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WITNESS BASED FRACTIONAL SECOND ORDER TERMINAL MULTISEGMENT SLIDING MODE CONTROL OF SRM POSITION DIRECTIVE SYSTEM

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ABSTRACT:

This paper shows the position regulation system problem of Synchronous Reluctance Motor(SRM) subject to parameter uncertainties and external disturbances. A novel fractional second-order nonsingular terminal Multisegment sliding mode control (F2NTMSMC) is proposed and the finite-time stability of the closed-loop system is ensured. For the estimation and feedforward compensation for the lumped disturbances of SRM, a multisegment sliding mode disturbance observer is developed (MSMDO). The combined control scheme of F2NTMSMC and MSMDO can not only improve the performance of the system but also reduce the chattering problem quickly. Developed simulation Results show that the proposed control method is strongly robust and also attain satisfactory position tracking performance as well as deal with the various uncertainty of the system.

Keywords: Synchronous Reluctance Motor (SRM), Fractional second-order nonsingular terminal Multisegment sliding mode control (F2NTMSMC), Multisegment sliding mode disturbance observer is developed (MSMDO)

1. INTRODUCTION

The Synchronous Reluctance Motor (SRM), though not widely used, maybe an interesting alternative in comparisons with other AC motors, indeed, it retains some of the features of the Permanent Magnet Synchronous Motor (PMSM), but is cheaper thanks to its magnet less design. As the magnetic (cross-)saturation effects are important, it is necessary to model them correctly, in particular for sensorless operation at low velocity. The rotor construction is more robust than either induction motors or PMSMs. On the other side, the absence of rotor cage means that SynRMs operate at lower temperatures than induction motors, increasing their lifetime since the cool running of the rotor also means lower bearing temperatures, which in

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turn increase the reliability of the bearing system The SynRM load torque is imposed by a Magtrol HD-815 hysteresis dynamometer and it is precisely adjusted using a Magtrol DSP6001high s peed programmable controller. This device also provides the speed and torque signals to the power analyzer, which allows calculating the motor mechanical power (Figure 1). To achieve high-performance control, various advanced control methods have been proposed, such as adaptive control, robust control [4], multisegment sliding mode control etc.

Fig 1 Schematic Representation of Experimental set up

In Feng et al. [1] and Yu et al. [2], the non-singular terminal sliding mode controllers (NTSMC) were developed to achieve finite-time tracking control of systems and overcome the singularity problem. Moreover Yan et al. [3] combined NTSMC with second-order SMC to design the second-order NTSMC (2NTSMC) for the finite-time convergence of system states. The 2NTSMC possesses fast convergence and high control precision; besides, it can eliminate chattering behavior of control signals. In order to show the best performance of the control system robustness, the observer-based control method is often adopted, such as [4]. Fractional order calculus extends integer order to nonintegral order and provides an excellent tool for describing complex dynamic features. Recently, some researchers have proposed some fractional-order SMC methodologies. Dadras and Momeni [5] introduced fractional-order TSMC (FTSMC) to integer-order nonlinear systems. However, the chattering problem of control inputs still exists. Aghababa [6] designed a chatter-free terminal sliding mode controller for nonlinear fractional-order dynamical systems. Therefore, designing an FTMSMC whose order number is greater than 1 for nonlinear dynamic systems is still an open problem. To improve robustness during the reaching phase of SMC and reduce the conservativeness of selecting switching control gains, a multisegment sliding mode disturbance observer (MSMDO) is employed to provide feed-forward compensation for parameter uncertainties and external disturbances. Consequently, the closed-loop system can achieve global robustness and improve disturbance rejection performance. In this paper, a new fractional second-order non-singular terminal sliding mode controller (F2NTMSMC) is proposed to ensure fast and finite-time convergence of the SRM system.

2. MODELLING OF SYNCHRONOUS RELUCTANCE MOTOR

By considering a typical vector control scheme as shown in Fig 2. The parameters considered for the modelling of synchronous reluctance motor tabulated in Table 1.

Table 1 Fixed parameter simulation

Variable	Value
σ_d	0,056
σ_q	0,2
R_s	7,8 Ω
L_d	0,4 H
L_q	0,08 H
T_D	0,1 s
T_Q	0,046 s
p	2
J	0,038
B	0,0029
T_c	0 N.m

The control objective is to design a F2NTMSMC with MSMDO to track the reference trajectory Ɵd in finite time. In the next section, the design of F2NTMSMC and MSMDO will be conducted.
The rotor dynamics and the MTC torque equation of the SRM given are rewritten as follows:

$$\frac{d\theta_m}{dt} = \omega_m$$
$$\frac{d\omega_m}{dt} = -\frac{B_m}{J_m}\omega_m + \frac{T_e}{J_m} - \frac{T_L}{J_m}$$
$$T_e = K_1 i_s^2 \sin(2\,\delta). \qquad (1)$$

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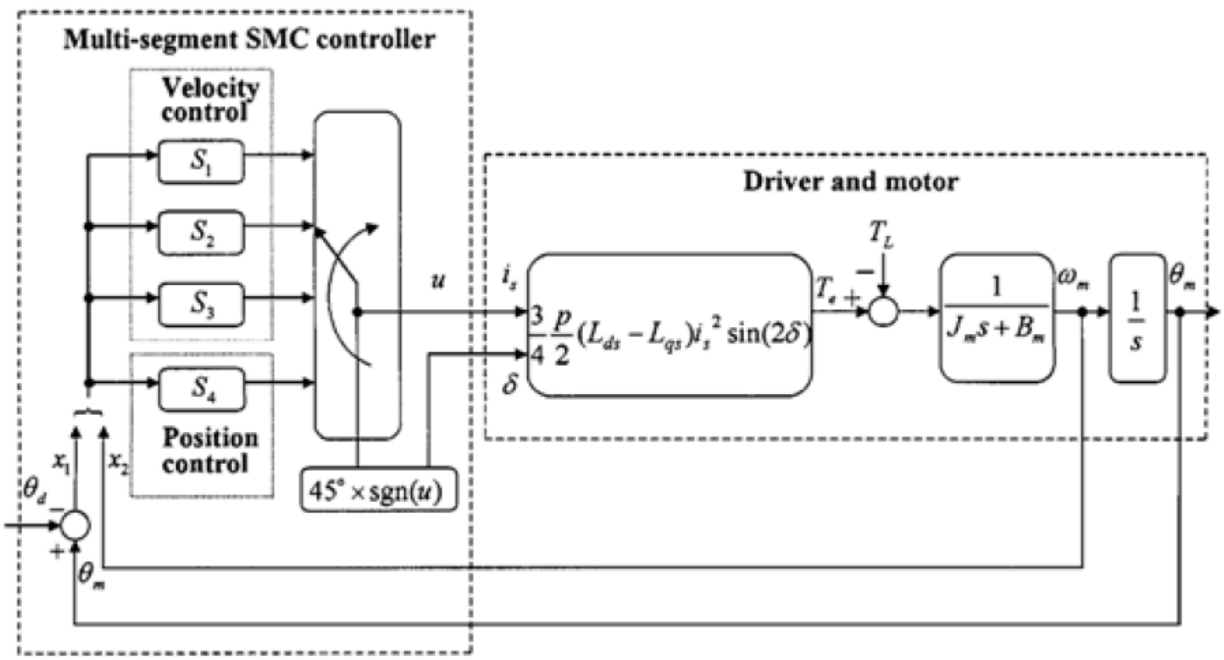

Fig 3 closed loop model of SRM

The incremental motion is to move an object at rest at a time to a fixed desired position at the time , and then stop it. The control process is subjected to the desired velocity and acceleration. So the incremental motion control is performed under velocity control in obedience to the desired velocity profile, whereas stopping is done by position control mode. One first has to select a velocity profile that rapidly changes the load position in a discrete step. The velocity profile (i.e., the motor and load angular velocity as a function of time) should satisfy the motion constraints of the system.

2.1 LAW OF FRACTIONAL ORDER CALCULUS

Definition 1 The Caputo fractional derivative of the order of a continuous function is defined as follows:

$$D^{\alpha}_{*a} f(t) = J^{n-\alpha}_{a} D^{n} f(t) = \frac{1}{\Gamma(n-\alpha)} \int_a^t \frac{f^{(n)}(\tau)}{(t-\tau)^{\alpha-n+1}} d\tau,$$

$$a \le t \le b, \quad n = \lceil \alpha \rceil . \qquad (2)$$

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Definition 2. The αth-order fractional integration of function f(t) the terminal value α are given by,

$$D_{t_0}^{-\alpha}\left(D_{t_0}^{\beta} f(t)\right) = D_{t_0}^{\beta-\alpha} f(t) - \sum_{j=1}^{m}\left[D_{t_0}^{\beta-j} f(t)\right]_{|t=t_0} \frac{(t-t_0)^{\alpha-j}}{\Gamma(1+\alpha-j)},$$
$$m-1 \le \beta \le m. \quad (3)$$

Definition 3. The Gr¨unwald-Letnikov fractional derivative of order of a continuous function is defined as follows:

$$^{\mathrm{GL}}D_a^{\alpha} f(x) = \lim_{\substack{h\to\infty \\ mh=x-a}} \frac{1}{h^{\alpha}} \sum_{k=0}^{m} (-1)^k \binom{\alpha}{k} f(x-kh), \quad \alpha > 0. \quad (4)$$

3. FRACTIONAL ORDER DESIGN OF MSMC OF SRM

3.1. Fractional second-order non-singular Terminal Multisegment Sliding Mode Control

The fractional-order nonsingular fast terminal multisegment sliding mode controller is an attempt to achieve equivalence between fast convergence and nonsingularity. Then develop the F2NTMSMC to achieve chattering-free and robust tracking of the position. And then, a multisegment sliding mode disturbance observer is designed to estimate and compensate uncertainties and disturbances, which can increase the robustness of the control system and improve control performance. Thus, a control scheme with F2NTMSMC and MSMDO is presented. The multisegment sliding mode surfaces are shown in equation

$$s_1(t) = D^{r_1}x + a_1 x + a_2 \mathrm{sig}^{\lambda_1}(x),$$

$$s_2(t) = D^{r_2}x + a_3 x + a_4 \mathrm{sig}^{\lambda_2}(\dot{x}),$$

$$s_3(t) = D^{r_3}x + a_5 \mathrm{sig}^{\lambda_3}(x) + a_6 \mathrm{sig}^{\lambda_4}(x),$$

$$s_4(t) = D^{r_4}x + a_7 \mathrm{sig}^{\lambda_5}(x) + a_8 \mathrm{sig}^{\lambda_6}(\dot{x}),$$

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(5)

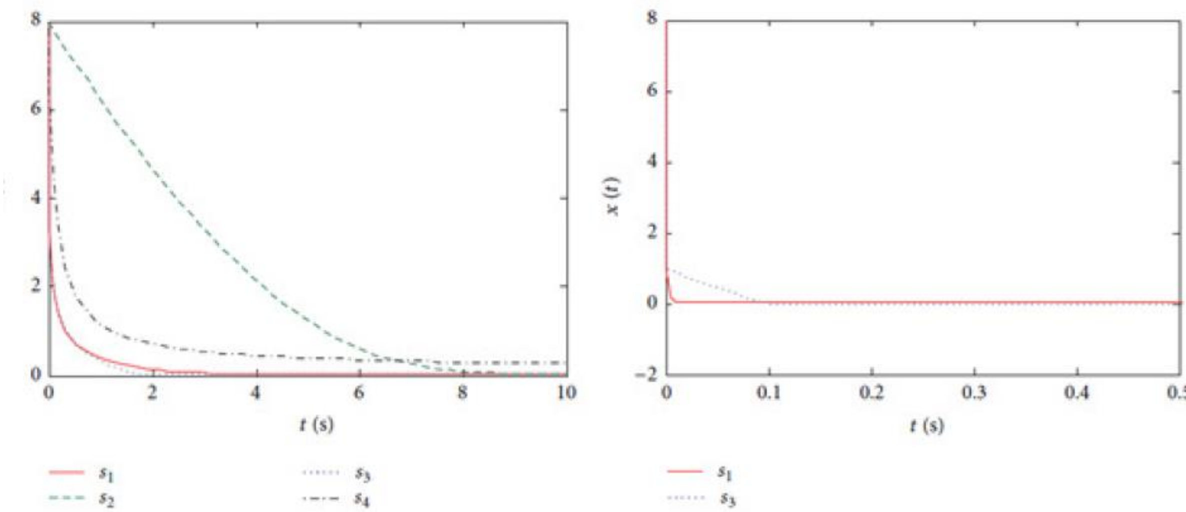

Fig 4 Convergence conditions of $s1,\ldots,4$

It can be seen from Figure 2 that $s1(t)$ and $s3(t)$ have faster convergence rate than $s2(t)$ and $s4(t)$. For the more detailed comparison between $s1(t)$ and $s3(t)$, The parameters of $s1(t)$ and $s3(t)$ are tuned with the optimal integrated time absolute error (ITAE) criterion by minimizing the following formula:

$$J_{\text{ITAE}} = \int_{t_0}^{\infty} t\,|x(t)|\,dt. \tag{6}$$

A nonsingular fast terminal sliding surface is selected to ensure s(t) reach zero in finite time and realize second-order sliding mode control:

$$\sigma = s + \alpha s^{g/h} + \beta \dot{s}^{p/q}, \tag{7}$$

The following continuous terminal sliding mode reaching law [29] is introduced to guarantee system states converge to sliding surfaces in finite time and increase system robustness:

$$\dot{\sigma} = \left(-\phi\sigma - \gamma\sigma^{m/n}\right)\dot{s}^{p/q-1}, \tag{8}$$

The equation of time shown as follows.

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$$t_{s_1} = t_{r_1} + 2\tau_1^{-q/p} \frac{p}{p-q} V(0)^{(p-q)/2p} \times F\left(A, B, C, -\frac{\tau_2}{\tau_1} V(0)^{(g-h)/2h}\right), \quad (9)$$

Thus, the second-order multisegment sliding mode control is achieved. s and $\dot{s}$ are driven to reach $\sigma = 0$ in finite time and then remain on $\sigma = 0$ to realize the sliding mode motion. Both s and $\dot{s}$ reach zero in finite time $t\ s1$. After s reaches zero, the system will stay on the sliding mode motion and the tracking error e will converge to zero in finite time $t\ s0$ which is calculated.

4. VALIDATION OF RESULTS

Eventually, the fractional-order terminal sliding mode controller with SMDO is designed as shown in the below fig. t

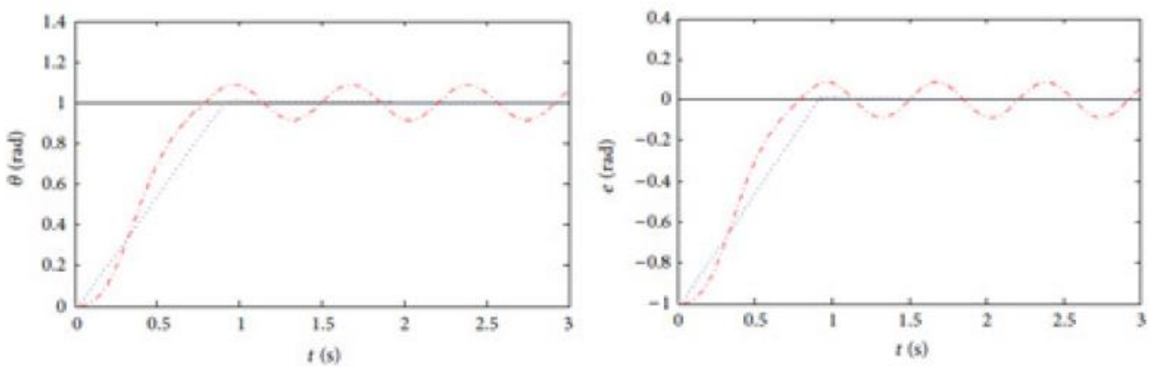

Fig 5 Position tracking performance and errors

5. CONCLUSION

In this paper, a switching control law is determined to drive system states to the designed sliding surface and subsequently constrain system states to the surface hereafter. Meanwhile, the finite-time stability is proved by using fractional Lyapunov theory. Moreover, an MSMDO is applied such that uncertainties and disturbance can be estimated and compensated. Eventually,

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simulation results verify good robustness and fast convergence of the proposed fractional control approach.

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