

PID Optimization of CNC Machine Tool Feed Servo System based on SOA Algorithm

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Abstract

The high-precision feed control of CNC machine tools generally adopts an AC servo system driven by a permanent magnet synchronous motor. This paper first establishes a mathematical model for the system, and then uses SOA optimization algorithm, PSO optimization algorithm and GA genetic algorithm to tune the system PID parameters, and finally compares the advantages and disadvantages of SOA algorithm in PID parameter optimization.

Keywords

CNC Machine Tools; PID Control; SOA Algorithm.

1. Introduction

PID control is one of the typical industrial controls. For PID control, the main difficulty lies in the PID parameter tuning. In the current industrial control, PID parameter tuning mostly relies on empirical methods. According to continuous debugging, we try to get a more reasonable PID parameters meet the requirements of the system. With the emergence of intelligent algorithms, some algorithms, such as SOA, PSO, GA, etc., have better robustness and can provide reference for system PID parameter tuning, so that the system converges to the best state.

The functions of each calibration link of the PID controller are as follows:

- (1) Proportional link: It reflects the deviation $e(t)$ of the control system proportionally. Once the deviation occurs, the controller immediately takes effect to reduce the deviation.
- (2) Integral link: Mainly used to eliminate static error and improve the non-difference of the system. The intensity of the integral action depends on the integral time constant T_i . The larger T_i is, the weaker the integral action, and vice versa.
- (3) Differential link: It reflects the change trend of the deviation signal, and can introduce an effective early correction signal into the system before the deviation signal becomes too large, thereby speeding up the action of the system and reducing the adjustment time.

SOA directly simulates human intelligent search behavior, based on the traditional direct search algorithm, the concept is clear, clear, and easy to understand. It is a new type of swarm intelligence algorithm in the field of evolutionary algorithm research. It adopts the PID parameter tuning optimized by SOA, which has fast convergence and robustness. Features such as good stickiness.

2. PMSM mathematical model of CNC machine tool feed servo system

Under the situation of rapid industrial development in modern times, the AC servo system driven by permanent magnet synchronous motors can enable CNC machine tools to achieve higher control accuracy. Permanent magnet AC servo motors are generally divided into built-in and external-mounted [1]. The main differences between the two are: the reluctance of the

d-axis in the built-in type and the embedded type is greater than that of the q-axis, which belongs to the salient-pole synchronous motor; Hidden pole synchronous motor.

Assumptions:

- (1) Do not consider the interference of environmental factors on winding resistance, such as temperature;
- (2) Does not consider core loss
- (3) Eliminate the saturation of the magnetic circuit, and each winding is determined to be linear mutual inductance and linear self-inductance;
- (4) Stator three-phase windings with a symmetrical structure, and the magnetic potential generated by the stator windings in the motor air gap is sinusoidal, regardless of the high-order harmonics in the space;
- (5) No-load potential of sine wave;
- (6) The motor damping winding can be transformed into two equivalent independent damping windings, and after the equivalent, the d and q direction axes are in a short-circuit state respectively.

Generally, as long as the above conditions can be met, it belongs to an ideal motor [2], but in engineering applications, the actual motor can generally be studied as an ideal motor, and errors are allowed within a certain range. As shown in Figure 1, the equivalent structure coordinates in the figure can be expressed as an idealized PMSM [3].

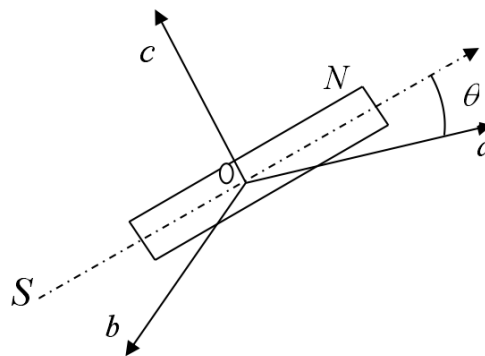


Figure 1. PMSM equivalent structure coordinates

In Figure 1, Oa , Ob , and Oc are the three axes of the three-phase stator winding respectively. The electrical angle between the axis of the stator a-phase winding and the axis of the rotor is defined as θ , and then the relevant equations of PMSM can be established:

$$\begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} = \begin{bmatrix} R_a & 0 & 0 \\ 0 & R_b & 0 \\ 0 & 0 & R_c \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} \varphi_a \\ \varphi_b \\ \varphi_c \end{bmatrix} \quad (2-1)$$

$$\begin{bmatrix} \varphi_a \\ \varphi_b \\ \varphi_c \end{bmatrix} = \begin{bmatrix} \cos 0^\circ & \cos 120^\circ & \cos 240^\circ \\ \cos 240^\circ & \cos 0^\circ & \cos 120^\circ \\ \cos 120^\circ & \cos 240^\circ & \cos 0^\circ \end{bmatrix} \begin{bmatrix} L_a i_a \\ L_b i_b \\ L_c i_c \end{bmatrix} + \begin{bmatrix} \cos \theta \\ \cos(\theta - 120^\circ) \\ \cos(\theta - 240^\circ) \end{bmatrix} \varphi_f \quad (2-2)$$

In equations (2-1) and (2-2), φ_a , φ_b , and φ_c are the three flux linkages of the three-phase stator winding, i_a , i_b and i_c are the three currents of the three-phase stator winding, u_a , u_b , u_c represents the three voltages of the three-phase stator windings, R_a , R_b and R_c the resistance of the three-phase stator windings, and $R_a = R_b = R_c = R$, $L_a = L_b = L_c = L$ is the inductance of the three-phase stator winding, φ_f represents the rotor magnetic field The equivalent flux linkage [4]. Three-phase stator alternating current can generate a rotating magnetic field, but due to two symmetrical windings with orthogonal phases, when two alternating currents with a phase difference of 90° are passed through, a rotating magnetic field can also be generated. Therefore, if you want to find the motor-related control laws and establish a mathematical

model that is easier to implement, you can use the principle of vector conversion to establish the coordinate structure of the permanent magnet synchronous motor. The d-q coordinate system in which the rotor rotates synchronously can make the rotor pole, The d axis coincides with each other, and the q axis is over 90° electrical angles forward along the direction of rotation, and then all the parameters of the permanent magnet synchronous motor stator are transformed into the d-q rotating coordinate system [5].

According to the above-mentioned state equation, we can draw the PMSM feed servo system block diagram as shown in Figure 2.

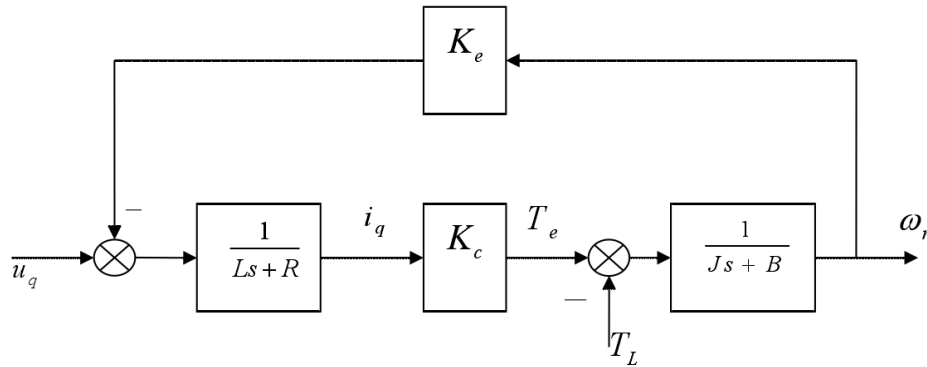


Figure 2. Block diagram of PMSM feed servo system

In this figure, $K_e = p_n \varphi_f$ represents the motor back-EMF constant, and $K_c = 1.5 p_n \varphi_f$ represents the motor torque coefficient.

The mathematical model of the CNC machine tool feed servo system in the field-oriented ($i_d=0$ control mode) can use the following transfer function, as shown in formula (2-3):

$$G_M(S) = \frac{K_c}{LJS^2 + (RJ + LB)S + BR + K_c K_e} \quad (2-3)$$

Among them, B is the total viscous damping coefficient, L is the winding inductance of the motor, R is the resistance of the motor coil, $K_e = p_n \varphi_f$ is the back-EMF constant of the motor, J is the total moment of inertia, and $K_c = 1.5 p_n \varphi_f$ is the torque coefficient of the motor [6], Given simulation parameters: determine the value of the inductance $L = 8.0e - 3(H)$, the resistance value $R = 2.5(\Omega)$, the total moment of inertia and the total coefficient of viscous damping as $J = 0.8e - 3(km.m^2)$ and $B = 0.01(N.m/(rad/s))$ respectively, the magnetic pole $p_n = 4$, and the magnetic flux $\varphi_f = 0.18(Wb)$ of the permanent magnet.

Substituting the parameters into:

$$G_M(S) = \frac{1.05}{6.8 \cdot 10^{-6} S^2 + 2.47 \cdot 10^{-3} S + 0.7925} \quad (2-4)$$

3. PID optimization of CNC machine tool feed servo system based on SOA algorithm

3.1. Coding of parameters

Let the number of individual searchers in the population P be S , and the position vector of each particle is composed of three control parameters of the PID controller, that is, the dimension of the individual position vector $D=3$. The population can be represented by an $S \times D$ matrix:

$$P(S, D) = \begin{bmatrix} K_p^1 & K_i^1 & K_d^1 \\ K_p^2 & K_i^2 & K_d^2 \\ \dots & \dots & \dots \\ K_p^S & K_i^S & K_d^S \end{bmatrix}$$

Taking into account the diversity of the control system, the user can determine the value range of each parameter, and the initial population can be randomly generated within the allowable value range.

3.2. Selection of fitness function

In the process of search evolution, SOA algorithm only uses fitness value to evaluate the pros and cons of individuals or solutions, and as a basis for future search for individual location updates, so that the initial solution gradually evolves to the optimal solution. The fitness function is the link between the searcher optimization algorithm and the control system, and it guides the algorithm to continuously evolve according to the requirements of the control goal. In order to obtain satisfactory dynamic characteristics of the transition process, the absolute value of the error time integral performance index is used as the minimum objective function for parameter selection. In order to prevent the control amount from being too large, the square term of the control input is added to the objective function. The objective function is selected as shown in formula (3-1):

$$F = \int_0^{\infty} (\omega_1 |e(t)| + \omega_2 u^2(t)) dt \quad (3-1)$$

Among them, $e(t)$ is the system error, $u(t)$ is the controller output, and ω_1 and ω_2 are the weights.

In order to avoid overshoot, penalty control is adopted, that is, once overshoot occurs, the amount of overshoot is regarded as one of the optimal indicators. At this time, the optimal indicator is equation (3-2):

$$\text{if } e(t) < 0, F = \int_0^{\infty} (\omega_1 |e(t)| + \omega_2 u^2(t) + \omega_3 |e(t)|) dt \quad (3-2)$$

Where ω_3 is the weight, and $\omega_3 \gg \omega_1$, usually $\omega_1 = 0.999$, $\omega_2 = 0.001$, $\omega_3 = 100$.

3.3. Algorithm flow

The principle of PID parameter tuning based on SOA is shown in Figure 3.

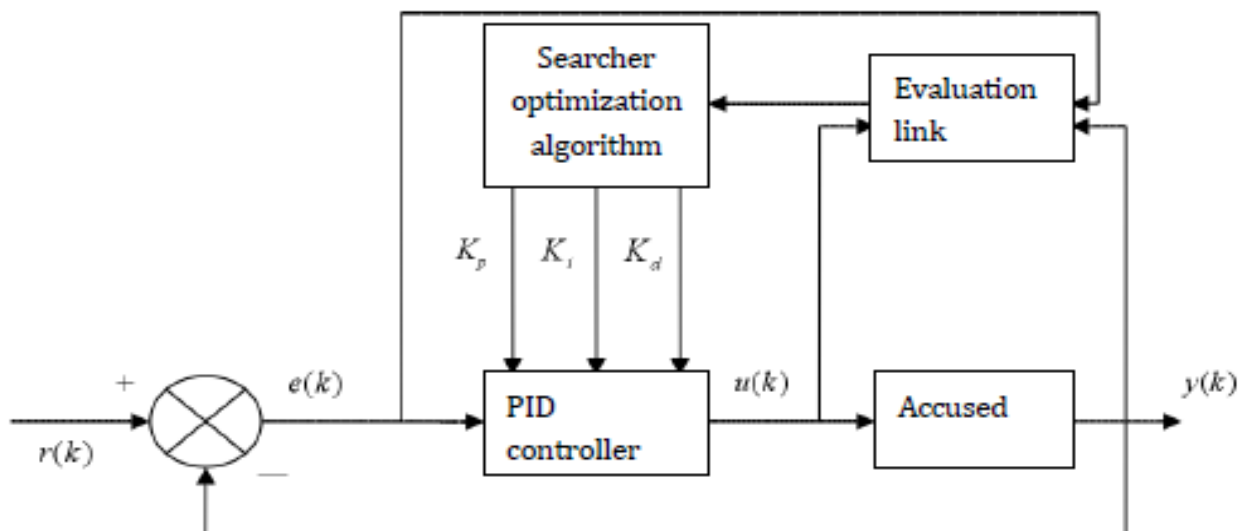


Figure 3. Principle diagram of PID parameter tuning based on SOA

After the parameter encoding and fitness function are determined, the SOA algorithm used for PID parameter tuning is as follows:

(1) Initialize the position of each individual searcher, and randomly generate an $S \times D$ position matrix.

- (2) Calculate the fitness value of individual searchers according to equations (3-1) and (3-2).
- (3) Compare the location of each individual searcher with the best location in history. If the current location is better, record the current location as the best location in the history of the individual.
- (4) Compare the position of each individual searcher with the best position in the history of the population. If the current position is better, record the current position as the best position in the history of the population.
- (5) Update the position according to the formula.
- (6) If the end condition is not reached, return to step (2).

4. Simulation analysis

The object is simulated by SOA algorithm, PSO algorithm and GA algorithm. The population size is 30, and the maximum number of iterations is 100. Using MATLAB tool, three algorithm parameter optimization results can be obtained.

Table 1. SOA algorithm, PSO algorithm and GA algorithm parameter optimization results

parameter	KP	KI	KD
SOA optimization results	0.0409	64.3602	0
PSO optimization results	0.1094	67.6368	0
GA optimization results	0.2695	67.2737	0

After obtaining different control parameters, if you want to analyze the parameter control effect after tuning, you need to bring the parameters back to the original control system, and then use MATLAB to simulate the change trend of the system step output response and output error , The simulation results are shown in Figure 4 and Figure 5.

It can be seen from Figure 4 and Figure 5 that from the results of SOA optimization algorithm, PSO optimization algorithm and GA genetic algorithm tuning the system PID parameters, GA genetic algorithm has the fastest convergence speed, but the error is greater, while SOA The optimization algorithm converges slightly slower, but the error is smaller, while the PSO algorithm is in the middle. From the results of the algorithm, we can see that the SOA algorithm has its advantages in PID parameter optimization, but it also has disadvantages.

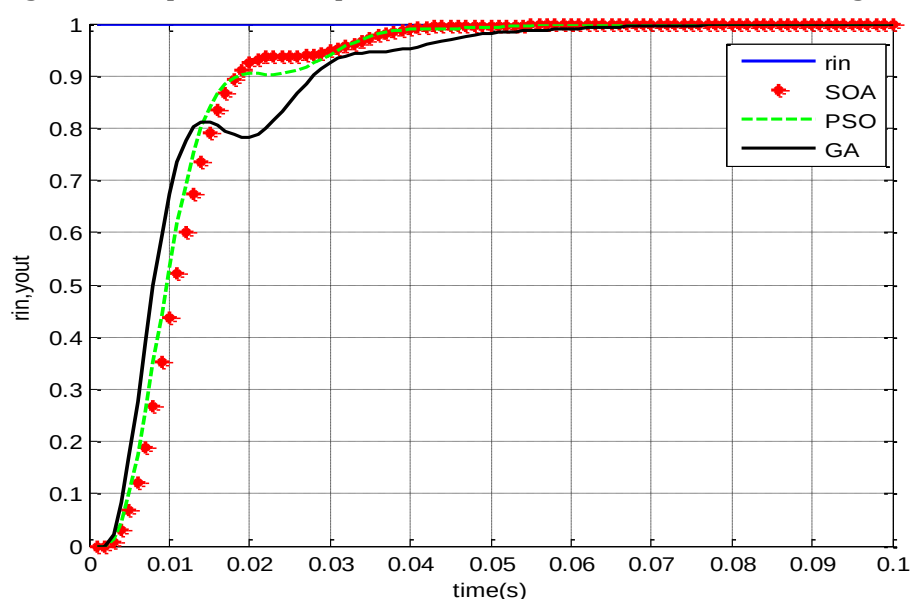


Figure 4. Comprehensive output step response curve

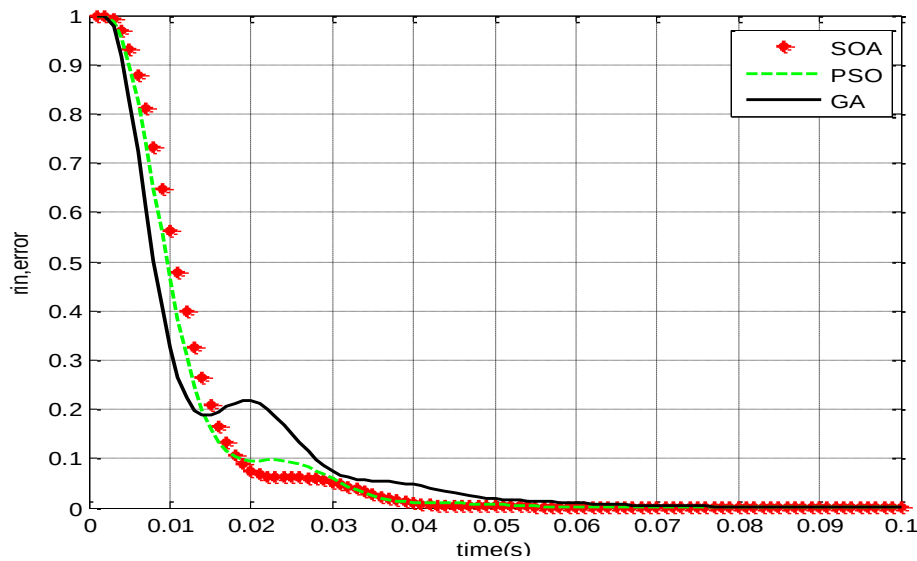


Figure 5. Comprehensive output step response error curve

5. Conclusion

The feed servo system determines the accuracy of a CNC machine tool, and whether the servo system can exert its maximum effect is determined by its control parameters. Therefore, in order to obtain the desired effect, the most direct way is to select a suitable method to tune the control parameters. In order to study the optimization effect of SOA algorithm in the servo system, the article uses the SOA algorithm to tune the system controller parameters and analyzes its related performance, and uses the PSO optimization algorithm and GA genetic algorithm to carry out the second-order delay system PID parameter tuning. It can be seen that the SOA algorithm has the advantages of fast convergence speed, high accuracy, and small error.

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