Decoupling Control Based on Linear/Nonlinear Active Disturbance Rejection Switching for 3 Degrees of Freedom HMB

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Background

Comared with the conventional bearings, magnetic bearings possess many advantages such as no friction and abrasions, no lubrication and no sealing, high speed, high precision and long life, which have innovated the traditional supporting forms fundamentally. Hybrid magnetic bearings with permanent magnet biased flux are among the most recommended magnetic bearings for reducing cost and consumption. Hence, hybrid magnetic bearings have a broad prospect of application in high-speed machine tool spindle, nuclear energy, flywheel energy storage system, and so on.

Objectives

- Good performance of the 3 degrees of freedom 6-pole hybrid magnetic bearing (3-DOF 6-pole HMB) system while occurred the external disturbance.
- Outstanding decoupling performance between the variables in different directions.

Conclusion

- The effect of the configuration and suspension forces mathematical models of the 3-DOF 6-pole HMB is analyzed.
- Using the linear/nonlinear active disturbance rejection switching control (SADRC), the 3-DOF 6-pole HMB system is converted into a multivariable, decoupled and linear system..
- The Simulating results show that the control system has achieved good performance, and the SADRC has a better capability to inhibit the disturbances from the input of the system.
- The experimental results show that the proposed controller has good static/dynamic stability and outstanding decoupling performance.

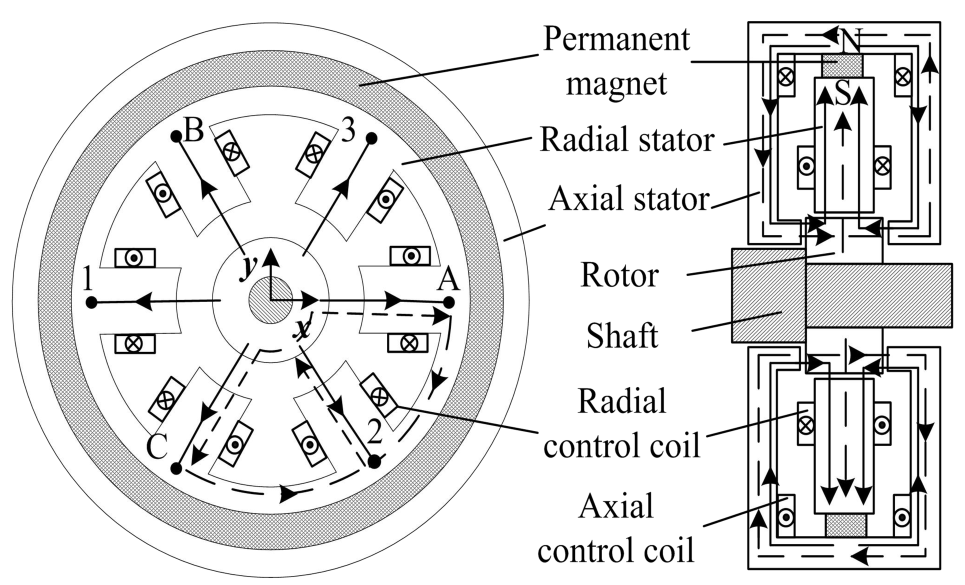
Modeling

Configuration and Working Principle

The configuration and magnetic circuits of the 3-DOF 6-pole HMB are shown in the figure.

While operating, the axial single degree of freedom is controlled by the two axial coils with DC. The six coils generate rotating magnetic flux to control the radial 2 degrees of freedom.

Thus the rotor can be suspended at the equilibrium position by regulating the value and direction of control fluxes.



Suspension Forces Mathematics Models

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

$$\begin{cases} F_j = \dfrac{G_j^2}{2\mu_0 s_r}\left(N_r i_j + \dfrac{M}{M+N}F_m\right)^2 \\ F_Z = \dfrac{G_{Z2}^2 - G_{Z1}^2}{2\mu_0 s_a}\left(N_Z i_Z + \dfrac{M}{M+N}F_m\right)^2 \end{cases}$$

Supposing that the rotor has a small displacement z in the axial positive direction, x and y in the radial positive direction. Through the rotor's force analysis of the 3-DOF 6-pole HMB, we can derive the 6-order state equations of the system.

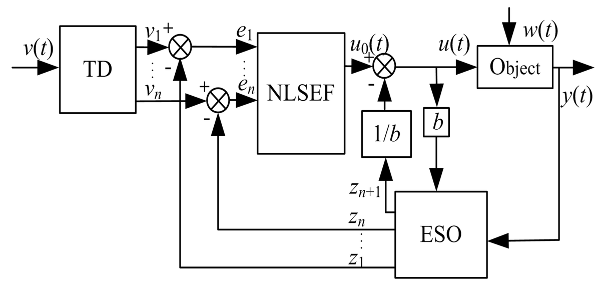
Method

ADRC Algorithm

A classical ADRC mainly consists of three parts:

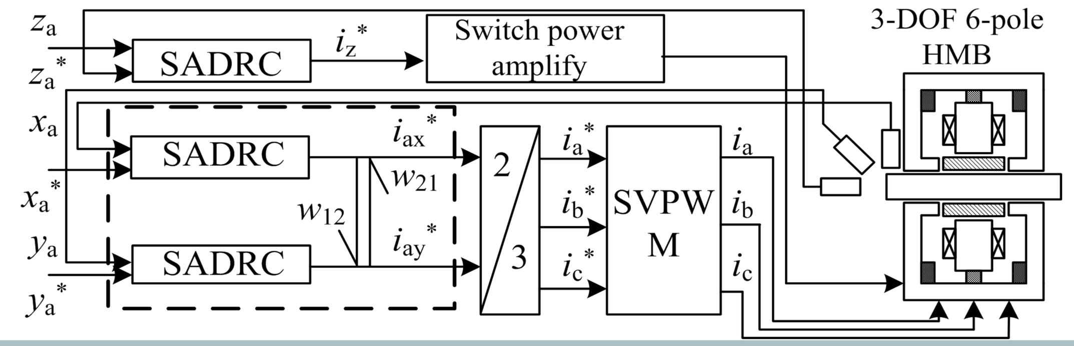
- Tracking Differentiator (TD)
- Extended State Observer (ESO)
- NonLinear State Error Feedback (NLSEF)

An ADRC for an Nth-order system is shown in the figure.



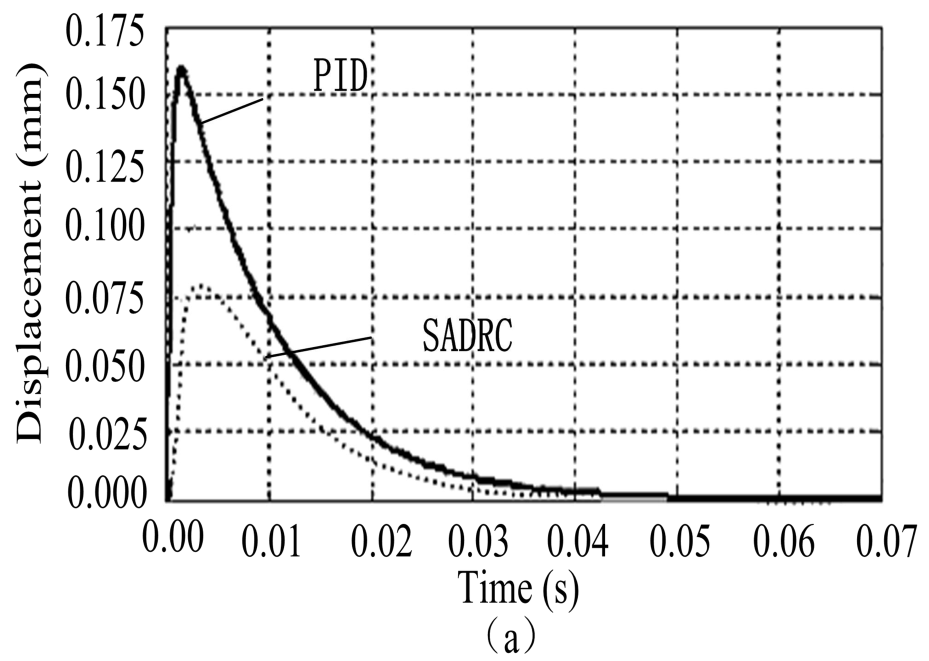
Scheme of SADRC

- **NLADRC analysis:**
Decreasing the performance of the NLESO sharply if the amplitude or derivate of the total disturbance turns too big.
Amplifing the noise during the steady state due to high gains and has an adverse impact on the stability.
- **LADRC analysis:**
Superior to the NLADRC in parameter tuning and theoretical analysis.
- **Scheme of SADRC:**
To realize the decoupling control of the 3-DOF 6-pole HMB, a scheme of SADRC is presented in the figure.



Results

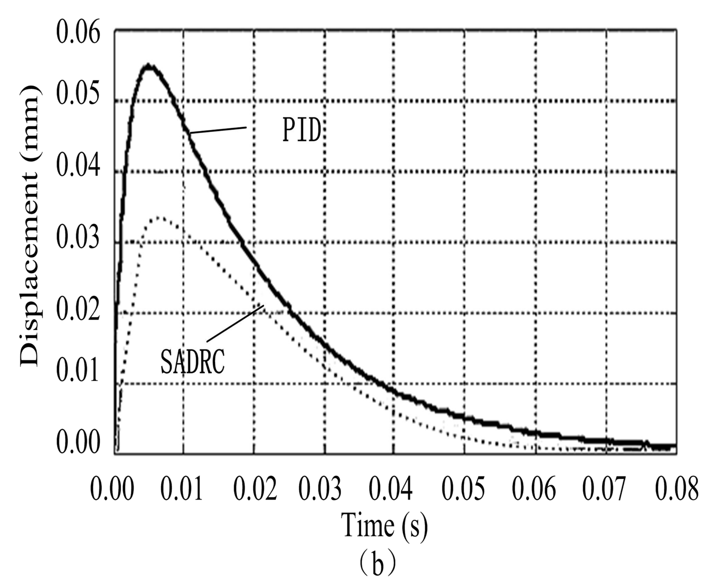
Control System Simulation Test

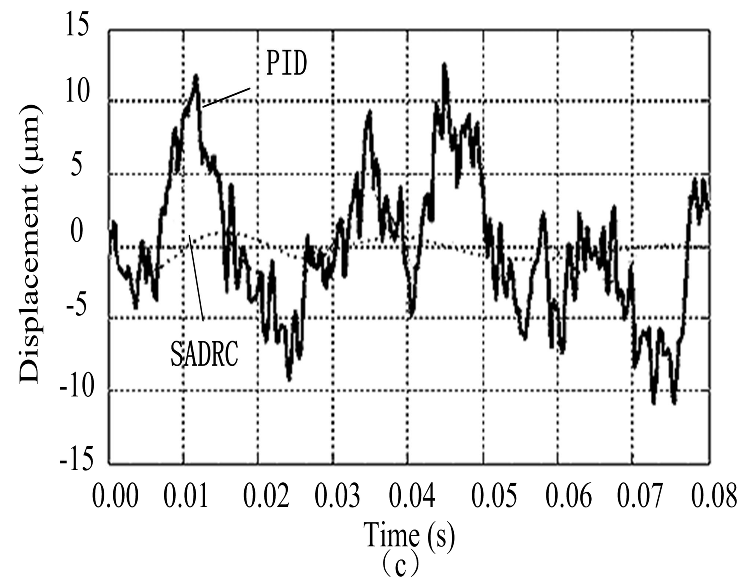


The influence of applied a step input to the radial y-direction is studied when the rotor is suspended steadily, and the response curves under the PID control and the SADRC are shown in the figure.

The curves in the figure both increase smoothly, and rise time of them are almost the same because of the same duration of the step input. However, it can be seen that compared with the PID control, the variation of curve under ADRC is much smaller.

The response time of system with SADRC is 40 ms, which is less than that with PID control, and the steady-state error of system is approximate 0.





In the above figures, there is the interfered response curves in the x-direction and z-direction, which is influenced by step input signal in the y-direction. From the simulation results, it can be seen that the fluctuations under SADRC in the y-direction and z-direction are much smaller than that under the PID control.

The response times of system under SADRC in y-direction and z-direction are both less than that under the PID control.

Experiment Research

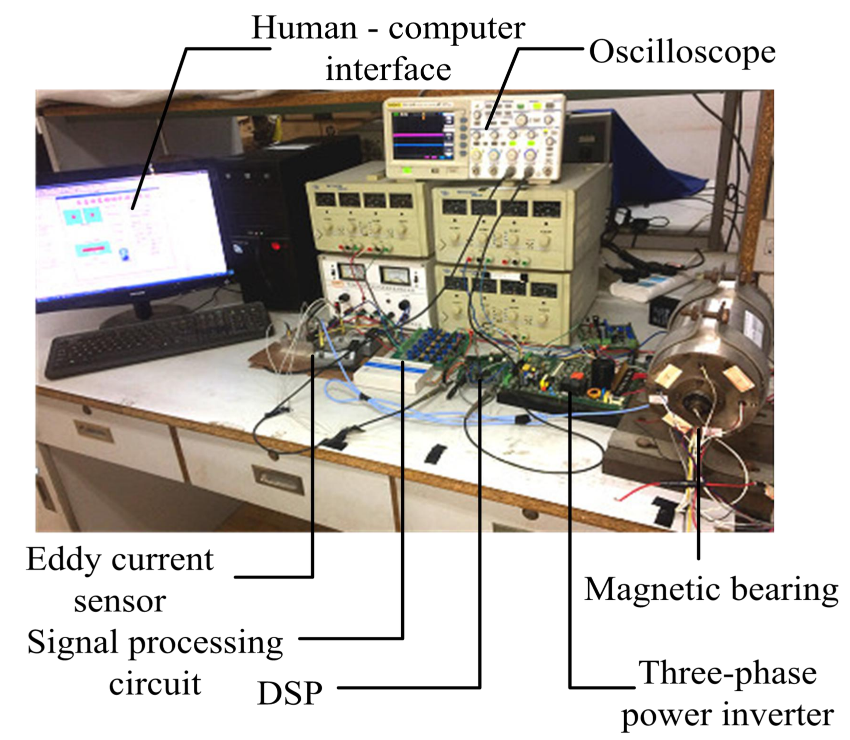
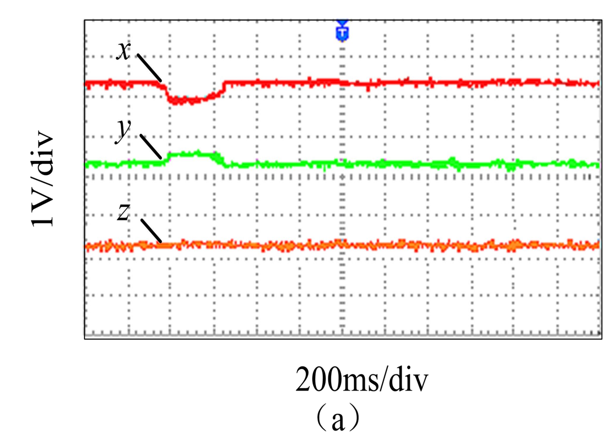
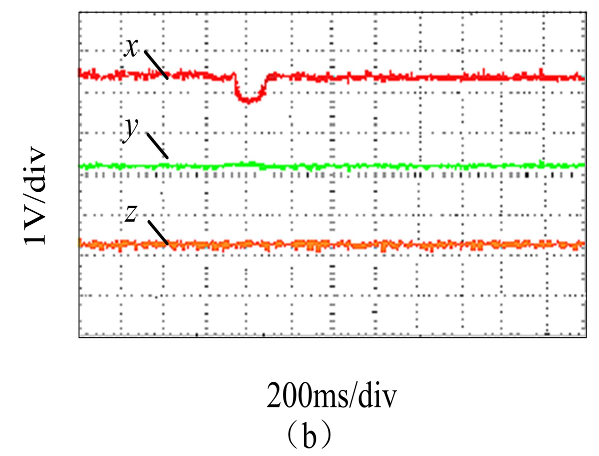


Image of a prototype which is designed and implemented to make research.





A external force of 200 N is applied in the x-direction when the rotor is suspended steadily. The displacement output voltage waveforms under the PID control and the SADRC control in the figure.

The variations of the waveforms in the x and y-directions adopt the SADRC control are less than that adopt the PID control while occurred the external disturbance. Moreover, the response time of the rotor adopt the SADRC is less than half of that of the PID.

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