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Investigations of the static and dynamic characteristics of water-lubricated hydrodynamic journal bearing considering turbulent, thermohydrodynamic and misaligned effects

Huihui Feng[1a], Shuyun Jiang[2b], Aimin Ji [*3a]
a: School of Mechanical and Electrical Engineering; Hohai University; Changzhou, Jiangsu 213022, PR China.
b: School of Mechanical Engineering, Southeast University, Jiangning District, Nanjing, Jiangsu 211189, PR China.
Email: [1] fenghh@hhu.edu.cn; [2] jiangshy@seu.edu.cn; [3] jiam@hhuc.edu.cn
*Corresponding author: Aimin Ji

Abstract

A misaligned thermohydrodynamic (THD) model considering turbulent-flow is presented to predict the performance of water-lubricated hydrodynamic journal bearing (WHJB). The load capacity, frictional power loss, flow rate, mid-plane pressure distribution, translational, tilting and coupled translational-tilting dynamic coefficients versus the rotary speed, eccentricity ratio and tilting angle are analyzed; quantitative comparisons between models considering and without considering turbulent, THD and misaligned effects are given. Results show that the turbulence improves the load capacity while the THD effect decreases it; the THD effect reduces the frictional power loss significantly while the turbulent effect is weak; at large rotary speed and eccentricity ratio, the THD and turbulent effects on the dynamic coefficients should be fully considered at both of aligned and misaligned conditions.

Keywords
Water-lubricated bearing; Turbulent flow; Thermohydrodynamics; Misalignment

1. Introduction

Water-lubricated hydrodynamic journal bearings have attracted increasing attentions for their potential applications as support elements in high-speed spindles. Compared with oil hydrodynamic bearings, water-lubricated hydrodynamic bearings have lower frictional power loss and temperature rise at high speed and are environmental protection; compared with gas hydrodynamic bearings, the WHJBs have larger stiffness and better damping [1, 2]. However, with the improvement of spindle rotary speed, the bearing has a large Reynolds number, and the water film is highly turbulent, the heat generation will happen. Meanwhile, in practice, journal misalignment usually exists due to external load, manufacturing and assembly errors. So, for WHJBs used in high-speed spindle, it is necessary to investigate the static and dynamic performances of WHJB considering turbulent, thermohydrodynamic (THD) and misaligned effects.

Systematic studies on WHJBs have been carried out in the past thirty years. Yoshimoto et al. [1] analyzed the stability of water-lubricated hydrostatic conical bearing with spiral grooves according to the mass flow continuity equation and mass continuity equation. The flow is considered to be laminar and the perturbation method was used to calculate the dynamic coefficients of the bearing. Majumdar et al. [3] analyzed the performances of an axial grooved water-lubricated journal bearing according to the laminar Reynolds equation by using the perturbation method. Gohara et al. [4] and Hanawa et al. [5] adopted the laminar model to study the static characteristics of water-lubricated hydrostatic thrust bearing with membrane restrictors and capillary restrictor, respectively. Gao et al.[6] carried out numerical analysis of hydrodynamic water-lubricated bearing by commercial software FLUENT. However, as noted above, the water film is considered laminar and isothermal due to a low rotary speed.

Recently, many researchers focused on the effect of turbulence [7, 8], inertia [9-11] or heat generation [7,9,10] on the static and dynamic performances of high-speed water-lubricated bearings. Wang, Pei and et al. [7] pointed out that when the rotary speed of hybrid water-lubricated bearing is high, the turbulence and THD effect should be taken into consideration. Yuan et al. [8] investigated the static and dynamic characteristics of a hybrid water-lubricated journal bearing based on the turbulent Reynolds equation theoretically and experimentally. San Andrés et al. [9] proposed a bulk flow turbulent model to simulate the static and dynamic performances of a hydrostatic water-lubricated bearing considering the fluid inertia terms. This model included both of the pressure and shear dominated turbulent flows. Comparison of theoretical results with experimental results shows the accuracy of the proposed model. Recently, Rohmer and San Andrés [12] designed a test apparatus to test the static performance of a water-lubricated thrust bearing. Lin, Jiang, et al. [10] established a THD model considering the influences of cavitation, inertia and turbulence for water-lubricated thrust bearing with spiral groove. Results show that the inertial effect increases the maximum temperature rise and the static characteristics while the cavitation effect reduces those characteristics. However, the above studies mainly focused on the performances of water-lubricated bearings in aligned condition.

In practice, the bearings are always in misalignment due to external load, assemble mistake or manufacturing mistake. In this situation, the bearing tilts around its axes with small angles. Zhang et al. [13] and Mallya et al. [14] analyzed the load capacity and friction coefficient of hydrodynamic water-lubricated journal bearing under misalignment. The water film is dominated by laminar flow and considered to be isothermal. Xu et al. [15] studied the dynamic characteristics of the oil lubricated bearing by numerically solving the turbulent Reynolds equation and energy equation. In the study, the motion of the bearing is simplified as two degree-of-freedom (2DOF) motion with eight dynamic coefficients. Research showed that the performance of misaligned oil-lubricated journal bearings at a large eccentricity ratio is greatly influenced by thermal

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