Design of the Self-Adaptive Sliding Mode Position Controller based on Genetic Algorithm Optimization for the Servo Motor Drive System

Leiming Jiao[1],Yanhong Luo[1],Pengqiao Zhang[2],Linlin Li[3],Xiangtian Zheng[4],Ge Qi[1],Hong Jia[5],Hengyu Liu[1]

1. College of Information Science and Engineering,Northeastern University,Shenyang,China
2. Yingkou Power Supply Company, State Grid Liaoning Electric Power Co.Ltd,Yingkou,China
3. Qianhai Shenzhen FellowPlus Internet Financial Services Inc,Beijing,China
4. Department of Electrical Engineering,Tsinghua University,Beijing,China
5. State Grid Chaoyang Electric Power Supply Company,Liaoning Province,Chaoyang,China

ramon_jason@sina.com,neuluo@gmail.com,zpq19911218@126.com,767488056@qq.com,zheng-xt13@tsinghua.edu.cn, 1010713403@qq.com,jiahong1985@163.com,859870406@qq.com

Abstract—**The self-adaptive sliding mode position controller based on genetic algorithm optimization is designed for the servo motor drive system. Firstly, the self-adaptive sliding mode position controller is researched to estimate the magnitude of the unknown disturbance in the perturbed system. Then, the adaptive genetic algorithm is used to optimize the ideal adaptive parameters and switching parameters. In the end of the paper, several simulation experiments are carried out to test the performance of the system. The results show that the adaptive genetic algorithm has better control performance and position tracking response for the system parameter variation and external load disturbance.**

Keywords—the self-adaptive sliding mode control; genetic algorithm; optimization

I. INTRODUCTION

Because of its full digital, highly integrated, intelligent and so on, the servo motor drive controller is widely used in the fields of industrial robots. However, there are still some problems. First, although the sliding mode control is widely used because of its strong robustness to system parameter variation and external load disturbance, the control strategy must know in advance the parameter variations and the boundary value of external load disturbance. In fact, the boundary values of these uncertainties are difficult to obtain in the practical application because of their complexity. Second: although the self-adaptive sliding mode position control strategy can be used to estimate the magnitude of the unknown disturbance in the perturbed system, it is impossible to obtain good control performance by using the fixed adaptive parameters.

In order to overcome the shortcomings of the traditional servo motor drive controller, the self-adaptive sliding mode position controller is used to estimate the magnitude of the unknown disturbance in the perturbed system, and the improved genetic algorithm is used to optimize the ideal adaptive parameters and the switching parameters to make the controlled system have better dynamic characteristics.

II. THE SELF-ADAPTIVE SLIDING MODE POSITION CONTROLLER

As a new solution for the current servo motor drive system, the sliding mode control is proposed. However, due to the variation of the system parameters and the unknown of external disturbances, and the boundary value of the system uncertainty is difficult to obtain, so, the stability and control precision of the system need to be improved. The design is based on Lyapunov theory, combining with the sliding mode variable structure control and the self-adaptive control law to design a self-adaptive sliding mode position controller, and effectively improves the control performance of the system. In order to ensure the stability of the system, the boundary value of the system uncertainty is usually larger than the actual boundary value, which will make control effect is too strong. Therefore, we design a simple adaptive control technique to obtain the adaptive gain $\hat{g}_0$ and $\hat{g}_1$ of the unknown constants g_0 and g_1. The adaptive error of the gain g_0 and g_1 is defined as:

$$\tilde{g}_0 = \hat{g}_0(t) - g_0, \tilde{g}_1 = \hat{g}_1(t) - g_1 \tag{1}$$

The servo motor drive system is an uncertain dynamic system. The system equation[1] can be written as:

$$\dot{x}(t) = Ax(t) + Bu + Be(t, x) \tag{2}$$

Where $x(t) \in R^n$ is the state vector, $u(t) \in R^m$ is the input, $e(t,x) = Dx(t) + Eu + F$, $A \in R^{n \times n}$, $B \in R^{n \times m}$ are constant matrixs, and the matrix B is full rank, D, E and F are the unknown functions which satisfy the corresponding dimension. The adaptive sliding mode control law of the system is assumed to be:

$$u = u_b + u_s + u_{adp} \tag{3}$$

Where $u_b = Kx$ (K is a state feedback gain matrix) is a state feedback control, u_s is a nonlinear switching control, and u_{adp} is adaptive control. The u_s and u_{adp} are respectively designed as:

$$u_s = -k(CB)^{-1} sign(s) \tag{4}$$

$$u_{adp} = -(B^T C^T s) \| s^T CB \|^{-1} [\hat{g}_0(t) + \hat{g}_1(t) \| x \|] \tag{5}$$

Where k is a positive constant, $sign(s)$ represents vector $[sign(s_1), sign(s_2), \cdots, sign(s_m)]$.

$$sign(s_i) = \begin{cases} +1 & s_i > 0 \\ -1 & s_i < 0 \end{cases} \quad i = 1, 2, \cdots, m-1, m \tag{6}$$

The self-adaptive law of the gain g_0 and g_1 is designed as:

$$\hat{g}_0 = \| s^T CB \| , \quad \hat{g}_1 = \| s^T CB \| \| x \| \tag{7}$$

Where $\hat{g}_0$ and $\hat{g}_1$ are respectively the estimated values of g_0 and g_1. The adaptive gain initial value is zero.

A. Design of Integral Sliding Mode Switching Surface and Switching Rules

In this paper, the sliding mode control switching surface is designed as a sliding mode controller with integral operation, and the switching surface is designed as follows:

$$S(t) = CX(t) - C\int_0^t (A + BK) X(\tau) d\tau \tag{8}$$

Where C=[1 β], β is the switching parameter. The selection of C must satisfy that CB is nonsingular, and K is the state feedback gain matrix. From the above, we can see that when the system is in the sliding mode, the system characteristic is equivalent to:

$$\dot{X}(t) = (A + BK) X(t) \tag{9}$$

The eigenvalues of the system (A+BK) are determined by the K value in the sliding mode, and the appropriate K value is chosen to make the poles of the system fall in the left half plane, so as to make the position error converge to zero. The design of the switching rule must ensure that satisfies the sliding conditions. The switching rule is designed as:

$$\begin{aligned} u &= KX(t) - k(CB)^{-1} sign(S(t)) \\ &- (B^T C^T S(t)) \| S(t) CB \|^{-1} [g_0(t) + g_1(t) \| x \|] \end{aligned} \tag{10}$$

B. Design of the Self-adaptive Sliding Mode Position Controller

Design of the sliding mode position controller must know the boundary value of the uncertainty. However, in the actual operation process, it is very difficult to measure the change of system parameters and the external load disturbance in advance. Therefore, in this paper, the self-adaptive control method is used to make the control of the system adapt to the change of system uncertainty and disturbance automatically. The system block diagram of is shown in Fig.1.

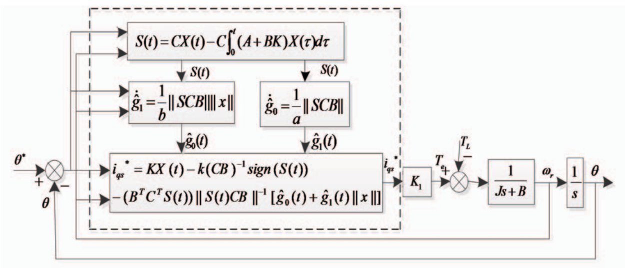

Fig.1. The system block diagram of the self-adaptive sliding mode controller

The self-adaptive law is designed as:

$$\dot{\hat{g}}_0 = \frac{1}{a} \| SCB \| , \quad \dot{\hat{g}}_1 = \frac{1}{b} \| SCB \| \| x \| \tag{11}$$

Where $\hat{g}_0$ and $\hat{g}_1$ are respectively the estimated values of g_0 and g_1 , a and b represent adaptation parameters, and $a > 0$, $b > 0$. So the self-adaptive sliding mode position controller is designed as:

$$\begin{aligned} u &= KX(t) - k(CB)^{-1} sign(S(t)) \\ &- (B^T C^T S(t)) \| S(t)CB \|^{-1} [\hat{g}_0(t) + \hat{g}_1(t) \| x \|] \end{aligned} \tag{12}$$

III. DESIGN OF THE SELF-ADAPTIVE SLIDING MODE CONTROLLER BASED ON GENETIC ALGORITHM OPTIMIZATION

Although the formula (11) can estimate the values of g_0 and g_1 , it is impossible to obtain good control performance by using the fixed adaptive parameters a and b . So, the genetic algorithm is used to optimize the adaptive parameters a , b and the switching parameter β , so that the position error converges quickly and the overall control performance is improved. The formula (11) shows that the estimated adaptation law always get a positive, and all kinds of uncertainties such as the tracking error caused by the error of sensor will make the estimated value of $\hat{g}_0$ and $\hat{g}_1$ increase, unless the switching surface converges quickly to zero, otherwise, when time tends to infinity, the estimated value tends to infinity. As a result, the drive system is saturated and the system is unstable.In order to avoid the phenomenon, we introduce an estimation index γ .The adaptation law becomes:

$$\dot{\hat{g}}_0 = \gamma \frac{1}{a} \| SCB \| , \quad \dot{\hat{g}}_1 = \gamma \frac{1}{b} \| SCB \| \| x \| \tag{13}$$

If the value of the switching surface $S(t)$ is greater than the predetermined value S_0 , which indicates that the system state trajectory deviates from the switching surface, so, it is necessary to update continuously $\hat{g}_0$ and $\hat{g}_1$ .The sliding mode controller drives the state trajectory of the system back to the switching surface quickly, at this time, $\gamma = 1$. Conversely, if the value of the switching surface $S(t)$ is less than the predetermined value S_0 , which indicates that the control system is robust, so, the adaptive gain $\hat{g}_0$ and $\hat{g}_1$ maintain the value of the last operation, at this time, $\gamma = 0$.

A. Adaptive Genetic Algorithm

For the traditional genetic algorithm[2], the crossover rate p_c and the mutation rate p_m are the basis of the gene in the mating and mutation operations, and usually set to constants, which are too small to make the system easily fall into the local extremum and unable to escape. On the contrary, if the crossover rate p_c and the mutation rate p_m are too much, the system can escape from the local extremum, but it is difficult to be stable and convergent because of the high frequency of crossover or mutation, so the value of p_c is between 0.5~1, and the value of p_m is between 0.001~0.05.

Adaptive genetic algorithm(AGA)[3] is proposed by Srinivas and Patnaik on the basis of the traditional genetic algorithm, which can adjust the crossover rate p_c and the mutation rate p_m dynamically according to the fitness function value. When the system falls into the local extremum, the p_c and the p_m will increase to escape from the local extremum, and after leaving the local extremum, they will be constant. The standard form of AGA is [4]:

$$\begin{cases} p_c = k_1 \dfrac{f_{\max} - f'}{f_{\max} - f_{avg}}, & f' \geq f_{avg} \\ p_c = k_3, & f' < f_{avg} \end{cases} \tag{14}$$

$$\begin{cases} p_m = k_2 \dfrac{f_{\max} - f}{f_{\max} - f_{avg}}, & f \geq f_{avg} \\ p_m = k_4, & f < f_{avg} \end{cases} \tag{15}$$

Where $f_{\max}$ and f_{avg} represent respectively the highest fitness value and the average fitness value of a generation, f' is a larger fitness value for the two individuals to be crossed, and f is the fitness value of the individual to be mutated. Taking into account the integrity (between generations and generations) [5], set $f_{\max} = 10^5$. In addition, in order to ensure that the value of p_c and p_m can be adjusted adaptively and is between 0~1, set the values of k_1 , k_2 , k_3 and k_4 in the interval(0,1), generally take $k_1 = 1$, $k_2 = 0.5$, $k_3 = 1$, $k_4 = 0.5$.

There are six factors that must be considered in the adaptive genetic algorithm: the definition of chromosome, the selection of the initial population size, the definition of individual fitness function, how to copy, cross and mutation.

Specific steps are as follows:

1) Read the initialization file: According to the specific analysis of the given problem, the most basic feature information is extracted. Determine the optimal variable according to this information.

2) Determine the operating parameters of AGA: Population size, crossover probability, mutation probability.

3) Generate initial population: Genetic algorithm (GA) is used to search the solution space with a large number of feasible solutions. Many of the encoded feasible solutions are called chromosome populations.

4) Calculate the objective function value (individual fitness value).

This paper is to find the minimal objective function. The fitness function value can be set to the following equation:

$$G = g_{\max} - g_{obj}$$

Where G is the fitness function value, $g_{\max}$ is the fitness function value in the optimal state, and g_{obj} is the objective function value. In this paper, Sum of Absolute Error Criterion(SEA) is used as the objective function:

$$\sum_{k=0}^{N} | e(k) | \tag{16}$$

The formula (16) is used to evaluate, select, crossover and mutate for the new generation again, after continuously circling, the group's best individual fitness value and the average fitness value are increasing, until the best individual fitness value reaches a certain limit, or the best individual fitness value and the group's average fitness value will no longer increase, and satisfy the constraint conditions at the same time, then the iterative process converges and the algorithm ends.

B.Design of the Self-adaptive Sliding Mode Position Controller Based on Genetic Algorithm Optimization

The system block diagram of the self-adaptive sliding mode position controller based on genetic algorithm optimization is shown in Fig.2.

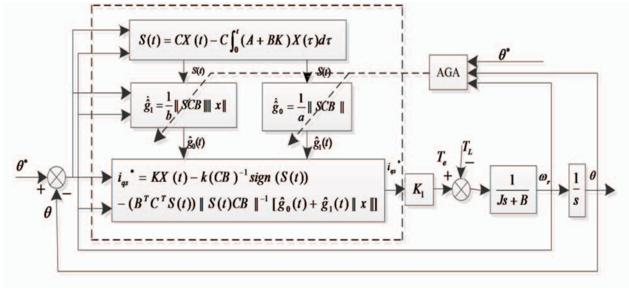

Fig.2. The system block diagram of the self-adaptive sliding mode position controller based on genetic algorithm optimization

In Fig.2, the given rotor position, the actual rotor position and rotor speed as the input of the genetic algorithm, the fitness function is calculated to obtain the optimal parameter value. Therefore, the adaptive parameters a , b and the switching parameter β can be adjusted online to improve the control performance of the system and accelerate the convergence speed of the system.

IV. SIMULATION

In order to verify the effect of the self-adaptive sliding mode position controller based on the genetic algorithm optimization, we design three kinds of conditions including parameter variation and external load disturbance and experiment has been caught out. The simulation results are shown in Fig.3, Fig.4 and Fig.5. The three conditions are as follows:

(1) $a = b = 10, \beta = 10$;

(2) $a = b = 5, \beta = 15$;

(3)In the case of (1), when $t = 4s$, the load suddenly increased $5.0 N \cdot m$.

In (1) and (2), the input signal is a periodic square wave signal, and the input signal is a step signal in (3). The simulation results show that, when the system parameters or external load changes, the tracking response of the self-adaptive sliding mode position controller is not very satisfactory. We use the adaptive genetic algorithm to adjust the self-adaptive parameters a and b and the switching parameters β on line. The results show that the adaptive genetic algorithm has better control performance and position tracking response for the system parameter variation and external load disturbance.

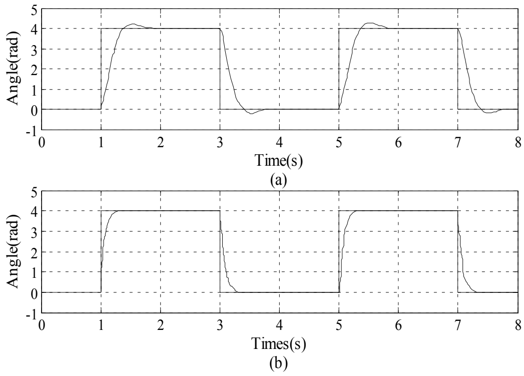

Fig.3. (a)Square wave tracking response of the self-adaptive sliding mode position controller

(b)Square wave tracking response of the self-adaptive sliding mode position controller based on genetic algorithm optimization

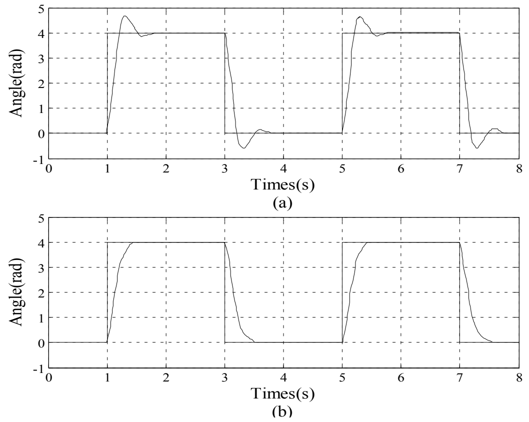

Fig.4. (a)Square wave tracking response of the self-adaptive sliding mode position controller

(b)Square wave tracking response of the self-adaptive sliding mode position controller based on genetic algorithm optimization

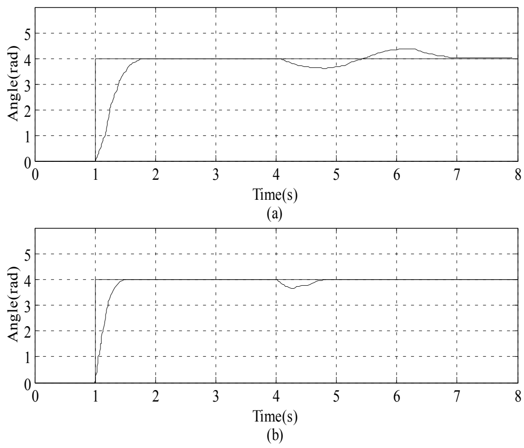

Fig.5. (a)Step response of the self-adaptive sliding mode position controller

(b)Step response of the self-adaptive sliding mode position controller based on genetic algorithm optimization

V. CONCLUSIONS

Now, AC servo system has gradually replaced DC servo system, which is developing towards intelligent, digital, miniature, modular direction. This paper proposed the self-adaptive sliding mode position controller based on genetic algorithm optimization, which provides a new solution for AC servo drive control system at present. The self-adaptive control law is used to estimate the magnitude of the unknown disturbance, which can avoid the limitation of the traditional variable structure controller. And the adaptive genetic algorithm is used to optimize the ideal adaptive parameters and the switching parameters, so that the controlled system has better dynamic characteristics. It greatly improves the flexibility and application range of the drive controller, and improves the stability, safety and control precision of the control system.

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