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A novel method to model effects of natural defect on roller bearing

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ABSTRACT

The assumption that the defects extend axially throughout rollers or raceways was widely adopted in previous studies, however, this is hardly the situation in natural defects. A contact model that considered the geometric feature of natural defect was developed to analyze effects of defect on roller-raceway contact. The contact stiffness expression for defected roller-raceway was derived by numerical fitting. The contact stiffness expression was introduced into the quasi-static model of roller bearing to model defected roller bearing. The contact load distribution and stiffness of roller bearing were simulated under different defect sizes and operating conditions. Results demonstrate that roller bearing was insensitive to natural defects and the prevailing fatigue criteria is not applicable to roller bearing.

1. Introduction

Defects caused by fatigue spalling will degrade bearing performances and eventually lead to bearing failure. The modeling for defected bearings has been widely researched, which provided mechanistic models for simulating and understanding the effects of defect on bearing. Recent studies attempt to diagnose defects [1,2] and predict useful life [3,4] of bearings through establishing a correlation model between defect and its vibration response. These studies have given enough accurate diagnostic and predictive results for ball bearing, however, they are not suitable for roller bearings due to the difference between contact type of ball bearings and that of roller bearings. Experiments have shown that roller bearings remain useful even when the defect degree is well beyond the failure criteria [5,6] that the appearance of first spalling or the defect area growing to 6.5 mm^2. The experimental results indicate that the effects of defect on roller bearings have not been accurately modeled in previous studies. To provide the foundation for accurate defect diagnosis and life prediction of roller bearings, the defected roller bearing model considering the characteristics of contact type and natural defects is required.

Defects of roller bearing is considered as the depression due to material spalling. The assumption that defects extend axially throughout the rollers or raceways is widely adopted in modeling of defected roller bearings. Rollers passing over such “through” type defect will go into the defect depression, which will result in additional displacement and curvature variations as shown in Fig. 1. Through the introduction of the contact load change due to additional displacement and the Hertz contact stiffness change due to curvature variations [7,8][7,8] into bearing dynamic model, the vibration response of defected roller bearing can be modeled. Several researchers analyzed the vibration response of roller bearing with different width of “through” type defect [9], and proposed the measuring technique of defect width based on decomposition using wavelet transform [10,11]. The assumption of “through” type defect is adopted so that the defect of roller bearing can be modeled in the same way as that of ball bearing, however, natural defects of roller bearing rarely extend the entire axial length of roller or raceway [5,12]. Fig. 2 demonstrates a typical natural defect of roller bearing, which shows clearly that the defect is “non-through” in nature. Rollers passing over such “non-through” type defect are still supported by non-defect region as shown in Fig. 3, therefore, the rollers will not go into the defect depression. In comparison with the prevailing assumption of “through” type defect, authors believe treating defects as the “non-through” type depression reflects geometric feature of the natural defects more faithfully. Since “non-through” type defect cannot be modeled and analyzed by the existing methods, it is necessary to propose a new method to model the “non-through” type defects of roller bearings.

Contact condition of roller-raceway directly affects the motion of bearings component [13,14,15], therefore, the present paper attempts to model the effects of “non-through” type defect on roller bearing performance by considering the change of roller-raceway contact stiffness. In general, the roller-raceway contact is simplified to a two-dimensional plane strain problem and solved using Hertz line contact theory. However, the geometric feature of roller and raceway, especially the features of defect, cannot be modeled accurately and completely in this two-dimensional contact model. Recent contact modeling [9,16,17] have

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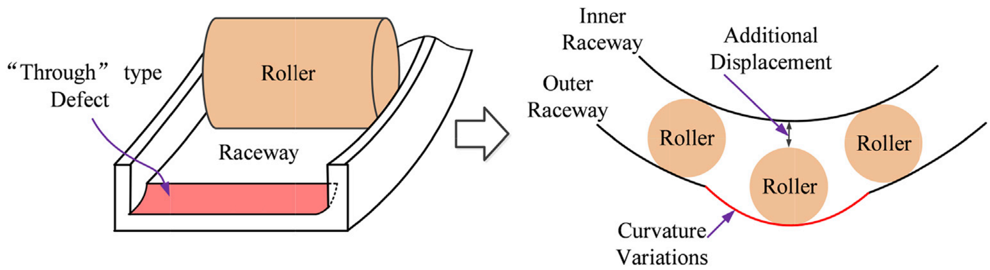

Fig. 1. The model of "through" type defects of roller bearing.

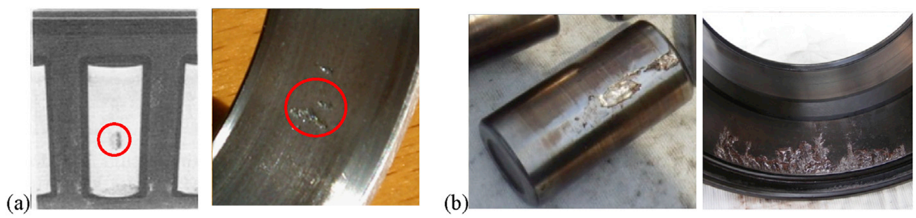

Fig. 2. The natural defect of roller bearing: (a) Early fatigue spalling [5,12]; (b) Severe fatigue spalling.

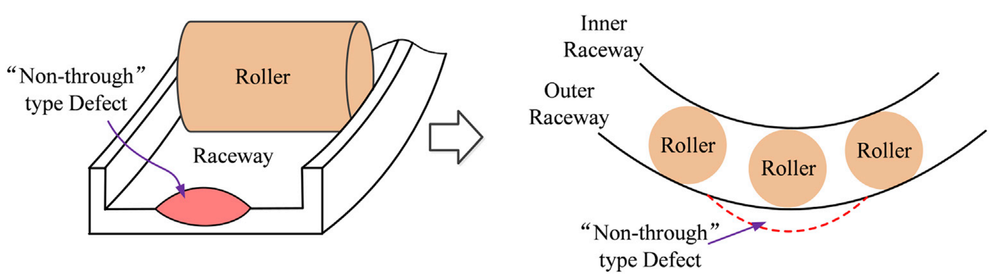

Fig. 3. The model of "non-through" type defects of roller bearing.

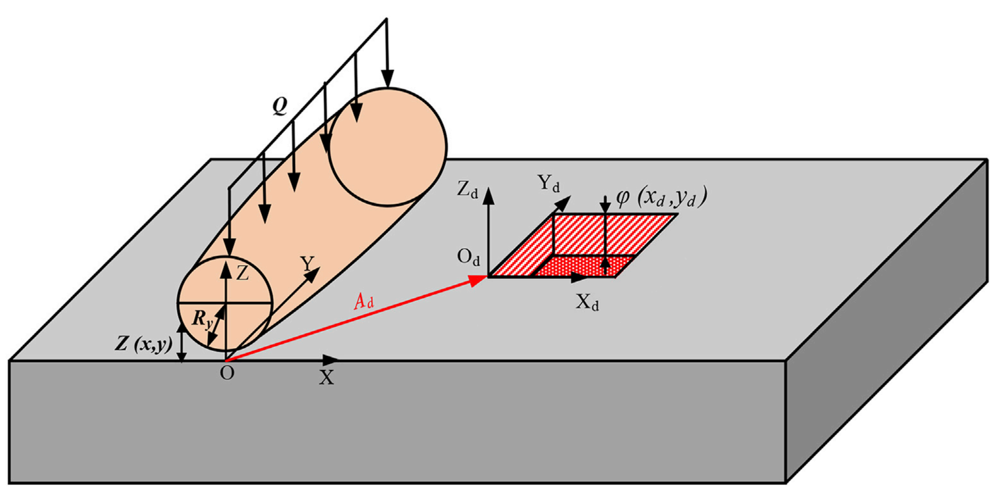

Fig. 4. The equivalent contact model of roller-raceway.

been undertaken to overcome the limitations of the two-dimensional contact model by using non-Hertz line contact theory in an effort to model the complex surface features of contact bodies, and got a solution with enough accuracy needed. However, no studies, to the authors' knowledge, have analyzed the effects of "non-through" type defect on roller-raceway contact stiffness.

This paper develops a defected roller-raceway contact model through the modification of initial clearance function in the non-Hertz line contact theory, and analyzes the effects of different degrees of "non-through" type defect on roller-raceway contact. Through the roller-raceway contact analysis, the change of contact stiffness due to defect is obtained. Then contact stiffness expressions under different defect degree are derived by numerical fitting to simplify the subsequent simulation. The defected roller bearing is modeled by incorporating the change of contact stiffness into three-degrees of freedom (3-DOF) quasi-static model of roller bearings. Finally, the effects of defect on roller bearings under different operation condition are simulated based on the newly developed model. In contrast to existing model, the proposed model could faithfully simulate the effects of natural defect, namely "non-through" type defect, on roller bearings. This is particularly important for accurately diagnosing fault and predicting life of roller bearings.