Active Disturbance Rejection Decoupling Control for Three-Degree-of-Freedom Six-Pole Active Magnetic Bearing Based on BP Neural Network

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Backround

Compared with the conventional mechanical bearings, magnetic bearings possess many promising advantages such as: its mechanical contact; no lubrication; no wear, long life, high-speed, and high precision, which have innovated the conventional supporting forms fundamentally. Due to these advantages, magnetic bearings have a broad prospect of application in high-speed machine tool-spindles, high-speed systems, gears, motors, etc. Because of the strong nonlinearity and coupling effects, it is difficult to achieve the high precision and high-speed operation of the magnetic bearings: active disturbance rejection control can handle these problematic well.

Objectives

Good-performance of the three degrees of freedom six-pole active magnetic bearing (3-DOF 6-pole AMB) system while occurred the external disturbance.

Outstanding decoupling performance between the variables in different directions.

A. Configuration and Working Principle

The configuration and magnetic circuit of the 3-DOF 6-pole AMB are shown in the figure. Due to the existence of the macromagnetic material, the magnetic flux forms a loop along the axial stator, the axial gap, the rotor, the radial air gap and radial stator. Radial control flux forms a loop along the radial stator, the radial gap and the rotor.

B. Suspension Force Mathematical Models

According to the equivalent magnetic circuit method and the configuration of the 3-DOF 6-pole AMB, radial and axial suspension force mathematics models can respectively be obtained as:

\[
\begin{align*}
F_r & = k_r i_r + k_x x \\
F_a & = k_a i_a + k_y y \\
F_z & = k_z i_z + k_z z
\end{align*}
\]

Supposing that the rotor has a small displacement: \(x\) in the axial positive direction, \(y\) and \(z\) in the radial positive direction. Through the rotor’s force analysis of the 3-DOF 6-pole AMB, we can derive the static equations of the system.

\[
\begin{align*}
\frac{dI}{dt} & = T_S - 3 N_{iSS} r \delta \mu + \alpha_0 I \\
b & = \frac{\tau}{T_S} - 3 N_{iSS} r \delta \mu
\end{align*}
\]

C. Decoupling control design of 6-pole AMB

The coupling between different degrees of freedom are neglected in the external disturbance of the system. Therefore, the 3-DOF 6-pole AMB system is converted into a multi-variable decoupled and linear system. The decoupling control block diagram of the six-pole AMB based on ADRC-BP is shown in picture.

A. Simulation result

Assuming that the system is subjected to external disturbances with amplitudes of 120° varying according to sine. The figure on the right is the estimation curve of \( \gamma \) to the disturbing force. As can be seen from the figure, when the system is subjected to 150N external disturbance force, the estimation error of ADRC-BP to the total disturbance is the smallest.

B. Experimental Result

The length of air gap is designed to be 0.5 mm, however, to protect the experimental instruments, an auxiliary bearing was adopted to limit the rotor rotation to a 0.25 mm circle, which is placed on the end of the bearing so that it has no effect on the 3-DOF 6-pole AMB.

The variance of the external force of 100 N are shown in below figure. When the ADRC-BP controller is adopted, the variation in the collection are significantly reduced compared with that of ADRC. Consequently, the rotor system to the original position faster using the ADRC-BP controller when the system is subjected to the external disturbance.

In this paper, by using the ADRC-BP, the 3-DOF 6-pole AMB system is converted into a multi-variable, decoupled, and linear system. The effects of the configuration and suspension forces mathematical models are analyzed. The whole system of the 3-DOF 6-pole AMB in decoupling control based on ADRC-BP is designed. The simulation and experimental results indicate that, compared with the ADRC, the ADRC-BP can significantly suppress the interference and reduce the response time of the rotor. The above conclusions will be helpful to the high precision and high-speed control of the AMB system.