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Pattern Recognition of Unbalanced Rigid Rotor Bearing Forces

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ABSTRACT: In industrial rotatory machines, different forces in rotor bearings are generated due to various impaired mechanical sources, namely bearing misalignment and nonhomogeneous mass distribution (unbalance). By precisely analyzing and diagnosing the produced patterns of bearing forces, one can determine the unbalance parameters such as quantities of masses, their distance from the rotational axis, and characteristics of corresponding parallel planes. Consequently, it will be possible to formulate pragmatic protocols according to which the maintenance engineers of rotatory systems will pinpoint properties of problematic imbalance masses and then straightforwardly balance them. In the procedure of conducting this research, several exemplary imbalance masses are deployed on a rotatory mechanical shaft and the equations of motion and forces in perfectly aligned rigid bearings are extracted. Then, by applying a neural network-oriented system the patterns of bearing forces are recognized and the characteristics of the nominal masses including magnitudes, distances from the rotational axis, angles as well as the unbalance type are determined. The accuracy of predicting 8 variables of balancing masses was 41% and after eliminating the redundant overlaps from principal components, the accuracy of predicted 5 variables of balancing masses significantly increased to 95%. Also, by implementing another comprehensive neural network system, it was shown that by exerting two separate balancing masses, the applicability of this method in balancing any faulty systems with dynamic unbalance is possible.

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1- Introduction

Even in the most ideal and perfectly designed mechanical systems, mechanical impairments are inevitable [1]; these faults and deficiencies are generally created due to the production and installation processes [2]. As a result, maintenance engineers have bestowed a demanding job, which the productivity, effectiveness, and vitality of plants' machines and apparatuses make them more requested. Based on recent research up to 60 percent of the total expenses of an industrial machine are related to its reparation and maintenance procedures [3]. Generally speaking, machines' maintenance and health monitoring can be defined in four distinctive branches, namely: reactive, preventive, predictive, and proactive; and the main principles of this research are greatly relied on and the latest field. To explain the proactive method simply, it is a combination of three other disciplines that regulates the monitoring, maintenance, and reparation programs based on current faults and changes their course according to mechanical impairments existing in the industrial facilities. Impairments that ignoring them would lead to countless monetary and nonmonetary losses [1]. Nowadays, one of the major failures that are responsible for about 40 percent of mechanical defects of industrial machines is the non-homogenous distribution of mass particles in rotatory facilities so-called unbalance [3]. Unbalance can be classified into static unbalance, couple unbalances, semi-static unbalance and dynamic unbalance, which is the general form of unbalance and is investigated in normal and overhung rotors in this research. Jian et. al. [4] established a technique to compensate for the electromagnetic forces generated due to unbalance impairment. This algorithm diminished the balancing error to 10 percent. Tiwari and Kumar [5] by using a model based algorithm based on an experimental method presented a method based on which all of the required parameters needed to balance an unbalance rotor with external electromagnetic forces, are determined. This paper provides a general standard based on which maintenance engineers can simply identify the unbalance characteristics and apply them in the reparation process. The aforementioned standard is produced based on patterns of generated forces in journal bearings. The following topics are surveyed in this research:

Introducing a well-designed technique for diagnosing dynamic unbalance properties in different working planes without measuring the position and velocity of bearings and only by means of acceleration for the first time;

Providing a set of extracted force patterns and its analysis,

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which can be exerted on faulty systems by maintenance engineers;

Appreciably simplifying the installation, diagnosis, and reparation procedures by application of relatively inexpensive accelerometers;

Diminishing the total number of sensors required for the diagnosis of dynamic unbalance to two;

Providing rotational orbits with acceptable quality at high speeds;

Design and application of neural network system automate the diagnosis procedure.

2- Methodology

It is necessary to first establish the dynamic model of a rotor to examine its dynamic unbalance of it. Also by having equations of motion of the exemplary rotor, the system analysis, the extraction of vibrational patterns, and consequently effects of each variable along with their overlaps in output frequency would be possible. To this end, an exemplary rigid rotor with 15 imbalance masses with different magnitudes and radiuses, which are distributed in 3 parallel planes perpendicular to the rotor axis, has been considered (Fig. 1). Accordingly the dynamic equations of the abovementioned rotor have been extracted based on D'Alembert's principle, and the final equations would be as indicated in Eqs. (1) to (5).

$$\ddot{\theta}=\frac{-\left[\tau+\sum_{i=1}^{15}-m_i r_i g\cos\left(\theta_i\right)\right]}{I_{yy}+\sum_{i=1}^{15}m_i r_i^2} \tag{1}$$

$$R_{Ax}=-\sum_{i=1}^{15}\left[m_i r_i\ddot{\theta}\sin\left(\theta_i\right)+m_i r_i\dot{\theta}^2\cos\left(\theta_i\right)\right]+\frac{\sum_{i=1}^{15}\left[l_i m_i r_i\ddot{\theta}\sin\left(\theta_i\right)+l_i m_i r_i\dot{\theta}^2\cos\left(\theta_i\right)\right]}{l_B} \tag{2}$$

$$R_{Az}=-\sum_{i=1}^{15}\left[m_i g-m_i r_i\ddot{\theta}\cos\left(\theta_i\right)+m_i r_i\dot{\theta}^2\sin\left(\theta_i\right)\right]-\sum_{i=1}^{3}m_i g+\frac{\sum_{i=1}^{15}\left[l_i m_i g-l_i m_i r_i\ddot{\theta}\cos\left(\theta_i\right)+l_i m_i r_i\dot{\theta}^2\sin\left(\theta_i\right)\right]+\sum_{i=1}^{3}\rho_i m_i g}{l_B} \tag{3}$$

$$R_{Bx}=-\frac{\sum_{i=1}^{15}\left[l_i m_i r_i\ddot{\theta}\sin\left(\theta_i\right)+l_i m_i r_i\dot{\theta}^2\cos\left(\theta_i\right)\right]}{l_B} \tag{4}$$

$$R_{Bz}=-\frac{\sum_{i=1}^{15}\left[l_i m_i g-l_i m_i r_i\ddot{\theta}\cos\left(\theta_i\right)+l_i m_i r_i\dot{\theta}^2\sin\left(\theta_i\right)\right]}{l_B}+\frac{\sum_{i=1}^{3}\rho_i m_i g}{l_B} \tag{5}$$

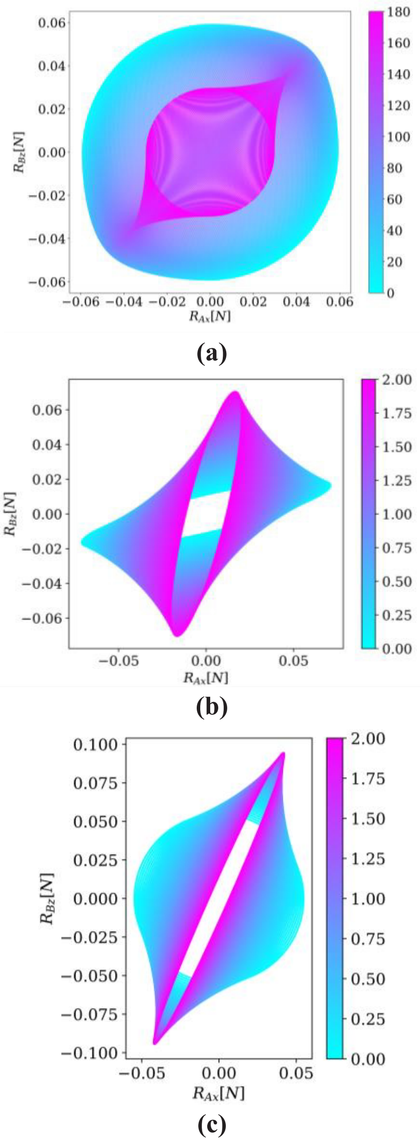

Fig. 1. sample diagrams of force patterns in symmetrical dynamic unbalance for: (a) angular difference of unbalance particles, (b) unbalance distance from bearings, and (c) distance of unbalance center from bearings

In this research the Eqs. (1) to (5) are comprehensively used to extract force patterns of the unbalance rotor, and consequently to feed input datasets of a neural network system.

3- Results and Discussion

By extracting generated forces of each four accelerometers and depicting them against each other the force patterns are created which greatly help maintenance engineers to diagnose dynamic unbalances. By plotting these patterns and changing unbalance variables various diagrams are produced that by choosing and tracking pertinent values a particular unbalance can be diagnosed and then perfectly eliminated. Figs. 1-a, 1-b, and 1-c generally show diagrams of patterns of changing unbalance parameters, namely unbalance angular difference, unbalance distance from bearings, and distance of unbalance center from bearings, respectively.

To put it further this paper makes use of unbalanced force patterns to develop and train neural network-based systems that can lead to a generalized protocol that automatizes the diagnosing process. To simplify the training procedure the meaningful data points have been extracted from these patterns in the form of particular unique ellipses – a single ellipse shows an unbalance which can be satisfied with various unbalance parameters. Also, by means of a neural network, it's been validified that only two accelerometers would be enough to diagnose and repair an unbalance defect in a rigid rotor – by precisely predicting other ellipses by just one ellipse which can be created by two sensors.

4- Conclusion

In conclusion in this paper validation and identification of force patterns of unbalanced rotors and designing a simplified neural network to automatize balancing procedure have been considered. To this end, a rigid rotor with rigid bearings is modeled and consequent forces in four accelerometers are extracted. By using these equations of motion the rigid rotor dynamic principles are validified, and a set of force patterns are extracted to be used both directly by maintenance engineers and indirectly by neural networks. Maintenance and health monitoring engineers by applying these force patterns can balance an unbalanced rotor with a simplified procedure. By utilizing AI-oriented systems it's been made possible to use only two accelerometers to measure acceleration signals.

References

[1] C. Scheffer, P. Girdhar, Practical machinery vibration analysis and predictive maintenance, Elsevier, 2004.

[2] M.L. Adams, Rotating machinery vibration: from analysis to troubleshooting, CRC Press, 2000.

[3] G.A. Correa JC, Mechanical Vibrations and Condition Monitoring, Academic Press, 2020.

[4] Z. Jian, W. Huachun, W. Weiyu, Y. Kezhen, H. Yefa, G. Xinhua, S. Chunsheng, Online unbalance compensation of a maglev rotor with two active magnetic bearings based on the LMS algorithm and the influence coefficient method, Mechanical Systems and Signal Processing, 166 (2022) 108460.

[5] R. Tiwari, P. Kumar, An innovative virtual trial misalignment approach for identification of unbalance, sensor and active magnetic bearing misalignment along with its stiffness parameters in a magnetically levitated flexible rotor system, Mechanical Systems and Signal Processing, 167 (2022) 108540.

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