Measurement 104 (2017) 142–150

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Study of measurement method for large imbalance evaluation based on dynamic electromagnetic force

Qiuxiao Wang [a,*], Zhaofu Wu [b], Dequan Wang [b], Xiaoyan Fu [b]

[a] State Key Laboratory of Mechanical Transmission, Chongqing Univ., Chongqing 400044, China
[b] School of Mechanical Eng., Chongqing Univ., Chongqing 400044, China

ARTICLE INFO

Article history:
Received 2 April 2016
Received in revised form 24 February 2017
Accepted 7 March 2017
Available online 14 March 2017

Keywords:
Electromagnetic force
Vibration
Dynamical balance
Imbalance identification

ABSTRACT

While identifying the imbalance of the workpiece with large eccentric mass, grave error would be produced due to failing to guarantee the linearity of both the balance machine and measuring system. A method was present to improve the measurement accuracy of imbalance identification. It utilized a controllable electromagnet that generated the controllable electromagnetic force to attenuate the unbalance vibration synchronously, so as to avoid the vibration signal exceeding the liner range. Model of equivalent magnetic circuit of the electromagnet was established, and the relationship between the coil current and the dynamic electromagnetic force was analyzed by finite element modeling. The influence on the electromagnetic force of some factors such as temperature and air gap was investigated. The control system and strategy were also developed. Test results indicated that this method is applicable for large imbalance evaluation with high precision.

1. Introduction

Some rotating workpieces with large eccentric mass usually have special shapes and a large original unbalance amount, such as crankshaft, camshaft, balance shaft, and satellite scanning antenna. These components often play a critical role for the normal operation of the relevant machinery equipment, which decides the requirement of high dynamic balancing precision. However, an obvious measurement error will be caused due to the vibration exceeds the linear range of the measurement system while detecting the mass unbalance of these workpieces by existing universal dynamic balancing machine. The balancing accuracy is affected seriously accordingly. Therefore, different kinds of measuring strategies and balancing methods for those special components should be developed. Literatures [1–5] presented some new methods or novel structures to determine the state of unbalance of some special components or assemblies such as tail rotor [1], centrifugal compressor [2,3] gyrostat satellite [4] and the high pressure rotor in an aero-engine assembly [5].

Dynamic balancing technology has been studied by many researchers for a long time. The conventional methods of balancing can be categorized into two groups: the modal balancing method and the influence coefficient method [6]. The modal balancing technique was presented by Bishop [7] and further investigated by several authors such as Kellenberger [8], Miwa and Shuzo [9] and Kim and Sung [10]. But with such method, the critical speed mode shape of the rotor must be known in advance and mass distribution determined from the geometry of the rotor is not accurate. The latter method was developed by Goodman [11]. It has been improved and tested by several researchers, such as Lund and Tonneson [12], Tessarzik and Badgley [13] and Everett [14]. Influence coefficient method has the attraction of requiring less a priori knowledge of the system and techniques have been well developed to make optimum use of redundant information. However, this method not only requires an accurate measurement of vibration phase angle to obtain the acceptable results, but also requires the assumption of both the machine and measuring system [15]. At present, active automatic balancing and online balancing technology have attracted more and more attention. Zeng and Wang [16,17] proposed an innovative online automatic dynamic balancing system based on the principle of the electromotor and the influence coefficient method. Here, the noncontact magnetic force generated by the stator of the balancer drives the balance disc mounted on the rotor for weight adjustments. Tadeusz et al. [18] presented an analysis of the automatic balancing of a rigid disk mounted on an elastic shaft. It was shown that the balls can compensate a part or all of the rotor unbalance depending on the positioning of the drums. There were vibratory forces that push the balls to new positions to compensate for rotor unbalance.

---

[*] Corresponding author.
E-mail address: wqxiao1963@163.com (Q. Wang).

http://dx.doi.org/10.1016/j.measurement.2017.03.020
0263-2241/

Electromagnetic balancers have been utilized in some investigations for their advantage of using a noncontact balancing process. An open-loop control method for rotor-imbalance control using magnetic bearings was studied in these papers [19,20]. To minimize the imbalance response, a synchronous force was applied to the rotor through magnetic bearings. The magnitude and phase of the force were calculated from the vibration signal caused by the unbalance mass. Ma and Pei [21] proposed a novel active online electromagnetic balancing method based on static magnetic-field analysis and an active online electromagnetic balancing device was developed. The core of this method was controlling the amplitude and direction of the resultant force counteracted the centrifugal force due to the imbalanced mass.

Those methods mentioned above are mainly suitable for the measurement for a smaller unbalance amount. While measuring the large unbalance amount, the precision and stabilization of the measuring system cannot be guaranteed due to the oversized vibration magnitude caused by the large unbalance mass. In this paper, the new method utilizes the electomagnetic force to suppress the excessive vibration, which can weaken the vibration signal to meet the requirement of the linearity of the measuring system. In addition, given that parameters of the electromagnet can be adjusted to generate a wide range of electromagnetic force, this new method is more practical for large unbalance mass identification.

The rest of this study is organized as follows. In Section 2, the work principle and structure of this active method were illustrated in detail. Finite Element Method (FEM) analysis was performed on the electromagnet, as described in Section 3, and important factors influencing the electromagnetic force were determined. The control system and strategies for this method were also discussed in Section 4. To verify the feasibility of this method, experiments were conducted in Section 5 and conclusions are drawn at last.

2. The work principle and structure

Vibration of the supporting structure of the dynamic balancing machine will be caused when the rotor rotates because of the mass imbalance of the workpiece. Exciting force which caused the vibration can be expressed as

$$F_{exc} = Me\omega^2 \cos \omega t \tag{1}$$

$$F_{exc} = F_u e^{j(\omega t+\theta)} = mr\omega^2 e^{j(\omega t+\theta)} \tag{2}$$

where M, e and ω are the eccentric mass, partiality distance and the angular velocity of the rotor, respectively. m is the unbalance mass, F_u is the centrifugal force caused by m, r is the action radius of m, θ is the phase of F_u.

In order to reduce the amplitude of the vibration of the supporting structure, a balance force with 180° phase differences and same frequency towards the exciting force should be exerted on the vibration center. So how to generate a balance force satisfies the above conditions.is the focus of this paper. It has been discovered that the electromagnetic force can be regulated via the research on attraction characteristic of the AC electromagnetic magnet. By controlling the exciting current of the electromagnetic coil, a kind of electromagnetic attractive force with sinusoidal waveform can be produced. Given that the electromagnetic attractive force is unidirectional, two magnets with same parameters should be placed symmetrically on the springy board of the supporting structure and make them operate alternately. To ensure the frequency of the electromagnetic force and the exciting force is consistency, current controlled pulse width modulation (PWM) technique was adopted.

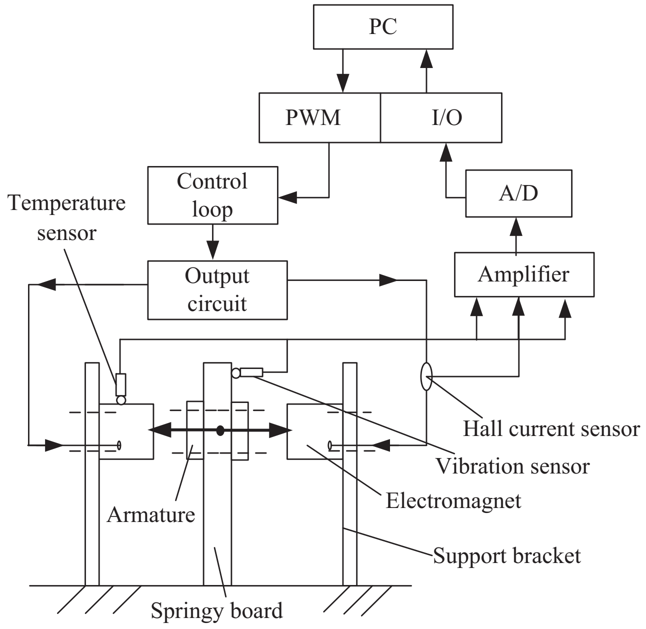

Fig. 1. The working principle and structure.

Fig. 1 illustrates the system composition and measure principle. While the unbalanced workpiece rotates, exciting force generated and vibration of the springy board will be caused. Using the dynamic electromagnetic force produced by PWM control to compensate the exciting force, which decrease the amplitude of the exciting force. Hence the vibration was weakened and the linearity of the supporting system can be guaranteed. The specific process for imbalance identification is as follows. Firstly, a vibration pickup is used to collecting the residual vibration signal through the vibrate testing. Secondly, the residual vibration signal is processed by the influence coefficient method mentioned in [12] to obtain the value of the residual exciting force. Then the value of the exciting force can be gained by summing up the value of the electromagnetic force F_{mag} and residual exciting force F_{res}. Finally, the value of the mass imbalance can be calculated out according to Eq. (1) or Eq. (2). Fig. 2 shows the interaction of multiple forces mentioned before.

3. Simulation and analysis of the factors influencing the electromagnetic force

3.1. Magnetic circuit model of the E-magnet

The E-type and direct-acting alternating electromagnet has many advantages including simple structure, convenient control and can generate electromagnet force with a wide range. The

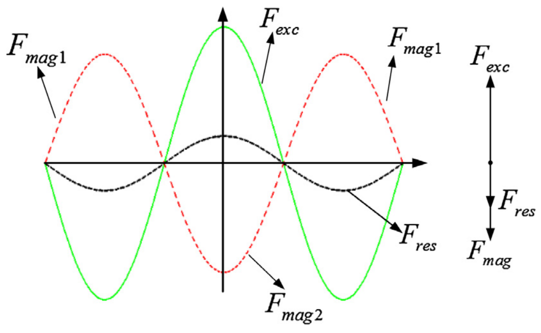

Fig. 2. Force diagram and vector model.