

ANALYSIS OF MODEL-FREE SLIDING MODE CONTROL OF PERMANENT MAGNET SYNCHRONOUS MOTOR

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Abstract – In order to solve the problem that some parameters and inductance of the motor are easily affected by the external environment and its own losses during the actual operation, a new model-free sliding mode control method is presented in this research. By taking the embedded permanent magnet synchronous motor as the research object, the hyperlocal model of the speed ring of the embedded permanent magnet synchronous motor, the new model-free sliding mode control strategy of the speed ring of the embedded permanent magnet synchronous motor, and the controller are designed. Simulation and semi-physical simulation experiments are carried out for the model-free sliding mode control system of PMSM. The results show that as compared to the proportional integral (PI), the control method proposed in this research has a smaller ripple on the motor torque and d-q axis current, indicating that the control is more stable. Moreover, semi-physical simulation shows that the model-free sliding mode control method proposed in this research is superior. The research has important theoretical significance for realizing stable operation of permanent magnet synchronous motor.

Keywords: Permanent Magnet Synchronous Motor, Model-Free Sliding Mode Control, Matlab Simulation, The Controller, The Observer.

1. Introduction

With the rapid development of the world economy, driven by energy conservation and environmental protection, low-carbon economy has penetrated the field of transportation. However, as an important power source in the field of transportation, the motor and its driving system have higher and higher requirements. Transportation must meet the requirements of low energy consumption and low pollution under the premises of safe and reliable operation [1,2]. With the evolution of research on traction motor in rail transit electric locomotive, it has developed from DC motor to current AC asynchronous motor, which has good application effect, mature technology, and sound control effect. Moreover, the development of permanent magnet materials, permanent magnet synchronous motor has also achieved rapid development, and scholars continue to innovate and improve its control technology [3].

Permanent Magnet Synchronous Motor (PMSM) has the advantages of small size, high power, low noise, better overload capacity, higher reliability, and easy to achieve high-performance control. As a result, PMSM has been widely applied, such as robot industry, aerospace field, and electric locomotive

field [4-5]. At present, most PMSM control systems adopt PI control system with a simple algorithm and easy implementation. However, the PI control system can't meet the changes of system parameters, environmental disturbance, and nonlinear, multi-coupling PMSM control system. A permanent magnet motor control method with stronger robustness and better control performance is needed [6]. With the progress of science and technology, many scholars have proposed more and more advanced control methods, such as adaptive control, predictive control, and sliding mode variable structure control.

Among these control methods, due to the stronger robustness and faster response speed of sliding mode variable structure control in the case of system parameter perturbation and external disturbance, motor control has attracted much attention [7-8]. However, in the case of complex operating environment and changeable operating conditions, the internal parameters of PMSM traction motor, such as inductance and resistance, are easily affected by external changes. Modern control theories such as sliding mode variable structure control are mostly based on specific system models for controller design. Once the motor parameters are perturbed, the controller performance of the motor will be affected to some extent [9-10].

Therefore, it is urgent to find a reliable and straightforward control method to control PMSM.

To sum up, in order to ensure the regular operation of PMSM under complex and changeable environment, the Interior Permanent Magnet Synchronous Motor (IPMSM) is taken as the research object and a model-free sliding mode control strategy is proposed. By combining model-free control theory with sliding mode structure control, the model-free control method is constructed to reduce the controller's dependence on the motor model. Then, the controller is designed. At last, the speed of PMSM is simulated by Matlab and semi-physical simulation. It is expected that the research can provide a good idea for model-free control of PMSM.

$$a_0y^{(n)} + a_1y^{(n-1)} + \dots + a_{n-1}y + a_ny = b_0u^{(m)} + b_1u^{(m-1)} + \dots + b_{m-1}u^{(n)} + b_mu \quad (1)$$

In Eq. 1, $a_j (j=1,2,L,m)$ and $b_j (j=1,2,L,m)$ are system correlation coefficients; j represents the order of the system; u represents the input variable of the system; y is the output variable of the system. According to the control idea of model-free control method, Eq. 1 can be changed into Eq. 2.

$$y^{(n)} = au + F \quad (2)$$

In Eq. 2, a is a scaling factor input to the system; F is the value estimated by the algorithm for the system control input u and system output y . There is a special note that F will not identify and distinguish the unmodeled part of the system from the uncertain factors. n is the order of the system, $n \geq 1$.

In some nonlinear complex systems, the input and output of the system can be replaced by a simple super-local model. In this way, the expressions of the single-output and single-input first-order local model of the system are as follows.

$$\frac{dy}{dt} = \alpha U + F \quad (3)$$

In Eq. 3, α represents non-physical constants; y is the output variable; u represents the input variable; F represents the known and other undetermined parts of the system.

F in Eq. 3 is a real variable of the super-local model in the dynamic system, then Eq. 4 can be obtained.

$$F = y - \alpha u \quad (4)$$

Therefore, the control input of the model-free controller can be expressed as follows.

$$u = \frac{-F + y^* + u_c}{\alpha} \quad (5)$$

2. Methodology

2.1 An introduction to model-free control methods

In the early 20th century, a model-free control method based on super-local model was proposed. And this method developed rapidly after it was proposed, and has been applied to various industries such as motor control and rail transit. The main idea is to construct the local model for the input and output of the control system, and then design the model-free controller. Because the local model is used, this method can reduce the dependence of the control on the system model and further increase the robustness of the controller to various external disturbances [11-13].

For a single output single input system, it can be represented by the following n -order fractions.

In Eq. 5, y^* represents the expected output value of the local system; u_c represents the feedback in the model-free controller control input.

The Eq. 5 is substituted into Eq. 3 to obtain Eq. 6 and Eq. 7.

$$\frac{dy}{dt} = \alpha \left(\frac{-F + y^* + u_c}{\alpha} \right) + F = y^* + u_c \quad (6)$$

$$y^* - y + u_c = 0 \quad (7)$$

In Eq. 6 and Eq. 7, e represents tracking error; the feedback controller u_c can not only select the proportional integral controller, but also adopt the proportional integral differential controller

For the proportional integral model-free controller based on the super-local model, the control input of the system is as follows:

$$u = \frac{-\hat{F} + y^* + K_p e + K_e \int e}{\alpha} \quad (8)$$

In Eq. 8, \hat{F} is the estimated value of F ; K_p represents the proportional coefficient; K_i denotes the integral coefficient; $e = y^* - y$ is the system tracking error. Supposing $K_i = 0$, a proportional model-free controller is obtained.

For the permanent magnet synchronous motor, it is a relatively complex and changeable control object. In some cases, the system model is nonlinear. If something happens to the magnet, such as loss of magnetism, resistance, inductance parameters, and so on [14-16], the current state equation of the permanent magnet motor in the d-q axis can be written as follows.

$$\frac{di_d}{dt} = \frac{u_d}{L_{do} + \Delta L_d} - \frac{R_{so} + \Delta R_s}{L_{do} + \Delta L_d} i_d + \omega_e \frac{L_{qo} + \Delta L_q}{L_{do} + \Delta L_d} i_q + \omega_e \frac{\Delta \Psi_{rq}}{L_{do} + \Delta L_d} \quad (9)$$

$$\frac{di_q}{dt} = \frac{u_q}{L_{qo} + \Delta L_q} - \frac{R_{so} + \Delta R_s}{L_{qo} + \Delta L_q} i_q + \omega_e \frac{L_{do} + \Delta L_d}{L_{qo} + \Delta L_q} i_d + \omega_e \frac{\Delta \Psi_{ro} + \Delta \Psi_{rd}}{L_{qo} + \Delta L_q} \quad (10)$$

Through the transformation of Eq. 10, under the condition of perturbation and loss of magnetism of

some parameters, the current state equation of the motor in d-q coordinate is written as follows.

$$\frac{di_d}{dt} = \frac{u_d}{L_{do}} - \frac{R_{so} + \Delta R_s}{L_{do} + \Delta L_d} i_d + \omega_e \frac{L_{qo} + \Delta L_q}{L_{do} + \Delta L_d} i_q - \omega_e \frac{\Delta \Psi_{rq}}{L_{do} + \Delta L_d} \quad (11)$$

$$\frac{di_q}{dt} = \frac{u_q}{L_{qo} + \Delta L_q} - \frac{R_{so} + \Delta R_s}{L_{qo} + \Delta L_q} i_q + \omega_e \frac{L_{do} + \Delta L_d}{L_{qo} + \Delta L_q} i_d - \omega_e \frac{\Psi_{ro} + \Delta \Psi_{rd}}{L_{qo} + \Delta L_q} \quad (12)$$

$$- \frac{\Delta L_d}{L_{qo}(L_{qo} + \Delta L_q)} \quad (13)$$

When the permanent magnet loses its magnetism, the resistance and inductance are perturbed, then the local model expression of the electromagnet can be written as follows:

$$T_L + \frac{J}{n_p} \frac{d\omega}{dt} + B\omega_m = \frac{3}{2} n_p \Psi_{end} i_q + \Delta T_e \quad (14)$$

$$\frac{d\omega_e}{dt} = \frac{J}{n_p} \left(-\frac{3}{2} n_p \Psi_{end} i_q + \Delta T - B\omega_m - T_L \right) \quad (15)$$

According to the model-free control idea of the super-local model and the changes of Eq. 14 and Eq. 15, the super-local model expressions of the speed loop and current loop of the control system constructed based on the input and output of the control system of the permanent magnet synchronous motor are as follows:

$$\begin{cases} \frac{di_d}{dt} = \alpha_d u_d + F_d \\ \frac{di_q}{dt} = \alpha_q u_q + F_q \\ \frac{d\omega_e}{dt} = \alpha_\omega i_q + F_\omega \end{cases} \quad (16)$$

In Eq. 16, α_d is the voltage coefficient of stator d-axis of permanent magnet synchronous motor; α_q is the voltage coefficient of stator q axis of permanent magnet synchronous motor; α_ω is the current coefficient of permanent magnet synchronous motor stator q axis; F_d represents the suppression distribution of the system model; F_q shows the parameter perturbation of the system model; F_ω denotes the failure part of the system model, and all are bounded.

2.2 IPMSM speed loop super-local model

In the case of uncertainty of motor parameters, the expression of the speed equation of the permanent magnet synchronous motor is as follows:

$$\frac{d\omega_e}{dt} = -\frac{3}{2} \frac{n_p^2}{J} \Psi_{ext} i_q - \frac{B}{J} \omega_e + \frac{n_p}{J} (\Delta T_e - T_L) \quad (17)$$

Similarly, according to the model-free control theory of the super-local model, the input and output controlled by the speed ring of the synchronous motor can be used.

$$\omega = \dot{F} + \alpha i_q \quad (18)$$

In Eq. 18, α is the stator q-axis current coefficient of permanent magnet synchronous motor designed in this research; F is the uncertain part and the known part of the PMSM system parameters.

2.3 A new model-free sliding mode control strategy for IPMSM speed loop and the design of controller

The design idea of the new modeless controller of IPMSM speed loop is considered in this research is to manipulate the feedback controller U_c in the modeless control strategy as the sliding mode controller, and use the sliding mode observer to estimate the unknown quantity F.

In this research, the model-free controller of the speed loop is designed using the model-free control idea of the super-local model.

$$i_q = \frac{-F + \dot{\omega}_e^* + u_c}{\alpha} \quad (19)$$

Eq. 20 and Eq. 21 are obtained according to Eq. 18 and Eq. 19.

$$\dot{\omega}_e = \dot{\omega}_e^* + u_c \quad (20)$$

$$(\dot{\omega}_e^* - \dot{\omega}_e + u_c) \quad (21)$$

In order to combine the model-free control method with the sliding mode variable structure control method, the feedback controller in the model-free control strategy is designed as a sliding mode controller. IPMSM speed error is selected as the state variable.

$$\begin{cases} x_1 = \omega_e^* - \omega_e \\ x_2 = \int x_1 = \int \omega_e^* - \omega_e \end{cases} \quad (22)$$

The derivatives of x_1, x_2 in Eq. 22 and Eq. 23 are taken.

$$\begin{cases} \dot{x}_1 = -u_c \\ \dot{x}_2 = x_1 = \omega_e^* - \omega_e \end{cases} \quad (23)$$

$$u_c = cx_1 + \varepsilon \operatorname{sgn}(s_1) + \lambda s_1 = c(\omega_e^* - \omega_e) + \varepsilon \operatorname{sgn}(s_1) + \lambda s_1 \quad (27)$$

In Eq. 27, ε and λ represent the normal numbers to be designed.

When $s_1 \dot{s}_1 < 0$, then the sliding mode control can meet the temperature controlled by the sliding mode. When choosing the exponential approach law, Eq. 28 is obtained.

$$i_q = \frac{-F + \dot{\omega}_e^* + c(\omega_e^* - \omega_e) + \varepsilon \operatorname{sgn}(s_1) + \lambda s_1}{\alpha} \quad (29)$$

For the sliding-mode device, there is an unknown term F in Eq. 29. An aggregate slide-out is performed to estimate the estimated value.

$$\hat{\omega}_e = \alpha i_q + k \operatorname{sgn}(\omega_e - \hat{\omega}_e) \quad (30)$$

$e = \omega_e - \hat{\omega}_e$ is defined as the observer dynamic error. According to Eq. 18 and Eq. 30, the error of the observer can be expressed as follows:

$$\dot{e} = F - k \operatorname{sgn}(e) \quad (31)$$

In this research, the error variable e is taken as the sliding mode surface to select the k value.

$$i_q = \frac{-F + \dot{\omega}_e^* + c(\omega_e^* - \omega_e) + \varepsilon \operatorname{sgn}(s_1) + \lambda s_1}{\alpha} \quad (33)$$

In order to reduce the chattering caused by the traditional switch function, Sigmoid function H(e) is needed to replace the symbol function, which can be expressed as follows.

$$H(e) = \frac{2}{1 + e^{-a(e)}} - 1 \quad (34)$$

In Eq. 34, $a > 0$, the slope of the Sigmoid function can be adjusted by a.

In order to reduce steady-state error, integral sliding surface should be selected.

$$s_1 = x_1 + cx_2 \quad (24)$$

In Eq. 24, $c > 0$, c represents the constant number of band designs.

The derivative of Eq. 24 is taken and Eq. 23 is substituted into Eq. 24 to obtain Eq. 25.

$$s_1 = cx_1 + \dot{x}_1 = cx_1 - u_c \quad (25)$$

In this research, exponential approach law is selected to design the controller to improve the dynamic quality of the system.

$$\dot{s}_1 = -\varepsilon \operatorname{sgn}(s_1) - \lambda s_1 \quad (26)$$

Eq. 27 can be obtained according to the combination of Eq. 24, Eq. 25, and Eq. 26.

$$s_1 \dot{s}_1 = s_1(-\varepsilon \operatorname{sgn}(s_1) - \lambda s_1) < 0 \quad (28)$$

By substituting Eq. 28 into Eq. 19, the model-free sliding mode control law of IPMSM vector control system designed in this research can be obtained as follows.

Therefore, it can be concluded that the observer equation will converge to zero asymptotically.

According to Lyapunov stability criterion and sliding mode accessibility conditions, error e will gradually converge to zero, thereby, Eq. 32 can be obtained from the sliding mode equivalence principle.

$$\hat{F} = k \operatorname{sgn}(e) \quad (32)$$

The observation value \hat{F} is substituted into the IPMSM model-free sliding mode control law of the speed loop of the vector control system, then Eq. 33 is obtained.

In order to verify the feasibility and effectiveness of the model-free sliding mode controller designed in this research, the maximum torque current ratio control strategy is adopted.

The simulation experiment of speed control of permanent magnet synchronous motor is carried out using Matlab software. The parameters used in the simulation experiment are shown in Table 1.

Table 1. Parameters of permanent magnet synchronous motor

Motor parameters	Values
Number of pole-pairs n_p /pair	3
The rotor flux linkage Ψ_r /Wb	0.896
Rotational inertia J /Kg·m ²	150
Damping coefficient $Nm·s$ /rad	0.001
Stator winding phase resistance R_s / Ω	0.02
Inductance of q-axis of stator winding L_q /H	0.003579
Stator winding d axis inductance L_d /H	0.001600

3. Results and Discussion

3.1 Analysis of simulation results

In this research, the initial speed of the simulation experiment is set to 50rad/s, and the speed is increased to 200rad/s within 0.5s. The initial torque value after starting the motor is set to 300Nm, and the torque is abruptly increased to 1000Nm within 2s. The remaining parameters of the motor are nominal values.

Figure. 1 is a comparison diagram of the change of PI control method and model-free sliding mode control method when the motor parameters remain unchanged. The model-free sliding mode control method proposed in this research has a relatively short response time in the case of sudden changes in speed and torque. When the torque of PI control method changes, the speed will decrease by 0.21rad/s, which can't be recovered immediately in a short time. In this research, the speed of model-free slide-mode void violation is reduced by 0.04rad/s, and it can be recovered to the stable value within 0.02s. Therefore, it can be concluded that the model-free sliding mode control method proposed in this research has a good control effect and is relatively stable when compared with PI control with a small fluctuation. Under the PI control method, the time needed to click to reach the stable state for the change of 1s torque is 0.04s.

However, the model-free sliding mode control method proposed in this research only needs 0.006s.

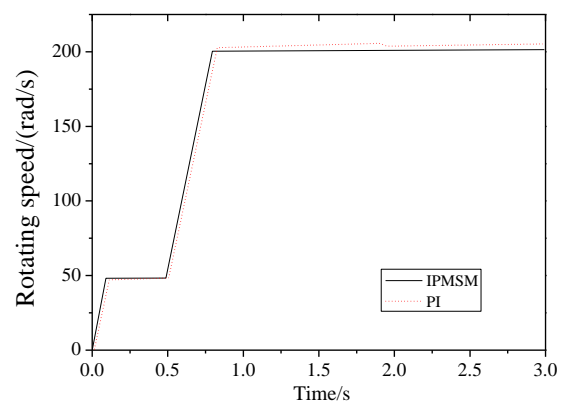
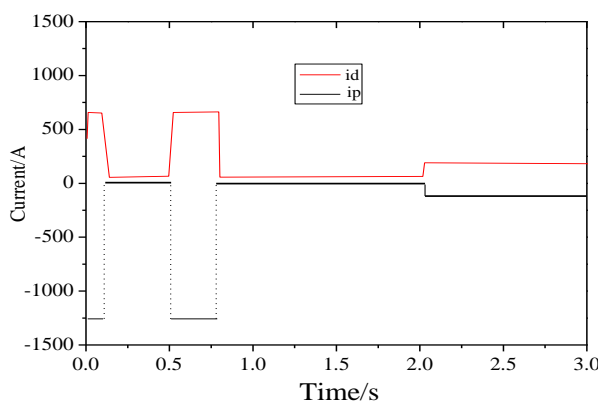
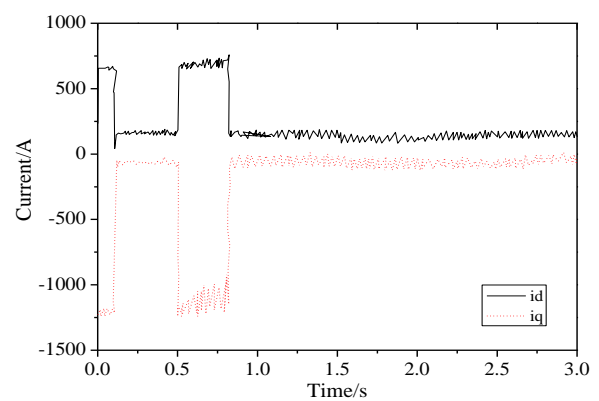


Figure 1: Motor speed response with constant motor parameters.

Figure 2 shows the change curve of current response time of d-q axis when inductance and resistance change under different control methods. Figure. 3 shows the torque response curves when inductance and resistance change under different control methods. When the inductance and resistance change, the model-free sliding mode control method proposed in this research has a smaller ripple on the motor torque and d-q axis current than the PI control method, which also indicates that the control is more stable.



(a) IPMSM control



(b)PI control

Figure 2: The current response curve of d-q axis when inductance and resistance change under different control methods.

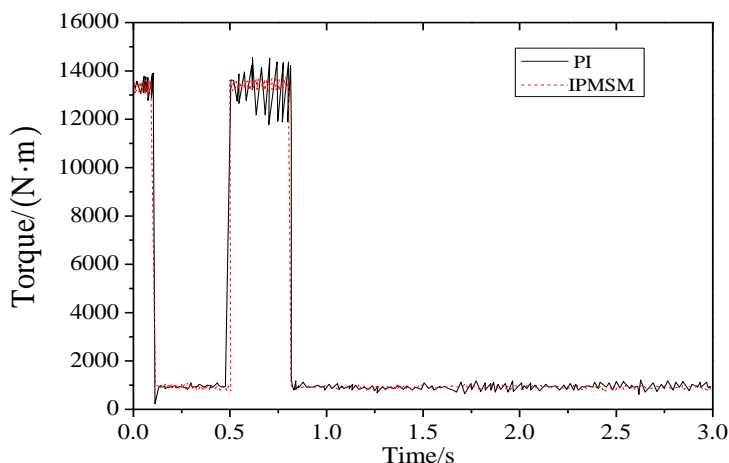


Figure 3: Torque response curves of inductance and resistance under different control methods.

To sum up, when the motor parameters change, the model-free sliding mode control method proposed in this research is better than the PI control method for the stability control of the motor. The model-free sliding mode control method proposed in this research has stronger robustness, better control accuracy, and faster corresponding time.

3.2 Analysis of semi-physical simulation results

In order to further verify the feasibility and effectiveness of the IPMSM method proposed in this research, RT-Lab simulation platform is used for experiments. RT-Lab simulation platform is a powerful real - time semi-physical simulation platform. The simulation platform is composed of P05600 simulator, DSP controller, multi - motor

system model of related connection line and software part, and monitoring surface of upper computer.

In this research, the initial speed of simulation experiment is set to 50rad/s, and speed is increased to 200rad/s within 0.5s. The initial torque value after starting the motor is set to 300Nm, and the torque is abruptly increased to 1000Nm within 2s. The remaining parameters of the motor are nominal values. The experimental results of the semi-physical simulation system are shown in Figure 4 and Figure 5.

Figure 4 shows the torque and speed waveforms under PI control when the motor parameters remain unchanged. Figure 5 shows the torque and speed waveforms under IPMSM control when the motor parameters remain unchanged. It is basically consistent with the simulation results of Matlab.

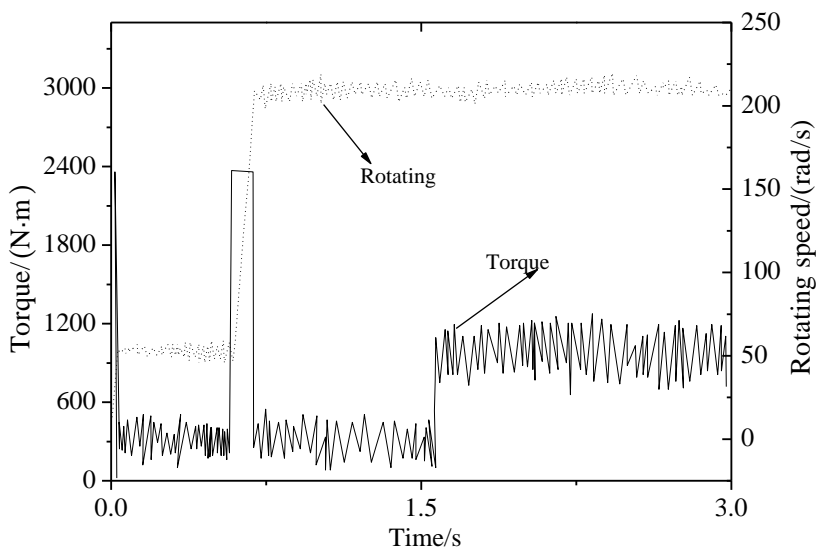


Figure 4: Torque and speed waveforms under PI control when motor parameters remain unchanged.

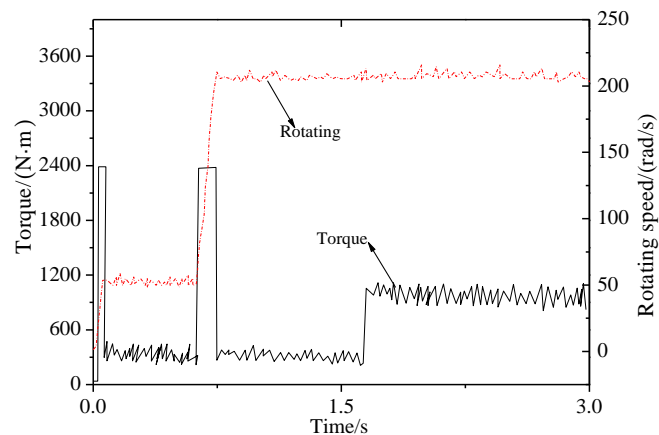


Figure 5: Waveform of torque and speed under IPMSM control when motor parameters remain unchanged.

Figure 6 shows the current experimental waveform of d-q axis under PI control when the motor parameters remain unchanged. Figure 7 shows the current experimental waveform of d-q

axis under IPMSM control when the motor parameters remain unchanged.

It is also basically consistent with the simulation results of Matlab.

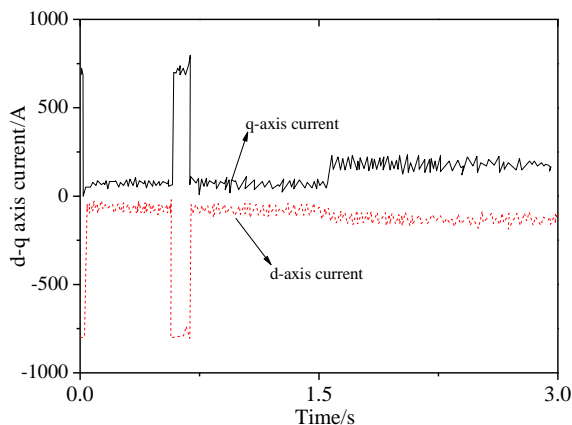


Figure 6: The current experimental waveform of d-q axis under PI control when the motor parameters remain unchanged.

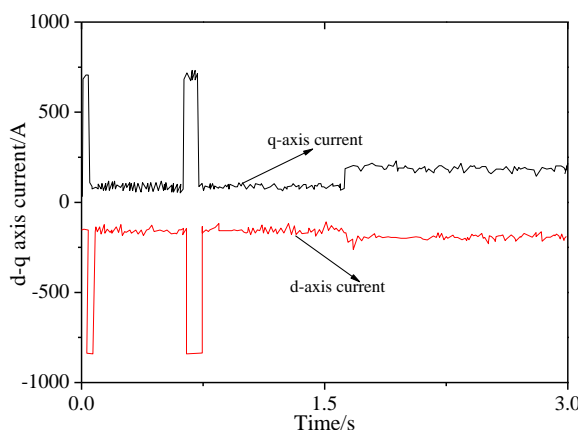


Figure 7: d-q axis current experiment waveform under IPMSM control when motor parameters remain unchanged.

Through the semi-physical simulation experiment, it is concluded that when the motor parameters have whatever changes, compared with the PI control method, the model-free sliding mode control method proposed in this research shows that the waveform pulsation obtained by the

experimental motor is smaller and the running state of the motor is more stable. Therefore, the experimental results are almost consistent with the simulation results. Furthermore, the model-free sliding mode control method proposed in this research is proved to be superior.

4. Conclusions

In order to improve the stability of the permanent magnet synchronous motor and reduce the dependence of the controller on the motor model, the embedded permanent magnet synchronous motor is taken as the research object and a model-free sliding mode control method is proposed. Firstly, the model-free control method is introduced in this research. Then the hyperlocal model of IPMSM speed ring, the new model-free sliding mode control strategy of IPMSM speed ring, and the controller are designed. Finally, the model-free sliding mode control method proposed in this research is simulated and semi-in-kind simulated.

The simulation results show that when the motor parameters change, the control method proposed in this research is better than the PI control method for the stability control of the motor. The model-free sliding mode control method proposed has stronger robustness, better control accuracy, and faster responding time. The semi-in-kind simulation experiment obtains the same results as the simulation experiment, which further verifies that the model-free sliding mode control proposed in this research shows excellent control performance in the motor operation control process.

The research has made a certain contribution to improving the stability of PMSM, but it still has certain limitations.

In this research, only the parameter changes of resistance, flux, and inductance are considered in the simulation experiment and the semi-physical simulation experiment. The influence of some unknown disturbance parameters on the control performance should be added in the subsequent research to expand the research depth.

References

- [1] Precup R E, Radac M B, Roman R C, et al. Model-free sliding mode control of nonlinear systems: Algorithms and experiments. *Information Sciences*, 2017, 381, pp. 176-192.
- [2] Wang H, Li S, Lan Q, et al. Continuous terminal sliding mode control with extended state observer for PMSM speed regulation system. *Transactions of the Institute of Measurement and Control*, 2017, 39(8), pp. 1195-1204.
- [3] Ahmed S, Wang H, Tian Y. Model-free control using time delay estimation and fractional-order nonsingular fast terminal sliding mode for uncertain lower-limb exoskeleton. *Journal of Vibration and Control*, 2018, 24(22), pp. 5273-5290.
- [4] Monaem Elmnifi, Moneer Alshilmany, Moftah Abd-raba (2019). Potential of Municipal Solid Waste in Libya For Energy Utilization. *Acta Mechanica Malaysia*, 2(1): 11-15.
- [5] Khorashadizadeh S, Sadeghijaleh M. Adaptive fuzzy tracking control of robot manipulators actuated by permanent magnet synchronous motors. *Computers & Electrical Engineering*, 2018, 72, pp. 100-111.
- [6] Zhang C, Wu G, Rong F, et al. Robust fault-tolerant predictive current control for permanent magnet synchronous motors considering demagnetization fault. *IEEE Transactions on Industrial Electronics*, 2017, 65(7), pp. 5324-5334.
- [7] S.K. Gugulothu, N. Prabhu Kishore, V. Phani Babu, Girish Sapre (2019). Computational Investigation of Mhd Free Convection on A Flat Vertical Plate Embedded with Micro Polar Fluid. *Acta Mechanica Malaysia*, 2(1): 16-22.
- [8] Su D, Zhang C, Dong Y. An improved continuous-time model predictive control of permanent magnetic synchronous motors for a wide-speed range. *Energies*, 2017, 10(12), pp. 2051.
- [9] Shahajada Mahmudul Hasan, Shahed Hasan Khan Tushar, Md. Hafizur Rahman, Anisur Rahman Shimu (2019). An Optimized Design of Electromagnet and Float for A Magnetic Suspension System. *Acta Electronica Malaysia*, 3(1): 14-18.
- [10] Zhang X, Zhang L, Zhang Y. Model predictive current control for PMSM drives with parameter robustness improvement. *IEEE Transactions on Power Electronics*, 2018, 34(2), pp. 1645-1657.
- [11] Yin X, Jiang Z, Pan L. Recurrent neural network based adaptive integral sliding mode power maximization control for wind power systems. *Renewable Energy*, 2020, 145, pp. 1149-1157.
- [12] Om Prakash Singh, Gaurav Kumar, Mukesh Kumar (2019). Role of Taguchi And Grey Relational Method in Optimization of Machining Parameters of Different Materials: A Review. *Acta Electronica Malaysia*, 3(1): 19-22.
- [13] Wang Y, Yan F, Chen J, et al. Continuous nonsingular fast terminal sliding mode control of cable-driven manipulators with super-twisting algorithm. *IEEE Access*, 2018, 6, pp. 49626-49636.
- [14] Liu C, Luo Y. Overview of advanced control strategies for electric machines. *Chinese Journal of Electrical Engineering*, 2017, 3(2), pp. 53-61.
- [15] Nigar Ali, Saeed Ahmad, Sartaj Aziz, Gul Zaman (2019). The Adomian Decomposition Method For Solving Hiv Infection Model Of Latently Infected Cells. *Matrix Science Mathematic*, 3(1): 05-08.
- [16] Trancho E, Ibarra E, Arias A, et al. PM-assisted synchronous reluctance machine flux weakening control for EV and HEV applications. *IEEE Transactions on Industrial Electronics*, 2017, 65(4), pp. 2986-2995.