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Thermal and tilt effects on bearing characteristics of hydrostatic oil pad in rotary table*

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Abstract: Hydrostatic pads are key components of a constant flow compensation hydrostatic rotary table. The tilt and thermal effects due to the partial load, the manufacturing errors and the friction must be considered. However, designers are more likely inclined to ignore these effects. In this work, the coupled characteristics of the tilt and thermal effects are studied. A coupled mathematical model to calculate the bearing properties of the pads is built. This model takes into consideration of tilt and thermal effects and is used to solve the flow problem by the finite difference method. The characteristics of the oil pad, including, the recess pressures, the load carrying capacity and the damping coefficients, are obtained and the tilt and thermal effects are analyzed. It is observed that the tilt has a tremendous impact on the bearing characteristics of the hydrostatic pad. The recess pressure, the load carrying capacity and the stiffness are reduced by 50% and the pressure distribution and the temperature distribution of the oil film also change significantly. When the pads work under a tilt operation, a larger land width is better for its bearing properties. It is also observed that the thermal effect is significant and cannot be ignored.

Key words: thermo-hydrodynamic lubricant, tilting, Reynolds equations, constant flow compensation

Introduction

Hydrostatic bearings are widely used in heavy machinery due to their advantageous characteristics of low viscous friction, high load-carrying capacity and high stiffness. Extensive and in-depth research has been carried out for the hydrostatic bearing technology, due to its widespread use and important role in the industry such as machine tools, telescopes, hydropower, and aircraft engines. The basic theory of the hydrostatic lubrication and the basic design of hydrostatic bearing systems can be found in Refs.[1-4]. These methods and theories are widely adopted by designers. However, some special factors should be considered, under various application conditions and manufacturing conditions.

Static and dynamic characteristics are the key properties of hydrostatic bearing systems and were widely studied. Zuo et al.[5] proposed a static loading experiment to determine the static and dynamic characteristics of conical hydrostatic bearings with different compensations. Guo et al.[6] used the finite element method to solve the flow of the fluid film in the conical bearing governed by the Reynolds equation. Using the pressure boundary condition, the bearing stiffness and the damping coefficients were calculated. The numerical results were compared with the experimental results. Gao et al.[7] analyzed the static and dynamic characteristics of hydrostatic guides with rectangle pockets and a PM flow controller.

As we all know, all mechanical parts have manufacturing errors, these errors can be divide in two parts: one is the surface roughness and the other is the geometric error. They both has some impact on the performance of the hydrostatic lubrication. Refs.[8-10]

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investigated the influence of the surface roughness on various performance characteristics of the hydrostatic thrust bearing based on Christensen roughness model. The roughness was found to have an important influence on the characteristics of the film. When the film thickness and roughness values have the same order of magnitude, the effects of the surface roughness cannot be ignored. Sharma et al.[11], theoretically investigated the influence of the dimple geometry on the fully textured hybrid thrust pad bearing operating with a non-Newtonian lubricant. The result is useful to optimize the sizes of the dimple diameter and depth for the bearing performance. Ramesh et al.[12] used experimental and numerical methods to study the friction characteristics of micro-textured surfaces. Their results indicate that the friction in the case of textured surfaces is 80% lower than that in the case of un-textured surfaces. In this work , the surface roughness effects can be ignored, since the surface roughness of the pad and the guide rail is lower than the thickness of the oil film ($ra < 8\ \mu\text{m}$, where the initial film thickness is 100 μm for 9.5 m hydrostatic rotary table).

The geometric error to some extent is equivalent to tilting due to its larger wavelength. The tilt effect was extensively studied. Liu et al.[13] developed a three-dimensional theoretical model to study the effect of disturbances on the dynamic performance of a wavy-tilt-dam (WTD) mechanical seal. Yadav et al.[14], numerically analyzed the influence of the tilt and the different recess shape on the static and dynamic performance characteristics of the hydrostatic thrust pad bearing system. The numerically simulated results indicate that the tilt significantly affects the dynamic and static characteristic parameters. De Pellegrin et al.[15] presented an isoviscous, isothermal model to investigate the influence of hydrostatic recesses on a spring-supported tilting pad thrust bearing. These studies mainly focused on the hydrostatic bearing with a constant supply pressure, which were not coupled with thermal effects.

The thermal effects also attracted many studies. Aksoy and Aksit[16] established a coupled thermo-elastohydrodynamics model to predict 3-D thermal, structural and hydrodynamic performance of foil bearings. Dobrica and Fillon[17] proposed a complete thermo-hydrodynamic (THD) steady state model and applied the model to the slider pocket bearing. The constructed model was solved using the finite volume method. The pressure distribution and the velocity fields in the fluid, as well as the temperature distribution across the fluid and solid pad were obtained using this method. Laraqi et al.[18] proposed a 2-D analytical solution to determine the temperature distribution of a thin fluid film confined between two parallel planes on a relative motion. Deresse and Sinha[19] analyzed the thermal and roughness effects on the characteristics of finite rough tilted pad slider bearings. The modified equations for Reynolds number, momentum, continuity and energy were coupled and solved using the finite difference method. Wang and Lu[20] investigated the effect of viscosity on cavitation characteristics of a high speed sleeve bearing.

On the whole, the studies of the tilt effect left many problems unsolved. In fact, it is often difficult to maintain a parallel state between the guide and the supporting oil pad of the turntable due to the manufacturing error, the partial load and the local deformation. Thus, it is necessary for studies to focus on the impact of tilting. In this work, simplified equations of motion, continuity and energy are developed and solved using the finite difference method. Then, the pressure distribution and the temperature distribution of the hydrostatic oil film are obtained. In addition, the recess pressure, the load carrying capacity, the stiffness coefficients and the damping coefficients at different tilting angles are analyzed.

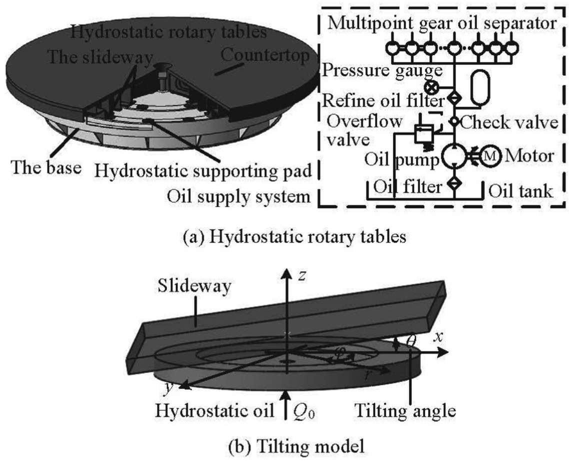

Fig.1 The schematic diagram of tilting model between guide and hydrostatic pad

1. Mathematic model

Hydrostatic rotary tables are widely used in heavy machine tools due to its excellent performance. The schematic diagram of a typical hydrostatic rotary table is shown in Fig.1(a). It mainly consists of the base, the countertop, the supporting system, and the driving system. The supporting system includes supporting oil pads, preloaded oil pads, the radial bearing and the oil supply system. The supporting oil pad is a circular step pad and the rotary table has many supporting pads. They are arranged under the countertop. The preloaded oil pad is the annular step recess pad and provides a pre-pressure to enhance the stiffness of the turntable. The radial bearing is mounted on the center of the turntable. These pads contain a constant flow oil, and in every pad the flow rate is almost the same and there is little interaction between the oil pads by

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