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Investigation the effect of internal radial clearance on the nonlinear dynamic response of a balanced rotor supported by deep groove ball bearings

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Abstract

In this paper an analytical model is proposed to investigate the effect of internal radial clearance in nonlinear dynamic behavior of a rotating system supported by deep groove ball bearings. In this case, the only excitation mechanism is the parametric excitation which induces the ball pass frequency which is detected in the vibration spectra. The variation of vibration amplitude for different internal radial clearance is carefully analyzed. The rolling element contacts modeled with nonlinear springs based on Hertzian contact which is stiff in the direction of contact and soft in the opposite direction. The differential equations are solved iteratively using a modified Newmark numerical integration technique. The results are presented in the form of fast Fourier transforms. The obtained results are compared with those ones in reliable literatures.

Keywords: Deep groove ball bearings, nonlinear, internal radial clearance, Newmark method

Introduction

Rolling bearings are widely used in industrial machinery. In spite of their simple structure they have a complicated dynamic behavior.

The first researches on the dynamic behavior of ball bearings were conducted by Perret [1] and Meldau [2]. Perret considered a deep groove ball bearing with the elastic deformation between race and balls due to Hertzian theory. The bending of the races was not taken into account in this model. In Meldau model 2D motion of shaft center were studied in absence of inertia and damping forces. Yamamoto [3] performed an analytical investigation on the dynamic behavior of a vertical rotor supported with ball bearing including radial clearance. Sunnersjo [4] investigated the parametric excitation both theoretically and experimentally. Its model contains damping and inertia considerations. Mevel and Guyader [5] and Fakuta et al. [6] modeled a ball bearing supporting a horizontal rotor with constant radial loading separately. Wensing [7] derived the equations of motion for a system supported with deep groove ball bearings. Sopanen and Mikkola [8, 9] developed a dynamic model of a deep-groove ball bearing with six degrees of freedom.

The early works on the effect of internal radial clearance on the nonlinear vibration of rotor were performed by Yamamoto [3]. Ehrich [10, 11] studied and higher order sub harmonic of bearing clearances. Tiwari et al. [12] studied the effect of the ball bearing clearance on the dynamic response of a rigid rotor. Sopanen and Mikkola [8] Studied some specific classes of internal radial clearance and Harsha [13] investigated arbitrary values of internal radial clearance. There are several classes for radial internal clearance in deep groove ball bearings. In this work the vibrations of the bearings are studied for different values of radial internal clearance. Five different classes of radial internal clearances (C2, C3, C4, C5 and Normal Class) are studied. In this case, the only excitation mechanism is parametric excitation which generates vibrations at ball pass frequency or varying compliance frequency. Since the rotor is completely balance, no shaft frequency or its harmonics must be appeared in the vibration spectrum of the rotor. In the present work an analytical model is proposed to investigate the effect of internal radial clearance on the dynamic behavior of deep groove ball bearings.

Parametric Excitation

The vibrations generated in ball bearings can be ascribed to different mechanisms. Most of these mechanisms are related to imperfections in the bearing, such as waviness, roughness, damage, fatigue spalls and dirt. However, at all times even perfect ball bearings generate vibrations due to the rotation of the loaded rolling elements. When the rolling element set and the cage rotate with a constant angular velocity, a parametrically excited vibration is generated that is transmitted through the outer ring. The characteristic frequency of this vibration which and is called the ball pass frequency equals

$$f_{bp} = N_b f_c \tag{1}$$

Which N_b is the number of balls and f_c is the cage frequency.

Nonlinear dynamic Modeling of the System

The structural vibration analysis of rolling element bearings for normal condition developed using a spring mass model with nonlinear springs. The outer ring of the bearing fixed in a rigid support and the inner ring rigidly joined with the rotating shaft. A constant radial vertical force acts on the bearing. Because of existing nonlinearities, a nonlinear force will be appeared.