Experimental Investigation of Nonlinear Vibration for Unbalanced Rotor-Bearing System

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Abstract— In this paper, nonlinear dynamic motion analysis for cylindrical roller bearing with unbalanced rotor at high speed operation were evaluated. Cylindrical roller bearings are utilized for high radial load and speed. At high loading condition & speed a small amount of unbalanced weight may significantly affect the dynamic motion behavior of rotor system. Also, parametric vibration is one of unavoidable vibration characteristics of roller bearing which is there for thermal compensation. Thus, present research paper is focusing on study of nonlinear behaviors of cylindrical roller bearing at high speed with unbalanced forces and variance compliance as non-linearity. Experimental evaluation for proposed system has investigated in this paper with FFT and observed different harmonic, sub harmonic & super harmonic responses.

Key words: Unbalanced Rotor, Cylindrical Bearing, Variance Compliances, FFT

I. INTRODUCTION

Today's world of increase manufacturing growth, all machineries were desire to be of light weight and high speed. All rotating machineries of process industries are working on bearings. So, dynamic motion analysis of bearings has become significant and critical to evaluate mechanical system. High speed rotor has unbalanced force & parametric sources of vibration. Clearance in bearing is essential for press fit assembly of rotating elements and the elastic restoring force are responsible parametric vibration. Elastic non linearity of material has significant effect on dynamic motion of system. Geometrical & Material non linearities have significant affect the rotor motion. Unbalance of rotor itself determine the number of rotations which may not synchronize with rotation and system identified as Aperiodic or chaotic motion. In these conditions, the monitoring signals detected at the machine bearings will themselves be periodic & non periodic when signals were not synchronous with the driving rotation. If the nonlinear nature of the system is ignored, incorrect interpretations about their source can be recorded as responses. the system is bi-periodically excited by the presence of unbalanced forces (Harsha2005). Sinou (2009) has examined effect of unbalanced force on non-linear behavior of rotor-bearing system. Sinou (2009) evaluated with harmonic balance method for soft & flexible rotor which was placed upon flexible supports. Harsha and Kankar (2004), Harsha et al. (2006) and Kankar et al. (2012) examined the effect of surface waviness of bearing component and its effect on stability of shaft-roller system. Authors have theoretically studied effect of varying number of balls along with effect of waviness for non-linear dynamic motion behavior. Nataraj and Harsha (2008) were examined the effect damping and stiffness as source of nonlinearity in ball bearing, also non-linear dynamic motion of shaft bearing system were investigated with cage run-out and varying number of balls. Earlier, Tiwari et al. (2000) considered the effect of unbalance and clearance in horizontal rotor and found the presence of chaos in the response. The effects of finite number of rolling elements, unbalanced force, bearing loads and damping are considered by Zhang et al. (2013). Researchers also examined the effect of stiffness and it's correlation with stability rotor-bearing system considering varying number of rollers and uneven load distribution to study the nonlinear motion of system.

Pandya et. al. (2012 & 2013) has studied the effect of localized defects which is present in all parts of ball bearing. Pandya et. al. (2012 & 2013) is the one who studied the effect of localized defect experimentally and numerically. Aditya et. al (2015) were developed mathematical model considering 2 DOF of shaft-bearing to investigate the non-linear vibration response due to varying speed and uneven load. It has been concluded that the unbalanced rotor results in various unstable regions with higher amplitudes of vertical vibrations.

Yadav et. al. (2017 & 2013) were developed mathematical model for cylindrical roller bearing 305 C3 make NTN. Material nonlinearities such as damping & stiffness at Hertzian contact included and model were investigated up to 9000 RPM. Geometrical non linearities such as IRC (internal radial clearance) and unbalanced forces for ball bearing were studied. Authors were identified different dynamic motion condition such as periodic, multi periodic, quasi- periodic and chaotic considering different non-linearities in system.

State-of-art literature review lead to conclude that earlier researchers were considered IRC (Internal radial clearance), fluctuating speed, defects, material non-linearity such as damping & stiffness as source non-linearity, which causes non-linear responses of system. Present study attempts to examine the effect of uneven load & material non-linearity which were attempted by limited researchers as discuss earlier. Limited researchers were validated their work with own experimental outcomes. Due to lack of experimental study, the presented studied is related with experimental analysis.

II. EXPERIMENTAL SET UP:

An experimental test rig is connected to a data acquisition system through proper instrumentation. The test rig has been set up on a M.S base plate which is supported on adjustable rubber pad to minimize the vibration responses from the ground as shown in Figure1.

Experimental setup developed at Green-ksv skill development center which included a set of shafts mounted on cylindrical roller bearing mounted in bearing housing. Shaft bearing system operated by a DC motor of 4HP with external servo controller. To acquire and analyze the data, CoCo-80 is used. It is a handheld data recorder, dynamic signal analyzer and vibration data collector. Special piezoelectric pickup type of sensors (accelerometers) are used with frequency range of 1-30 KHz, measurement range +/- 500g peak, resolution of 0.005 g and resonant frequency of 70 KHz.

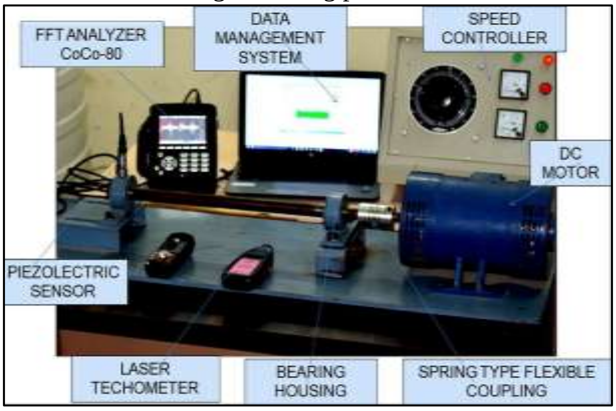

Fig. 1: Experimental setup

Fig. 2: Unbalanced Rotor

The speed of the shaft recorded with the help of a laser tachometer, which directly reads the rpm of the shaft with the help of a florescent reflector tag stuck on the shaft as shown in Figure 1. To develop unbalanced shaft condition, a symmetrically machined disc has been mounted on shaft and unbalanced shaft force was induced with small unbalanced mass on it as shown in Figure 2.

Speed (RPM)	Max Peak	Other Peak	Experimental Frequency ((HZ) X)	Theoretical Frequency ((HZ) X)
500	6X	0.5X,2X,3X,4X,5X,7X,9X	8.954	8.33
1000	3X	0.5X,X,2X,3X,4X,5X	16.33	16.667
1500	X	0.5X,1.5X,2X,2.5X,3X,3.5X	25.16	25
2000	1.5X	0.5X,X,2X,3X,4X	33.67	33.333
2500	X	0.5X,2X,3X,4X, 6X,8X	41.56	41.667
3000	0.5X	X,X,1.5X,2X,3X,4X,7X,8X,9X	50	50
3500	0.5X	X,2X,6X,7X,8X	58.75	58.333
4000	X	0.5X,2X,3X,4X,5X,6X	66.41	66.667
4500	0.5X	X,2X,3X,4X,5X,6X	74.69	75
5000	0.5X	X,2X,4X,5X,6X	83.75	83.33

Table 1: List of unbalances(X) peak:

III. CONCLUSIONS

In this paper, an experimental study has been conducted with speed as control parameter. The experimental analysis has been done for the speed from 0 to 5000rpm with help of tool like frequency responses. The main objective of experimental analysis is to study that how the dynamic behavior of rotor supported by cylindrical roller bearings is changed with speed. Based on Figure 3 (a to j) and Table 1, following point can be concluded:

1) From Table 1, it has been concluded that from 500rpm to 3000rpm number of super harmonic peaks are more. Then, from 3500 rpm to 5000rpm number of super harmonic peaks is decreased drastically. The system behavior is known as super harmonic because different peaks like x, 2x, 3x, 4x …. have been found.
2) Very dense spectrum has been observed at 500 rpm, 1000 rpm,1500 rpm ,3500 rpm and 4000 rpm as shown in Figure1 (a to c & g, h). So, the system behavior is chaotic.
   It can be concluded that behavior of system is multi-periodic at 3000 rpm, because only sharp peaks have been observed as shown in Figure 1 (f).
3) In Figure 1(d, e, i, j), very dense small peaks have observed around the major peaks. So, it can be inferred that the system behavior is quasi-periodic at 2000 rpm,2500 rpm, 4000 rpm and 5000 rpm.

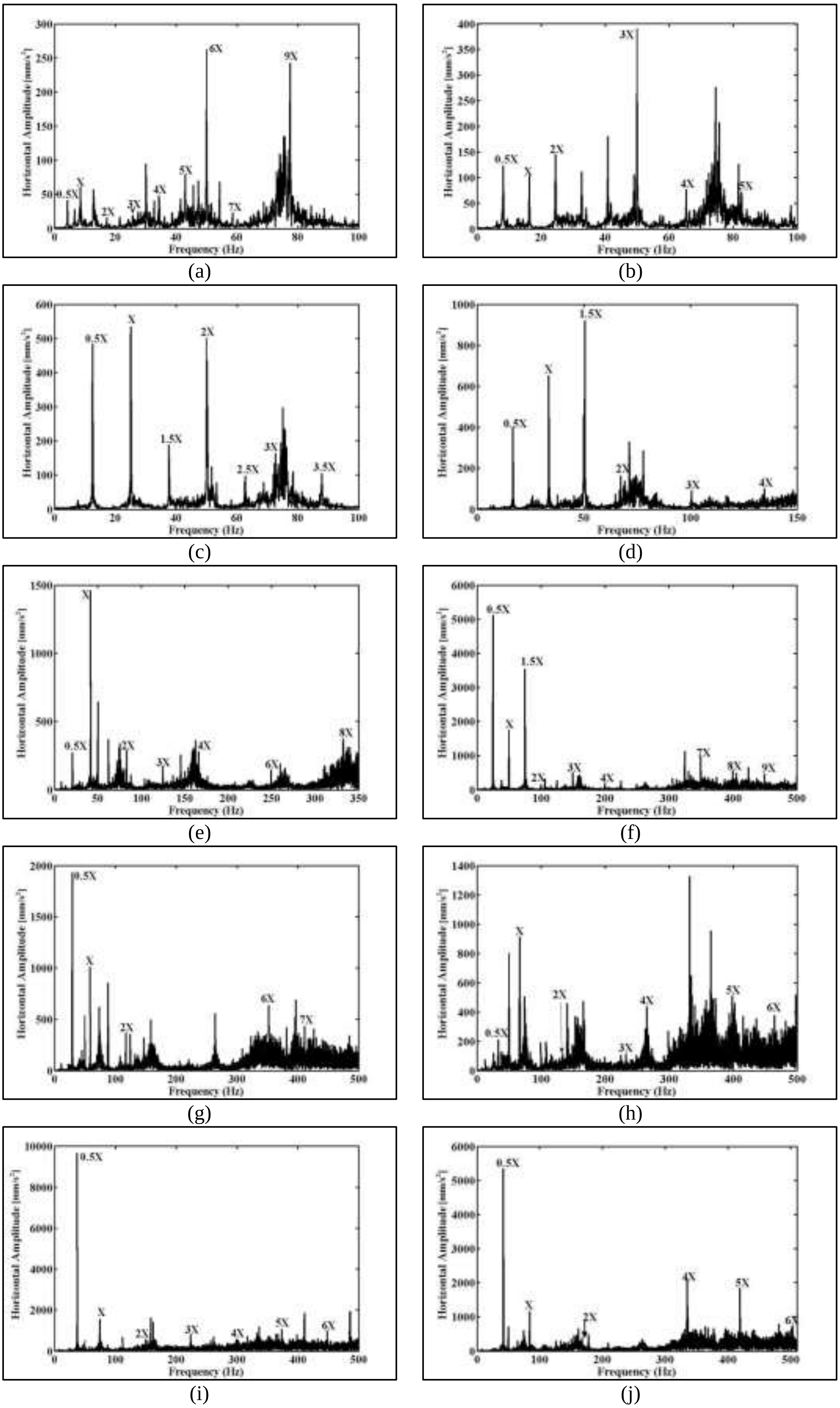

Fig. 3: FFT plots at (a) 500RPM (b) 1000RPM (c) 1500RPM (d) 2000RPM (e) 2500RPM (f) 3000RPM (g) 3500RPM (h) 4000RPM (i) 4500RPM (j) 5000RPM

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