Unbalanced Vibration Response Reduction of Rotor Using Active Magnetic Actuator Based on PD Control

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An active control method based on the proportional-derivative (PD) feedback control strategy using an active magnetic actuator (AMA) is proposed for suppressing rotor vibration caused by rotor unbalance. The control current of the AMA is adjusted according to the real-time displacement of the rotor through the PD feedback algorithm to produce an electromagnetic force to reach the vibration response reduction of the unbalanced rotor. The motion equation of the rotor-bearing AMA system is established and transformed into a state equation for designing a control strategy based on the PD feedback. Finally, the test rig is set up and the verifications of simulation and experiment are carried out. The simulation and experimental results show the effectiveness of the proposed method for the suppression of the rotor unbalance vibration.

1. INTRODUCTION

Due to the existence of the residual unbalance of the rotor, the rotating machinery will produce vibration and noise during operation, and increase the mechanical wear. As the speed increases, the unbalanced force will show a square-fold surge, so even a small imbalance at high speeds will still produce greater vibration. It may cause the mechanical instability and even an accident when the vibration is serious. The control of the rotor unbalance vibration is divided into passive control and active control. The passive control structure is simple, which is suitable for simple working conditions and low requirements for stability. Active vibration control can be combined with different control strategies and has higher adaptability and stability. The active magnetic bearing (AMB) uses a controllable electromagnetic force to suspend the rotor and can be used for the active control of the rotor vibration. The AMB is only installed as a rotor active control device that provides electromagnetic force stiffness and damping, not as a static load support, commonly referred to as an active magnetic actuator (AMA). Compared with other active control devices, an AMA has the advantages of no contact, no lubrication, low energy consumption, and so on.

A lot of research on the active control of rotor vibration using the unique advantages of AMB has been carried out. In the active control field of rotor unbalance vibration, Kumar et al. proposed a 12-pole radial AMB which used AC excitation to counteract the unbalance. Roy et al. used a viscoelastic control law in AMB to suppress unbalance vibration. The second-order sliding mode control was applied in Kandil et al. to adjust the AMB system to a wide rotational speed operating range. Zheng and Feng proposed a rotor unbalance feed-forward compensation control based on a new adaptive notch filter. Cui et al. proposed an adaptive control method for the unbalanced vibration of active-passive hybrid magnetically suspended rotor based on the sliding mode observer combining with the notch filter. Tang et al. designed an integrated controller to suppress the first and two order bending modes of the rotor. Mao and Zhu established the dynamics model of an AMB rigid-rotor system and proposed an unbalanced compensator based on a real-time variable-step-polygon-iterative-seeking algorithm for the unbalance coefficients of the rotor to suppress rotor vibration. Among the methods for reducing rotor vibration, some of them are generally applied at bearing locations, due to the AMB as a static load support, where the vibration is not as severe as at the rotor spanned away from the bearings. However, the reduction of rotor vibration is poor in that the location of the control force is far away from the location of the excitation.

This paper focuses on the reduction of unbalanced rotor vibration by using an AMA in a rotor-bearing system. Firstly, the dynamic equation of the rotor-bearing AMA is established and then transformed into the state space expression. The unbalanced mass is applied to the system, and the unbalanced response of the state equation is obtained by using the ode45 solver in the MATLAB software. Then, an active control method based on the PD feedback is proposed. The unbalance vibration is decomposed into two orthogonal directions, and two real-time control currents are obtained, respectively, according to the displacement of the rotor to generate the electromagnetic force for suppressing the rotor imbalance vibration. Finally, the feasibility of this algorithm on an unbalanced vibration suppression is verified by experiments at different rotating speeds.

2. MODELING AND ANALYSIS OF TEST RIG

2.1. Description of Test Rig

The test rig of the rotor-bearing AMA system is shown in Fig. 1. The main components included a rotor, disk, tilting pad bearing, AMA, sensor, data acquisition system, control system, and drive system. The length of the rotor was 876 mm, the outer diameter was 50 mm, the material was 40Gr, and both ends were supported by the tilting pad bearing and were driven by an electric spindle through the coupling. The diameter of the disc was 270 mm, the thickness was 25 mm, and its material was 45 steels. The AMA consisted of a stator and rotor; the stator consisted of 12 poles. The energy loss and coupling...