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Impact of lubricant traction coefficient on cage's dynamic characteristics in high-speed angular contact ball bearing

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Abstract In this paper, the formulas of elasto-hydrodynamic traction coefficients of three Chinese aviation lubricating oils, 4109, 4106 and 4050, were obtained by a great number of elasto-hydrodynamic traction tests. The nonlinear dynamics differential equations of high-speed angular contact ball bearing were built on the basis of dynamic theory of rolling bearings and solved by Gear Stiff (GSTIFF) integer algorithm with variable step. The impact of lubricant traction coefficient on cage's dynamic characteristics in high-speed angular contact ball bearing was investigated, and Poincaré map was used to analyze the impact of three types of aviation lubricating oils on the dynamic response of cage's mass center. And then, the period of dynamic response of cage's mass center and the slip ratio of cage were used to assess the stability of cage under various working conditions. The results of this paper provide the theoretical basis for the selection and application of aviation lubricating oil.

1. Introduction

As one of basis parameters for dynamic design of rolling bearing, lubricant traction coefficient is affected by the combined impacts of slip velocity, rolling velocity and contact stress between roller and raceway, the temperature of lubricating oil, etc. Any changes in the above-mentioned factors might revise the traction behavior of lubricant between roller and raceway, causing the changes of collision force and collision frequency between cage and ball, which directly affect the stability of cage. Three types of Chinese aviation lubricating oils, namely 4109, 4106 and 4050, are commonly used for lubrica-

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tion of angular contact ball bearing for high-speed spindle under various working conditions. However, owing to the different physics, chemistry and mechanics properties of lubricants, the systematic researches in the connections of lubricant traction coefficient and cage's dynamic characteristics are quite rare.

In 1971, Walters[1] firstly built the analytic model of high-speed ball bearing, which set the foundation of dynamic analysis of high-speed ball bearing. Gupta[2–5] built the dynamics differential equations of ball bearing with six degrees of freedom, and then studied the cage's whirl orbit. By stimulating, Gupta P K indicated that the frictional coefficient between ball and raceway had great impact on cage's whirl orbit, but he did not further study the influencing factors of cage's stability. Further to previous research, Gupta[6] studied the relationship between structural parameters of cage pocket clearance, guide clearance and cage stability, but neglecting the impact of lubricant properties on the stability of cage. Based on the simplified traction model of lubricant, Boesiger et al.[7] studied the impact of operation conditions on cage's whirl orbit and unsteady characteristic frequency in ball bearing, pointing out that oil lubrication was more preferable than grease lubrication in terms of cage stability. Lord and Larsson[8] did the experimental studies of elasto-hydrodynamic traction properties for VG46, VG68 and VG150, analyzing the impact of lubricant properties on lubricant film and traction coefficient, but their research did not involve the impact of lubricant properties on cage's stability. Rahman and Ohno[9] did the experiments of the fatigue life and impact performance of bearings, which were lubricated by eight types of synthesized lubricants, analyzing the lubrication film between cage and ball and the reasons for cage's failure. In addition, in their research, they indicated that lubricant traction coefficient had great impact on cage's failure. Based on the quasi-dynamic theory of angular contact ball bearing, Deng and Hao[10] studied the effect of different working conditions and structural parameters on the offset of cage's mass center, which had been used to assess cage's stability. Pederson et al.[11] developed a flexible cage model with six degrees of freedom in deep groove ball bearing, and studied cage's instability and ball-to-cage pocket contact forces. Based on dynamic theory of angular contact ball bearing, Liu and Deng[12] studied the effect of working conditions and structural parameters on cage's whirl orbit and the speed deviation ratio of cage, which were used to assess the cage's stability. Based on dynamic theory of rolling bearing, Deng and Xie[13] studied the dynamic characteristics of cage in high-speed angular contact ball bearing, pointing out that too big or too small pocket clearance and the guiding clearance of cage were adverse to cage's stability. Sathyan et al.[14] conducted various tests such as run-in test, temperature test, and over-lubrication test to study the instability of cage in ball bearings, and the study results show that square pocket retainers are more stable compared to circular pocket retainers. Ashtekar and Sadeghi[15] developed a 3D explicit finite element model (EFEM) of the cage to analyze the cage dynamics, deformation, and resulting stresses in a ball bearing under various operating conditions. Ye[16] studied the effect of cage clearance ratio, bearing load and bearing rotation speed on cage's whirl orbit and the speed deviation ratio of cage, suggesting that too big or too small pocket clearance and guiding clearance of cage were not beneficial to cage's stability. Abele et al.[17] promoted two new image evaluation algorithms to capture cage's whirl with sensors installed on a bearing test rig, and analyzed the cage motion in an angular contact ball bearing under the operation conditions. All the above mentioned researches mainly focused on the impact of bearing working conditions and structural parameters on cage's dynamic characteristics and stability, while the impact of lubricant traction coefficient on cage's dynamic characteristics and stability has not aroused any attention.

In this paper, the formulas of elasto-hydrodynamic traction coefficients of three Chinese aviation lubricating oils, 4109, 4106 and 4050, are obtained through a great number of elasto-hydrodynamic traction tests. The nonlinear dynamics differential equations are built on the basis of dynamic theory of rolling bearings and solved by Gear Stiff (GSTIFF) integer algorithm with variable step. The impact of lubricant traction coefficient on cage's dynamic characteristics is investigated, and Poincaré map is used to analyze the impact of three types of aviation lubricating oils on dynamic response of cage's mass center and the slip ratio of cage. The period of dynamic response of cage's mass center and the slip ratio of cage are used to assess cage's stability and the research results of this paper provide theoretical basis for the selection of aviation lubricating oil.

2. Elasto-hydrodynamic traction coefficient tests

The tests of elasto-hydrodynamic traction coefficients for three Chinese aviation lubricating oils, 4109, 4106 and 4050, were conducted by using a self-made test rig. The construction of test rig is shown in Fig. 1, where B direction denotes the left view of local type view.

According to the dynamic viscosity and temperature-viscosity coefficient, the three Chinese aviation lubricating oils, 4109, 4106 and 4050, are categorized to the low viscosity lubricant, medium viscosity lubricant, and medium viscosity, high-temperature resistant lubricant, respectively.

The parameters of aviation lubricant oil, 4109, 4106 and 4050, are shown in Table 1, where η_0 is dynamic viscosity at ambient temperature, α pressure-viscosity coefficient, β temperature-viscosity coefficient, and K thermal conductivity.

The formulas of elasto-hydrodynamic traction coefficients μ of 4109, 4106 and 4050 were obtained by applying the curve fitting technic to the test data.

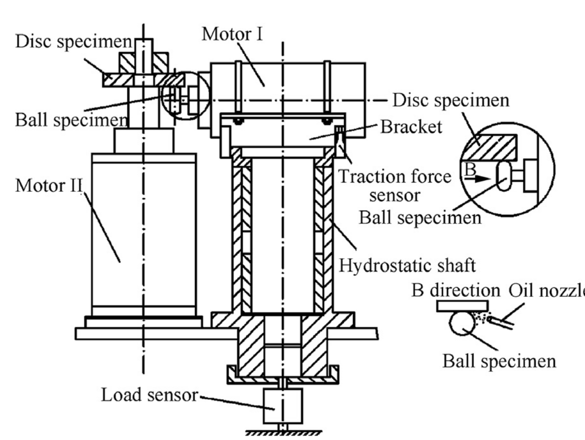

Fig. 1 Construction of test rig.