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RESEARCH OF SPEED SLIDING MODE OBSERVER FOR PERMANENT MAGNET SYNCHRONOUS MOTOR FOR ELECTRIC VEHICLE

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Abstract:-
Permanent magnet synchronous motor is the most drive motor of electric cars, to solve the problem of permanent magnet synchronous motor without position sensor speed control system has speed detection delay, error detection, slow dynamic response etc. The speed of sliding mode observer for permanent magnet synchronous motor used in electric vehicles, analyzes the structure and principle of sliding mode observer, combined with the mathematical model of PMSM, the design of electric vehicle speed sliding mode observer for permanent magnet synchronous motor. The simulation speed of sliding mode observer designed by MATLAB, the simulation results show that the speed of sliding mode observer for permanent magnet synchronous motor in electric vehicle design has the advantages of fast detection speed, small detection error, fast dynamic response etc.:

Keywords:- *PMSM;Speed Sliding Mode Observer; Electric Vehicl*

INTRODUCTION

Motor drive system as a source of electric cars, the level of its performance directly determines the quality of electric cars pros and cons. Nowadays, the vast majority of electric cars are driven by permanent magnet synchronous motor, and the focus of control permanent magnet synchronous motor is the way to get the speed and angle information quickly and accurately. At present, the speed observation of permanent magnet synchronous motor has been studied deeply at home and abroad.

By combining the reduced-order observer and the multi-sampling theory, the literature [1] presents a method that can effectively estimate the rotation speed and rotation angle from the low-resolution Hall position signal. However, because it is still subject to the Hall sensor, so this method can only be satisfied with the low-end servo applications. Literature [2] proposed an improved voltage model rotor flux observer, which improved the dynamic and static performance of speed identification, and especially improved the speed identification performance at low speed. In order to solve the problem of large computational complexity of sigma points, literature [3] proposed a new non-linear filter using the single-line hypersphere sampling method and designed a H_∞ robust spherical unscented Kalman filter observer to calculate the rotation speed of permanent magnet synchronous motor Perform state observations. Literature [4] designed the speed observer based on fuzzy PI regulator and the simulations were performed on a speed observer based on a conventional PI regulator which results show that this method is more robust to disturbance. In literature [5], Lyapunov stability criterion is taken as the basis of design. With using variable structure control method to counteract the unknown part a rotational speed observer and a rotor resistance recognizer are designed. Literature [6] proposed a speed-and-flux observer scheme for asynchronous motor without speed control which improved the design theory of sliding mode observer based on complex sliding-mode surface. The simulation and experimental results verify that the effectiveness of the observer and system performance. Literature [7] proposed a new sliding mode speed observer based on the position signal as the sliding mode variable and the high order sliding mode variable structure algorithm the results show that this method improves the speed detection accuracy and improves the system Steady-state and dynamic performance.

In this paper, the mathematical model of permanent magnet synchronous motor is given firstly. Then the structure and principle of the sliding mode observer are analyzed. According to the mathematical model of the permanent magnet synchronous motor under the α-β coordinate system, the speed sliding mode observer is designed. The simulation results show the speed sliding mode observer of permanent magnet synchronous motor for designed electric vehicle reduces the lag time of observation speed and improves the observation precision.

Permanent Magnet Synchronous Motor Mathematical Model

According to the principle of permanent magnet synchronous motor (PMSM), the analysis model of PMSM as shown in figure 1 can be obtained. Where d - q axis is the actual rotor position, □ is the actual rotor position angle.

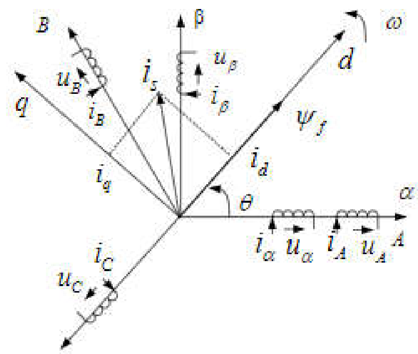

Fig. 1 Analytical model of PMSM

The dynamic model of permanent magnet synchronous motor in the □-□ reference axis coordinate system can be expressed as follows:

$$i_\alpha = -\frac{R}{L} i_\alpha + \frac{\psi_f}{L}\omega \sin\theta + \frac{u_\alpha}{L} \qquad (1)$$

$$i_\beta = -\frac{R}{L} i_\beta + \frac{\psi_f}{L}\omega \sin\theta + \frac{u_\beta}{L} \qquad (2)$$

$$\dot{\theta} = \omega \qquad (3)$$

$$\dot{\omega} = -\frac{B}{J}\omega + \frac{P_n^2 \psi_f}{L} i_\beta \cos\theta - \frac{P_n^2 \psi_f}{L} i_\alpha \sin\theta - \frac{P_n}{J} T_L \tag{4}$$

Where u_α and u_β are the α and β axis stator voltages, respectively;αI and βiare αand βaxis stator currents, respectively; L is the stator winding inductance; R is the stator resistance; ψ_f is the permanent magnet flux; P_n is the number of pole pairs; T_L is the load torque; J is the moment of inertia; B is the damping coefficient; ω is the rotor speed speed. $\dot{i}_\alpha$ 、$\dot{i}_\beta$ 、$\dot{\theta}$ and $\dot{\omega}$ are the differential of i_α 、i_β 、θ and ω

2 Design of Speed Sliding Mode Observer

2.1 The principle of sliding mode observer

The general second-order system can be expressed by the following state equation:

$$\begin{cases} \dot{x}_1 = x_2 \\ \dot{x}_2 = f(t, x_1, x_2, u) + \xi(t, x_1, x_2, u) \end{cases} \tag{5}$$

Where is $\xi(t, x_1, x_2, u)$ the Uncertainties and disruptions of this system and the constructor is constructed as follows

$$\begin{cases} \dot{\hat{x}}_1 = \hat{x}_2 + z_1 \\ \dot{\hat{x}}_2 = f(t, x_1, \hat{x}_2, u) + z_2 \end{cases} \tag{6}$$

Where $\hat{x}_1$ and $\hat{x}_2$ are the estimated states, z_1 and z_2 are corrections and its expression is

$$\begin{cases} z_1 = \lambda |x_1 - \hat{x}_1|^{1/2} sign(x_1 - \hat{x}_1) \\ z_2 = a \cdot sign(x_1 - \hat{x}_1) \end{cases} \tag{7}$$

Suppose the initial value of the observer is $\hat{x}_2 = 0, \hat{x}_1 = x_1$ and define $e_1 = x_1 - \hat{x}_1, e_2 = x_2 - \hat{x}_2$ to get the estimation error equation.

$$\begin{cases} \dot{e}_1 = e_2 - \lambda |e_1|^{1/2} sign(e_1) \\ \dot{e}_2 = F(t, x_1, x_2, \hat{x}_2) - a \cdot sign(e_1) \end{cases} \tag{8}$$

Where

$$F(t, x_1, x_2, \hat{x}_2) = f(t, x_1, x_2, u) - f(t, x_1, \hat{x}_2, u) + \xi(t, x_1, x_2, u),$$

Assuming that the system is stable, that means, input $u = U(t, x_1, x_2)$ is bounded, so the system is bounded. And there is a constant η can make

$$|F(t, x_1, x_2, \hat{x}_2)| < \eta \tag{9}$$

For any t, x_1, x_2 and $|\hat{x}_2| \le 2\sup|x_2|$ are true.

Let a and λ satisfy the inequality:

$$\begin{cases} a > \eta \\ \lambda > \sqrt{\frac{2}{a-\eta}} \frac{(a+\eta)(1+p)}{(1-p)}, 0 < p < 1 \end{cases} \tag{10}$$

Assuming that the parameters in the observer select αandλaccording to the above rules, the observer state can converge to the system state within a limited time, that is, the parameters chosen in $(\hat{x}_1, \hat{x}_2) \to (x_1, x_2)$ are mainly α and λ. These two parameters are usually defined by the following two equations: $\alpha = \alpha_1 \eta, \lambda = \alpha_2 \eta^{1/2}$, , Where a_1=1.1 and a_2=1.5 are the number that has been determined.

2.2 Speed Sliding Mode Observer

The state observer shown below is constructed according to Equation 1 and Equation 2

$$\begin{cases} \dot{x}_1 = -\frac{R}{L}\hat{x}_1 + \frac{1}{L}u_\alpha + \frac{\lambda_f}{L}x_3\omega \\ \dot{x}_2 = -\frac{R}{L}\hat{x}_2 + \frac{1}{L}u_\beta + \frac{\lambda_f}{L}x_4\omega \\ \dot{x}_3 = x_4\omega \\ \dot{x}_4 = -x_3\omega \end{cases} \quad (11)$$

Where: State variables x_1 and x_2 are measurable. According to Eq.11, the following sliding mode observer can be constructed:

$$\begin{cases} \dot{\hat{x}}_1 = -\frac{R}{L}\hat{x}_1 + \frac{1}{L}u_\alpha + \frac{\lambda_f}{L}u_1 \\ \dot{\hat{x}}_2 = -\frac{R}{L}\hat{x}_2 + \frac{1}{L}u_\beta + \frac{\lambda_f}{L}u_2 \\ \dot{\hat{x}}_3 = -u_2 \\ \dot{\hat{x}}_4 = -u_1 \end{cases} \quad (12)$$

According to the principle of the sliding mode algorithm, the sliding mode functions u_1 and u_2 can be tabulated as follows :

$$\begin{cases} u_1 = -U_1\left[\beta_1 sign(\sigma_1) + sign(\dot{\sigma}_1)\right] \\ u_2 = -U_2\left[\beta_1 sign(\sigma_2) + sign(\dot{\sigma}_2)\right] \\ \sigma_1 = \hat{x}_1 - x_1 \\ \sigma_2 = \hat{x}_2 - x_2 \end{cases} \quad (13)$$

Where: $U_1, U_2, \beta_1, \beta_2$ are sliding mode function gain.

Based on Eqs.12 and Eqs.13, an estimate of the rotation can be calculated:

$$\hat{\omega} = \sqrt{(u_1)^2 + (u_2)^2} \quad (14)$$

Under the condition of the sliding mode algorithms u_1 and u_2 Eq.13, where the sliding mode gain satisfies the following conditions, can ensure sliding mode function reaches $\sigma_1 = \dot{\sigma}_1 = 0$ and $\sigma_2 = \dot{\sigma}_2 = 0$

$$\begin{cases} U > \frac{E}{K_m} \\ \beta \geq \frac{2E + K_m U}{K_m U} > 1 \end{cases} \quad (15)$$

Where: E, K_M, K_m ,,are all suitable positive constant.

For the PMSM speed control system, according to Eqs.11 and Eqs.12, and under the conditions of 111ˆii−=σand 222ˆii−=σ, can get: $\sigma_1 = \hat{i}_1 - i_1$ and $\sigma_2 = \hat{i}_2 - i_2$, can get:

$$\begin{cases} \ddot{\sigma}_1 = -\frac{R}{L^2}u_\alpha + \frac{\lambda_f}{L}(\omega\cos\theta + \dot{\omega}\sin\theta) \\ \ddot{\sigma}_2 = -\frac{R}{L^2}u_\beta + \frac{\lambda_f}{L}(-\omega\sin\theta + \dot{\omega}\cos\theta) \end{cases} \quad (16)$$

Where: $u_\alpha, u_\beta, \omega, \theta$,,, the parameters of these permanent magnet synchronous motors are bounded. So there must be positive constants E, K_M, K_m ,,to satisfy the convergence condition of the sliding mode function.

$$\begin{cases} 0 < K_m \leq \ddot{\sigma}_{1,2} \leq K_M \\ \left|\dot{\ddot{\sigma}}_{1,2}\right| \leq E, E > 0 \end{cases} \quad (17)$$

So the sliding mode function of the hanger shown in Eq.13 can converge to the sliding surface and the observer is stable.

Controller structure diagram shown in Figure 2.

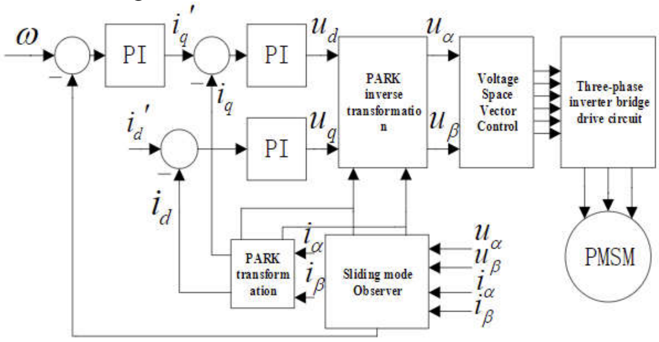

Fig. 2 Schematic diagram of controller structure

3 Simulation Results

In order to verify the validity of the speed sliding mode observer proposed in this paper, a simulation study is carried out on MATLAB. The parameters of the motor in the simulation are shown in Table 1.

Tab.1 Parameters of permanent magnet synchronous motor

Parameter	Value
Power rating/kW	1.5
Rated voltage/V	310
Rated current/A	6.4
Rated torque /N.m	7.2
Rated speed /(r/min)	1500
Stator resistance /Ω	1.2
$d-q$ axis inductance /mH	5.22
Number of pole pairs /Piece	4
Rotor permanent magnet flux Linkage ψ_f /Wb	0.162

Select the permanent magnet synchronous motor in the simulation set the speed of n_{ref}□$1000r$ / min Simulation time is set to 0.1s, No-load start, the simulation results are shown below.

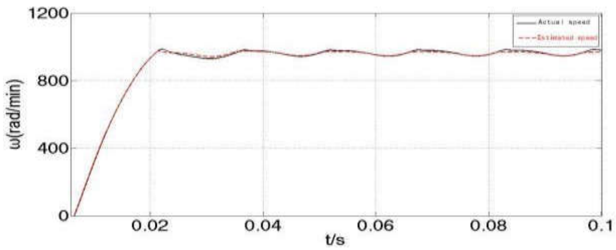

Fig.3 Actual speed and observation speed during starting

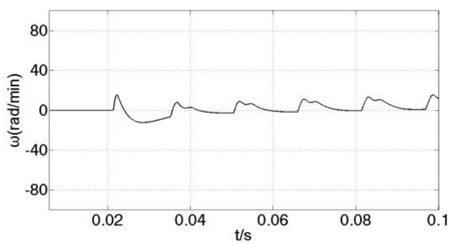

Fig.4 Observation speed error at starting

Figure 3 shows the actual motor speed at startup and the speed observed by the sliding mode observer in the simulation. Figure 4 shows the error between the actual speed and the observed speed. It can be seen from Figures 3 and 4 that the Sliding mode observer observation effect is very good, speed observation error of about 2%.
Select the permanent magnet synchronous motor in the simulation set the initial speed, n_{ref} □500r / min,When the simulation time is 0.05s, the set speed is changed to 1000r /min , and the simulation result is as follows.

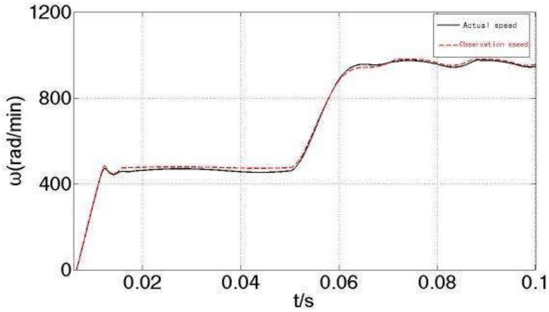

Fig.5 The speed jump at the actual speed and speed observation

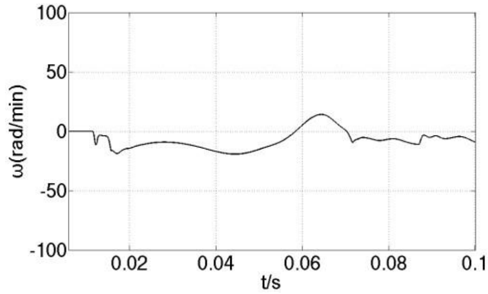

Fig.6 Observation speed error during speed jump

Figure 5 shows the actual speed and observed speed when the speed jumps in the simulation.
Figure 6 is the actual speed and observation of the error rate, as can be seen from Figure 5 and Figure 6 that the effect of the sliding mode observer is very good, the absolute value of the maximum error does not exceed 20rad /min and the observation lag time is very short, the observation accuracy is high.

4 Conclusion

In this paper, the sliding mode algorithm is applied to the speed control of PMSM system for electric vehicle. According to the mathematical model of the motor in □-□coordinate system, a sliding mode sliding mode observer for PMSM for electric vehicle is proposed and designed. Observed speed value is calculated from the rotor position through the sliding mode, the article rigorous proof of the stability of the observer. And the final simulation results also show that the observer can improve the accuracy and timeliness of speed detection, so as to improve the control performance of the motor.

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