Direct Control of Bearingless Permanent Magnet Slice Motor Based on PM Flux Observer

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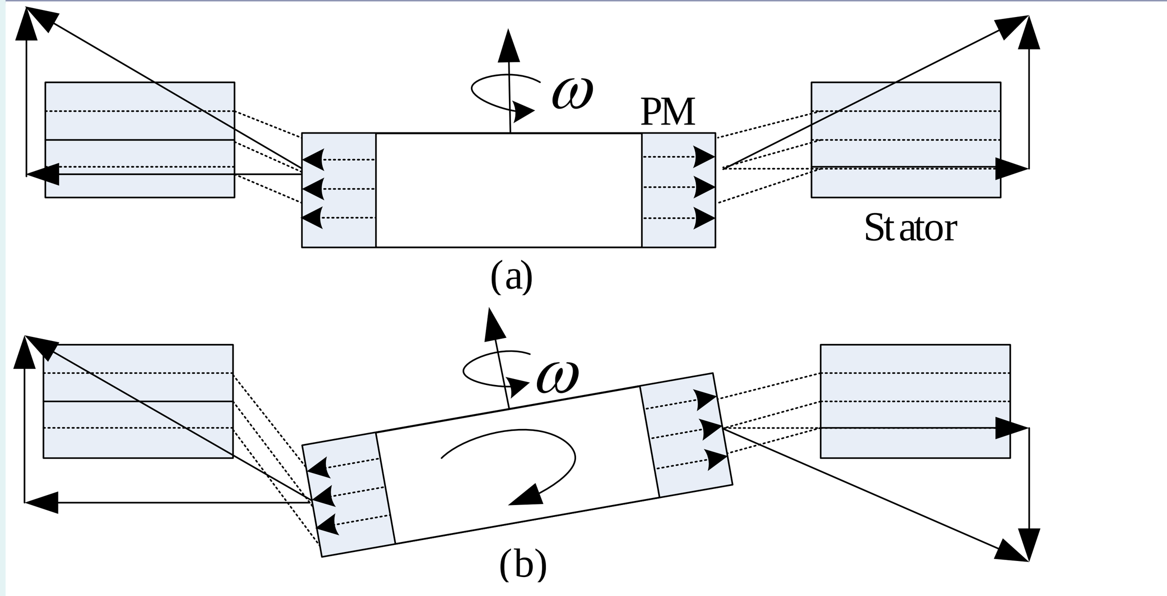
Backgrounds

A bearingless permanent magnet slice motor(BPMSM) is attracted by its slice rotor, which also inherits the merits of the magnetic bearing, such as no friction, no wear, no lubrication, long life, and so on. Compared with other fully magnetically levitated systems, such system simplifies the mechanical structure and reduces the difficulty of control, which lead to an important research value and application potential prospects in the special electric drive fields, such as medical industry, semiconductor, and chemical industry.

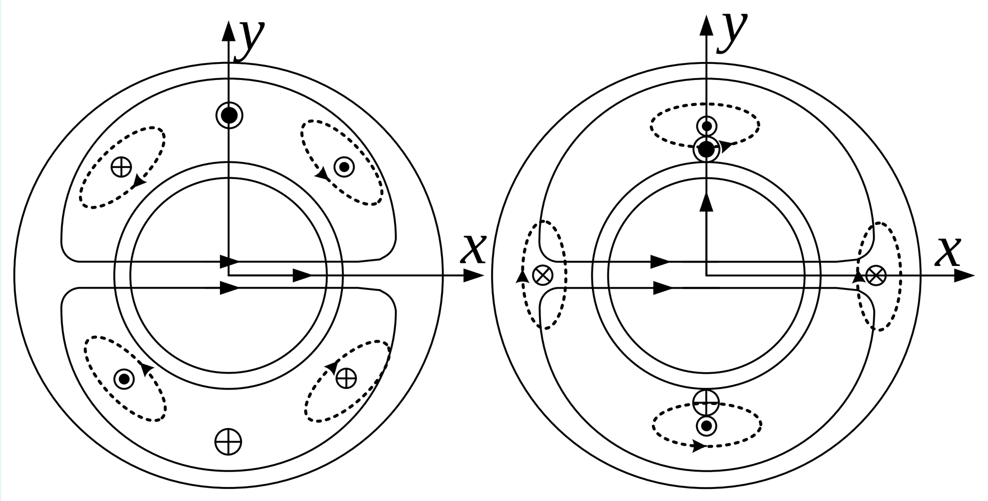
Objectives

- Designing displacement controller and constructing diect control model
- Testing the suspension force and torque characteristics by simulation and experiments

Basic structure and working principle of the BPMSM



The PM rotor is passively stabilized by reluctance force in the axial and tilting directions.



(a) x-direction (b) y-direction

As a function of the two magnetic fields with different numbers of pole pairs, the original balanced air-gap magnetic field is broken and in this case a radial suspension force can be generated to realize the rotor stabilization. As shown in (a), the flux density in x-axis positive direction is strengthened and by contrast, that in x-axis negetive direction is weakened. Thus, a suspension force component *F* is generated in the x-direction.

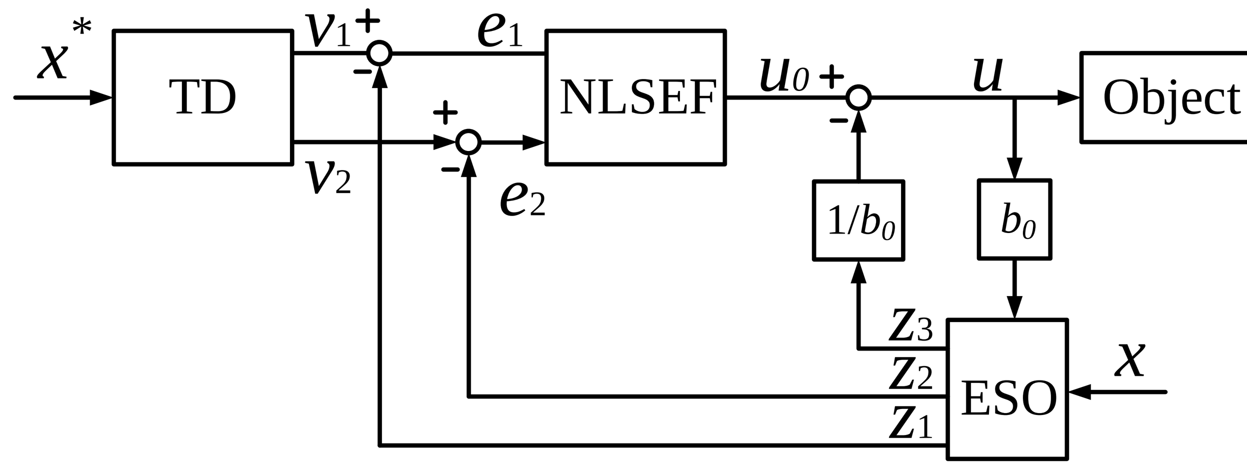
Displacement controller based on ADRC

motion equation of rotor displacement

$$\begin{cases} m\ddot{x} = F_x + F_{sx} + F_{dx} \\ m\ddot{y} = F_y + F_{sy} + F_{dy} \end{cases}$$

$$\frac{d^2 s}{dt^2} = \frac{F_k}{m} + \frac{k_s}{m} s + \frac{F_d}{m}$$

Principle diagram of ADRC displacement regulator



$$\frac{d^2 s}{dt^2} = \frac{F_k^*}{m} + w(t)$$

Direct Control Model

Electromagnetic torque

Torque observation:

$$T_e = 1.5 P_M \left(\psi_{M\alpha} i_{1\beta} - \psi_{M\beta} i_{1\alpha} \right)$$

Reference voltage calculation:

$$\begin{cases} u^*_{M\alpha} = R_{M1} i_{M\alpha} + \psi^*_{M1} \cos(\mu_1 + \Delta\delta) - \psi_{M1} \cos\lambda_1 / T \\ u^*_{M\beta} = R_{M1} i_{M\beta} + \psi^*_{M1} \sin(\mu_1 + \Delta\delta) - \psi_{M1} \sin\lambda_1 / T \end{cases}$$

Suspension force

Suspension force observation:

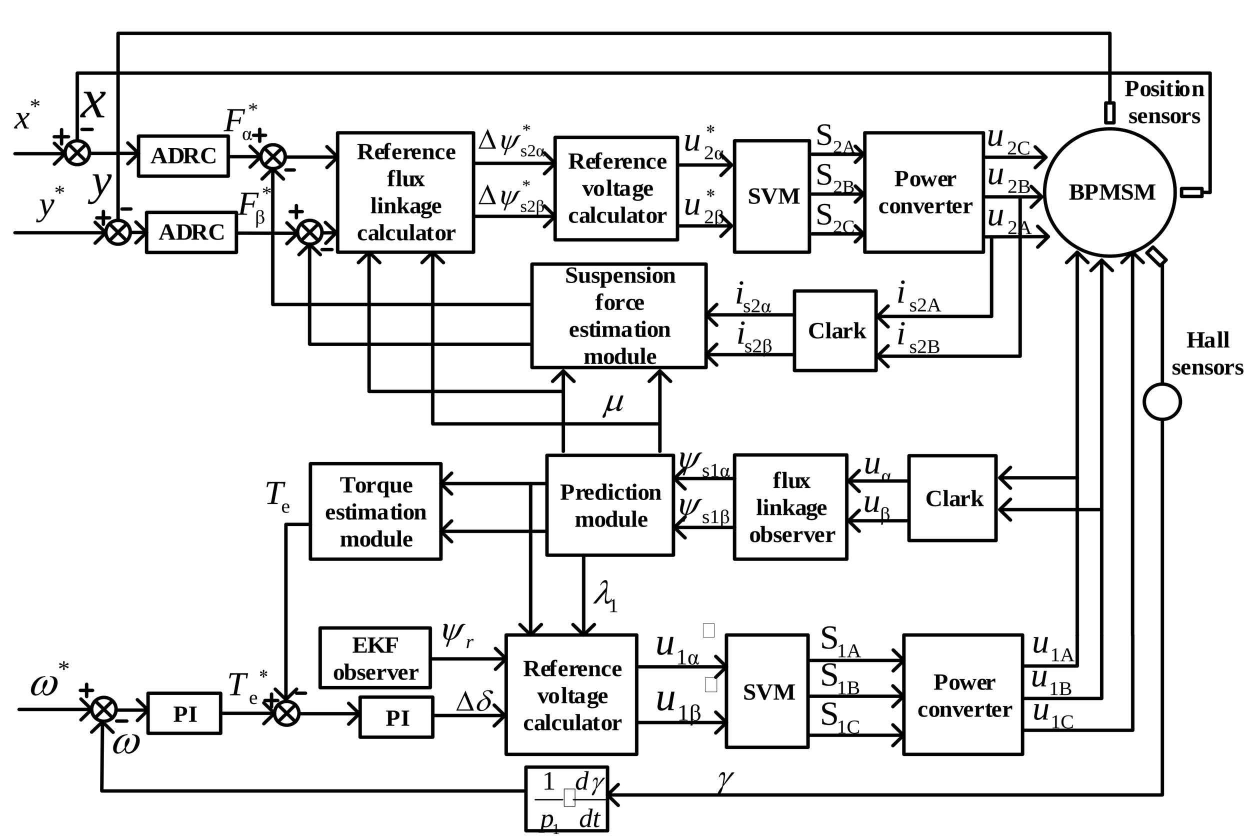
$$\begin{cases} F_\alpha = k_m L_B \left(i_{B\alpha} \psi_{m\alpha} + i_{B\beta} \psi_{m\beta} \right) \\ F_\beta = k_m L_B \left(i_{B\beta} \psi_{m\alpha} - i_{B\alpha} \psi_{m\beta} \right) \end{cases}$$

Reference voltage calculation:

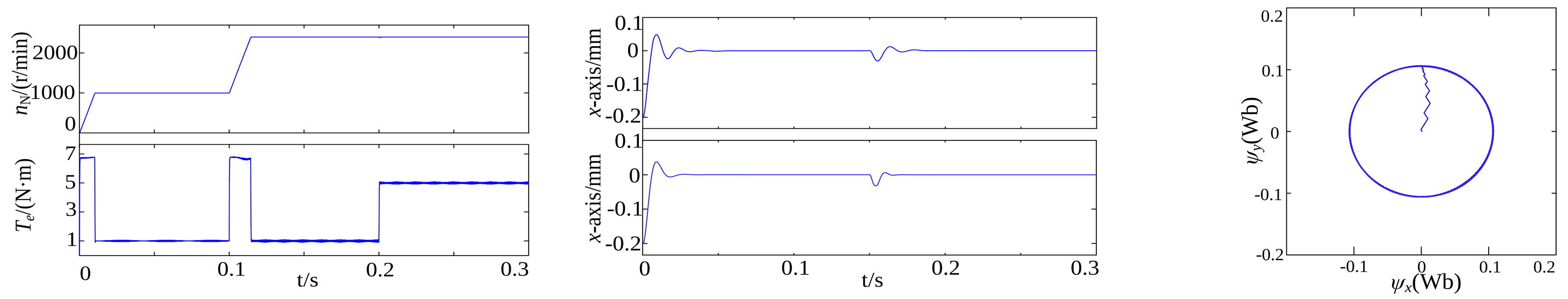
$$\begin{cases} u^*_{2\alpha} = R_{s2} i_{2\alpha} + k_M^{-1} \psi_m^{-1} \left(\Delta F_\alpha \cos\mu + \Delta F_\beta \sin\mu \right) / T \\ u^*_{2\beta} = R_{s2} i_{2\beta} + k_M^{-1} \psi_m^{-1} \left(\Delta F_\alpha \sin\mu - \Delta F_\beta \cos\mu \right) / T \end{cases}$$

Simulations

Direct control system of the BPMSM



Simulation results



(a) (b) (c)

As shown in (a), speed is set to 1000 rpm, speed overshoot is under 0.2%, and the fluctuating error of speed in steady state is less than 10rpm. Motor load torque is 1 N·m at starting, and then added to 5 N·m at 0.2 s. The pulsating movement of torque is less than 10%. fig. (b) shows the comparison results of the rotor radial displacement curves in the x-direction when two different displacement control methods are used in direct control, respectively. When ADRC used instead of the traditional PI controller, the floating time becomes shorter, the vibration amplitude of the rotor becomes smaller, and the stable suspension can be recovered more quickly after the disturbance. Fig. (c) shows the tracking performance of torque windings flux linkage, the fluctuating error of the amplitude in steady state is very small.

Conclusion

- ✓ The ADRC is applied to the suspension force control system, the suspension force disturbance rejection performance isoptimized , and the dynamic performance of the motor is effectively improved.
- ✓ The observational lag is compensated by the direct control module, which greatly increase the control accuracy and response speed of the suspension force.
- ✓ The decoupling control of the BPMSM is realized and a good speed regulation performance is achieved.