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A fast integral sliding mode controller with an extended state observer for position control of permanent magnet synchronous motor servo systems

Key words: Permanent magnet synchronous motor (PMSM); Sliding mode controller; Extended state observer; Robust control; Motion control

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Motivation

- A nonlinear sliding surface (SS) has much lower convergence speed compared with a linear one. This phenomenon occurs especially when the system state is far away from the equilibrium.
- Prior knowledge of the boundary of lumped disturbance is required to obtain enough robustness. However, this is impossible in real applications, so the robustness is not satisfactory and steady state fluctuation is inevitable.

Main idea

- A modified integral sliding mode controller is developed, which has a fast-sliding surface and a continuous reaching law.
- An extended state observer is applied to measure the internal and external disturbances. Therefore, the disturbances can be compensated for in a feedforward manner.

Method

1. Fast integral sliding surface:

A fast integral SS is designed as follows:

$$s = \dot{e} + \beta_{\mathrm{I}} e^{\gamma_1} + \alpha_{\mathrm{I}} \int_0^t e^{\gamma_2}(\tau)\,\mathrm{d}\tau, \tag{6}$$

where β_{I}, α_{I}, γ_1, and γ_2 are positive parameters with $\gamma_1>1$. To obtain a high convergence speed, γ_2 is defined as

$$\gamma_2 = \begin{cases} m_{\mathrm{I}}/n_{\mathrm{I}}, & |e| \geq \delta, \\ n_{\mathrm{I}}/m_{\mathrm{I}}, & |e| < \delta, \end{cases} \tag{7}$$

where m_{I} and n_{I} are positive odd integers with $m_{\mathrm{I}}>n_{\mathrm{I}}$ and δ is the switching value.

2. Second-order linear extended state observer (ESO):

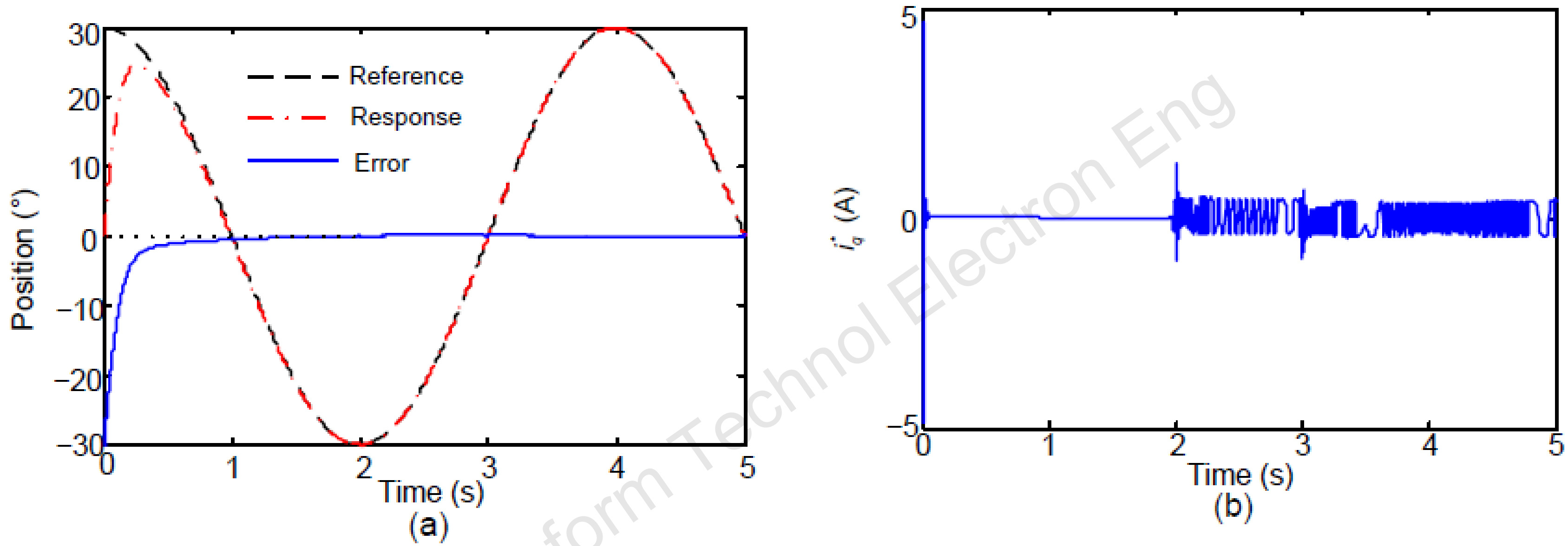
$$\begin{cases} \dot{\hat{x}}_2 = \hat{d} - 2p(\hat{x}_2 - x_2) + g(x)u, \\ \dot{\hat{d}} = -p^2(\hat{x}_2 - x_2) \end{cases} . \quad (13)$$

3. Robust fast continuous integral sliding mode control with a fast integral sliding surface and ESO:

$$u = u_0 - g^{-1}(\boldsymbol{x})\hat{d}. \quad (16)$$

$$u_0 = -g^{-1}(\boldsymbol{x})\left[f(\boldsymbol{x}) + \beta_{\mathrm{I}}\gamma_1 e^{\gamma_1 - 1}\dot{e} + \alpha_{\mathrm{I}} e^{\gamma_2} - \ddot{x}_{\mathrm{ref}} + k_{1\mathrm{I}} s + k_{2\mathrm{I}} | s |^{q_{0\mathrm{I}}/p_{0\mathrm{I}}} \operatorname{sgn}(s) \right] .$$

Major results



Tracking performances of the proposed method in simulation: (a) position response; (b) control input

External load torque T_L=30 N·m is added at t=2 s and removed at t=3 s. A fast and high-precision control performance is achieved. Additionally, the disturbance effect is eliminated effectively.

Major results

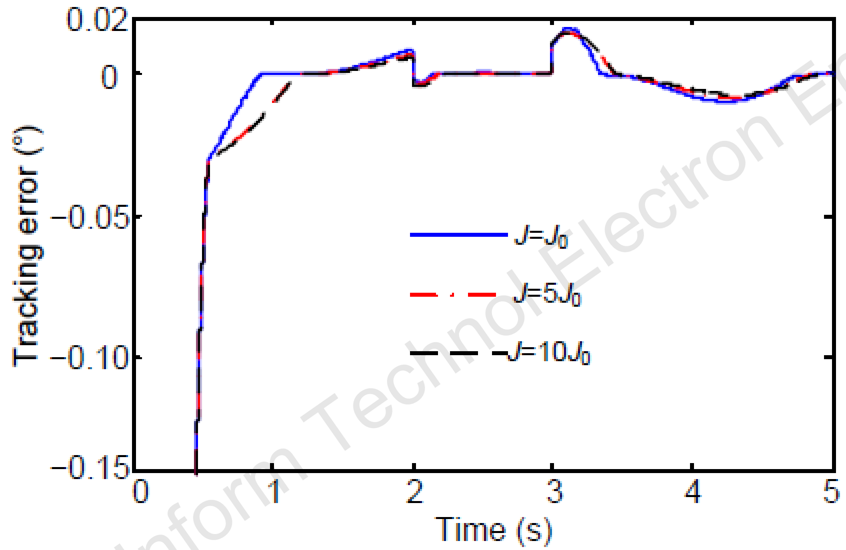


Fig. 6 Tracking performance of RFCISM under system inertia variations in simulation

The transient response remains fast and accurate, regardless of the internal parameter variations.

Major results

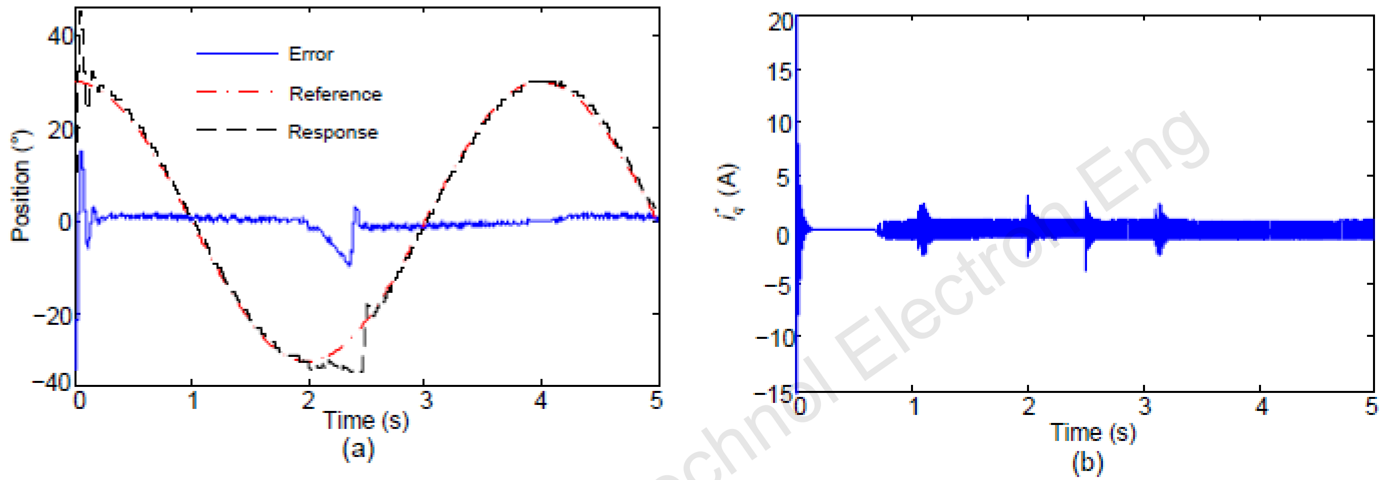


Fig. 11 Tracking performances of FCISM in the experiment: (a) position response; (b) control input i_q^*

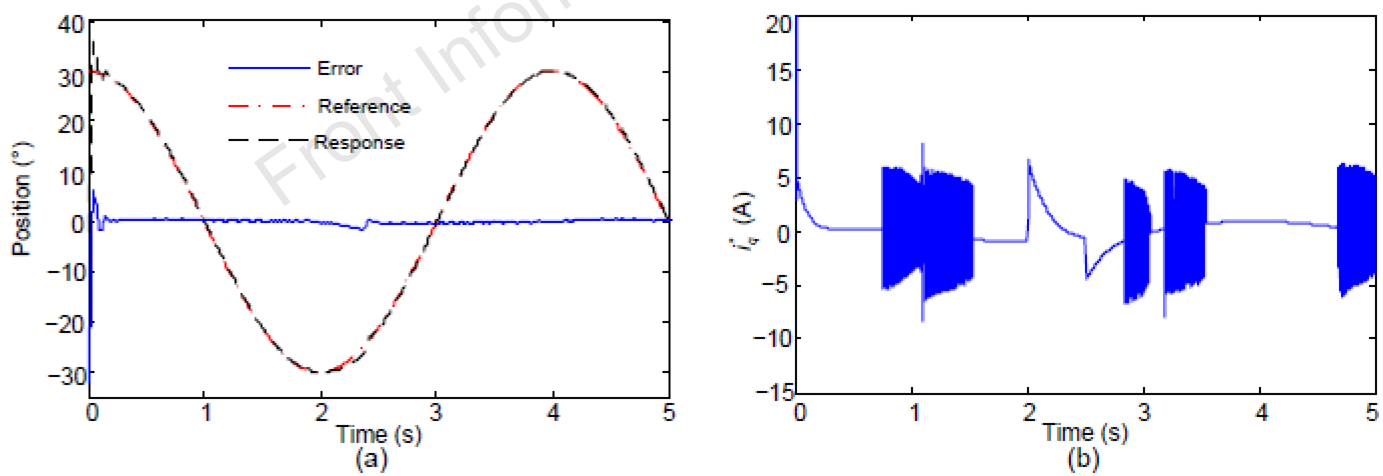


Fig. 12 Tracking performances of RFCISM in the experiment: (a) position response; (b) control input i_q^*

Major results

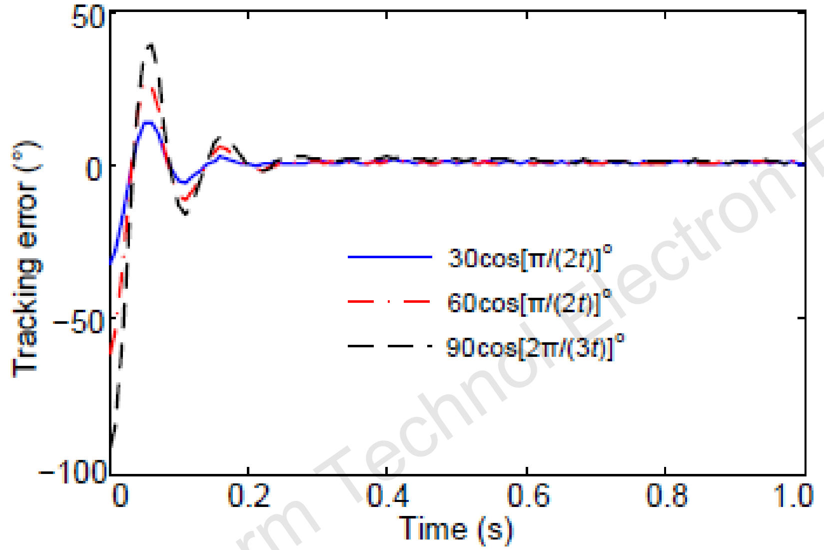


Fig. 14 Tracking performance of RFCISM for different position references

The overshoot and settling time increase with the increase in amplification or frequency. However, the tracking performance remains desirable in all cases. It is evident that the proposed control system has superior performance in tracking a wide range of target positions.

Conclusions

- The conventional integral sliding surface was modified so that fast convergence can be obtained.
- A continuous reaching law was applied in the controller design. Consequently, the chattering problem of the conventional sliding mode controller can be solved to some extent.
- An extended state observer was adopted to estimate and compensate for system disturbances, so the disturbance rejection capability of permanent magnet synchronous motor systems can be improved remarkably.