Research on optimization of improved ant colony algorithm in the temperature control process of cold creep forming

Yiming Xu¹, Naijia Liu² and Peng Xue¹*  
¹School of Electrical and Electronic Engineering, Changchun University of Technology, Jilin,130012, China  
²School of Electrical and Electronic Engineering, Changchun University of Technology, Jilin,130012, China  
*Corresponding author’s e-mail: xuepeng@ccut.edu.cn

Abstract. In the process of cold creep forming, the temperature control has problems such as low accuracy and slow response speed. Moreover, the conventional PID temperature controller has poor anti-interference ability and low control accuracy. This paper designs a PID control strategy based on improved ant colony algorithm which is applied to the temperature control of cold creep forming. With the help of Matlab simulation software, a temperature controller simulation model is established, and certain improvements are made to the model on the basis of the traditional ant colony algorithm, applying to search for the optimal parameter combination in PID control. The simulation results show that the designed control strategy can find a better parameter combination than the PID control of the ant colony algorithm. Therefore, the application of this control method to the cold creep forming temperature control system can effectively improve the product quality and production efficiency of the cold creep forming process.

1. Introduction
In recent years, with the continuous development of cold extrusion forming technology, a new type of cold extrusion forming technology-cold creep forming control technology has been widely used in metal plastic forming [1]. During the cold creep forming process, many factors such as the heat produced by material, the friction between the screw and barrel of the extruder, and the speed of the extruder motor will cause the internal temperature of the system to fluctuate greatly, and the temperature output value cannot be effectively guaranteed. The temperature control of the creep forming process becomes extremely complicated [2].

The temperature control of the traditional cold extrusion system adopts the conventional PID control method in general, but the conventional PID control cannot automatically adjust the parameters and it consumes a lot of time and manpower. Aiming at the above problems, this paper designs a PID control strategy based on improved ant colony algorithm. This control method can find the optimal parameter combination quickly and effectively and realize the optimal control of the temperature in the cold creep forming process.

2. Model establishment of temperature control system for cold creep forming
It is crucial to establish a mathematical model of the temperature control system for cold creep forming, which is the basis for ensuring the efficient operation of the temperature control system for
cold creep forming[3]. As a new type technology of cold extrusion forming, its extruder temperature control system generally adopts a separate instrument control scheme. The heating and cooling method is electric heating coil zone heating, and the temperature controller adopts traditional PID control technology. The initial temperature is generally set according to the most suitable temperature for processing metal components.

In the process of temperature control, the dynamic characteristics of electric heating equipment are usually regarded as a line system. One or two inertial links are connected in series with a pure lag link, which is often approximated as a first-order inertial link. This approximation in most cases is reasonable. The electric heating device refered to this article is an electric heating wire, and the equivalent model is[4]:

$$G(x) = \frac{K e^{-\tau x}}{T x + 1} (1)$$

Where $K$ is the static gain of the controlled object, $T$ is the time constant of the controlled object, and $\tau$ is the lag time of the controlled object.

3. Improved ant colony algorithm

3.1 Ant Colony Algorithm

As a simple and easy swarm intelligent search algorithm, ant colony algorithm has the characteristics of distributed computing, strong robustness, and easy combination with other intelligent algorithms[5]. This paper makes certain improvements based on the ant colony algorithm and applies it to the PID controller to find the optimal combination of PID parameters. In the research of ant colony algorithm, the traveling salesman (JSP) problem is usually selected to obtain its mathematical model. State transition formula: the state transition probability of ant $k$ moving from node $i$ to node $j$ at time $t$ is:

$$p_{ij}^{k}(t) = \begin{cases} \frac{[\tau_{ij}(t)]^{\alpha} [\eta_{ij}(t)]^{\beta}}{\sum_{s \in \text{allowed}_k} [\tau_{is}(t)]^{\alpha} [\eta_{is}(t)]^{\beta}}, & j \in \text{allowed}_k(2) \\ 0, & \text{otherwise} \end{cases}$$

In formula (2), allowed$_k = \{C \in \text{tabu}_k\}$ is the set of elements that can be selected and not walked in the forward direction of ant $k(k = 1, 2, 3, ... m)$, $C = \{c_1, c_2, c_3, ..., c_n\}$ is non-repeated continuous paths and $\alpha$ is the pheromone heuristic factor, which represents the parameter of path selection bias or emphasis. As the value of $\alpha$ increases, ant $k$ is more inclined to choose the route that the ant has taken before, indicating that the closer the connections between individuals are. $\beta$ is the expected heuristic factor, which represents the degree of expected selection. As the value of $\beta$ increases, the state transition probability will become more greedy principle [6]. $\tau_{ij}(t)$ is the pheromone of the path when ant $k$ moves from node $i$ to node $j$ at time $t$. $\eta_{ij}(t)$ is the heuristic function of ant $k$ moving from node $i$ to node $j$ at time $t$. The value of $\eta_{ij}(t)$ is the reciprocal of path $d_{ij}$, the expression is as follows:

$$\eta_{ij}(t) = \frac{1}{d_{ij}} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} (3)$$

Global adjustment criterion: Only the ant whose solution searched in the previous cycle is closer to the optimal solution than other ants is allowed to adjust the pheromone. The number of pheromone on $(i, j)$ at time $t + h$ can be updated according to certain rules:

$$\tau_{ij}(t + h) = (1 - \rho) \cdot \tau_{ij}(t) + \Delta \tau_{ij}(t) (4)$$

$$\Delta \tau_{ij}(t) = \sum_{m=1}^{n} \Delta \tau_{ij}^{k_m}(t) (5)$$

In formula (4), $\rho$ is the pheromone volatilization coefficient, and the value space of $\rho$ is $\rho \in (0, 1)$; In formula (5), $\Delta \tau_{ij}^{k_m}(t)$ is the pheromone left by ant $k$ on the path $d_{ij}$ at time $t$.

Because of the different expressions of $\Delta \tau_{ij}^{k_m}$, this article selects the Ant-Cycle model as the ant colony algorithm model:

$$\Delta \tau_{ij}^{k_m}(t) = \begin{cases} 0, & \text{if the kth ant passes through } (i, j) \text{ in this cycle} \\ \frac{Q}{d_{ij}}, & \text{otherwise} \end{cases} (6)$$
In formula (6), $Q$ represents the pheromone intensity, and $L_k$ is the total search length of ant $k$ in this cycle.

### 3.2 Improvement of ant colony algorithm

When the traditional ant colony algorithm solves problems, as the number of ants increasing continuously, the global search performance of the traditional algorithm is greatly improved, and it is not easy to fall into local extreme values and other puzzles. In view of the slow global search speed of traditional ant colony algorithm, this paper makes certain improvements to the search strategy of ants in ant colony algorithm. More specially, the ant used to search is increased to two instead of original one, and the two ants start from the same starting point and forward to different directions. The search is over when the two ants encounter again, and the sum length of the search paths of the two ants is the experimental cycle length.

Improvement of the state transition formula:

$$Y = \begin{cases} \arg \max [\tau_{ij}[t]^{\alpha} \cdot [\eta_{ij}[t]]^{\beta}, & \text{if } q \leq q_0 \\ \text{Choose according to formula 2-1}, & \text{if } q > q_0 \end{cases} \quad (7)$$

In the above formula, $q$ obeys the uniform distribution of $(0, 1)$, and $q_0 \in [0, 1]$, the smaller $q_0$ is, the greater the randomness of the corresponding transition probability. $D$ represents the set of all the paths that ant $k$ traverses in a search process:

$$D = \{ D[k] | D[k] = \sum_{i,j \in C} d_{ij}[k], k = 1, 2, \ldots, m \} \quad (8)$$

$$d(N)_{\min} = \{ D[K] \}_{\min} \quad (9)$$

$$d(N)_{\text{aver}} = \sum_{k=1}^{m} d[k] \quad (10)$$

Equation (9) is the shortest path taken by the $k - t^h$ ant in the $N - th$ search cycle; Equation (10) is the average value of the total path taken by all ants in the $N - th$ search cycle. Only when $d(N)_{\min} \leq d(N - 1)_{\min}$ and $D[k] < d(N)_{\text{aver}}$, the ant will update the pheromone according to formula (6).

Limit the value of the number of pheromones to the interval $[\tau_{\text{max}}, \tau_{\text{min}}]$, where $\tau_{\text{min}}$ is a value that can reduce the probability of algorithm stagnation, and $\tau_{\text{max}}$ is a value that can reduce the probability of abnormal accumulation of pheromone. After the search of the two ants is over, the optimal solution in the current search process is retained, and the value of $\tau_{ij}(t)$ is judged based on formula 2-5, and then selected by the threshold function. The specific formula is as follows:

$$\tau_{ij}(t + h) = \begin{cases} \tau_{\text{min}}, & \tau_{ij}(t) \leq \tau_{\text{min}} \\
\tau_{\text{min}}, & \tau_{\text{min}} < \tau_{ij}(t) < \tau_{\text{max}} \\
\tau_{\text{max}}, & \tau_{ij}(t) \geq \tau_{\text{max}} \end{cases} \quad (11)$$

Meanwhile, an adaptive adjustment strategy is adopted for the value of the pheromone volatilization coefficient $\rho$, and there is a negative feedback relationship between the pheromone volatilization coefficient $\rho$ and the algorithm’s global search performance. Therefore, the dynamic pheromone volatilization coefficient $\rho$ can be used to make the value of $\rho$ adaptively decrease as the number of cycles increases, and the threshold function is used to further restrict the change of the value of $\rho$. The expression is as follows[7]:

$$\rho(t + h) = \begin{cases} \xi \rho(t), & \xi \rho(t) > \rho_{\text{min}} \\
\rho_{\text{min}}, & \text{otherwise} \end{cases} \quad (12)$$

In formula (12), $\xi$ is the volatilization constraint coefficient, which is a constant and $\xi \in (0, 1)$.

### 4. Improved ant colony algorithm PID controller design

#### 4.1 Improved ant colony algorithm PID controller principle

In this paper, the path search method of ants in the ant colony algorithm is improved to some extent, and
the three parameters of PID control $K_p$, $K_i$, $K_d$ are optimized by the improved ant colony algorithm, and the optimal parameter combination is searched.

$$y(t) = K_p \left[ e(t) + \frac{1}{K_i} \int_0^t e(t) \, dt + K_d \frac{de(t)}{dt} \right]$$ (13)

Where $K_p$ is the proportional gain constant, $K_i$ is the integral time constant, and $K_d$ is the derivative time constant. The operation of the PID controller can be summarized as the input quantity $r(t)$ and output quantity $y(t)$ of the system at all times, to produce a corresponding deviation $e(t)$, and the improved ant colony algorithm is used to generate search results Optimal combination of PID parameters to optimize the control effect of the system.

The improved ant colony algorithm is used to search for the optimal parameter combination of the three parameters of the PID controller $K_p$, $K_i$, and $K_d$, which can be represented on the $x0y$ plane of the rectangular coordinate system. Assuming that they all have three valid digits, there are 9 lines with the same spacing and length on the plane of $x0y$ and perpendicular to the $x$-axis are $L_1$, $L_2$, ..., $L_9$. Among them, $L_1$, $L_2$, $L_3$ are the three digits of $K_p$, $L_4$, $L_5$, and $L_6$ are the three digits of $K_i$, and $L_7$, $L_8$, and $L_9$ are the three digits of $K_d$ [8]. Assuming that any two ants start at the same time from the origin of the coordinates, when they meet at any point on the line segment $L_9$, one cycle ends, and the shortest path at this time is the sum of the paths passed by the two ants. The path taken by the two ants $a$ and $b$ in this cycle can be expressed as:

Path$_a$: $0$-$Node(x_{1,a}, y_{1,a})$-$Node(x_{2,a}, y_{2,a})$-$Node(x_{3,a}, y_{3,a})$-$Node(x_{9,a}, y_{9,a})$

Path$_b$: $0$-$Node(x_{1,b}, y_{1,b})$-$Node(x_{2,b}, y_{2,b})$-$Node(x_{3,b}, y_{3,b})$-$Node(x_{9,b}, y_{9,b})$

Node$(x_{i,a}, y_{i,a})$ are all above the line segment $L_i$. The three parameters of the PID controller can be obtained by the following formula:

$$
K_p = (y_{1,a} + y_{1,b}) \times 10^4 + (y_{2,a} + y_{2,b}) \times 10^0 + (y_{3,a} + y_{3,b}) \times 10^{-1}
$$

$$
K_i = (y_{4,a} + y_{4,b}) \times 10^0 + (y_{5,a} + y_{5,b}) \times 10^{-1} + (y_{6,a} + y_{6,b}) \times 10^{-2}
$$

$$
K_d = (y_{7,a} + y_{7,b}) \times 10^0 + (y_{8,a} + y_{8,b}) \times 10^{-1} + (y_{9,a} + y_{9,b}) \times 10^{-2}
$$

4.2 Improved ant colony algorithm PID parameter optimization steps

(1) Parameter initialization, set the number of ants $m$, the maximum number of cycles $N_{\text{max}}$, define two ants $a$, $b$ and two one-dimensional arrays Path$_a$, Path$_b$ containing 9 elements that participate in the search each time, and route the two ants The ordinate of each node of the path is stored in sequence.

(2) Two ants start searching from the same starting point. Two ants calculate the probability of two ants reaching the next node, and store the ordinates of the nodes reached during this period in Path$_a$, Path$_b$ in turn. If two ants meet at the 9th node, proceed the next step, otherwise the two ants continue to search until they meet at the 9th node.

(3) Adjust the value of the volatilization coefficient $\rho$ adaptively and update the pheromone $\rho_{ij}(t)$.

(4) If the maximum number of cycles has not been reached at this time and the paths of all the ants that have been searched are different, reset the ants to 0 and return to step 2 to search again; if the path
of the ants is the same or the maximum cycle is reached at this time Times, then go to the next step.

(5) By using each element in the array Patha and Pathb of ants a and b calculate the corresponding PID parameters \( K_p, K_i, K_d \).

(6) Output the optimal combination of \( K_p, K_i, K_d \) parameters.

5. Simulation and experiment

In the Matlab simulation environment, the code to improve the ant colony algorithm was written, and the temperature PID controller model was built using Simulink. The operating parameters of the improved ant colony algorithm are the number of ants \( m = 50 \), the pheromone volatilization factor \( \alpha = 1 \), the expected heuristic factor \( \beta = 2 \), the information volatilization coefficient \( \rho = 0.1 \), and the number of iterations \( N = 180 \).

![PID parameter value of each generation](image)

Figure 2. This figure shows the parameter values of \( K_p, K_i, \) and \( K_d \) of each generation after 180 iterations.

In order to verify the anti-interference ability of the improved ant colony algorithm PID control, the interference signal is added at the position of 50s.

![Step response curve with interference signal added](image)

Figure 3. This figure shows the step response curve with interference signal added.

To verify the effectiveness of the designed cold creep forming temperature controller, the simulated stable temperature of creep processing is 10℃, and the improved ant colony algorithm is used to find
the best parameter combination for temperature PID control. In the process of cold creep forming temperature control, the optimal parameter combination found by the improved ant colony algorithm is applied to the temperature controller and the overshoot is very small, which can quickly reach the initial temperature set by the system Near the value, and it is not easy to fluctuate after reaching a stable state.

Figure 4. It shows the error value between the actual temperature and the expected temperature output by the improved ant colony algorithm in the iterative process.

Figure 5. It shows the temperature output curve of the cold creep forming system.

6. Conclusion
Overall, this paper assumes a PID control strategy based on an improved ant colony algorithm, establishes a temperature intelligent control system model and applies it to the cold creep forming process. The control method is verified by simulation experiments and the improved ant colony algorithm PID control is compared with the traditional ant colony algorithm PID control output response waveform [9]. The simulation results show that the PID control method based on the improved ant colony algorithm compensates the disadvantages of the slow reaction rate and poor anti-interference ability referred to the traditional ant colony algorithm PID control, furthermore the new method realizes
more effectively self-tuning parameters leading the temperature always stable around at the system setting value. In addition, the new method saves the processing time of cold creep parts, and improves the production efficiency of the processing, and is regarded as an effective method for the temperature control of cold creep forming technology.

Acknowledgments
Research on Key Technologies and Application of Automated Production of Automotive Air Conditioner Liquid Storage
Item Number: 20180201129GX

References
[1] Zhang leilei. (2017) Research on the Cold Extrusion Technology of the Sun Gear of the Wheel-side Reducer. Master thesis, Chongqing University of Technology, Chongqing.
[2] Yu baiwen, Xue peng. (2020) Optimal control of moth flame algorithm in cold creep forming system. Modern electronic technology, 88-93.
[3] Zhang fan, Li zhuangju. (2019) Research on Optimization of Central Air Conditioning Chilled Water System Based on Improved Ant Colony Algorithm. Master thesis, Beijing Architecture University, Beijing.
[4] Chen Mingxia, Zhang han, Li shunyan. (2019) Temperature Control System of Plastic Extruder Based on Chaos Ant Colony Algorithm. Master thesis, Guilin University of Technology, Guilin.
[5] Jiang jin. (2014) Distribution route optimization information service based on ant colony algorithm and its software implementation. Master thesis, Northeast Forestry University, Harbin.
[6] Luo yanmei. (2019) Research on multi-objective workshop scheduling based on improved ant colony algorithm. Master thesis, Guangdong Ocean University, Zhenjiang.
[7] Yang dong. (2017) Research on Thrust Distribution and Optimization Algorithm Based on Fault Tolerance of Ship Propulsion. Master thesis, Harbin Engineering University, Harbin.
[8] Yu kai, Zhang jiugen, Zhu yuan. (2019) Central air-conditioning chilled water system genetic ant colony algorithm optimization research control. Master thesis, Nanjing University of Technology, Nanjing.
[9] Wang chenglong. (2016) Research on Control Algorithm of Quadrotor Aircraft. Master thesis, Guilin University of Electronic Technology, Guilin.