EFFECTS OF THE ROTOR SYSTEM ON BALL BEARING DYNAMIC CHARACTERISTICS

Ioannis Gravalos[1*], Spyros Loutridis[2], Dimitrios Moshou[3], Theodoros Gialamas[1], Dimitrios Kateris[3], Panagiotis Xyradakis[1], Zisis Tsiropoulos[1], Anastasios Georgiades[1]

[1]Technological Educational Institute of Larissa, School of Agricultural Technology, Department of Biosystems Engineering, 41110 Larissa, Greece.
Phone: +320-4210684216, Fax: +320-2410282209, E-mail: gravalos@teilar.gr
[2]Technological Educational Institute of Larissa, School of Technological Applications, Department of Electrical Engineering, 41110 Larissa, Greece.
[3]Aristotle University, School of Agriculture, Department of Hydraulics, Soil Science and Agricultural Engineering, 54124 Thessaloniki, Greece.

Abstract

The stiffness, rotational accuracy and vibration characteristics of a rotor system are partly controlled by the ball bearings that support it. A horizontal rotor system demonstrates interesting vibration behavior because of the unbalance force and the varying compliance effects. In this paper, the effects of the vibration of the rotor system on ball bearing dynamic characteristics are studied. The dynamic behavior of the rotor-bearing system is investigated experimentally under different operating conditions regarding speed, load and position. The vibration of the rotor-bearing system was recorded with single axis accelerometers in the frequency range from 1 Hz to 15 kHz. The sensors were mounted on the ball bearings body. A Vibrotest 60 (Brüel & Kjaer) portable data logger-analyser was used to monitor, record, and analyze the results in the frequency range of interest. The analysis of frequency spectra show the appearance of instability in the dynamic response as the speed, disk load and disk position of the rotor-bearing system is changed.

Introduction

Vibration generated by rotating machinery has always been an interesting subject in automobiles, agricultural machinery and industrial machines. High speed rotating machine elements supported by ball bearings has been widely used in rotating machinery systems (electric motors, gearboxes, etc.), because of ease of maintenance and reduced rotor dynamic instability [1]. In the field of rotor dynamics (rotating machinery dynamics), many researchers have found that a large number of parameters, which include stiffness distribution of a rotating shaft, disk properties and bearing support stiffness can influence the dynamic behaviour of a rotor-bearing system [2], [3], [4] and [5]. Rotating element failures are one of the foremost causes of failures in rotating machinery systems. For this reason, many researchers have studied the rotor-bearing system on a fault diagnosis basis [6], [7] and [8].

Ball bearings are commonly used machine elements in rotating machinery systems. They have been employed as one of the essential parts in different mechanical equipments. Because of the requirement of acquiring higher performance in the design of rotor-bearing systems, the accurate prediction of vibration characteristics has become increasingly important [9]. An analysis of ball bearing dynamic behavior is essential in order to predict the whole system response. The rotor-bearing system displays nonlinear behavior due to nonlinear contact force, which exists between the various components of the bearings: rotating elements, races and shafts [10]. The effect of varying compliance on bearing static equilibrium was studied by many researchers: Gupta [11] developed a dynamic model for dynamic performance simulations of a ball bearing. Gad [12] simulated the axial and radial vibration phenomena of a rotor supported by ideal or non ideal ball bearings. De Mul et al. [13] presented a five degree of freedom model for calculation of the equilibrium and associated load distribution in ball bearings. Harsha et al. [14] observed the effect of surface waviness and internal radial clearance of ball bearings on the vibration characteristics of a balanced rotor with two degrees of freedom. Purohit and Purohit [15] developed a theoretical model to observe the effect of varying the preload and number of balls on the vibration characteristics of a defect free system. A two-degree of freedom system is considered with the assumption that there is no friction between the balls and raceways and that both bearings are positioned symmetrically so that their moving parts are synchronized.

In this paper, the effects of the vibration of the rotor system on ball bearing dynamic characteristics are analysed. The dynamic behavior of rotor-bearing system is investigated experimentally under different operating conditions (varying speed, disk load and disk position).

Method and Materials

The experimental set up of the rotor-bearing system is shown in Fig. 1. The rotor-bearing system was mounted on a cast-iron frame insulated from the surrounding environment with rubber dampers in order to remove possible external disturbances and was driven through belt transmissions by an electric 1.2 hp dc motor. A dc voltage controller was used to adjust the power supply so that the electric motor speed could be continuously increased or decreased in the range between 0 and 3800 rpm. Two dial gauge method is used to correct the shaft misalignment and base line signal has been measured at different speeds 800, 1800 and 3600 rpm to check the concentricity. The rotor shaft was supported by two identical ball bearings and had a length of 466 mm with a diameter of 19 mm. The bearings were mounted on aluminium housings which were in turn fixed to the cast-iron frame. One or two identical massive disks of 160 mm in diameter and 19 mm in thickness were mounted separately or together on the rotor shaft at different positions (drive end bearing, shaft centre, and non drive end bearing). Each disk weighs around 3700 grams. The disks were clamped to the shaft by means of semi-circular plates and bolts.

To measure the vibration of the rotor system on ball bearings, the following instrumentation was used: a) a Vibrotest 60 (Brüel & Kjaer) portable data logger-analyser was used to monitor, record and distinguish the appropriate frequency ranges, and b) two single axis accelerometer sensors (type AS-065) with a frequency range from 1 Hz to 15 kHz. The vibration acceleration sensors were attached on the bearing housings. The bearing housings have threaded holes for the installation of the sensors. The vibrations were measured on the X-axis. Frequency spectra were analysed in one-third (1/3) octave bands, from 1 Hz to 4 kHz. The vibration magnitude was expressed in terms of Root Mean Square values (RMS).

Identification of dynamic behavior of rotor-bearing system is conducted under different operating conditions. Specifications for the three test cases are presented below:

- Test Case 1: Rotor-bearing system with one disk on centre of rotor at different dc motor speeds (800, 1800 and 3600 rpm).
- Test Case 2: Rotor-bearing system rotating at 1800 rpm with one disk assembled at different positions (drive end bearing, shaft centre, and non drive end bearing).

- Test Case 3: Rotor-bearing system rotating at 1800 rpm with different disk loads on centre of rotor (3700 and 7400 grams).

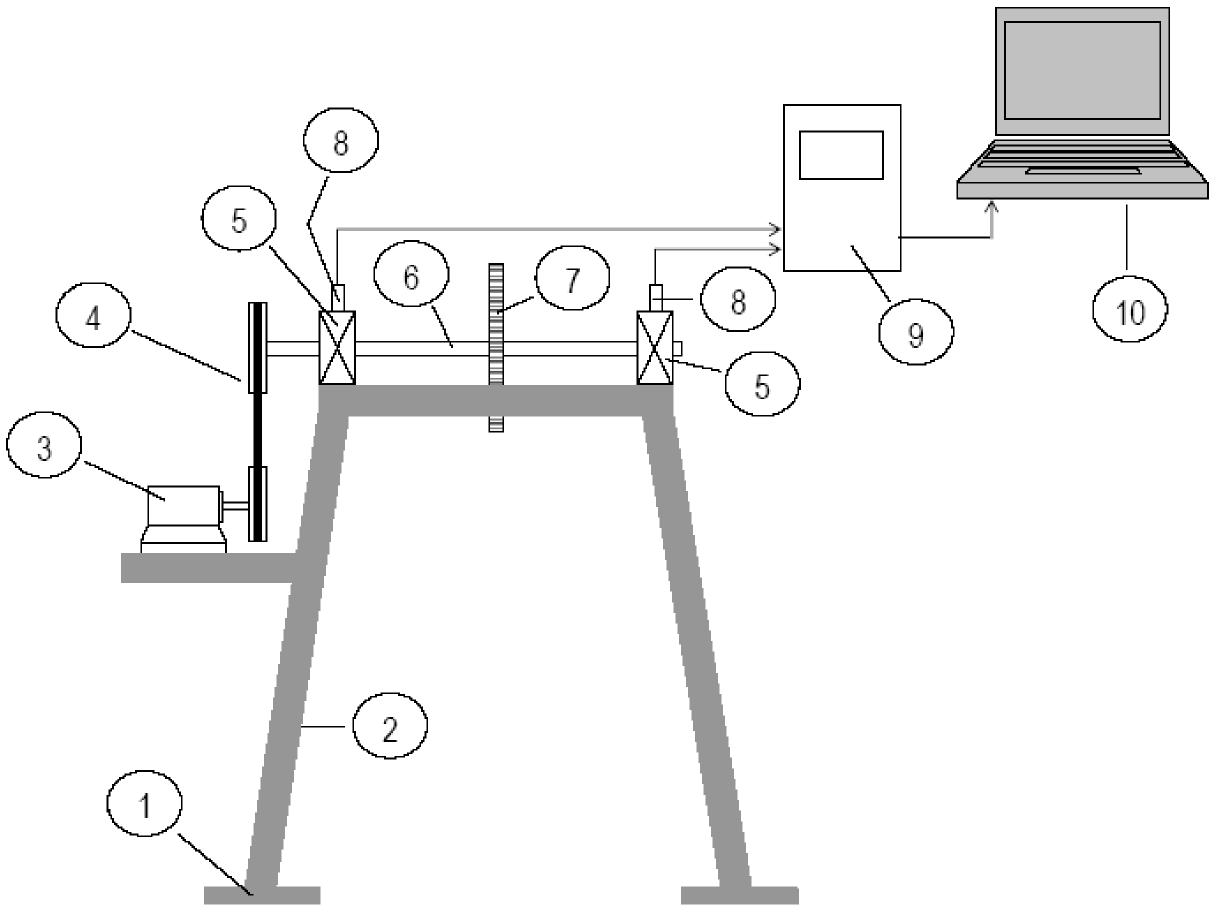

Figure 1. Experimental set up of rotor-bearing system
1- Vibration damper, 2- Frame, 3- dc Motor, 4- Belt transmissions, 5- Ball bearings, 6- Rotor shaft, 7- Disk, 8- Accelerometers, 9- Vibration analyser, 10- Computer

Results and discussion

The rotor-bearing system has the outer race of the two ball bearings fixed to a rigid support and the inner race fixed rigidly to the shaft. A constant vertical radial force acts on each bearing. The excitation is due to the unbalance force which introduces the rotational frequency and the varying compliance vibrations of the bearing which arise because of the geometric and elastic characteristics of the bearing. The measured frequency spectra were obtained for the three test cases described above. Frequency spectra that are measured experimentally using the dual channel vibration analyzer are shown in Figs. 2 - 4. Table 1, shows the peak acceleration values at the test cases under consideration.

Fig. 2 shows the response of rotor-bearing system with one disk on centre of rotor at different dc motor speeds (800, 1800 and 3600 rpm), the peak amplitude of vibration is appeared to higher dc motor speeds.

Table 1. Peak acceleration values at different test cases

Test cases	Drive end bearing		Non drive end bearing	
	Frequency	Acceleration values	Frequency	Acceleration values
	[Hz]	[m/s^2]	[Hz]	[m/s^2]
Test case 1: Rotor-bearing system with one disk on centre of rotor at different dc motor speeds				
800 rpm	2312.50	0.3629	2212.5	0.1716
1800 rpm	2267.19	2.0879	2307.81	1.2872
3600 rpm	2309.38	5.0915	2975.00	1.8305
Test case 2: Rotor-bearing system rotating at 1800 rpm with one disk assembled at different positions				
At shaft centre	2926.56	2.0879	2307.81	1.2872
Near drive end bearing	2267.19	1.4976	2143.75	1.0889
Near non drive end bearing	2209.38	1.0971	2043.75	0.6705
Test case 3: Rotor-bearing system rotating at 1800 rpm with different disk loads on centre of rotor				
0 grams	2346.88	1.5149	3139.06	0.8275
3700 grams	2267.19	2.0879	2307.81	1.2872
7400 grams	2343.75	2.0455	3087.50	1.1122

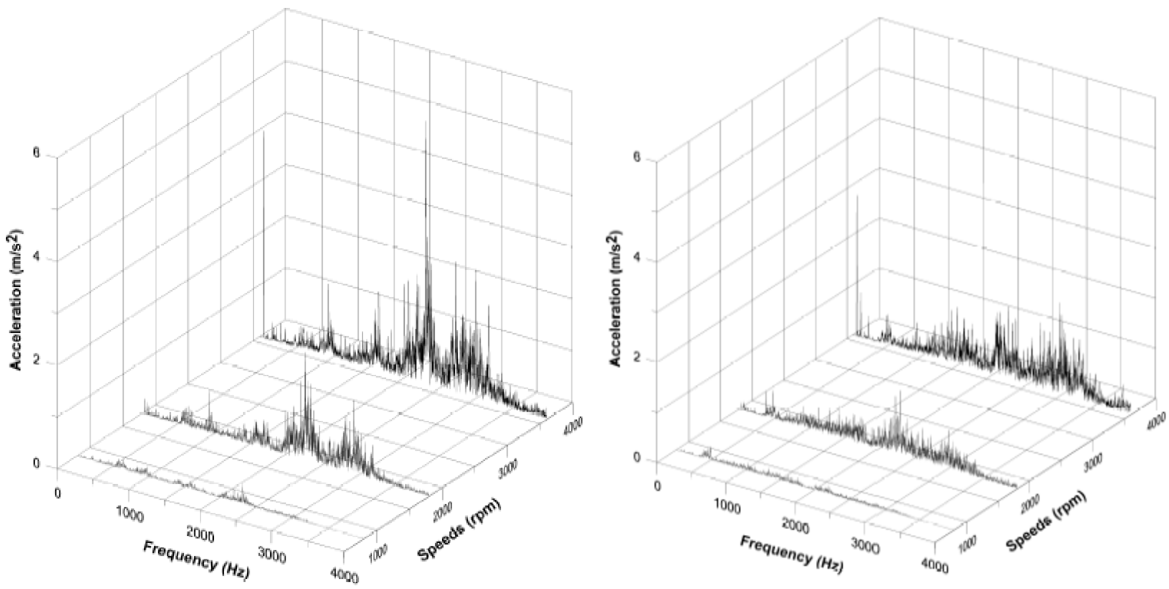

Figure 2. Frequency spectra of rotor-bearing system with one disk on centre of rotor at different dc motor speeds. a) Drive end bearing, b) Non drive end bearing.

Fig. 3 shows the response of rotor-bearing system rotating at 1800 rpm with one disk assembled at different positions (drive end bearing, shaft centre, and non drive end bearing). The peak amplitude of vibration appears at drive end bearing when disk was assembled at shaft centre (at Hz 2926.56 - acceleration value = 2.0879 m/s^2). Fig. 4 shows the vibration response of rotor-bearing system rotating at 1800 rpm, when disk load is increased from 3700 to 7400 grams there is slightly increase in the peak amplitude of vibration at the drive end and non drive end bearings.

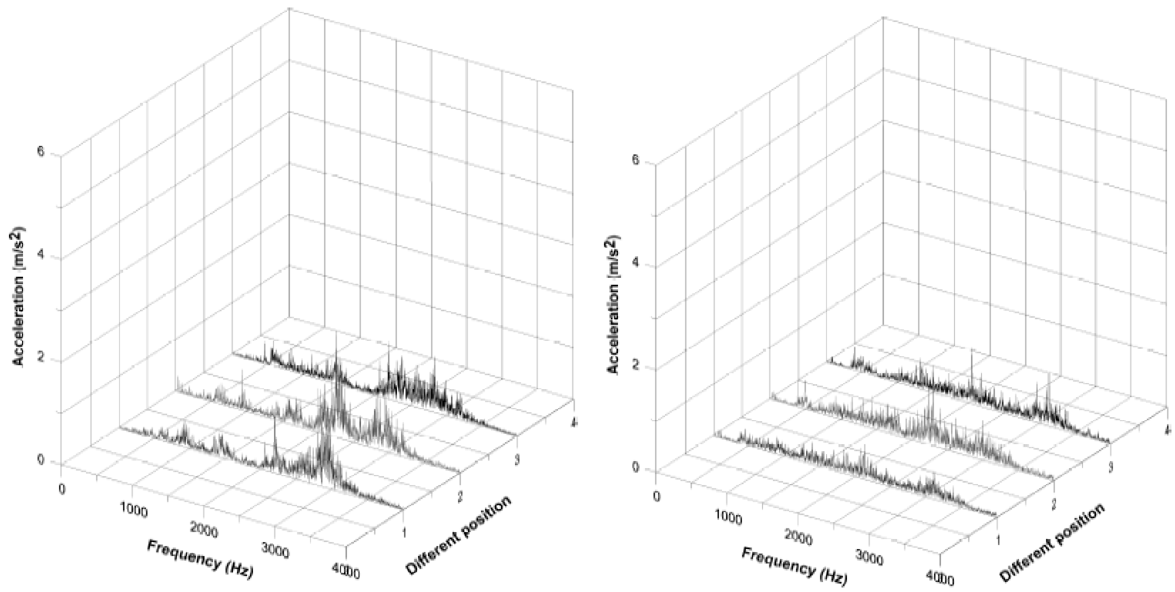

Figure 3. Frequency spectra of rotor-bearing system rotating at 1800 rpm with one disk assembled at different positions. a) Drive end bearing, b) Non drive end bearing.

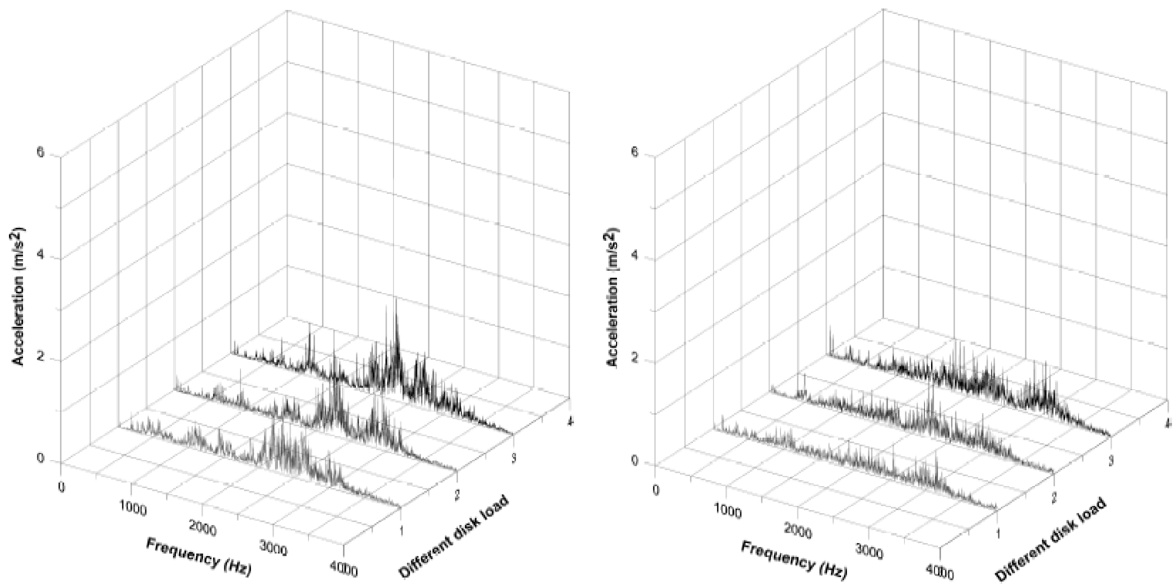

Figure 4. Frequency spectrum of rotor-bearing system rotating at 1800 rpm with different disk loads on centre of rotor. a) Drive end bearing, b) Non drive end bearing.

Conclusions

In the present study, the nonlinear vibration response of a rotor-bearing system was examined due to variations in the dc motor speed, disk position and disk load. The nonlinear dynamic response of drive end bearing is found to be associated with the belt transmission frequency. The electric motor rotational speed is one of the most important parameters in the dynamic analysis of a rotor bearing-system and it is useful for controlling the system vibrational response. The disk position is also an important parameter for the vibration analysis of a rotor bearing-system and should be carefully considered during the design stage. It is also shown that the system response is not sensitive to variations of the disk load.

References

[1] Lee,D.S.-Choi,D.H.: A dynamic analysis of a flexible rotor in ball bearings with nonlinear stiffness characteristics. International Journal of Rotating Machinery, 3(2),1997,p.73-80.

[2] Gargiulo,E.E.: A simple way to estimate bearing stiffness. Machine Design, 52,1980,p.107-110.

[3] Lim,T.C.-Singh,R.: Vibration transmission through rolling element bearing, Part I: Bearing stiffness formulation. Journal of Sound and Vibration 139 (2),1990,p.179-199.

[4] Tiwari,M.-Gupta,K.: Dynamic response of an unbalanced rotor supported on ball bearings. Journal of Sound and Vibration, 238(5),2000,p.757-779.

[5] Sadeghi,M.H.-Zehsaz,M.-Jafari,S.: The effect of bearing stiffness on the frequency response function of a turbo-pump shaft- comparative study. European Journal of Scientific Research, 139(3),2010,p.381-395.

[6] Mechefske,C.K.-Mathew,J.: Fault detection and diagnosis in low speed rolling element bearings Part I: The use of parametric spectra. Mechanical Systems and Signal Processing, 6(4),(1992),p.297–307.

[7] Bolaers,F.-Cousinard,O.-Marconnet,P.-Rasolofondraibe,L.: Advanced detection of rolling bearing spalling from de-noising vibratory signals. Control Engineering Practice, 12(2),(2004),p.181–190.

[8] Lou,X.-Loparo,K.A.: Bearing fault diagnosis based on wavelet transform and fuzzy inference. Mechanical Systems and Signal Processing, 18,2004,p.1077-1095.

[9] Bai,C.-Zhang,H.-Xu,Q: Effects of axial preload of ball bearing on the nonlinear dynamic characteristics of a rotor-bearing system. Nonlinear Dyn, 53,2008,p.173-190.

[10] Harsha,S.P.: Nonlinear dynamic analysis of an unbalanced rotor supported by roller bearing. Chaos, Solitons and Fractals, 26,2005,p.47-66.

[11] Gupta,P.L.: Dynamics of rolling element bearings, parts I to IV. ASME J. Lubr. Technol., 101,1979,p.293–326.

[12] Gad,E.H.-Fukata,S.-Tamura,H.: Computer simulation of rotor axial and radial vibrations due to ball bearings. Mem. Fac. Eng. Kyushu Univ., 44(2),1984,p.169–189.

[13] de Mul,J.M.-Vree,J.M.-Maas,D.A.: Equilibrium and associated load distribution in ball and roller bearings loaded in five degrees of freedom while neglecting friction. Part I: general theory and application to ball bearings. ASME J. Tribol., 111,1989,p.142–148.

[14] Harsha,S.P.-Sandeep,K.-Prakash,R.: The effect of speed of balanced rotor on nonlinear vibrations associated with ball bearings. Int. J. Mech. Sci., 45,2003,p.725–740.

[15] Purohit,R.K.-Purohit,K.: Dynamic analysis of ball bearings with effect of preload and number of balls. Int. J. of Applied Mechanics and Engineering, 11(1),2006,p.77-91.