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APPLICATION OF ADAPTIVE FUZZY SLIDING MODE CONTROL TO ALTERNATING CURRENT SERVOMOTOR SYSTEM

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ABSTRACT

In the use of servo motor control system, some characteristics of motor, such as non-sinusoidal flux of motor mover caused by end effect, nonlinear friction, will make the effects of the servo system bad. So we must use some control strategies with high robustness to suppress these disturbance. In this paper, a design method of fuzzy sliding mode control system with adaptive integral sliding mode surface, and applied to the position control of servo motor system. Adaptive fuzzy sliding mode control system consists of fuzzy control and switching control, using fuzzy controller to simulate feedback linearization control rate, output error using the switching control to compensate the sliding mode controller. Control algorithm is derived from the Lyapunov stability theory, which can guarantee the stability of the system. Simulation results show that, the system performance is the satisfaction, and it's robust with regard to the parameter variations and external load disturbance.

KEYWORDS

Adaptive control, fuzzy control, sliding mode control, servo motor.

1. INTRODUCTION

According to a study, AC servo system with its superior performance, are widely used in various industries. In order to improve the performance of AC servo control system adopts a variety of excellent control strategy [1]. At the end of twentieth Century, the researchers put forward the concept of fuzzy sliding mode controller [2,3]. The main advantage of the fuzzy sliding mode control system is the number of fuzzy rules than the feedback linearization control system much less. In order to guarantee the performance of the system, many researchers are devoted to the control of sliding mode variable structure control is applied to the servo motor system [4].

Sliding mode variable structure control can improve the system to speed of response, realize the positioning of no overshoot, improving robustness against load disturbances and robustness of parameter changes. A researcher proposed sliding mode control algorithm for disturbance compensation, real-time tracking of load thrust change, improve the system robustness to disturbances [5]. A researcher designed neural network adaptive sliding mode controller for AC servo system, automatic adjustment of the sliding mode controller using RBF network to gain switching [6]. Based on a study, using genetic algorithms to optimize the membership function of the fuzzy variable curve, which makes the system reacts faster, reduce chattering, which make the system more stable [7].].

In this paper, combined with the current advanced intelligent control algorithm, using the integral sliding surface design function switching, and adopts the adaptive law and fuzzy approximation theory to design an adaptive fuzzy sliding mode control system, this system can automatically adjust the fuzzy control with the adaptive fuzzy rules, and can significantly reduce the number of fuzzy rules [8-10]. The system design of dynamic adjustment of the position controller, realized to reduce the chattering and decreases the steady-state error of the balance between, weakens the influence of the system parameter variations and external disturbances on control performance [11]. The system is proved through simulation, the effectiveness of the designed system and the control of motor in high precision under high speed movement.

2. MATHEMATICAL MODEL OF SERVO MOTOR

The object of this research is the permanent magnet synchronous motor AC servo system. The permanent magnet is installed on the rotor of permanent magnet synchronous motor through access, alternating current in the stator windings, so as to produce a rotating magnetic field and rotation, the rotation of the rotor speed and stator windings have the same speed rotating magnetic field [12-14].

In order to facilitate the analysis of the problem, the following hypothesis:.

(1) Ignore the magnetic saturation and iron loss, the winding inductance and mutual inductance are linear;

(2) The conductivity of the permanent magnet is zero;

(3) The stator winding zero damping;

(4) The three-phase symmetrical windings magnetic potential along the air gap circumferentially according to sine distribution;

Based on the above assumptions, we can obtain the mathematical model of permanent magnet synchronous motor in two-phase stationary coordinate system under d-q:

The d axis voltage balance equation:

$$L_d \frac{di_d}{dt} + Ri_d = u_d + L_q v i_q \tag{1}$$

The q axis voltage balance equation:

$$L_q \frac{di_q}{dt} + Ri_q = u_q - v\varphi - L_d v i_d \tag{2}$$

Electromagnetic torque:

$$T_e = \frac{3\pi}{2\mu}[i_q\varphi + (L_d - L_q)i_d i_q] \tag{3}$$

The mechanical motion equation:

$$T_e = T_L + B\omega_r + Jp\dot{\omega}_r \tag{4}$$

In order to make the permanent magnet synchronous motor control performance is like DC motor, usually adopts the method of vector control technology in the id=0 to realize the linearization and decoupling control, it can be the mathematical model of permanent magnet synchronous motor into a DC motor model, which can be modeled on the operation control method of DC motor. So the electromagnetic torque Te is expressed as:

$$T_e = \frac{3\pi}{2\mu} i_q \varphi = T_L + B\omega_r + Jp\dot{\omega}_r \qquad (5)$$

Where: i_d is the stator d axis current; i_q is the stator q axis current; u_d is the stator d axis voltage; u_q is the stator q axis voltage; L_d for the stator d axis inductance; L_q is the stator q axis inductance; R is the stator resistance; M is the stator quality; B is a viscous friction coefficient; v is motor stator electric machine speed; φ is permanent magnet flux; T_e is electromagnetic torque; T_L is load torque; ω_r is the rotor angular velocity; p is pole pairs.

3. DESIGN AND ANALYSIS OF ADAPTIVE FUZZY SLIDING MODE CONTROLLER

Sliding mode variable structure control is a typical robust control. The sliding mode can be designed and has nothing to do with the object parameters and disturbance, so its design is simple and robust. Fuzzy control of error mapping range can reach a specific, small, can weaken the jitter of sliding mode control. Adaptive control can automatically outside upper bound total uncertainty is evaluated, ensures the sliding mode control system can satisfy the Lyapunov stability condition, so as to ensure that the system can achieve the uniform stability. Adaptive fuzzy sliding mode variable structure control method is a kind of new control algorithm integrated the above three kinds of the advanced algorithm, it has better robustness [15,16].

3.1 Integral Sliding Mode Control Based on Sliding Model Surface

Following the single input single output nonlinear systems:

$$\theta(t) = f(\theta,t) + g(\theta,t)u(t) + d(t) \qquad (6)$$

Type: f and g are unknown nonlinear functions, and the $g>0$, u is control the input function, $\theta(t)$ is the system output function signal function, $d(t)$ into the external interference.

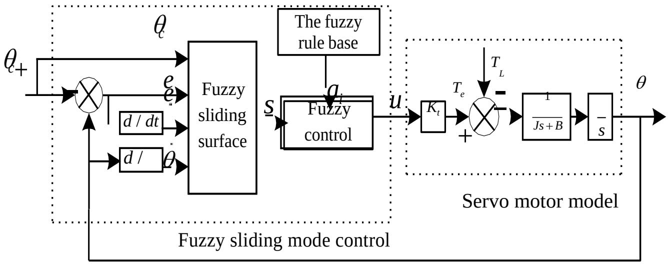

Figure 1: Servo motor fuzzy block diagram of control system.

Servo motor fuzzy sliding mode control system structure diagram as shown in Figure 1.

The definition of track error:

$$e(t) = \theta(t) - \theta_c(t) \qquad (7)$$

Type: $\theta_c(t)$ as a function of the actual output signal detection.

The definition of integral sliding mode surface:

$$s(t) = e(t) + k_1 e(t) + k_2 \int e(t)dt$$

Type: k_1 and k_2 for non zero is constant.

If the sliding mode control is an ideal state, then $s(t) = s(t) = 0$. That is:

$$e(t) + k_1 e(t) + k_2 e(t) = 0 \qquad (9)$$

Through the determination of k1 and k2, the tracking error e(t) will be near zero.

Assume that f, g and d(t) is known, according to the formula of 6~9, the controller can obtain ideal

$$u^*(t) = g(\theta,t)^{-1}[-f(\theta,t) - d(t) + \ddot{\theta}_c(t) - k_1\dot{e} - k_2 e] \qquad (10)$$

By type 8:

$$\dot{s}(t) = \ddot{e}(t) + k_1\dot{e}(t) + k_2 e(t) = g(\theta,t)[u_{fz} + u_{vs} - u^*(t)] \qquad (11)$$

In order to promote the status of $s(t)$ and α approaches zero, consider the following Lyapunov function:

$$V_1[s(t),\alpha] = \frac{1}{2}s^2(t) + \frac{g(\theta,t)}{2\beta_1}\alpha^T\alpha$$

In order to make $V_1[s(t),\alpha] \le 0$, adopts the adaptive function and the switching control function:

$$\begin{cases} \dot{\tilde{\alpha}} = \dot{\hat{\alpha}} = -\beta_1 s(t)\xi \\ u_{vs} = -E(t)\operatorname{sgn}[s(t)] \end{cases} \qquad (12)$$

Type: sgn(·) for the sign function.

In order to alleviate the requirement on the bound of approximation error bound estimation, servo motor adaptive fuzzy sliding mode control system design with, as shown in Figure 2.

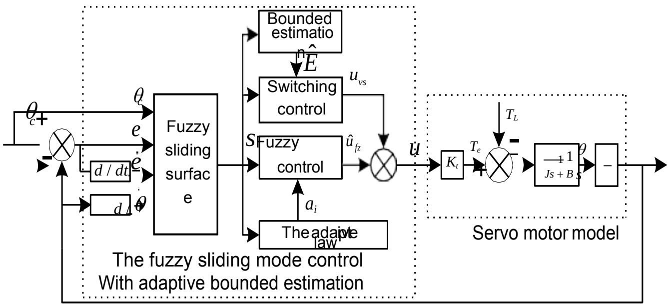

Figure 2: With adaptive servo motor bounded estimation of the fuzzy sliding mode control system structure diagram.

Use $\hat{E}(t)$ instead of $E(t)$, then the type 12 variable for:

$$u = -\hat{E}(t)\operatorname{sgn}[s(t)] \qquad (13)$$

Type: $\hat{E}(t)$ estimates for gain switching function. The definition of the estimation error:

$$E(t) = \hat{E}(t) - E \qquad (14)$$

In order to make the states of $s(t)$, α and $E(t)$ tends to zero, the Lyapunov function is defined as:

$$\begin{aligned} V(t) &= V_1(t) + \frac{g(\theta,t)}{2\beta_2}\tilde{E}^2 \\ &= \frac{1}{2}s^2(t) + \frac{g(\theta,t)}{2\beta_1}\alpha^T\alpha + \frac{g(\theta,t)}{2\beta_2}\tilde{E}^2 \end{aligned} \qquad (15)$$

Type: β and β for a positive constant. Then:

$$\begin{aligned}\dot V(t)&=\dot V_1(t)+\frac{g(\theta,t)}{\beta_2}\tilde E\dot{\tilde E}\\&=g(\theta,t)\tilde\alpha^T[s(t)\xi+\frac{1}{\beta_1}\dot{\tilde\alpha}]+s(t)g(\theta,t)(u_{vs}-\varepsilon)+\frac{g(\theta,t)}{\beta_2}\tilde E\dot{\tilde E}\\&=-E(t)|s(t)|g(\theta,t)-\varepsilon s(t)g(\theta,t)+\frac{g(\theta,t)}{\beta_2}[\hat E(t)-E]\dot{\hat E}(t)\end{aligned} \quad (16)$$

In order to make the $V(t)\le 0$, define the adaptive law:

$$\hat E(t)=\beta_2\ s(t) \quad (17)$$

Then type 17 variables for:

$$\begin{aligned}\dot V(t)&=-\hat E(t)|s(t)|g(\theta,t)-\varepsilon s(t)g(\theta,t)+[\hat E(t)-E]|s(t)|g(\theta,t)\\&=-\varepsilon s(t)g(\theta,t)-E|s(t)|g(\theta,t)\\&\le|\varepsilon|s(t)g(\theta,t)-E|s(t)|g(\theta,t)\\&=-(E-|\varepsilon|)s(t)g(\theta,t)\le 0\end{aligned} \quad (18)$$

3.2 The Realization of Adaptive Fuzzy Sliding Mode Controller

We can know from the analysis section, the adaptive fuzzy controller with fuzzy rules first function on the sliding surface of $s(t)$ fuzzy processing, and then in the use of fuzzy input using Lyapunov stable adaptive laws satisfying, the ultimate realization of the adaptive fuzzy control. At the same time, in compensation for adaptive fuzzy output, using the adaptive sliding mode switched linear control, the final form of time-varying nonlinear system adaptive to the control of the fuzzy sliding mode controller.

4. SIMULATION AND ANALYSIS

Parameters of the servo motor is taken as:
Inductance L_d= 18.75m、L_q =18.75mH, Resistance R = 12Ω , Quality $M=24k$, The coefficient of friction $B=0.2N\cdot s/m$, Magnetic pole distance $\tau=35mm$, Flux value $\psi=0.286Wb$, The target input step signal $v_{ref}=1rad/s$.

Adaptive fuzzy sliding mode linear motor control system simulation results are as follows:

Figure 3 is the unit step response curve of the order of the controller output; Figure 4 for the system position tracking curve; to the superiority of the fuzzy sliding mode adaptive control algorithm to verify the proposed, at the same time with the classic PID control comparison, select $K_P=50$, $K_i=200$, $K_d=0.5$, the results as shown in figure. Figure 5 is a PID position tracking curve; error map Figure 6 is the comparison of two algorithms.

We can be seen from Figure 4, the proposed adaptive fuzzy sliding mode control of the output result is obviously better than the classic PID control, faster response, no overshoot, steady state error is zero, reach the target position is faster than the PID control.

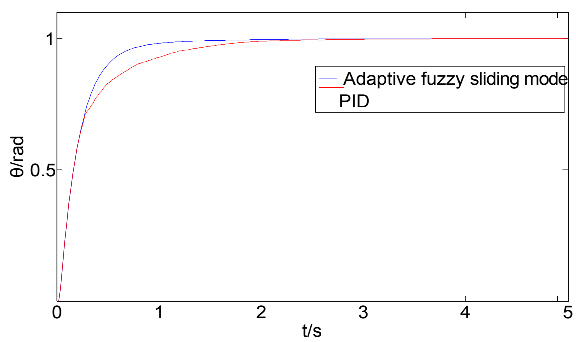

Figure 3: Controller output step response curve.

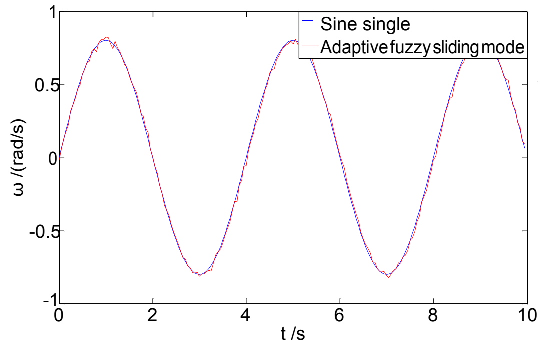

Figure 4: The system position tracking curve.

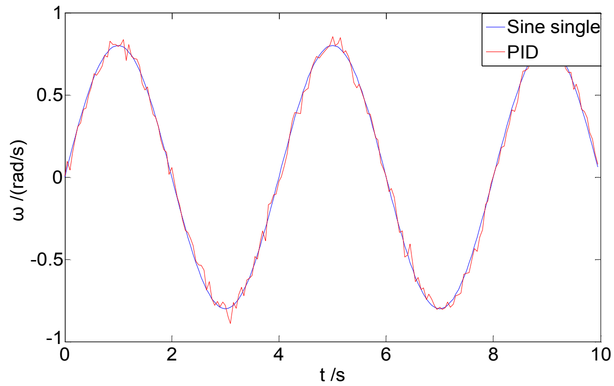

Figure 5: PID position tracking curve.

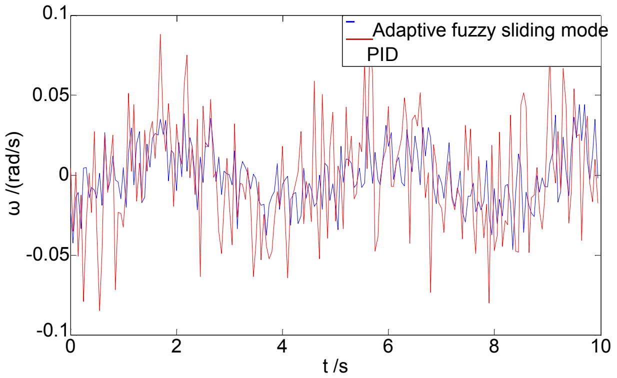

Figure 6: Compare the error map.

From Figures 4, 5, and 6, it can be seen in the presence of system uncertainties, the traditional PID control tracking performance declination, and chattering phenomenon, and even causes the system output response shock. Fuzzy sliding mode control not only has the stable tracking performance of adaptive is proposed in this paper, and the transient performance is satisfactory.

5. CONCLUSION

In this paper, the boundary estimation with adaptive fuzzy sliding mode control is applied to the servo motor position control system, successfully design and application of adaptive technology in the fuzzy sliding mode controller is stable among the. The adaptive law of Lyapunov stability theory can automatically adjust the fuzzy rules, so as to ensure the stability of the system, at the same time using adaptive sliding mode switching linear control to compensate for the adaptive fuzzy output, can be time-varying and nonlinear system control. Compared with the traditional PID algorithm, the adaptive fuzzy sliding mode control with fast stability, in position output accuracy higher, more satisfied precision positioning of high pressure heater deceleration linear motor transport work platform requirements. According to the simulation results, the fuzzy sliding mode control algorithm has good control characteristic of adaptive is proposed in this paper, to improve the output precision of the position control system of permanent magnet synchronous motor, obtain satisfactory tracking response.

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