Research on Position Servo Control Based on Improved MFAC

Chen HUANG, Aiping XIAO※, Lei ZHAO,Hua QIAN

Abstract**—**An improved model-free adaptive control algorithm in motor position control is designed, and use genetic algorithm for parameter optimization model-free adaptive control algorithm. Through the MATLAB software simulation and experimental tests, verify parameters of model-free adaptive control algorithms and improvement of model-free adaptive control algorithms for motor position control have good results.

Keywords**—**MFAC, Position Servo Motor, Genetic algorithm.

I. INTRODUCTION

THE DC servo motor is used in a number of areas, including industrial and agricultural production, robot technology, energy exploitation, medical instrument and daily household appliances. Application of control technology of DC servo motor is directly related to the control performance of the control system. The traditional control strategy is represented by PDI control. The control system of commercial DC servo motor generally adopts the PID control algorithm. Such control systems include MCDC3303/06S DC brush motor controller and MCBL3303/06S DC brushless motor controller developed by FAULHABER of Germany, the EPOS2 series DC motor controller developed by Maxon of Swiss, and the MLDS DC motor controller developed by Xi' an Langming Technology Co., Ltd. However, setting of P, I and D parameters of the PID control algorithm requires rich experience. Improper adjustment may result in poor control performance or even instability. In recent years, with development of modern control theory, some advanced control algorithms are applied to control of DC servo motor, such as self-adaptive control, fuzzy control and neural network control. Due limit of the processing speed of the controller processor, with the addition of great operand of many advanced algorithms and complicated algorithms, now this technology is still in the simulation stage and can not be applied to the actual control. For this reason, this paper proposes an improved model-free self-adaptive control algorithm, for which the genetic algorithm is used to optimize the parameters, so as to ensure precise position control of servo motor. The simulation and experiment are used to verify its effect.

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II. DIGITAL MODEL OF THE MOTOR

The equivalent circuit of separately excited DC motor under rated excitation is shown in Fig. 1. In the figure, I_d refers to the armature current; L_a refers to the armature inductance; *E* refers to the reverse electromotive force of the motor; R_a the load torque; U_a the armature voltage; T_e the electromagnetic torque; T_L the load torque; and n the motor speed. Equations (1) and (2) can be obtained through Fig. 1.

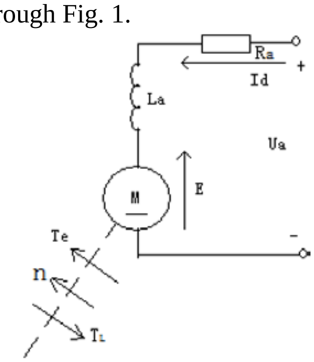


Fig.1 DC motor equivalent circuit

$$U_a = R_a I_d + L_a \frac{dI_d}{dt} + E \tag{1}$$

$$T_e - T_L = \frac{GD^2}{375} \bullet \frac{dn}{dt} \tag{2}$$

Where, GD^2 refers to the torque of the motor shaft; Equations (3) and (4) can be obtained through Equations (1) and (2):

$$U_a - \frac{30}{\pi} \bullet C_e \bullet \frac{d\theta}{dt} = \frac{R_a}{C_m} \bullet (T_e + T_L \frac{dT_e}{dt}) \tag{3}$$

$$T_e - T_L = \frac{30}{\pi} \bullet \frac{T_m C_m}{R_a} \bullet C_e \bullet \frac{d^2\theta}{dt} \tag{4}$$

Where, Cm is the torque current ratio; $T_m = \frac{GD^2 R_a}{375 C_e C_m}$ is the motor time constant Ce is the torque constant, E=Ce , $\omega = \frac{2\pi n}{60} = \frac{d\theta}{dt}$. The following transfer function can be obtained through Laplace transformation of Equations (3) and (4).

$$\frac{n}{U_a - T_L \bullet \frac{R_a(T_l s + 1)}{C_m}} = \frac{1/C_e}{T_m T_L s^2 + T_m s + 1} \tag{5}$$

The 241295 DC brush motor of Maxon is selected. Please refer to Table 1 for the motor parameters.

Tab.1 Motor parameters

Supply voltage	24V
Rated power	150W
Rated speed	6930rpm
Armature resistance	0.316Ω
Torque constant	30.2mNm/A
Motor time constant	4.67ms
Armature inductance	0.082mH
Resolution of coder	500-line

Plug the motor parameters into Equation (5) to obtain the following Equation (6), which reflects the transitive relation between the angle of the motor rotation and the armature voltage.

$$\frac{\theta(s)}{U_a(s)} = \frac{33.18}{0.000001212s^3 + 0.00467s^2 + s} \quad (6)$$

As the resulting model-free self-adaptive control algorithm will be used in the motor controller, and is targeted at the discrete system, the above digital model of DC brush motor should go through discretization. The MATLAB discrete function "C2D" is used to convert the continuous system into a discrete one. Then the discrete model can be obtained as below:

$$y(k) = 0.103y(k-1) + 282.257u(k-1) + 2.181u(k-2) \quad (7)$$

Where, y(k) is the speed output value; u(k) is the voltage input value.

Due to impact of load and environmental parameters, during operation of the motor, its speed variation is uncertain. With the addition of the non-linearity of the motor speed process, it is very difficult to measure the model parameter of the dynamic process and build the digital model of the system. Therefore, when the digital model of the controlled system is completely unknown, or the model is highly uncertain, or there will be remarkable structural change of the controlled process, which means it will be difficult to express with a digital model, or when the modeling cost and control benefit are not satisfactory, the model-free control method is preferred.

III. Improvement and Simulation of MFAC Algorithm

A. *Model-free self-adaptive control algorithm*

Model-free self-adaptive control (MFAC) method requires only the input data and output data of the controlled system, and requires no digital model or recognition process of the controlled process, or controlled design for any specific controlled object, or complicated manual calibration of controller parameters. The MFAC uses pseudo-partial-derivative of the input and output data estimating system to realize the self-adaptive control of the non-linear system.

The MFAC control algorithm based on the tight-form linearization is as follows:

$$\phi(k) = \phi(k-1) + \frac{\eta_k \Delta u(k-1)}{\mu + |\Delta u(k-1)|^2}(\Delta y(k) - \phi(k-1)\Delta u(k-1)) \quad (8)$$

$$\phi(k) = \phi(1) \text{ ,if } \phi(k) \le \varepsilon \text{ or } |\Delta u(k-1)| \le \varepsilon \quad ,(9)$$

$$u(k) = u(k-1) + \frac{\rho_k \phi(k)}{\lambda + |\phi(k)|^2}\left[y^*(k+1) - y(k)\right] \quad (10)$$

Where, $\phi(k)$ is the pseudo-partial-derivative based on the tight-form linearization; $\phi(1)$ is the initial value of $\phi(k)$; $y(k)$ is the output data of the controlled object; $u(k)$ is the input data of the controlled object; $y^*(k+1)$ is the set value of the controlled object; η_k and ρ_k are step series; $\eta_k \in (0,2]$, $\rho_k \in (0,1]$; μ and λ are weight factors; $\lambda > 0$, $\mu > 0$; ε is a positive number that is sufficiently small.

The control steps of MFAC control algorithm can be obtained as below according to Equations (8) through (10):

(1) Initialize parameters η_k, ρ_k, μ, λ, ε and $\phi(1)$;

(2) The $\phi(k)$ pseudo-partial-derivative is calculated according to Equation (8); if $\phi(k)$ satisfies Formula (2) $\phi(k) \le \varepsilon$ and $|\Delta u(k-1)| \le \varepsilon$, let $\phi(k) = \phi(1)$.

(3) The controller output $u(k)$ can be calculated according to Equation (10).

(4) Repeat Steps (9) and (10) in cycles.

B. *Improvement and simulation of MFAC algorithm*

Matlab simulation of the above motor model is carried out using the MFAC algorithm, with the simulation result obtained as shown in Fig. 2. According to the figure, we can find out that if MFAC control algorithm is directly applied to the position control of DC servo motor, the convergence can not be realized and the expected control effect can not be reached. Therefore, improvement of the algorithm is needed.

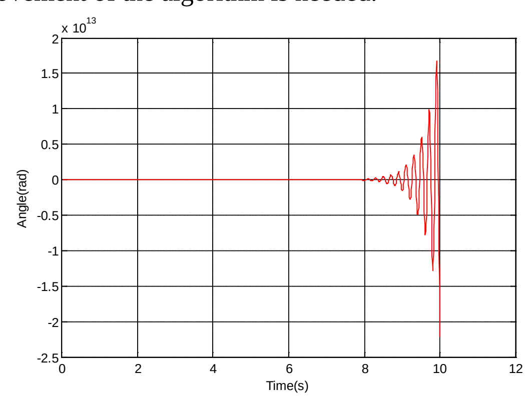


Fig.2 The control effect of MFAC on motor position

If we remove the term u(k-1) from Equation (10):

$$u(k) = u(k-1) + \frac{\rho_k \phi(k)}{\lambda + |\phi(k)|^2}\left[y^*(k+1) - y(k)\right]$$

Then the Equation (10) will be converted into Equation (11) as follows:

$$u(k)=\frac{\rho_k\phi(k)}{\lambda+|\phi(k)|^2}\left[y^*(k+1)-y(k)\right] \quad (11)$$

Where, $y^*(k+1)-y(k)=error(k+1)$,

let $A(k)=\frac{\rho_k\phi(k)}{\lambda+|\phi(k)|^2}$, then:

$$u(k)=A(k)error(k+1) \quad (12)$$

Equation (12) is equivalent to a proportional controller with variable coefficient. We use Equation (12) to do the matlab simulation. Set the angle to 100 ° for simulation, and the simulation results are given in Figure 3. According to the simulation results, the improved MFAC algorithm can be directly applied to position control of DC servo motor.

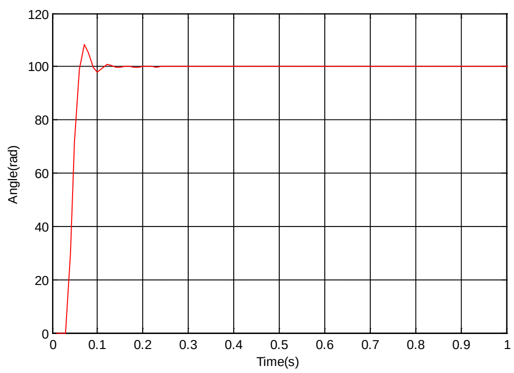


Fig.3 The control effect of Improved MFAC on motor position

C. Application of Genetic Algorithm for Parameter Optimization

To avoid fluctuation of the control effect resulting from problems related to parameter setting, the genetic algorithm is used to optimize the parameters to achieve a satisfactory control effect. Four parameters, η_k, ρ_k, μ and λ need to be calibrated in the MFAC algorithm. It is found out through experimental research that the parameter η_k poses a very small impact on the control performance of the algorithm, which means it can be ignored. Therefore, only the remaining 3 parameters need improving. In this paper, overstrike is used as the first index for evaluation. Therefore, the principle of parameter optimization is that there is no overstrike.

Set the motor angle for simulation to 100°. Use the genetic algorithm to optimize the model-free control algorithm to obtain the following parameters: μ =10.022, ρ_k =0.813 and λ =0.106. Use the genetic algorithm to optimize the three parameters of PDI controller, namely, K_p, K_I and K_d, and the optimized parameters are respectively 0.0997, 0.0002 and 0. The parameter setting for regular model-free self-adaptive control algorithm is as follows: μ =100, ρ_k =1.0 and λ =40. The simulation comparison results of the three control algorithms are shown in Fig. 4.

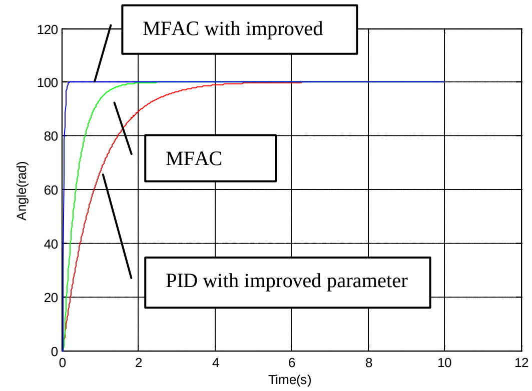


Fig.4 The control effect of Parameter optimized MFAC on motor position

It can be drawn from Fig.4 that the control effect of the MFAC algorithm is the best, and the response speed is the fast after the parameters are optimized using the genetic algorithm, followed by the PID control algorithm after the parameters are optimized using the genetic algorithm. The control effect of the ordinary MFAC algorithm is the poorest because no parameter optimization is done.

To verify the control effect of the improved MFAC algorithm, comparative experiment is carried out between the improved MFAC algorithm and the PID algorithm.

IV. Motor Control Experiment of Improved MFAC Algorithm

A. Empty load experiment

Through simulation, we find out that the improved MFAC algorithm can be applied to position control of the servo motor, and can obtain satisfactory control effect. To verify this conclusion, a motor controlled is designed to carry out actual position control experiment. The STM32 chip is used for the motor controller as the main controller. The BTS7960 chip is used to constitute the H-bridge drive circuit. The controller can send orders to control operation of the motor via the serial port or CAN bus. The motor used for the experiment is the maxon 241295 DC brush motor used for previous motor digital model. The motor feeds back the position through the coder, with a resolution of 500 lines per round. Please see Fig. 5 for the motor controller and motor.

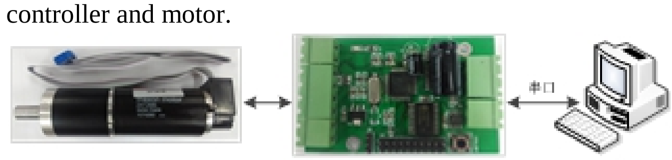


Fig.5 DC brush motor servo control system

The improved MFAC algorithm is applied to the location control of the motor, and the position setting value is 100,000 lines. The controller sends the actual position through the serial port to the computer. The experiment results are shown in Fig. 6.

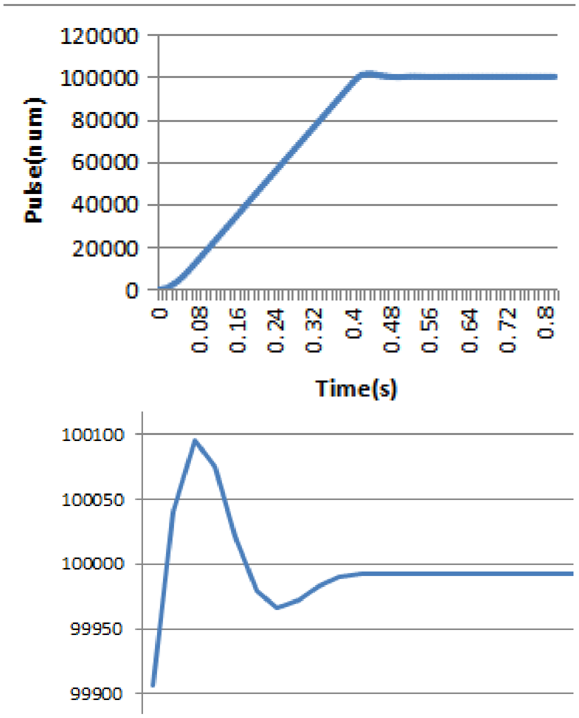
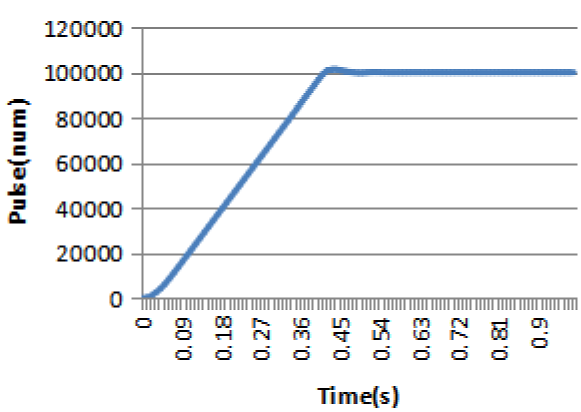


Fig.6 Experimental results

As shown in Fig. 6, there is static error in the system, and therefore the value can not be stabilized at the set value accurately. To eliminate error, we introduced the integration element, after which the error was significant during the initial stage, and the integration effect was strong, which may easily result in overstrike. To avoid excessive overstrike, the integration separation form is adopted, which means that the integration element is only introduced when the motor position is close to the set value. This way, the algorithm is improved as shown in Equation (13). Fig. 7 shows the control effect diagram of the improved algorithm. As indicated in the figure, the static errors are eliminated and the control effect is greatly improved.

$$B = \begin{cases} 0, \left[y^*(k+1) - y(k) \right] > \beta \\ 1, \left[y^*(k+1) - y(k) \right] < \beta \end{cases}$$

$$u(k) = \frac{\rho_k \phi(k)}{\lambda + |\phi(k)|^2} \left[y^*(k+1) - y(k) \right] + B \sum \left[y^*(k+1) - y(k) \right] \quad (13)$$



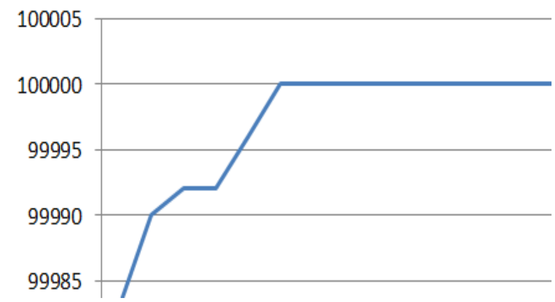


Fig.7 Experimental results

The MFAC algorithm and PID control algorithm are respectively applied to the position control of the servo motor. The position set value is 100,000 lines. The experiment results are shown in Fig. 8.

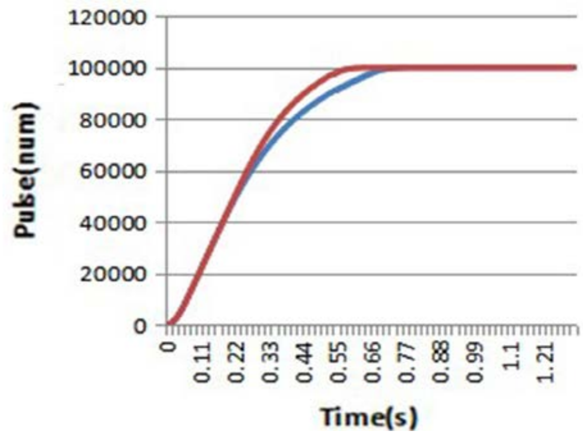


Fig.8 Comparative experimental results

As shown in Fig. 8, in the actual application, the response speed of the improved MFAC algorithm is better than PID control algorithm when there is no overstrike. The accuracy of matlab simulation results are verified through actual experiment.

B. *Application load experiment*

Comparison experiment is carried out using the professional servo motion platform to test the performance of the motor control system. Shown in Fig. 9 is the fully enclosed 2D DC servo motion control experiment platform developed by Shenzhen Zhongke Open Intelligent Technology Co., Ltd. The platform has two variances, namely, the rectilinear motion of X axis and the rectilinear motion of Y axis, with a travel of 300mm, driven by two DC servo motors. The rotary screw mechanism is used to convert such into linear displacement. There is a Sino Ka-300 grating ruler on the platform respectively on the X axis and Y axis directions, which can be used to measure the actual operation position of the slipway. The pitch of the grating ruler is 0.02mm and the measuring range is 370mm. The maximum moving speed is 120m/min. Operating voltage is 5v; the interface is a 9-core plug and output signal is TTL signal.

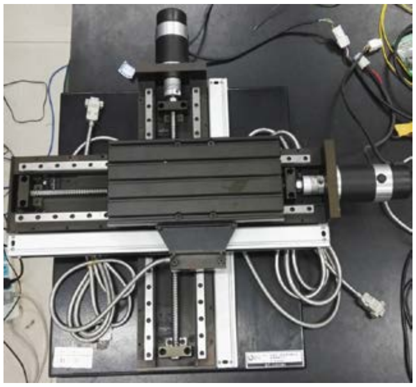


Fig.9 Full closed loop two dimensional DC servo motion control experiment platform

A driver manufactured by a domestic manufacturer is used as the control.

In the position simulation control experiment, PID control algorithm generally only uses the proportional element as a means of control. If the integration element or differential element is introduced, the overstrike will be significant as shown in Fig. 10. The MLDS2410 driver position loop uses only P parameter. Both I parameter and D parameter are 0. Control using only the proportional element can reduce the overstrike. However, the adjustment time will be increased. Shown in Fig. 11 and Table 2 are comparative test results in the position mode.

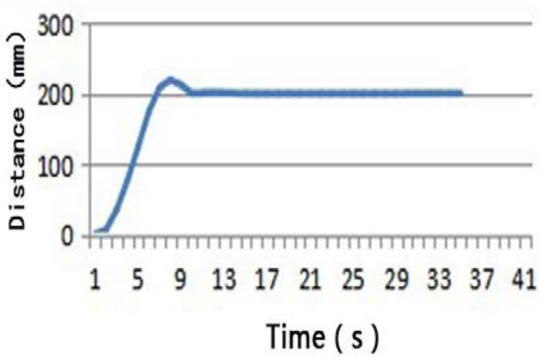


Fig10 Join PI parameter control result chart

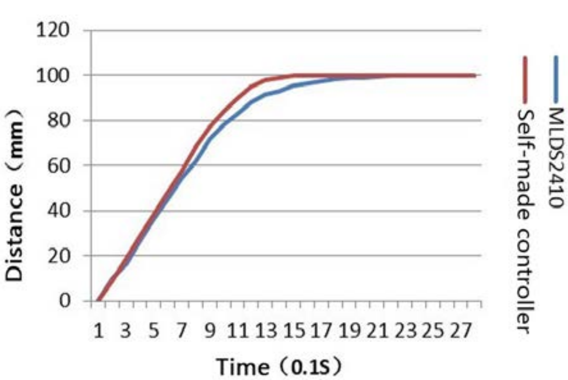


Fig11 Experimental results of position mode

Table2 Location mode test results table

Set position mm	Model	Actual position mm	Operation time S	Static error mm
30	MLDS2410	30	2.8	±0.04
	Self-made controller	30	2.3	±0.04
50	MLDS2410	50	3.2	±0.06
	Self-made controller	50	2.1	±0.06
100	MLDS2410	100	3.6	±0.04
	Self-made controller	100	2.4	±0.04
150	MLDS2410	150	4.7	±0.06
	Self-made controller	150	3.4	±0.06
200	MLDS2410	200	5.6	±0.04
	Self-made controller	200	4.1	±0.04

As indicated in Fig. 11 and Table 9, without overstrike, the DC servo motor design by the design institute enjoys faster response speed and shorter adjustment time as compared to MLDS2410 driver.

V. Conclusion

In this paper, the improved MFAC algorithm is applied to position control of DC servo motor, and the genetic algorithm is used to optimize the parameters. The matlab comparison simulation shows that the improved algorithm has better control effect and the performance of the algorithm is also verified. In addition, the DC servo motor control system sample unit is developed to conduct the motor position control experiment. The experiment results are consistent with the simulation results. The feasibility of the algorithm is verified. Through test, proper improvement of the algorithm is made to allow the algorithm to get the ideal control effect.

The simulation and experiment results indicate that the improved MFAC algorithm can demonstrate better control effect when applied to position control of motor and can meet the requirements for motor position control. This provides a theory foundation for further research and application of the algorithm.

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