Analysis and Suppression of Vibration in Rotor Systems Using Magnetic and Ball Bearing Composite Supports

Hang SHEN, Feng SUN, Chuan ZHAO, Xu BAI, Junjie JIN, Ran ZHOU, and Fangchao XU
School of Mechanical Engineering, Shenyang University of Technology, Shenyang 110870, China

1. Introduction

Rotor systems are integral components in various high-speed rotating machinery, including turbines, compressors, and motors[1]. The stability and performance of these systems depend on how well they manage vibrations. If vibrations are not controlled, they can cause mechanical failure, lower efficiency, and increase wear. Vibrations in rotor systems can come from many sources, such as unbalanced loads, bearing misalignment, and dynamic forces during operation.

Ball bearings have been used for a long time to support rotors because they are reliable and simple[2]. But, they have limits when it comes to damping high-frequency vibrations and supporting loads under different conditions. These problems can affect the long-term stability and accuracy of rotor systems, especially in harsh operating environments. Magnetic bearings have become a popular alternative because they do not have contact, which helps with precise rotor positioning and better vibration damping[3][4]. They reduce friction and wear, leading to better performance in controlling vibrations, especially at high speeds. But, magnetic bearings are often complex and sensitive to outside disturbances, requiring careful adjustment and monitoring.

Magnetic bearings offer good vibration damping and load support, especially at high speeds. However, their complexity and sensitivity to disturbances limit their use. A system combining magnetic and ball bearings helps overcome these problems. The magnetic bearings control vibrations, while the ball bearings provide structural stability and passive support.

2. Magneti and ball bearing composite support rotor system structure

Figure 1 shows the overall setup of the experimental platform for the porcelain composite supported rotor system. It has two main parts: the mechanical system and the electronic control system. The mechanical system includes radial and axial maglev bearings, rotors, angular contact bearings, motors, and support bases. The electronic control system includes displacement sensors, frequency converters, power amplifiers, dSPACE platforms, and host computers.

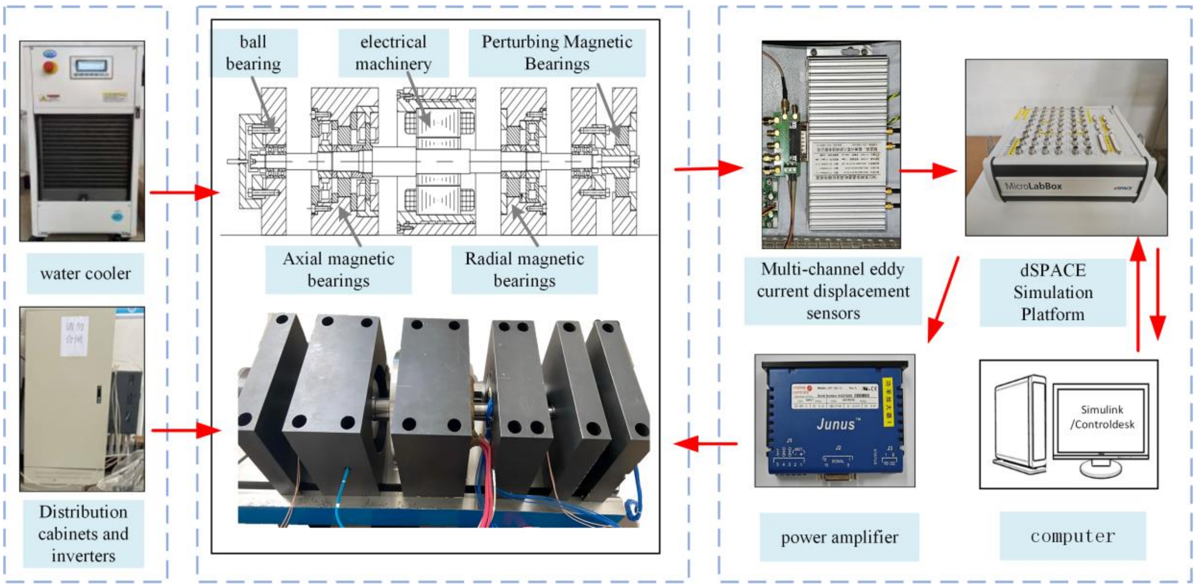

Fig. 1 General framework of the experimental platform of magnetic bearing and ball bearing composite support rotor system.

The control system of the magnetic-ball composite support rotor is built on the dSPACE simulation platform for development and debugging. dSPACE generates executable code from the Simulink control model in real time. It handles compilation, imports the code to the hardware system, and monitors the control system on the host computer. The motor used is a permanent magnet synchronous motor with a rated power of 15 kW and a rated speed of 500 Hz. The motor speed is adjusted by a frequency converter from the Goodrive350 series by Shenzhen Inventec Electric Co.

3. Mathematical Modeling of Magnetic and Ball bearing Composite Support Rotor System

First, the dynamic equations of the rotor are established using the discrete finite element method based on Timoshenko beam theory. Next, the equivalent magnetic circuit method is applied to develop the mathematical model of the magnetic bearing, combined with the PID control strategy. For the ball bearing, the centralized parameter method is used, which models it as a fixed stiffness support providing axial and radial support stiffness. Finally, the overall dynamic model of the system is formed by combining the kinetic equations of each unit.

The differential equation of motion for the magnet-ball double-supported rotor system can be expressed as

$$\begin{aligned} &\boldsymbol{M}_s\ddot{\boldsymbol{q}} + (\boldsymbol{C}_{total} \pm \Omega \boldsymbol{G}_s)\dot{\boldsymbol{q}} + \boldsymbol{K}_{total}\boldsymbol{q} = \boldsymbol{F}_{total} \\ &\boldsymbol{C}_{total} = \boldsymbol{C}_s + \boldsymbol{C}_b \\ &\boldsymbol{K}_{total} = \boldsymbol{K}_s + \boldsymbol{K}_b \\ &\boldsymbol{F}_{total} = \boldsymbol{F}_g + \boldsymbol{F}_u + \boldsymbol{F}_c \end{aligned} \tag{1}$$

where $\boldsymbol{M}_s$, $\boldsymbol{C}_s$, $\boldsymbol{G}_s$, and $\boldsymbol{K}_s$ are the mass, damping, gyroscopic, and stiffness matrices of the rotor; $\boldsymbol{K}_b$ and $\boldsymbol{C}_b$ are the ball bearing stiffness and damping matrices, respectively; and $\boldsymbol{F}_g$, $\boldsymbol{F}_u$, and $\boldsymbol{F}_c$ are the gravity, unbalance, and motor unbalance magnetic tension forces of the system, respectively.

4. Vibration analysis of composite supported rotor systems

The goal is to analyze the vibration characteristics of the rotor system supported by both magnetic and ball bearings, and to suppress its vibration. Using the established mathematical model, the vibration response of the rotor system is simulated and analyzed. The focus is on studying how the magnetic bearing's magnetic intervention helps suppress vibration in the rotor system under unbalanced excitation and milling disturbances.

5. Experimental analysis

Using the experimental setup shown in Fig. 1, vibration suppression experiments were conducted under unbalanced excitation and milling perturbation. These tests aimed to verify the effectiveness of using a composite support system of magnetic and ball bearings to suppress vibration, and to enhance the stability and accuracy of the rotor system.

6. Conclusion

To suppress the forced vibrations of the rotor during the machining process, this paper proposes a rotor system with a composite support of magnetic and ball bearings. The finite element method is used to create the dynamic model of the rotor system. Next, active control simulation of the magnetic bearing is used to achieve vibration suppression under different excitations. Finally, experimental verification is conducted using the constructed rotor system experimental bench to confirm the effectiveness of the vibration suppression.

References

[1] C. Ke, S. Qiu, K. Li, et al. “Numerical Computation and Experimental Research for Dynamic Properties of Ultra-High-Speed Rotor System Supported by Helium Hydrostatic Gas Bearings”, Lubricants, pp. 302,2024.

[2] F. Xu, et al. “A review of bearing failure Modes, mechanisms and causes”, Engineering Failure Analysis, pp. 107518, 2023.

[3] C. Liu., et al. “Review of research status and development of flexible rotor-magnetic bearing.” Proceedings of the CSEE, pp. 4602-4614, 2020.

[4] S. Chen, S. Lin, C. Toh. “Adaptive unbalance compensation for a three-pole active magnetic bearing system,” IEEE Transactions on Industrial Electronics, pp. 2097-2106, 2019.