Mechanism and Machine Theory 121 (2018) 259–272

Contents lists available at ScienceDirect

Mechanism and Machine Theory

journal homepage: www.elsevier.com/locate/mechmachtheory

Research paper

An investigation for the friction torque of a needle roller bearing with the roundness error

Jing Liu [a,b,*], Zhanglin Yan [a], Yimin Shao [a]

[a] State Key Laboratory of Mechanical Transmission, Chongqing University, 400030, PR China
[b] College of Mechanical Engineering, Chongqing University, Chongqing, 400030, PR China

ARTICLE INFO

Article history:
Received 4 August 2017
Revised 12 October 2017
Accepted 27 October 2017

Keywords:
Friction torque
Needle roller bearings
Roundness error
Grease lubrication

ABSTRACT

Needle roller bearings (NRBs) are key components in industrial machinery. The rotational accuracy and efficiency of the machinery are determined by the friction torques of their interior NRBs. This study proposes an analytical method for calculating the friction torque of a NRB without and with the roundness error. This model formulates the rolling friction torques produced by the elastic material hysteresis, slipping friction torques generated by differential slipping, viscous friction torques caused by the lubricating oil, slipping torques generated by the slipping between mating components, and centrifugal force of the needle roller. The friction torques of a healthy solid-grease-lubricated NRB calculated by Palmgren's, SKF's, Chiu and Myers's, and proposed methods are compared. The influences of the radial load, inner raceway velocity, and roundness error on the friction torque increment of an unhealthy solid-grease-lubricated NRB are analyzed by using the proposed method. Moreover, the results from Palmgrem's method, SKF's method, Chiu and Myers's method, proposed method, and Iqbal et al.'s experimental investigations are compared to validate the proposed method. It seems that this study can give a more accurate method for predicting the friction torque of the NRB with the roundness error compared to the previous empirical methods.

1. Introduction

Needle roller bearings (NRBs) are key components in industrial machinery. The rotational accuracy and efficiency of the machinery are determined by the friction torques of their interior NRBs. Thus, it is important to investigate the friction torques of the NRBs for the high precision and high speed industrial machinery.

Numerous research studies have been reported to analyze the friction torques of the rolling element bearings (REBs). Palmgren [1] used the experimental method to establish an empirical formulation for the friction torque of the REBs. Kakuta [2,3] and Snare [4–6] studied the friction torques caused by the elastic material hysteresis, slipping, hydrodynamic lubrication, and ball spinning for ball bearings. Todd and Stevens [7] discussed the influence of the groove radius of an angular ball bearing on the friction torque based on the experimental results. Gentle and Pasdari [8] developed an analytical method to calculate the friction torque between the ball and cage, and that between the cage and its guiding surface. Trippett [9] used an experimental method to analyze the influences of the radial load and lubrication conditions on the friction torques of the ball and needle bearings. Chiu and Myers [10] presented an empirical friction torque formulations for thrust and ra-

* Corresponding author at: State Key Laboratory of Mechanical Transmission, Chongqing University, 400030, PR China.
E-mail address: jliu@cqu.edu.cn (J. Liu).

https://doi.org/10.1016/j.mechmachtheory.2017.10.028
0094-114X/

dial needle bearings. Svenska Kullager Fabriken (SKF) Group [11] proposed a calculation method for predicting the friction torques of the REBs based on the experimental results. Ghanbari and Khanmohamadi [12] conducted an experiment method to study the influence of the operational conditions on the friction torques of the ball bearings. Iqbal et al. [13] introduced an experimental method to study the influences of the solid grease lubrication and conventional lubrications on the frictional power loss of a NRB. They also compared the experimental results with those calculated by the SKF's and Palmgren's methods. It should be noted that there were significant differences between the experimental results and those from the SKF's and Palmgren's methods.

The above review shows that most of published work focused on analyzing the friction torque of the healthy ball and roller bearings using the empirical formulations including Palmgren's and SKF's methods, experimental methods, and analytical methods. Although Iqbal et al. [13] improved the SKF's empirical method to calculate the friction torque of a healthy NRB, few work were reported to establish analytical methods for calculating the friction torques in the NRBs. However, the contact forces between the mating components in the REBs could be significantly influenced by the manufacturing errors and faults on the bearing component surfaces [14–20], which can affect the friction torques of the REBs.

Some works were reported to study the friction forces and torques in the unhealthy REBs. For instance, Babu et al. [21], and Liu and Shao [22] considered the Palmgren's friction torque model in their dynamic models to study the vibrations of a rigid rotor-ball bearing system with a localized fault. Liu et al. [23,24] formulated the Coulomb friction force in their finite element model for ball and roller bearings with a localized fault. Deng et al. [25] presented an analytical method to analyze the influence of the surface waviness on the friction torque of an angular contact ball bearing. Tong and Hong [26] developed a method to study the influence of the angular misalignment on the operational torques of a tapered roller bearing. Heras et al. [27] proposed a numerical method to calculate the friction torque in a slewing bearing due to manufacturing errors. Halminen et al. [28] established a multibody model to study the influence of the surface waviness on the friction torque of a touchdown bearing. Xu and Li [29] studied the influence of the surface waviness on the friction torque of a ball bearing in a planar multibody system.

The above review indicates that some previous works studied the influences of the misalignment and surface waviness on the friction torque of the tapered, ball, and touchdown bearings. In practice, the roundness error is also a major manufacturing error of the bearings. The frequency response range of the roundness error is from 2 upr (undulation per revolution) to 15 upr. The frequency response range of the surface waviness is from 15 upr to 250 upr. Since the geometrics of the roundness error are very different with those of the surface waviness, the influence of the roundness error on the friction torques of the NRB should be different with that of the surface waviness. However, the influence of the roundness error on the friction torques of the NRB was not reported in the literature. Therefore, the purpose of this paper is to fill this gap.

This study proposes an analytical method for calculating the friction torque of a NRB with the roundness error. This model formulates the rolling friction torques between the needle rollers and raceways produced by the elastic material hysteresis, the slipping friction torques generated by the differential slipping between the needle rollers and raceways, the slipping friction torque caused by roller rotation, the slipping friction torques generated by the bearing slope, the viscous friction torques caused by the rotation and churning torque of the needle rollers and cage in the lubricating oil, the slipping friction torques produced by the needle rollers and cage pocket, and the cage and its guiding surfaces, the slipping torques generated by the slipping between the seals and bearing components, and the centrifugal force of the needle roller. The friction torques of a healthy solid-grease-lubricated NRB from Palmgren's method, SKF's method, Chiu and Myers's method, and proposed method are compared. The influences of the radial load, inner raceway velocity, and roundness error on the friction torque increment of an unhealthy solid-grease-lubricated NRB are analyzed by using the proposed method. Moreover, the results from Palmgrem's method, SKF's method, Chiu and Myers's method, proposed method, and Iqbal et al.'s experimental investigations are compared to validate the proposed method.

2. Calculation methods for the frictional power loss

2.1. Palmgren's method [1]

Palmgren derived an empirical expression of the frictional torque for the rolling element bearings with moderate speeds, which included load dependent and independent components. The influences of the bearing speed and load were included, as well as the friction and viscous lubricant caused by the bearing loads. This empirical expression is determined by the bearing boundaries, which is given by

$$M_{\mathrm{Pal}} = M_0 + M_1 \tag{1}$$

where M_0 is determined by the lubricant oil, bearing speed, and bearing geometries, which is the load independent component. It is defined by

$$M_0 = \begin{cases} 10^{-7} f_0 (\nu n)^{\frac{2}{3}} d_m^3 \nu n \geq 2000 \\ 160 \times 10^{-7} f_0 d_m^3 \nu n < 2000 \end{cases} \tag{2}$$

where f_0 is a coefficient determined by the bearing type and lubricant conditions, whose values were provided in Ref. [30]; in this work, f_0 is equal to 1.5, 2.5, and 6 for the oil fog lubrication, the grease lubrication, and the oil spray lubrication con-