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The lubrication performance of water lubricated bearing with consideration of wall slip and inertial force*

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Abstract: The lubrication mechanism and the performance parameters with consideration of wall slip and inertial force are studied in this paper. Based on the modified Reynolds equation, the finite difference method is used to study the lubrication mechanism and the performance. Effects of the wall slip and the inertial force on the performance parameters are obtained, and found in good agreement with the results of FLUENT. It is shown that the wall slip and the inertial force do not significantly change the distribution of the pressure, the load capacity and the friction force. The inertial force slightly increases the pressure and the load capacity by 1.2% and 4.8%, while the wall slip reduces them by 8.0% and 17.85%. The wall slip and the inertial force increase the friction by about 15.98%, 2.33%, respectively. Compared with the wall slip, the inertial force is smaller, but cannot be neglected.

Key words: Water lubricated bearing, wall slip, inertial force effect, lubrication performance

Introduction

The fluid flow boundary condition is one of the most important factors which determines the fluid hydrodynamic performance and characteristics. In the classical fluid mechanics and the lubrication theory the so-called “no slippage boundary conditions” are often used, namely, no wall slip occurs on the solid-liquid interface, and the relative speed of motion between the fluid molecules on the solid surface and the solid interface is equal to zero. This hypothesis is verified by experiments in a macroscopic sense, and has been widely used in the theoretical analysis and the experimental researches. However, in recent years, with the development of the micro-nanometer science and technology, it is found that no slip boundary conditions are no longer valid under certain conditions. Boundary slip will occur in many instances[1,2], therefore affects the fluid behaviors and hydrodynamic characteristics. The influence of the wall slip on the lubrication performance of the water lubricated bearing comes to be an important issue. For instance, Spikes et al.[3] analyzed the influence of slippage on the fluid dynamic behaviors with consideration of the wall slip only on the static slider surface. It is found that the bearing load capacity is exactly half of that with no slippage when the limiting shear stress is equal to zero, but the corresponding friction is reduced by several orders of magnitude.

Consequently, Spikes[4,5] proposed the thought of designing the bearing of a very low coefficient of friction, believing that the existence of the boundary slip would reduce the friction coefficient of the bearing surface, but might have a more complicated influence on the fluid hydrodynamic characteristics. Ma et al.[6,7] et al. studied the influence of the wall slip on the hydrodynamic lubrication performance of a two-dimensional journal bearing (finite length journal bearing) based on the limiting shear stress model. Fortier et al.[8,9], Wang et al.[10] and Wu et al.[11] put forward the concept of heterogeneous slip, that is, the wall slip in different positions of the same solid surface of different slippage properties (i.e., with different limiting shear stresses). It goes beyond the framework of the classical lubrication theory[12], which holds that only

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the convergent gap can make the journal bearing generate the hydrodynamic pressure.

The water lubricated bearing is widely used in ships, water pumps and other mechanical systems for its various advantages, such as no pollution, wide source, safety and fire resistance. Its lubrication performance, reliability and safety help the safe and stable operation of the mechanical system. Therefore, the research and the improvement of the lubrication performance are of direct significance for the promotion and application of the water lubricated bearing.

Based on the modified Reynolds equation with consideration of both the wall slip and the inertial force, this paper investigates the lubrication mechanism of the water lubricated bearing through numerical methods, focusing on the pressure and thickness distributions as well as the variations of the bearing capacity and the friction force. The effects of the interface slip and the inertial force on the lubrication performance are analyzed, and the results are found to be consistent with the finite element analysis by the software FLUENT. This will help the structure design and optimization of the water lubricated bearing.

1. Derivation of modified Reynolds equation

1.1 *Theoretical basis of wall slip*

It is shown[13,14] that the wall slip only occurs in the surface with smaller limiting shear stress when there exists a relative motion between two surfaces with different limiting shear stresses.

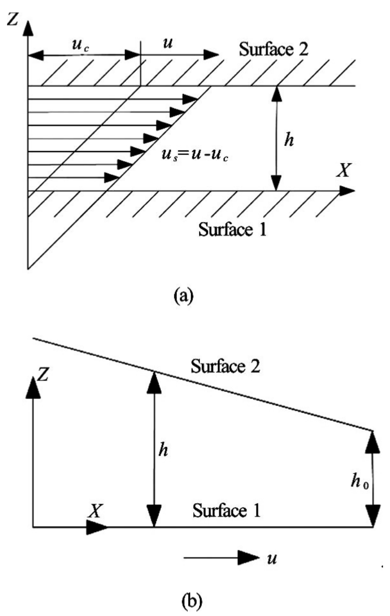

Fig.1 Schematic diagram of wall slip model

Figure 1(a) shows the schematic diagram of a wall slip model of the water lubricated bearing. Assuming that when the speed meets the criteria $u = u_c$, Surface 1 just reaches the critical state of the interface slip, which means that the interface limiting shear stress is reached, correspondingly, the critical shear stress τ_c is $\tau_c = \upsilon(u_c / h)$ (υ is the viscosity). With the increase of velocity on Surface 2, the wall slip starts to occur on Surface 1, the wall slip velocity u_s is $u_s = u - u_c$, h is the film thickness, u_c the critical slip velocity.

If there is no wall slip on any of the surfaces, the wall slip velocity is equal to zero, i.e. $u_s = 0$. When the wall slip begins to occur, the wall slip velocity is equal to the difference between the velocity of Surface 2 and the critical slip velocity, i.e., $u_s = u - u_c$. It was proposed[15,16] that when the interface tension of the lubricant medium becomes larger than that of the friction pair material, then the interface slip is very likely to happen.

Table 1 shows the interfacial tension of commonly used materials. The interfacial tension of a water lubricated rubber bearing is much smaller, the adhesion fracture of water molecular bonds occurs more easily. Similarly, the wall slip may also exist on the solid-liquid interface of the water lubricated Teflon bearing. Therefore, the influence of the wall slip on the lubrication performance should be fully considered in the lubrication mechanism study for the water lubricated non-metallic or polymer friction pair material bearing.

Table 1 Interfacial tension of commonly used materials

Material	Interfacial tension
Oil based lubricant	30 N/m
Water	73 N/m
Metal	500 N/m
Nitrile rubber	52.6 N/m
Teflon	18 N/m

Table 2 The ratio of viscous force to inertial force of commonly used lubricants

Lubricant	Viscous/inertial force ratio
Oil based lubricant	148:1-824:1
Water	1.67:1-11.3:1
Deep refrigerant	1.67:1-11.3:1
Liquid metal	1.67:1-11.3:1

1.2 *Theoretical basis of inertial force effect*

Generally speaking, Reynolds number is very small for conventional oil based lubricants. Table 2 shows the ratio of the viscous force to the inertial force of commonly used lubricants. It is large for the