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Friction Performance of Robot Joint Self-lubricating Bearing

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Abstract: With the rapid development of science and technology, especially the special mechanical structures that work under special working conditions, some bearings that work under extremely severe working conditions such as low temperature and high and low speeds, such as wind turbines, sometimes fail to lubricate. Relying on the transfer film provided by the self-lubricating material in the bearing provides lubrication for the normal operation of the bearing. At present, China is accelerating the development of self-designed large-scale wind turbines, such as high-end and sophisticated technologies, which put forward urgent requirements for long-life and high-stability self-lubricating composite materials. Therefore, the development and development of new self-lubricating materials in accordance with special conditions and studying the self-lubricating friction and wear mechanism of composite materials have extremely important value and significance for solving the problem of bearing life extension and reliability improvement under low temperature conditions. From the perspective of Kang friction science, the mechanism of self-lubricating bearings and the main influencing factors in their design and use were studied and discussed. From the aspects of material selection, sealing and lubrication, the specific suggestions improvement of self-lubricating bearing performance was proposed. This paper studies the friction performance of self-lubricating bearings for robotic joints. This article analyzes the working characteristics and structural characteristics of robotic joint self-lubricating bearings; analyzes the formation principle of PTFE self-lubricating transfer films; proposes a self-lubricating method for solid lubricant transfer films for robots. According to the analysis of research data, when 45 # steel is used to freeze PTFE, when using ethylene (PTFE) self-lubricating material, the surface microstructure of 45 # steel is concentrated on the PTFE-based self-lubricating material and the transfer film. The results show that when the tissue orientation is 0 °and 90 °, the displacement film is more uniform and the wear rate is smaller. When the angle is 45 °, the resulting transfer film is incomplete and excessively worn.

1. Introduction

Robot joint self-lubricating materials rely on low-cut materials or transmissive films to achieve

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excellent wear and anti-wear effects [1]. For economic, environmental and technical reasons, the use of self-lubricating materials in bearings has become a trend [2]. After applying this technology, there will be no need to lubricate the bearings, and its performance will exceed the limit of using traditional materials [3]. The extremely low temperature, ultra-high vacuum, high radiation, high speed and high load, special media, etc. urgently required by aerospace equipment solve typical problems [3-4]. The problem of friction and wear in the working environment provides strong technical support and provides an important basis for improving the durability of military equipment, thereby simplifying the design. Spherical linear bearings are spherical linear bearings suitable for bending or rotating swing, and have a self-adjusting function [5-6].

The self-lubricating spherical linear bearing of the robot joint is a layer of self-lubricating lubricating material adhered to the inner spherical surface of the bearing [7]. Robot joint self-lubricating spherical plane bearings have the advantages of compact structure, light weight, impact resistance, corrosion resistance, large bearing capacity, long service life, etc. [8-9]. It has characteristics that can be maintained during operation and does not need to add lubricants, and has been widely used in robot joints [10]. Robot technology is a new technology emerging in the field of modern automatic control [11]. Generally, the robot operating handle is required to achieve the specified positioning accuracy in addition to completing the predetermined movement, that is, accurate working accuracy and repeatability, and high reliability, but due to various deviations in the processing, manufacturing and use processes, it affects the normal operation of the robot. It is generally believed that there are four main factors that affect the robot's motion and attitude accuracy: (1) The structural parameters of the robot mechanism are errors, that is, errors of each component. (2) Dynamic errors caused by gaps and similar gaps after robot joints wear. (3) Elastic deformation and thermal deformation of components. (4) Joint servo placement error. The current methods for error analysis usually include calculation areas, elastic deformation of components, etc. [12-13]. Abstract components are treated as rigid objects and converted into structural errors to compensate for various errors that are completely different from the actual working conditions of the robot [14-15]. Robot arms can simulate human motion through paired movements. For example, industrial robot arms have 4 rotation pairs, so the friction performance of the motion pairs will greatly affect the operation of the robot to ensure the normal operation of the bearings [16]. Because the joint speed of the robot is low and the forward and reverse directions change frequently, it is difficult to establish a hydrodynamic lubricant film between the rolling body and the cage; joint bearings are usually lubricated with grease and have a reliable sealing system to avoid grease loss, but This will complicate the structure and increase the bearing size, and the contact sealing device will also increase the frictional resistance of the bearing. Robot joint bearings for special working conditions (such as high or low temperature, high vacuum, etc.), if grease lubrication is used, the lubrication effect may be lost. Solid lubrication has a simple structure, convenient maintenance, and good friction performance. Therefore, the theory and technology of solid lubrication have attracted more and more attention. According to the working conditions and structural characteristics of robotic joint bearings, this paper proposes a lubrication method using a solid lubrication transfer film on the robot joints [17].

PU considers vibration suppression and precise tracking as two major challenges in the control of elastic joint robots. In this study, an elastic articulated robot with precise position sensors on both the motor and link sides was developed to meet these challenges. Using the two-mass model of the elastic block and the LuGre friction model of joint friction, the elastic joint robot system is modeled and analyzed as an underactuated port-controlled Hamiltonian dissipative system (PCHD). The proposed elastic joint controller is integrated with friction compensation using a control method based on interconnection and damping distribution passiveness, resulting in a PCHD closed-loop system that can be effectively adjusted to suppress the vibration associated with the elastic joint. In addition, integral control is used to achieve high tracking accuracy. Experiments have been performed and the results have proven the high performance of the proposed control method [18]. Zheng believes that for an economical and practical parallel robot, there is a joint gap in its mechanical structure, and the influence of the joint gap on the position accuracy of the mobile platform and the vibration characteristics of the system cannot be ignored. In order to analyze the problem, a new idea is proposed with the Delta robot as the research object, that is, to study the elastic dynamic model with joint clearance and the vibration characteristics of the system. During the analysis process, it is known that the joint gap changes with the robot's motion state, which is random. Therefore, the kinematics of the Delta robot branch chain with joint gap was analyzed creatively using mathematical statistical principles and mathematical analysis was performed. The expected value of the probability density of the joint clearance vector in the joint coordinate system is used to quantitatively represent the value of the joint clearance before the shaft collides with the sleeve. However, because the joint gap is narrow, the acceleration inertial force of the shaft in the sleeve is ignored [19]. H thinks that tendon drives are widely used in robotics. The tendon compliance in this type of driver makes it suitable for soft robots (including wearable soft robots), but there are some issues that hinder its use. In general, the tendon should always maintain tension to prevent derailment from the spool. However, in soft robots, because there are no ball bearings, tendon tension generates high friction. Because the kinematics of a soft robot is basically non-linear and changes due to the deformation of the structure, the kinematic differences between the soft structure and the spool can cause tendon derailment. Moreover, maintaining tension in a wearable soft robot can cause safety issues. Linear actuators are available. However, the length of the linear actuator needs to be increased to accommodate the offset length of its tendon, which hinders its use in small-scale applications. To avoid this problem, he proposed a slack actuator using a spool. The space efficiency of the spool makes the mechanism smaller, and the one-way clutch applies one-way friction to the tendon to tighten the tendon around the spool. He introduced the design concept of the slack enabling mechanism, its design optimization, and system identification for force control [20].

The innovations in this article are: (1). The PTFE-based composites have been studied. The composites obtained have moderate and stable friction factors, good abrasion resistance, and good impact resistance. A test system for simulating the friction and wear of low temperature composite materials has been developed. It is found that the average friction factor of the composite material at low temperature is lower than the average friction factor at normal temperature, and the wear rate at low temperature is lower than that at normal temperature. It is verified that the developed PTFE-based composites perform well under low temperature. (2). The influences of the structural characteristics of PTFE-based composite materials and the environmental temperature on the friction properties of the composite materials are obtained. For PTFE-based composite materials with lower friction factors, the friction is further reduced, the reinforcing fiber phase should not be overfilled, and the amount of filled particles should be appropriate. Within a reasonable range, higher hardness materials have a certain improvement in improving wear resistance. This influence law provides a theoretical basis for the research and design of friction and wear of PTFE-based composites. (3). The thermal stability of PTFE-based composites has been improved, and the enthalpy and crystallinity have also been greatly improved. Nano-Cu particles are added to completely cover the substrate and form a complete conduction network. The thermal conductivity is greatly improved. This research provides theoretical support for the design of composite materials in thermodynamics.

2. Proposed Method

2.1. Methods that Affect the Friction and Wear Performance of Self-Lubricating Spherical Plain Bearings

There are many factors that affect the friction and wear behavior of self-lubricating compounds, and there are many ways to wear. Among them, the warmth of the environment is most affected by it.

(1) Speed

Spherical bearings have their own unique swing directions, while self-lubricating spherical flat bearings cause high roller swing speeds due to their different friction and wear properties. Assuming temperature, swing amplitude, and load conditions are the same, three different swing frequencies are used for the experiment. Maybe this phenomenon is due to the friction surface caused by the interaction between the rolling film and the free mill. As they continue to tighten, the particles enter the surface of the cushion and the P value gradually decreases. It can be concluded that the higher the swing rate, the greater the friction value.

(2) Load

Due to the special nature of self-lubricating bearing joints, the swing mode is different from other bearings and is affected by the degree of friction and wear. The experiments of relevant experts show that as the load increases, the friction and wear rate of the self-lubricating spherical surface will increase. When the load is 30kn, the friction coefficient under the initial load should be less than 20kn. In this case, the degree of wear of the object will also increase. At this time, the degree of wear will be particularly serious. As the visibility increases, the degree of friction damage will become more serious, and special fluctuations will also occur. From the above, it can be concluded that as the load increases, the rate of wear decreases more slowly after 33 hours of friction. Restore protection in five to twelve hours.

(3) Gasket material

In the process of rotating bearings, the inner and outer rings and the bearing pads flow against each other. An in-depth understanding of the different gasket materials is important to increase the frictional capacity and extend the life of the bearing. 1) PTFE composite materials: Experts emphasize that there are two main methods for bonding composite materials: adhesive friction and abrasive friction. The composition of the internal materials is different, so are the friction properties of the composites. When the FEP in the compliant material is between 10% and 35%, there is an important ability to improve the performance of the composite material, and both can prove to be reasonable. Among them, because of the interaction between different materials, mixed materials are more effective than single materials in improving friction properties. 2) Teflon fabric material: Teflon welding material has high friction and wear resistance. Related research data show that so far, the material has a low coefficient of resistance and a very good anti-wear effect. When exposed to metal objects, the heat will increase higher, and the hardness of the cutting part will decrease, while the internal components of the PTEF material will adhere to the metal surface when filling existing holes, which is the reason for the low coefficient of friction.

2.2. Forming Method of PTFE Self-Lubricating Transfer Film

The cage of the bearing is a PTFE-Based composite material. When the bearing rotates, due to the spin motion of the rolling element, friction will occur between the rolling element and the cage, because the rolling element contacts the surface of the micro convex body repeatedly and extrusion effect will form a small band on the contact surface of the PTFE cage. The SAE surface morphology indicates that there are many band-like groove marks on the PTFE surface after friction, which is the result of repeated contact and extrusion. Because the structure of PTFE is a strip structure, the adhesion force is much smaller than that of metal. During the rubbing process, the small fragments are peeled off and easily adhere to the surface of the metal, and are then filled in the tiny depressions on the surface of the rolling elements along the rubbing direction.

During the rubbing process, the strips of PTFE are continuously, gradually forming a transfer film adhered—flattened—reattached—and then flattened. The transfer film has a certain thickness (approximately 10 to 130 m), and its structure is a small band-like additional layer. For the same reason, during the friction process, a PTFE transfer film can be formed on the surface of each rolling element, the inner ring and the outer ring raceway. Because of the microscopic unevenness of the surface, the PTFE film is plowed (scratched) and squeezed and produces small fragments. Small fragments are adhered to the surface of the raceway, then are flattened and extended, gradually forming a PTFE lubrication transfer film. The thickness of the transfer film on the raceway is only 1/3 to 1/2 of the thickness of the transfer film of the rolling element.

The robot joint bearing is a four-point contact bearing (double half inner ring or double half outer ring), which is beneficial to the formation of the transfer film and the transfer film to be uniform and continuous. For high-speed bearings, the self-lubricating transfer film is formed between the rolling elements and the cage due to the collision of the elements, and the PTFE fragments generated are peeled off and adhere to the surface of the rolling elements. However, the speed of the robotic joint bearing is low, and the collision effect of the rolling elements is small, so to a certain extent, the formation of the transfer film mainly depends on the extrusion, plowing and adhesion of the micro convex body pressing the PTFE surface layer. The surface roughness of the rolling elements and the inner and outer ring raceways has a great effect on the formation of the transfer film. Studies have shown that continuous and uniform transfer films can be easily formed when the surface roughness Ra <1.6 μm. Other parameters of the surface profile (micro unevenness, radius of curvature, slope, wavelength, etc. of the microconvex body) will affect the formation of the transfer film and its formation speed. In addition, the contact pressure on the surface of the PTFE cage and the rolling element is a key factor, especially the formation of the primary transfer film. Therefore, in order to form a transfer film, it is necessary to maintain a certain contact pressure between the contact surfaces. In addition, in order to enhance the chemical affinity between the transfer film and the substrate, it is best to remove oil stains from the friction surface.

2.3. Classification Method of Self-Lubricating Bearings

Self-lubricating bearings can be divided into oil bearing and solid lubricating bearings according to their self-lubricating mechanism. Oily bearings are immersed in lubricants inside the bearing materials (metal bearings and phenolic oily bearings) or bearing materials (for example, oily polyoxymethylene, oily Mc-nylon cabinets). When running under friction, always keep the lubricating film layer on the main body of the grease-containing bearing material on the friction surface to ensure less wear on the working bearing without increasing lubrication or environmental pollution. Fat content is significantly affected by pressure, temperature, and fat viscosity, and fat consumption determines the life of the bed. For oily materials (such as polyoxymethylene), the oil is evenly and individually distributed in non-porous plastics. Create new surfaces for surface coating and friction surfaces. Therefore, during this period, greased bearings were introduced to accommodate dry friction. An unrepaired oil bearing is the exact opposite of a grease mechanism. The friction between the fabrics is low and the work is tight and sticky. Common solid oils include graphite, Mos :, ws :, PTFE, Pps, bp, nI and other inorganic, organic and soft metals. Easy to form strong lubricating film with low shear strength, low coefficient of friction and low friction surface. The differences between materials and preparation methods will lead to significant differences in performance and applications, as shown in Figure 1.

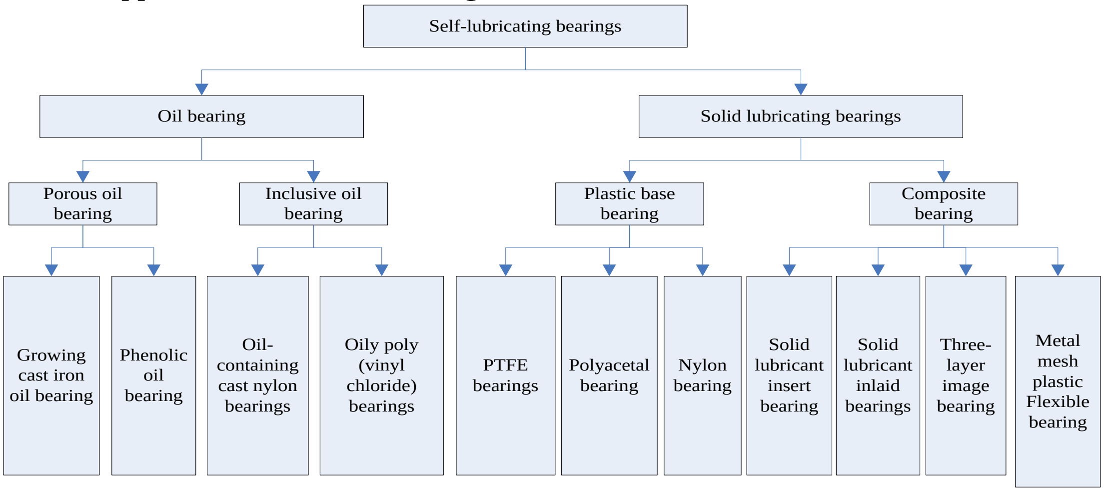

Figure 1. Classification of self-lubricating bearings

3. Experiments

3.1. Experimental Object

In order to study the friction performance of self-lubricating bearings, robot joint self-lubricating bearings are used as the research object of the friction performance of self-lubricating bearings. The self-lubricating liner of the self-lubricating bushing forms a friction pair with the outer surface of the test mandrel. The friction coefficient of the self-lubricating bearing is measured by measuring the friction coefficient between the pair.

3.2. Experimental Design

(1) Constant temperature of the experimental device at a certain temperature, and then use an electronic universal test machine to apply the radial load allocated to the bending, and use a torque robot combination to measure the friction torque of the test mandrel during rotation. Then adjust the load and measure the friction torque under different radial loads at the same temperature. After measuring all load points, change the temperature conditions and repeat the test procedure above until all temperature conditions are tested to obtain frictional torque at different temperatures and environmental conditions.

(2) Experimental design of starting torque test

The complete test system includes a rod support platform, a dynamometer support platform, and a wheel loader. Rotation torque test, rotation torque accessories, rotation torque device.

During the test, since the thin steel wire rope between the tip of the dynamometer and the loading point was horizontal, both the rod bearing and the dynamometer were placed on the support platform and positioned. Add weight until the inner and outer rings of the shaft drive bearing rotate or oscillate. (3) Experimental design of rotating friction torque test under radial load.

The complete test system includes a radial loading system, a bearing compression device, a test measurement and data acquisition system. The loading system includes: a platform for fixing the loading cylinder and the loading cylinder; a rolling support and supporting platform for the load compressor; and the test and data acquisition system is a load sensor, a dynamic voltmeter connected to the load sensor, a dynamic voltmeter connected to the load cell and a series of wheel loaders are used to test the friction torque under radial load, compression test system. During the test, a load was applied to the self-lubricating suction bearing by downloading the actuator. By increasing the weight at one end of the pulley, the swing arm accelerates the rotating shaft, which immediately activates the self-lubricating bearing. Note the threads around the pulley. The load measured by the load sensor is the sum of the frictional moments of rolling and self-lubricating spherical surfaces at both ends of the mandrel under radial load. Therefore, the difference between the rotational torque and the rolling friction torque of the coupling is the friction torque in the self-lubricating sphere under radial load. Based on the calculated friction moment, the static friction coefficient of the self-lubricating spherical surface under this radial load can be calculated.

3.3. Experimental Implementation

PTFE-Based composites are based on PTFE, which is modified by adding copper and graphite to improve overall performance. The friction pair used in the test: The upper sample is a PTFE composite material, the main component is 15% containing 8-3 copper powder, 5% graphite, and the rest is PTFE. The prepared raw materials were mixed and stirred uniformly in proportion, and pressed by a powder tabletting machine (60 MPa) to obtain a small cylinder with a size of about 10 mm × 25 mm, and finally sintered in a JHN-1 nitrogen-protected sintering furnace. The lower sample is a steel block of 69mm × 25mm × 12mm. The friction surface is processed by directional grinding to form a linear texture structure with a certain orientation. The angles between the microstructure orientation and the reciprocating direction are 0 °, 45 °, and 90 °, and the surface roughness Ra is 0.2 ~.

The experiments were performed on a multifunctional friction and wear tester, where the frictional contact surface of the tester was face to face. The friction method uses dry friction. Test conditions: room temperature, average linear speed 0.2654m / h, test axial load 4MPa, test speed 200r / min, time 40min. The friction coefficient is automatically recorded by the testing machine, and the amount of wear is obtained by measuring the change of the upper and lower samples before and after abrasion on an electronic balance. The trend of the amount of wear is consistent. Three repeated tests were performed under the same test conditions and the average results of the tests were obtained. After the test, the surface micromorphology of the opposite side was observed using a scanning electron microscope (HITACHIS-4800).

4. Discussion

4.1. Friction and Wear Analysis of PTFE-Based Composites

The results of the friction and abrasion test of the paired parts under the three surface microstructure orientations are shown in Figs. 2 to 3. It can be seen from Figure 2 that with the increase of the friction time, the friction factor in the 10 °direction stabilizes at about 0.157 under the steady state, while the friction factor in the 50 °and 90 °directions gradually increases, and the increase becomes larger after 25min, of which 10. The friction coefficients in the 0°and 90 ° directions are relatively low, and the friction coefficients in the 50 °direction are the largest. It can be seen from Figure3 that the friction amount of the composite specimen against the 47 °direction friction piece is the largest, followed by the 90 °direction and the 0 °direction is the smallest. The change in the amount of wear also further reflects the change of the three friction factors. The friction factor in the 48 °direction is the largest, which results in the largest amount of wear. The friction factor in the 10 °direction is relatively stable and small, resulting in a small amount of wear. This is because in the initial stage of friction, the polymer transfer is caused by mechanical action, that is, the polymer is cut by the micro-convex body on the surface of the counterpart, and the cut polymer particles adhere to the valleys on the surface of the counterpart. In the 10 °direction, this cutting action is the smallest, so the wear is the smallest. The other two microstructures have a larger cutting action, and the wear is relatively large.

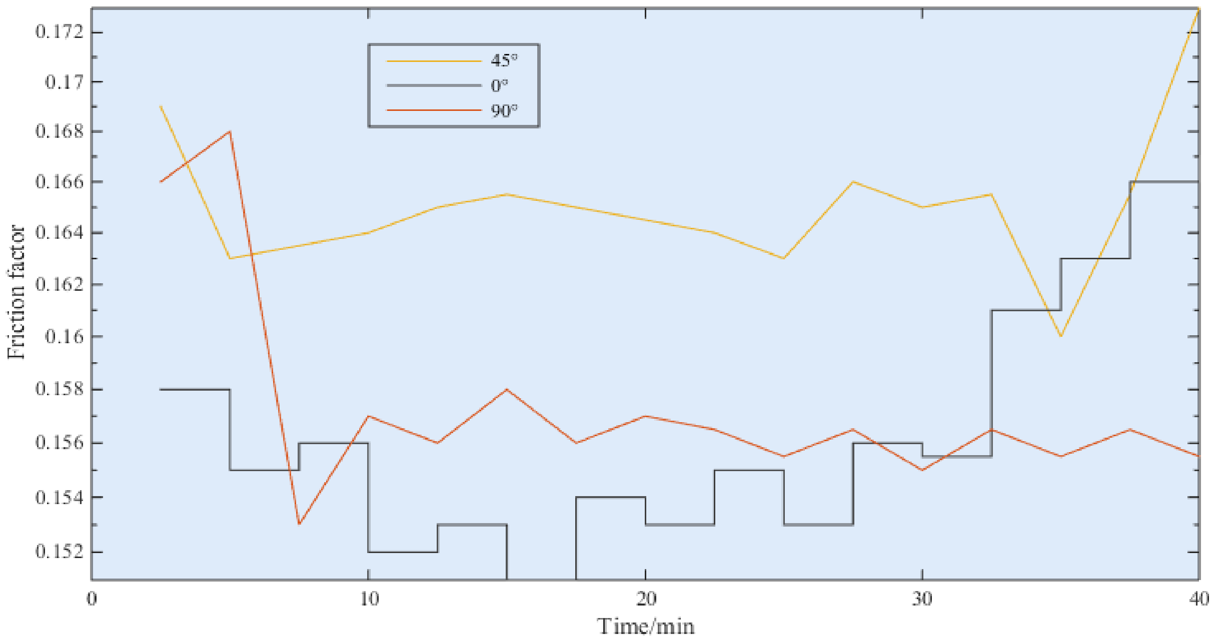

Figure 2. Friction factors in different orientations

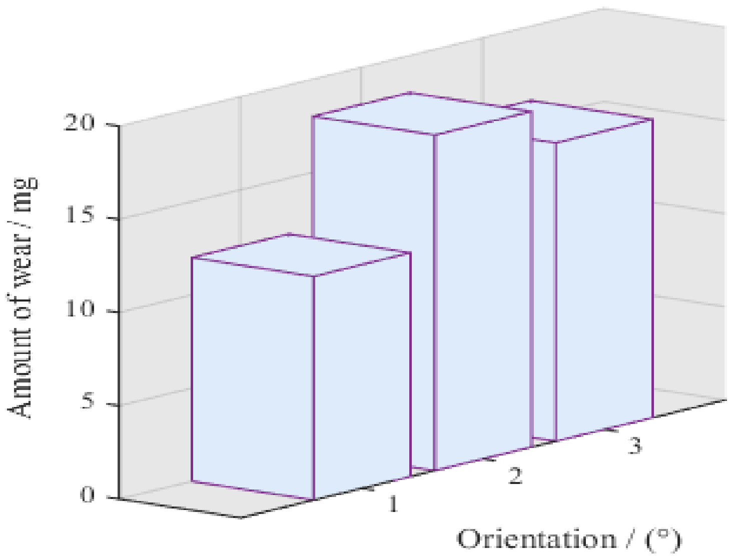

Figure 3. Amount of wear in different orientations

4.2. Analysis of Self-Lubricating Bearings under Load Conditions

The working conditions of sliding bearings mainly include the bearing pressure p and the product of pressure and speed pv, which reflects the loss of friction energy during the operation of the bearing, and the magnitude of friction heating is usually dry. The use of load has a considerable impact on operation under friction or low lubrication conditions. Table 1 lists the most commonly used self-lubricating load parameters. You can see how different materials and lubricants affect their load. Vehicle capacity and performance, workload conditions and application areas also vary widely.

Table 1. Use characteristics of self-lubricating bearings

material	Maximum allowable loadP(MPa)	Maximum allowable speed V(m/s)	Maximum allowable PV value($MPa \cdot m/s$)	Polar wire use temperature ($^{\circ}C$)
Powder metallurgy oil bearing	5	1.5	0.7	Normal temperature
Growing cast iron oil bearing	15	1.9	1.77	Normal temperature
Iron stem inlaid bearing	10	0.86	0.66	420
Offset Stem Bearing	9	0.88	1.3	280
MC nylon bearings	5	1.2	0.10	89
Oily phenolic bearings	12	1.4	1.03	Normal temperature
Oily polyacetal bearings	10	12	3.34	88
PTFE three-layer composite bearing	18	5	1.6	265

For self-lubricating bearings operating under dry friction conditions, it has a significant impact on speed and limited PV values. With the increase of speed, the material, proper load capacity and VP value will decrease to varying degrees. The reason is that with the increase of speed, the bearing will increase the friction and heat load on the working surface, which will change the performance of the surface material, and make the bearing wear and lubrication conditions worse, which has a significant impact on plastic bearings. Therefore, when selecting a self-lubricating bearing, the load and speed conditions under certain operating conditions should be analyzed and based on the allowable load at low speed, otherwise the combined effect of load and speed must be considered, as shown in Figure 4.

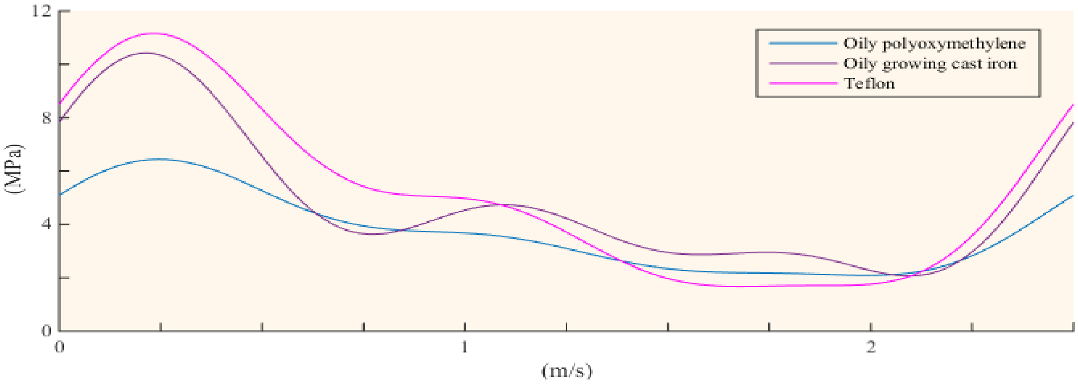

Figure 4. Curves for self-lubricating bearings

4.3. Influence of Temperature on the Performance of Robot Joint Self-Lubricating Bearings

Under dry friction conditions, the operating temperature of sliding bearings is mainly determined by the ambient temperature and the thermal effects of sliding friction. The effect of temperature on the performance of self-lubricating bearings is that changes in temperature will cause changes in the state of thermal load on the friction surface of the bearing and cause changes in the properties of the bearing material. For metallic porous oil-containing bearings, the fluidity of the lubricant contained in the material body is sensitive to temperature changes. When the temperature is high, the viscosity of the lubricating oil impregnated in the oil-bearing bearing decreases, the fluidity is good, and it is easy to ooze out of the bearing material; and at low temperatures, the viscosity of the lubricating oil must increase and thicken, making flow difficult. Both have a direct impact on the lubricating state on the friction surface of the bearing during operation and the durability of the impregnated lubricant. Therefore, the oil-containing self-lubricating bearings operating under different temperature conditions, the viscosity of the impregnated lubricating oil must also be different. Oil-containing bearings operating at low temperature environment should be impregnated with low viscosity and excellent anti-coagulation performance. Avoid the condensation of lubricating oil at low temperature to block the porous oil circuit, which will cause the bearing surface to be damaged due to lack of oil. On the contrary, when the operating temperature is high, in order to prevent the lubricating oil from oozing out too quickly, it will cause effective self-lubrication during bearing use to shorten the period, it is necessary to use high-viscosity lubricants to improve the retention ability of the lubricant in porous bearing materials. For plastic-based accommodating oil-containing bearings and solid self-lubricating bearings, there is no problem of lubricant retention, but an increase in temperature will significantly change the mechanical properties of the bearing material, such as a decrease in rigidity and strength, which makes the bearing load performance and shape stability worse. Figures 5 and 6 show the relationship between the compressive performance of plastic bearing materials and the change in PV value with temperature. It can be seen that when the operating temperature of plastic bearings increases, the load capacity will be doubled. Therefore, the design and use of plastic-based self-sliding bearings must analyze the temperature conditions and be limited to the allowable range (see Table l).

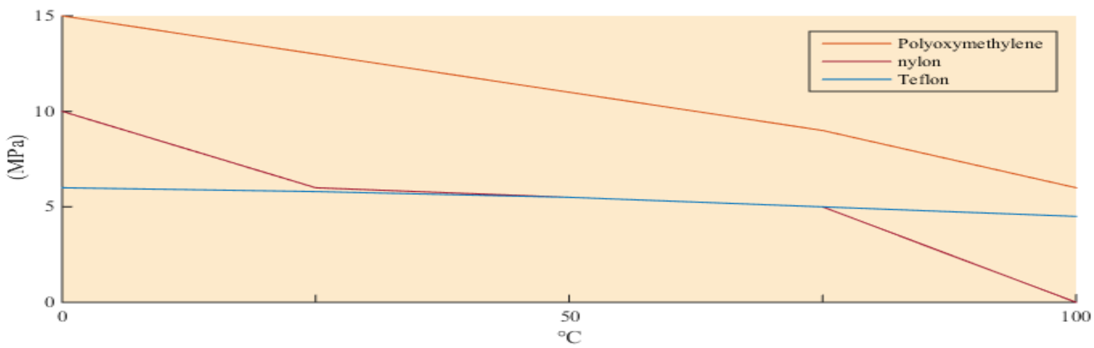

Figure 5. Maximum allowable load as a function of depression

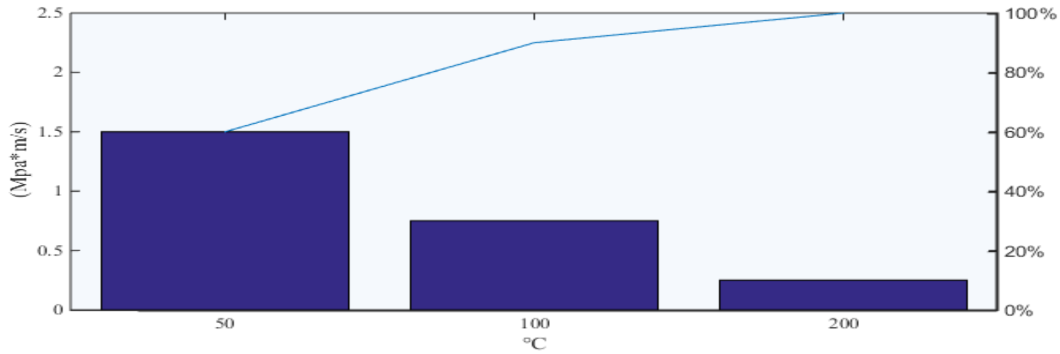

Figure 6. Effect of temperature on the limiting PV value of SF ~ 1 polytetraethylene component three-layer composite

4.4. Environmental Conditions for Self-lubricating Bearings

The design of self-lubricating bearings working under non-lubricating conditions must not only consider the impact of load, speed and temperature conditions on performance, but also be sensitive to environmental factors, especially the intrusion of dust and mud. Compared with oil-lubricated bearings, self-lubricating bearings do not have the problem of full leakage of lubricating oil. Therefore, the sealing of self-lubricating bearings often does not cause the designer to pay enough attention. However, due to the characteristics of self-lubricating bearings, dry friction or less lubrication, it also causes foreign bodies or impurities to enter the working gap of the bearing, which is difficult to be discharged in time, which causes the deterioration of the friction and lubrication conditions on the sliding surface. Figure 7 Simplified poly-formaldehyde bearing swing with a simple 0-type seal under multi-mud conditions. The wear test results show that even with a simple seal, the service life of self-lubricating bearings can be increased several times. Different lubricating materials have different environmental sensitivities. For porous oily bearings, the infiltration of dust and mud will block the pore outlets on the working surface of the bearing, preventing the lubricating oil contained in the body from extruding normally to the surface, causing the loss of self-lubricating functions and increasing friction and wear. The plastic-based self-lubricating bearing has a certain embedding ability for hard particles and foreign matter entering the working surface, and the ability to resist the invasion of dust and foreign matter is also superior to other bearing materials. Table 2 shows the comparative data of abrasive wear test of a group of oil-containing phenolic bearings and bronze alloy bearings. The wear resistance of phenolic bearings is an order of magnitude higher than that of bronze alloys. The effect of the increase on the wear condition of phenolic bearings is not obvious.

Table 2. Abrasive wear test results

Lubrication refers to the proportion of abrasive particles Amount of wear (mm) Bearing material	Tin bronze	Olein
0%	0.36	0.06
10%	0.6	0.05
20%	5.2	0.12

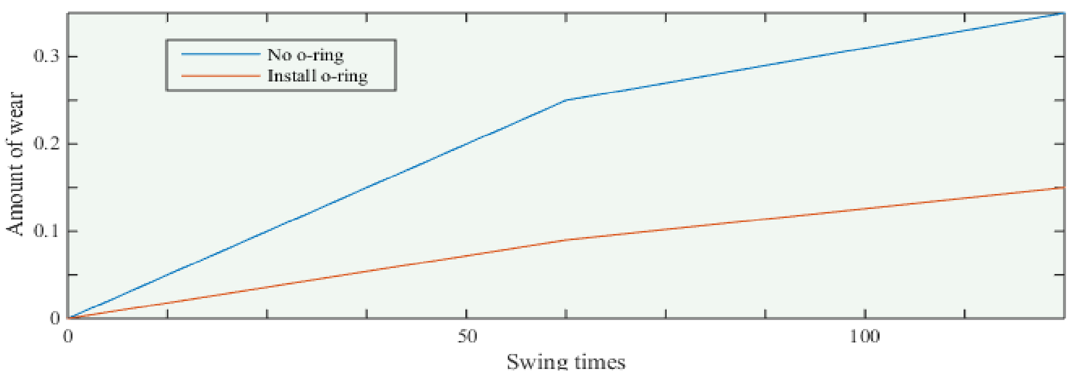

Figure 7. Swing wear test under mud paddle conditions

5. Conclusion

Looking at the research results of friction and wear performance of self-lubricating spherical plain bearings at home and abroad in the past 10 years, it can be seen that under the situation that self-lubricating spherical plain bearings are used more and more widely, the friction and wear performance is further improved and correctly evaluated, and bearing failure is minimized. The great harm brought by this is the development direction of self-lubricating spherical plain bearings. With the continuous improvement of the social economy, the demand for articulated bearings in the continuous development of science and technology is getting higher and higher, and the quality requirements are also getting higher and higher. Therefore, experts and bearing manufacturers should make a rational and scientific improvement of the friction and wear performance of self-lubricating joint bearings in a manner that is in the interest of the people and contributes to the economic development of society. This requires a scientific understanding and reasonable selection of the bearing pad material selection, speed, ambient temperature, etc., in order to ensure its manufacturing quality. This paper has studied robotic joints, and the cage of the bearings is filled with carbon fiber. The PTFE composite material can form a transfer film on the contact surface. This layer of transfer film has good self-lubricating properties, which has practical significance in robot applications, especially robot joint bearings that work under special conditions (such as high or low temperature, high vacuum, radiation, etc.) can predict that these joint bearings have a wide range of application prospects.

As a multi-phase material, the self-lubricating bearing composite is not only related to the macroscopic properties, but also to the properties of the component phases, the shape and distribution of the lubricating phase, and the interface characteristics between the reinforcing phase and the matrix. Observational characteristics are closely related. To grasp the effect of its mesostructure on the macroscopic properties of materials, it is not enough to study from the macro or micro perspective, and we should start to study the multi-scale effects of materials. Multi-scale science is one of the important branches of complex systems and has rich scientific connotation and research value. The multi-scale simulation research method considers the cross-scale and cross-level characteristics of space and time, and coupling related scales to improve simulation and calculation efficiency is an important method and technology for solving various complex materials and engineering problems, and has become a rapidly developing hotspot and Frontier research areas. The current research focuses on the coupling of finite element and discrete element and the coupling of finite element and molecular dynamics. Due to the lack of systematicness, completeness, and simulation software that the theoretical system can rely on for analysis, this research method is still in its infancy, and there have been few reports in the field of self-lubricating bearing tribology. Solve the theoretical and application problems of multi-scale simulation, make full use of the advantages of micro and macro mechanics analysis methods using cross-coupling algorithms, and many problems in the meso and macro fields of composite materials will be solved easily, which will certainly be in bearing self-lubricating materials and even the entire material. The field of engineering has caused a profound change.

The surface microstructure of the dual part has a great influence on the dry friction and wear performance of the PTFE-based self-lubricating bearing material, which is mainly reflected in the micro influence on the film formation quality of the transfer film, and then the macro friction and wear performance of the material. 0 °direction 45 # steel surface transfer film is more uniform and complete, the wear debris is a large flat sheet, the friction factor at steady state is small and relatively stable, and the wear is minimal; the 45 °direction transfer film is severely scratched and has a large area falling off, abrasive debris is severely curled, and the friction factor at steady state is the largest and the increase is obvious, and the amount of wear is the largest; part of the transfer film in the 90 °direction falls off, the abrasive debris is still flat, the friction factor is small but the increase is large.

The research on joint bearings has achieved great results in terms of gasket materials, friction and wear tests, and wear testers. But there are still some problems that need further research and solution. (1) There are still many problems in the study of tribological properties of self-lubricating gasket materials for joint bearings, such as the failure of self-lubricating bearing materials under mixed and complex conditions such as high temperature, high frequency and heavy load. (2) At present, the wear performance tests of joint bearings are mostly based on the rotary motion of a single bearing in the circumferential direction of a single axis, or the standard test block of the bearing material as the test object for linear reciprocating motion. There are still differences. Therefore, it is of great significance to study the wear test machine that simulates the real working conditions of spherical plain bearings. (3) The wear performance test of spherical plain bearings is mainly focused on the individuality tests of spherical plain bearings, and there is less research on general basic tests.

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Data sharing is not applicable to this article as no new data were created or analysed in this study.

Conflict of Interest

The author states that this article has no conflict of interest.

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