Design of Sliding Mode Predictive Controller for AC Servo System

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ABSTRACT: In order to solve the position control problem of AC servo system, a new control strategy for the position based on sliding mode control and predictive control is proposed. The sliding mode control law is deduced, and according to the dynamic matrix theory, predictive model, controller and corrector are designed. The sliding mode predictive controller can restrain the change of system parameters and load disturbance, improve the system dynamic and static characteristic. The simulation results show that sliding mode predictive controller can guarantee the robustness of the control system.

KEYWORD: Position Control; Sliding Mode Control; Predictive Control; AC Servo System

1 INSTRUCTIONS

In the traditional servo system, PID control usually is designed for AC permanent magnet synchronous motor. In the practical application, because of the complex parameters tuning method, traditional PID controller parameters are often bad tuning and poor adaptability [1-2]. In recent years, the application of predictive control and sliding mode variable structure control in AC servo system more and more widely. The advantages of sliding mode variable structure are well adaptability for the change of system parameters and less susceptible to outside interference [3-4]. Predictive control using multi-step prediction, rolling optimization and feedback correction control strategy, well control effect and strong robustness [5-6].

Considering motor parameter variation and disturbance effect, this paper designs the sliding mode predictive controller. Simulation results show the designed controller compared with traditional PID control has better robustness.

2 MATHEMATICAL MODEL OF PERMANENT MAGNET SYNCHRONOUS MOTOR

Hypothesis: an unsaturated magnetic circuit; the air gap magnetic field is a sine distribution; regardless of hysteresis and eddy current losses; the rotor without damping windings, the permanent magnet has no damping effect; $i_d=0$ control.

The permanent magnet synchronous motor mathematical model for d - q axis:

$$u_q = Ri_q + L(di_q / dt) + \omega_r \psi_f \quad (1)$$

$$u_d = -\omega_r Li_q \quad (2)$$

$$T_{em} = 1.5 p_n \psi_f i_q = K_t i_q \quad (3)$$

$$T_{em} = T_l + B(\omega_r / p_n) + (J / p_n)(d\omega_r / dt) \quad (4)$$

Where u_d , u_q is the stator voltage; i_q , i_d is stator current; L is the stator winding inductance ($L=L_d=L_q$); R , ω_r is the stator winding resistance and the rotor rotating angular velocity; ψ_f is rotor flux; p_n is pole pairs.

3 CONTROLLER DESIGN

3.1 Sliding mode variable structure position controllers

Considering the speed loop is much faster than the location response. In the derivation of the control rate, can be considered one order inertia and speed loop equivalent.

$x_2 = x_1$, under the step signal, the state equation:

$$\begin{cases} \dot{x}_1 = x_2 \\ \dot{x}_2 = -\frac{1}{T} x_2 - \frac{K}{T} u + \frac{1}{T} \dot{\theta}_{ref} \end{cases} \quad (5)$$

The sliding mode switching function is as follows:

$$S = c \ x_1 + x_2 \quad (6)$$

Let $c > 0$.

The sliding mode output is as follows:

$$u = \lambda_1 x_1 + \lambda_2 x_2 + \frac{1}{K} \dot{\theta}_{ref} \quad (7)$$

The controller parameters for the position loop of sliding mode variable structure are as follows:

$$\alpha_1 > 0, \beta_1 < 0$$

$$\alpha_2 > \frac{cT-1}{K}, \beta_2 < \frac{cT-1}{K}$$

The diagram for the position loop of sliding mode variable structure is as follows:

Figure 1. The diagram of sliding mode control

3.2 Predictive controllers

According to the dynamic matrix control theory, the predictive model as follows:

$$\begin{pmatrix} \hat{y}(k+1) \\ \hat{y}(k+2) \\ \dots \\ \hat{y}(k+n) \end{pmatrix} = \begin{pmatrix} a_1 & & 0 \\ a_2 & a_1 & \\ \vdots & \vdots & \ddots \\ a_n & a_{n-1} & \dots & a_{n-m+1} \end{pmatrix} \begin{pmatrix} \Delta u(k) \\ \Delta u(k+1) \\ \dots \\ \Delta u(k+m-1) \end{pmatrix} + \begin{pmatrix} y_0(k+1) \\ y_0(k+2) \\ \dots \\ y_0(k+n) \end{pmatrix} \quad (8)$$

$$\text{Let } \hat{Y} = [\hat{y}(k+1), \hat{y}(k+2), \dots, \hat{y}(k+n)]^T$$

$$\Delta U = [\Delta u(k), \Delta u(k+1), \dots, \Delta u(k+m-1)]^T$$

$$Y_0 = [y_0(k+1), y_0(k+2), \dots, y_0(k+n)]^T$$

$$A = \begin{pmatrix} a_1 & & 0 \\ a_2 & a_1 & \\ \vdots & \vdots & \ddots \\ a_n & a_{n-1} & \dots & a_{n-m+1} \end{pmatrix}$$

Equation (8) can be expressed as follows:

$$\hat{Y} = A\Delta U + Y_0 \quad (9)$$

Where A is a constant matrix dimension, n, m are the maximum prediction length and the control length.

The optimization criterion is as follows:

$$J = \sum_{j=1}^n [y(k+j) - w(k+j)]^2 + \sum_{j=1}^m \lambda(j) [\Delta u(k+j-1)]^2 \quad (10)$$

Let weighted control coefficient $\lambda(j) = \lambda$ is constant, and

$$W = [w(k+1), w(k+2), \dots, w(k+n)]^T$$

Then the equation (11) can be expressed as

$$J = (Y - W)^T (Y - W) + \lambda \Delta U^T \Delta U \quad (11)$$

$$\text{Let } w(k+j) = \alpha^j y(k) + (1-\alpha^j) y_r \quad (j=1, 2, 3, \dots, n)$$

Where α is softening coefficient.

Substiting (9) into (11):

$$\frac{\partial J}{\partial \Delta U} = 0$$

$$\Delta U = (A^T A + \lambda I)^{-1} A^T (W - Y_0) \quad (12)$$

The controlled increment is as follows:

$$\Delta u(k) = c^T (A^T A + \lambda I)^{-1} A^T (W - Y_0) = d^T (W - Y_0) \quad (13)$$

$$\text{Where } c^T = [1 \ 0 \ \dots \ 0], \quad d_r = c^T (A^T A + \lambda I)^{-1} A^T$$

The corrector is as follows:

$$y_0(k+i) = \hat{y}(k+i+1) + h_{i+1} e(k+i) \quad (i=1, 2, \dots, p-1) \quad (14)$$

$$y_0(k+p) = \hat{y}(k+p) + h_p e(k+1)$$

$h_1, h_2, \dots, h_p$ are error correction vector, $h_1=1$

The schematic diagram of the designed controller is as follows:

Figure 2. The control schematics of designed controller

4 SIMULATION EXPERIMENTS

The main parameters of the system are as follows:

$$J=0.00263 \text{ kg m}^2; K_r=1.11 \text{ N m/A};$$

$$B=0.000143 \text{ N m s}; L_d=L_q=0.05 \text{ H}; P_n=4.$$

Sliding mode position controller parameters: $c=47$, $\alpha_1=11$, $\beta_1=-14$, $\alpha_2=2 \times 10^{-2}$, $\beta_2=-5 \times 10^{-3}$.

Predictive control parameters: $m=6$, $n=12$.

The error setting value is 0.12.

The traditional PID controller parameters: $k_{p1}=12$, $k_{i1}=0.02$, $k_{d1}=0.005$.

4.1 Constant disturbance

If the disturbance of step input, adding the disturbance input signal at 1.1s, the value of 10N m, the simulation results in Figures 3-4. From the figures, the offset of traditional PID algorithm is larger. The sliding mode predictive control has strong anti disturbance ability and less affected by external disturbances.

Figure 3. Response curve of designed controller

Figure 4. Response curve of traditional PID controller

4.2 The variation of motor parameters

Assume that the system inertia is increased 5 times. Position response curve shows in Figures 5-6. It can be seen from the figures, using PID control, system curve will overshoot, and then gradually tend to smooth. The curve of sliding mode predictive control is stable.

Figure 5. Response curve of designed controller

Figure 6. Response curve of traditional PID controller

4.3 Sinusoidal tracking experiment

Assume tracking objective function is: $65\sin(0.7166t)$, Figures 7-8 are the error curve. It can be seen from the figures, designed controller compared with traditional PID control has good tracking characteristic.

Figure 7. Error curve of designed controller

Figure 8. Error curve of the traditional PID control

5 CONCLUSIONS

In order to solve the position control problem of AC servo system, a new control strategy for the position is proposed, which combined sliding mode control and predictive control. The sliding mode predictive controller can restrain the change of system parameters and load disturbance. Simulation

experiments show that the designed controller can guarantee the system robustness.

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