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Study on Excitation Forces Generated by Defective Races of Rolling Bearing

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Abstract

The vibrations generated by defective rolling elements bearing play vital role in dynamics of rotating machines. In this paper different approach for simulation and numerical analysis of defective bearing races presented by researchers have been compared and extended for multiple defects. This work has been attempted to demonstrate the way of modelling and simulation of local and distributed defect on inner and outer race of deep groove ball bearing. The bearing defect has been modelled as impulse train force or impact force to cause an additional deflection or excitation of rolling elements. The simulated results have been analysed in time and frequency domain. The characteristics defect frequency and its harmonics and amplitude of vibration response of defective bearing is broadly investigated through simulated results.

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Keywords: Rolling element bearing; Excitation force; Pulse shape; Impulse train force; Rolling element load; Local defect; Waviness.

1. Introduction

Rolling element bearings are widely used in the industrial and domestic applications. The proper working of bearing in the machinery is a great importance to avoid any unexpected accident and loss of economy in the industry. The varying rolling element load with respect to angular position of the cage or time varying contact forces results in variation of stiffness and generation of nonlinear vibrations [1-2].

The defects of rolling element bearings are mainly classified into localized defect and distributed defect. The local defects like pits and cracks are mainly occur due to long use of bearing, corrosion or manufacturing errors. While, the distributed defect like surface roughness, race waviness, off size rolling element and misaligned races occur due to manufacturing errors. These defects change the dynamic behaviour of rotor bearing systems. Therefore, researchers have considered the bearing defects in dynamic modelling of shaft bearing systems.

In review paper Shah and Patel [3] have studied various dynamic models of bearings having defect on the races. The bearing defects produce exciting force due to interaction of defect with rolling element [4-5]. McFadden and Smith [4] have suggested that each time a single inner race local defect strikes its mating element, a pulse of short duration is generated that excites the resonances periodically at the characteristic frequency related to the defect location. The rate of the repetition with which this impact occurs is known as the inner race element passing frequency, denoted here by BPFI.

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The authors have modeled the single point defect as an impulse described by an impulse function. Tandon and Choudhary [5] have extended the concept of McFadden and Smith [4] model to predict the vibration response of localized defective ball bearing. They have correlated finite duration pulses with width of bearing element's defects under radial and axial load. The authors have considered the regular shape like rectangular, triangle and half sine pulse during simulation. While, Patel et al. [6] have reported the forces generated due to additional deflection of balls when balls pass through defective bearing races. In recent paper Khanam et al. [7] have found the excitation forces mainly at three events, when the rolling element enters in inner race defect, impact with defect and exit edge of defect. In another study of Khanam et al. [8] have derived the impact force based dynamic model to predict the dynamic behavior of outer raceway single point defect based on the concept of excitation due to ball mass striking the raceway.

The researchers [9-12] have also studied the effect of races waviness and off size rolling element on vibration response for shaft bearing system. Babu et al. [11] have incorporated the combined effect of frictional moment and waviness of the races and balls as sinusoidal functions for various waviness orders and amplitudes. Harsha et al. [12] have concluded that severe vibrations occur for outer race waviness when balls and number of waves are equal.

The literature review revels that the presence of defects on the bearing races play vital role on dynamic behaviour of the machines. Therefore, in present study the numerical simulation for excitation forces generated by defective bearing has been carried out. Moreover, these excitation forces have been analysed in time and frequency domain. The concept of impulse train representing exciting forces generated due to inner race defect discussed in reference [4] has been extended for outer race defect and ball pass frequency of outer race (BPFO) has been validated numerically. The pulse shapes related to defect shape modelled by Tandon and Choudhary [5] have also been simulated. The impact force excitation [8] and excitation forces generated by bearing race waviness have been simulated and bearing defect frequencies have been validated numerically. Moreover, excitation forces generated due to multiple defects on either race have also been studied.

2. Load distribution and effect of local defect.

Based on the geometry of the bearing, the normal load on the ball/raceway at ball position 'θ' is calculated by the following equation [13].

$$P(\theta) = P_{max}\left[1-\left(\frac{1}{2\varepsilon}\right)(1-\cos\theta)\right]^{n} \text{ for } -\theta_1 < \theta < \theta_1$$
$$= 0 \quad \text{elsewhere.} \qquad (1)$$

A deep groove ball bearing SKF BB1B420206 is the study bearing. The detailed specifications and theoretical defect frequencies are tabulated in table 1. The load distribution and rolling elements position for a study bearing is shown in Fig. 1. The load zone for this bearing is 120^0 ($\theta_1 = \pm 60°$) and maximum radial load on rolling element found by eq. (1) is 139.8 N, that can be observed from Fig. 1(b). The short duration impulses are generated due to the interaction of the defect and rolling elements. These impulses may excite the resonance frequency of other machine components. The radial load 'P' at point of excitation, will affect the resultant excitation force, 'F (t)'.

Table 1 Bearing Specifications

Deep groove ball bearing	SKF BB1B420206	Number of balls (Nb)	8
Outer race diameter (do), mm	51.82	Inner race diameter (di), mm	39.38
Ball diameter (d), mm	10.36	Radial Load (Q), N	200
Local defect Width, mm	0.5	Speed of shaft (N_s), rpm	1500 (f_s =25 Hz)
Raceway waviness Amplitude, μm	0.01	Cage Frequency (*fc*)	$\frac{\omega_s}{2}\left(1-\frac{d}{D}\cos\alpha\right)$ = 9.76Hz
Ball Pass Frequency for Inner race (BPFI)	$\frac{N_b.\omega_s}{2}\left(1+\frac{d}{D}\cos\alpha\right)$ = 77.52 Hz	Ball Pass Frequency for Outer race (BPFO)	$\frac{N_b.\omega_s}{2}\left(1-\frac{d}{D}\cos\alpha\right)$ = 122.72 Hz