Chinese Journal of Aeronautics, (2017), xxx(xx): xxx–xxx

Chinese Society of Aeronautics and Astronautics
& Beihang University

Chinese Journal of Aeronautics

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Cage slip characteristics of a cylindrical roller bearing with a trilobe-raceway

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Received 19 September 2016; revised 5 July 2017; accepted 5 July 2017

KEYWORDS

Bearing rating life;
Cage slip ratio;
Dynamics;
Raceway contour;
Trilobe-raceway

Abstract Based on dynamic analysis of rolling bearings, the nonlinear dynamic differential equations of a cylindrical roller bearing with a trilobe-raceway were established and solved by the GSTIFF (gear stiff) integer algorithm with a variable step. The influences of structural parameters and the tolerance of the trilobe-raceway, working conditions of the bearing, and the outer ring installation method on cage slip characteristics were investigated. The results show that: (i) The cage slip ratio and bearing rating life of a cylindrical roller bearing with a trilobe-raceway would reduce when the low-radius (radius of the outer raceway contour at the lowest point) and D-value (difference value between the high and low points of the outer raceway contour) decrease, and the former (low-radius) contributes more significantly. (ii) The cage slip ratio of a cylindrical roller bearing with a trilobe-raceway rises with the increase of the bearing speed, and decreases with the increase of the radial force; the variation range increases with the increase of the low-radius. (iii) When the installation angle of the outer ring increases in a period, the cage slip ratio remains unchanged while the bearing rating life rises up a little. Therefore, when installing a cylindrical roller bearing with a trilobe-raceway, the location of the maximum radius shall be under that of the radial force to improve the bearing rating life. (iv) With the increase of the roundness of the base circle where the radius of the lowest points of the trilobe-raceway contour locates, the cage slip ratio rises gradually and the bearing rating life decreases.

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Peer review under responsibility of Editorial Committee of CJA.

ELSEVIER Production and hosting by Elsevier

1. Introduction

For high-speed cylindrical roller bearings in the application of aircraft engines, cage slip always happens due to high-speed and light-load conditions, and serious cage slip will lead to early failure of such bearings, which has a profound effect

http://dx.doi.org/10.1016/j.cja.2017.07.001
1000-9361

on the aircraft safety. One of the effective solutions to this light–load slip problem is to make the outer raceway of a cylindrical roller bearing to be a trilobe-raceway.[1] There are three man-made preload locations circumferentially equally-spaced on the outer ring raceway of a cylindrical bearing to increase preload onto more rollers, decrease the rotational speed difference at different positions, reduce bearing skidding, and improve its service life.

The skidding problem of bearings at high speed with insufficient load has always been a hot concern by scholars both at home and abroad. Harris[2] developed a skid prediction model for a high-speed roller bearing by means of a quasi static analytical method, and investigated the effects of bearing load, rotating speed, and number of rolling elements on bearing skidding. Poplawski[3] established a quasi dynamics analysis model for a high-speed roller bearing taking into consideration the guide surface between the cage and rings as well as the friction between the rolling element and the cage pocket, and analyzed the cage and roller slip as well as the film thickness and forces in the cage. Cavallaro and Nelias[4] presented an analytical model for high-speed cylindrical roller bearings with flexible rings, and investigated the relationship between ring deformation and bearing load distribution as well as roller slipping speed and load distribution. Takafumi et al.[5] proposed a theoretical model for cage slip of cylindrical roller bearings with the consideration of non-Newtonian fluid properties and temperature rise of lube oil, and analyzed the cage slip ratio under different speeds and loads. Arthanari and Marappan[6] experimentally analyzed the effects of rotating speed, radial load, and the number of rollers on cage slip of a cylindrical roller bearing. Takabi and Khonsari[7] built a dynamic model of a high-speed cylindrical roller bearing, and investigated the influence of different traction models on the sliding velocities and cage wear rate between rollers and races. Chinese scholars also did lots of research on bearing skidding. Li and Wu[8] established a dynamic analytical model for high-speed cylindrical roller bearings, and dynamically simulated the roller skew, axial movement, roller and cage slip characteristics, etc. Hu et al.[9,10] established a quasi static calculation model for inter-shaft cylindrical roller bearings, and analyzed the relationship between the roller slip ratio and radial load when bearing rings are under different working conditions. Tu and Shao[11] considered the acceleration phase of roller bearings, and presented an analytical model to study bearings' skidding characteristics under different forces and inner ring rotational accelerations. Chen et al.[12] developed a bearing dynamic model under a whirling condition taking into consideration the bearing skidding of a high-speed rolling bearing under the whirling condition, and analyzed the effects of various outer loadings, whirling frequencies, and whirling radii on the bearing skidding. Deng et al.[13] established a dynamic differential equation for a high-speed cylindrical roller bearing, and analyzed the effects of the clearance ratio of the cage, guiding type, etc. on the cage slip ratio and centroid trajectory. All the studies mentioned above have been focused on the performance analysis of cylindrical roller bearings under high-speed and light-load conditions, whereas studies on a cylindrical roller bearing with a trilobe-raceway have been focused on its raceway process technology,[1,14,15] and little research has been done on the theoretical research of the dynamics of a cylindrical roller bearing with a trilobe-raceway.

Therefore, this paper analyzes the dynamics of a cylindrical roller bearing with a trilobe-raceway based on the dynamic analysis of the roller bearing, establishes nonlinear dynamics differential equations for a cylindrical roller bearing with a trilobe-raceway, and then adopts the GSTIFF (gear stiff) integer algorithm with a variable step to solve these equations. The focus of this paper is to study the influences of structural parameters of the raceway and parameters of working conditions as well as the relationship between the outer ring installation method and cage slip. The present paper provides some theoretical basis for the structure design of a cylindrical roller bearing with a trilobe-raceway.

2. Calculation model of the trilobe-raceway

An outer ring with a trilobe-raceway can be obtained by a pre-deformation machining method,[1] and the principle of the method is shown in Fig. 1.

As shown in Fig. 1(a), a uniformly-distributed load F is applied to the 1/3 symmetrical outer surface of the roughcast of the bearing ring along the circumferential direction, which leads to an elastic pre-deformation shown in Fig. 1(b). Keep the applied load constant while grinding the raceway to its theoretical base circle dimension as shown in Fig. 1(c), and the required trilobe-raceway contour can be obtained as a result of the deformation resilience after releasing the load, as shown in Fig. 1(d). The radius of the trilobe-raceway at different azimuth angles after machining can be expressed as:

$$R_{\mathrm{e}}(\varphi) = R_{\mathrm{egm}} - R_{\mathrm{eg}}(\varphi) + R_{\mathrm{eo}} \tag{1}$$

where R_{eo} is the original radius before machining; $R_{\mathrm{eg}}(\varphi)$ is the radius of the raceway at different azimuth angles φ after the elastic deformation of the outer ring is generated because of the applied force; R_{egm} is the grinding radius, i.e., the theoretical base circle radius.

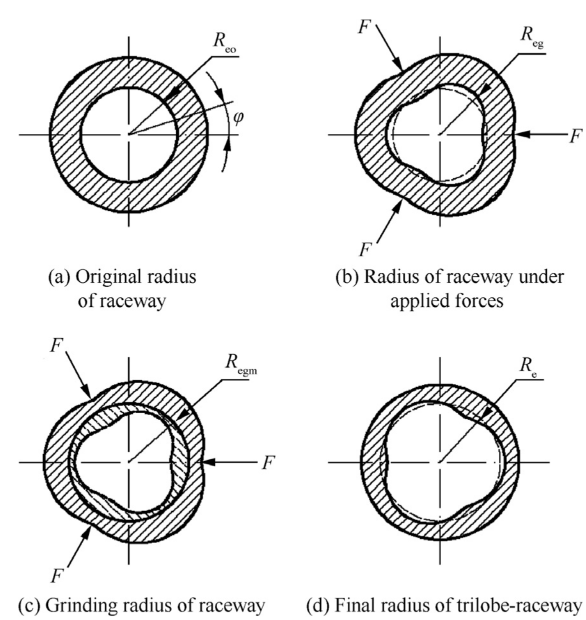

Fig. 1 Sketch map of the pre-deformation machining principle.

Please cite this article in press as: DENG S et al. Cage slip characteristics of a cylindrical roller bearing with a trilobe-raceway, *Chin J Aeronaut* (2017), http://dx.doi.org/10.1016/j.cja.2017.07.001