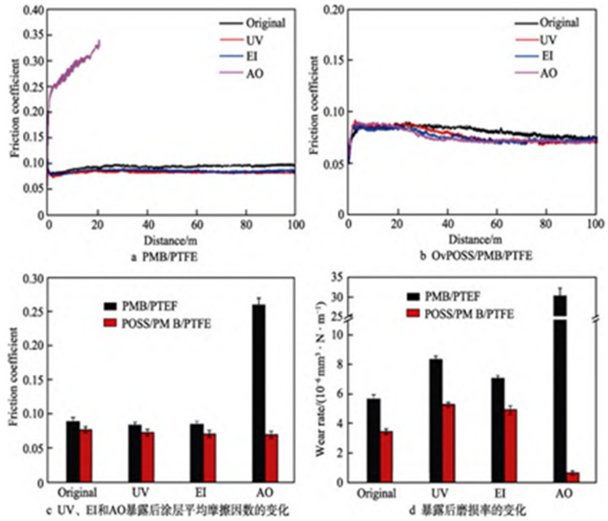

Figure 1. Friction coefficient and wear rate of two coatings

At present, DLC coating and MoS_2 coating are common self-lubricating joint bearing coating materials. MoS_2 material has a typical layered structure with relatively weak interlayer bonding, which helps to form a transfer film and reduce the friction coefficient. However, pure MoS_2 coatings suffer from short wear life and poor moisture resistance. Therefore, in recent years, there has been an increase in research on the modification of MoS_2 coatings. At present, MoS_2 composite coatings with metal and non-metal materials are effectively improved in terms of self-lubricating performance through different processes.

Scholars such as Li Yingchun [16] have successfully prepared MoS_2/graphite composite coatings with different ratios through spraying technology, covering the outer surface of the inner ring of the joint bearing. Research has found that when the mass ratio of MoS_2 to graphite is 3:1, the frictional performance of the coating reaches its optimal state. On the contrary, other proportion coatings showed significant damage during the wear process, causing the coating to lose its function. EDS spectroscopy analysis further revealed that the coating was affected by severe abrasive wear. Subsequently, Qiu et al. [17] studied the optimal ratio of graphite to MoS_2. The results showed that the graphite/MoS_2 composite coating with a mass ratio of 3:1 exhibited the best wear life and excellent adhesion.

In recent years, coated self-lubricating joint bearings have attracted attention and developed rapidly. This is mainly attributed to the excellent tribological properties of MoS_2 coatings, DLC coatings, etc. in vacuum environments. However, mature models in China are still relatively limited, and most research is still in the stage of basic material development. Further exploration is needed on how to apply newly developed outstanding coating materials to joint bearings.

4.2. The Influence of Service Conditions on Predicting Wear Amount

At present, spherical friction pairs are applied in multiple fields. Under different working conditions, the factors that affect the wear of spherical friction pairs mainly include speed, load, oscillation frequency, oscillation angle, friction temperature, environment, and other special working conditions. These factors have a significant impact on the wear performance of spherical friction pairs. In relevant studies, the influence of these influencing factors on the wear of spherical friction pairs under specific conditions has been explored.

TalatTevr ü z et al. [18] studied the use of PTFE copper mesh filling liner material in dry sliding bearings. Under the same experimental conditions, they found that the wear amount gradually increased in proportion to the speed and load. During the sliding process, the increase in wear caused by the increase in load is more significant than the increase in speed, reaching 1.4 times the increase in speed.

Qiu et al. [19] conducted research in the field of self-lubricating joint bearings, mainly focusing on the tribological properties of PTFE braided pads under different load conditions and swing frequencies, and analyzed their wear failure mechanisms using scanning electron microscopy (SEM) and energy scattering spectroscopy (EDS). The results show that as the oscillation frequency and load increase, the friction coefficient decreases and the wear amount increases. Especially under high-frequency oscillation conditions (4.8Hz), the sensitivity of wear to load is higher than that under low-frequency oscillation conditions (as shown in Figure 2).

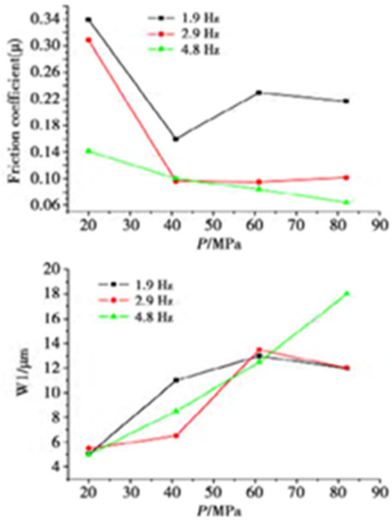

Figure 2. Diagram of the relationship between load, oscillation frequency, friction coefficient, and wear amount

Li Xijun et al. [20] conducted a comparative study on four different materials of joint bearings at a swing frequency of 1.9Hz, using different loads (3, 6, 9, and 12kN) as conditions. The research results indicate that as the load increases, the wear and friction temperature of the four types of bearings continue to increase.

Wei Libao et al. [21] found that under skewed working conditions, stress concentration occurs in the inner and outer rings of the joint bearing. Specifically, when the deviation angle reaches 1.5 °, the relative deviation of the inner and outer rings leads to uneven stress distribution, which in turn leads to significant stress concentration. This stress concentration phenomenon will increase local contact pressure and intensify wear, leading to premature failure of the joint bearing.

From this, it can be seen that as the speed, load, oscillation frequency, and friction temperature increase, the working conditions deteriorate, and the wear degree of the joint bearing intensifies, with an increasing trend in wear amount. These research results provide important theoretical basis for a deeper understanding of the wear mechanism of joint bearings and the development of corresponding protective strategies.

5. SUMMARY

In recent years, the wear problem of spherical friction pairs has attracted the attention of scholars at home and abroad. The prediction of wear on spherical friction pairs has important scientific significance and engineering value for the study of bearing life. However, the basic research on predicting the wear of spherical friction pairs in China is not yet sufficient. In order to meet the long-term and high-speed development needs of high-end equipment technology, further research on the wear of spherical friction pairs should be developed. When predicting the wear of spherical friction pairs, a model is usually established based on idealized conditions. However, these idealized assumptions may lead to some deviation between the simulation results and the actual situation. So, how to accurately simulate the wear data of spherical friction pairs and improve the accuracy of prediction methods is the development trend of research on wear prediction of spherical friction pairs. In summary, further development of methods for predicting the wear of spherical friction pairs requires consideration of factors such as real working conditions, material characteristics, surface roughness, and lubrication status, and the combination of advanced prediction methods to improve the accuracy and reliability of predicting the wear of spherical friction pairs.

CONFLICTS OF INTEREST

The authors declare that they have no conflict of interest.

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