Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 144 (2016) 751 – 758
Procedia Engineering
www.elsevier.com/locate/procedia

12th International Conference on Vibration Problems, ICOVP 2015

Model Development for Investigation of Localized Defects in Taper Roller Bearings Using Matrix Method of Dimensional Analysis

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Abstract

Catastrophic failures of the rotating machineries can be avoided by tracing the faults generated in the rolling contact bearings used for supporting these machines and are important sources of noise, vibration as well as sudden stoppage of the entire production or interruption of processes. A generalized model is developed using Matrix Method of Dimensional Analysis (MMDA) to establish dimensionless correlation between the response and consequence parameters for the assessment of localized surface defects in the different components of taper roller bearings tested on a developed test rig. Response surface methodology (RSM) is employed for the experimentation and to explore the dependence of various factors on the vibrations of these bearings. A numerical analysis performed in the study showed the effectiveness of MMDA model along with frequency domain scrutiny of the vibration data for detection of localized bearing defects.

Peer-review under responsibility of the organizing committee of ICOVP 2015

Keywords: Matrix method of dimensional analysis (MMDA); Response surface methodology (RSM).

1. Introduction

Antifriction bearings are the inevitable parts of aerospace, manufacturing, agriculture industries to name a few employing variety of such bearings in different applications. The vibration based damage detection in the bearing done by examining the bearing vibration frequencies and their amplitudes or analyzing the statistical parameters of the vibration signal referred to as frequency domain and time domain analysis respectively. One of the earlier attempts have made by P. D. McFadden and J.D.Smith [1] and developed mathematical model to describe the vibration produced by a single point defect on the inner race and further extended this work to detect multiple defects [2].

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Peer-review under responsibility of the organizing committee of ICOVP 2015
doi:10.1016/j.proeng.2016.05.080

The model presented by [3] predicted a frequency spectrum and corresponding peaks at characteristic defect frequencies with modulations in the case of a rolling element defect and an inner race defect under a radial load. The amplitudes at these frequencies also predicted for various defect locations considering the effect of both radial and axial load and pulse shape on the vibration amplitude. This paper [4], extended the bearing model using Hertzian contact theory to include rolling element centrifugal load, angular contacts and axial dynamics and illustrated their effects in a rigidly supported rigid and flexible Rotor Bearing Systems [RBS] and shown dependence of chaotic motion and jump phenomenon on the radial clearance. An analytical model developed here, [5] to investigate the nonlinear dynamic behavior due to cage run-out and varying number of balls and reported that, increasing the number of balls results into reduction in vibration amplitude. Choudhury and Tandon [6] developed a theoretical model that predicted significant frequency components and their harmonics at particular characteristic defect frequency. In this paper [7], a shaft-bearing model developed in order to investigate the rolling element vibrations for an angular contact ball bearing with and without defects and reported that the vibration energy increase with the advancement of the defect. Ghafari et.al [8] formulated nonlinear mathematical model and concluded that the localized defects along with interactions with speed generates chaotic vibrations. Multi-body dynamics of healthy and faulty rolling element bearings were modeled using vector bond graphs [9] and showed the relevance of the bond graph modeling in identification of the structural damages in the bearings. H. Ohta and N. Sugimoto [10] experimentally investigated vibrations of tapered roller bearings having distributed defects particularly waviness under several rotational speeds and axial loads. F.K.Choy et.al. [11], applied chaotic vibration analysis technique known as modified Poincare diagrams to identify damages in ball bearings and tapered ball bearings and their effectiveness in pinpoint damage compared in this study. Recently, R. G. Desavale et.al [12,13], developed a model based on experimental data to test damaged fibrizer roller bearings in different working conditions by method of dimensional analysis and reported that the method is effective in identification of the level of damages due to localized bearing defects. In this study analytical expressions have been derived for prediction of amplitudes of significant frequency components and numerical results are compared with the experimental results.

2. Mathematical Formulation

A numerical model is developed for the assessment of vibrations in taper roller bearing for the fault identification by MMDA considering different parameters affecting its dynamic behavior as listed in Table 1. Let, $D=(D_1, D_2,..., D_n)^T$ denote the design factors, $U=(U_1,U_2,...,U_n)^T$ denote the uncontrollable factors and $C=(C_1,C_2,...,C_n)^T$ denote the controllable factors. Suppose, the following function designates the dependence of bearing vibration response (Y) on these factors as,

$$y = f(D,U,C) \tag{1}$$

This relationship in equation (1) is derived using dimensional analysis. Where, function '*f*' represents the pragmatic relationship between response/dependent variables and independent variables. All variables involved in the dynamic behavior of the taper roller bearing can be expressed as in Table 1 in terms of three basic dimensions [14] — the length dimension L, the time dimension T and either the force dimension F or the mass dimension M. The system of dimensions FLTθ is used here. From the above set of factors, the pitch diameter, speed and radial load have been chosen as the repeating variables and the numbers of repeating variables are equal to number of fundamental dimensions [14, 15].The dimensional matrix of the repeated variables can be written as in Table 2.

The dimensional matrix of the unrepeated variables can be written as in Table 3. The dimensional matrix of the unrepeated variables is of the order (3xn), where 'n' is the number of unrepeated variables [16]. The number of dimensionless groups equals the number of the unrepeated variables. As per the MMDA, any n^{th} dimensionless group can be formulated as [16],

$$\frac{U_n}{R_1^{C_{1n}} R_2^{C_{2n}} R_3^{C_{3n}}} = F^0 L^0 T^0 = (\pi_n)$$