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Application of Improved Particle Swarm Optimization Algorithm in Converter Differential Pressure

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Abstract. In view of the characteristics of nonlinear, time varying and large disturbance of converter pressure difference control object. The control scheme of the converter differential pressure is analyzed. An improved particle swarm optimization algorithm (ISPO) is used to optimize the PID parameters of the converter differential pressure controller, which enhances the adaptive ability of the PID controller. At the same time, the inertia weight w adopts a nonlinear decreasing strategy and increases the extreme value perturbation operator. The evolutionary stagnation step t is set as the threshold value, and the individual and global extremum of the PSO are randomly perturbed by the extreme value perturbation operator, so that the system is always in an unbalanced state, In this way, the PSO algorithm is prevented from falling into a stagnant state, a new search path and domain are generated, the optimization of the three parameters of the PID is accelerated, and the probability of obtaining the optimal solution is greatly increased, and the optimization of the three parameters of the PID is accelerated. Finally, the simulation analysis and engineering application of matlab show that compared with the conventional PID control, the improved differential pressure of the converter controlled by the improved particle swarm optimization algorithm has the advantages of small overshoot, short adjustment time, good stability and strong antiinterference ability.

Key words: Converter gas; differential pressure; particle swarm optimization; PID optimization.

1. Introduction

In the process of converter steelmaking, a large amount of high-temperature and high-pressure flue gas containing CO is generated, which has important practical significance for the purification and recovery of CO in flue gas. The effect of converter gas recovery and flue gas emission reduction depends on the differential pressure control of the furnace mouth, which is generally required to be controlled within ±20 Pa [1]. However, the technical equipment and control methods of steelmaking enterprises in China are backward, especially for systems with nonlinear and large disturbances in industries such as converter differential pressure control. Conventional fixed-parameter PID control is often difficult to meet control requirements.

In recent years, various intelligent optimization algorithms have been proposed. The most mature algorithms commonly used for optimal problems are immune algorithm (AIA), ant colony algorithm

(ACO) and genetic algorithm (GA), but these algorithms converge slowly. , can not achieve the purpose of optimization very well. Particle Swarm Optimization (PSO) is especially suitable for the optimization of PID parameters because of its low parameters and fast convergence [2]. However, it is easy to fall into local extremes, slow convergence and low precision in the late evolution. To this end, Hook et al. [3], in the process of particle swarm optimization, remove random disturbance variables, only use inertia weights to adjust, avoid local optimization, and improve convergence efficiency. Zhou Renjun et al. [4] proposed a fuzzy self-correcting particle swarm optimization algorithm. The particle adaptive membership function established by fuzzy inference mechanism can correct the inertia weight according to its current fitness, improve the premature defect and enhance the global search ability. Wang Haolei [5] introduced the cross-operation of niche technology and genetic algorithm into binary quantum particle swarm optimization algorithm, which increased the global search ability of the algorithm and added graph theory to modify the particle in improving the efficiency of the algorithm. Compared with the standard PSO algorithm, the convergence speed and accuracy are improved, but this improved method is not an improved measurement from the PSO algorithm easy to fall into the local extremum, making the PSO algorithm description more complicated, which is not conducive to PSO. Convergence was quantified. In this paper, a PID controller with variable-parameter Gaussian gain function is proposed, and the modified particle swarm optimization algorithm is used to optimize the width of the gain function to realize the tuning of the converter differential pressure PID controller. And experimental applications.

2. Micro differential pressure control scheme of converter

2.1. The principle of analysis

The micro differential pressure control is the main control parameter in the gas recovery process of converter. The pressure inside the converter furnace is greater than the external pressure, which will cause gas to spurt out, resulting in waste of resources and pollution to the environment. If the pressure inside the furnace is less than the external pressure, air will be inhaled, resulting in CO combustion into CO2, also resulting in reduced gas recovery. In order to meet the requirement of looking at the fire process, the pressure difference between furnace mouth and atmosphere is usually controlled as micro differential pressure in engineering [6], the setting value of micro pressure difference is generally from 5 to 15Pa.

In the process of converter steelmaking, the port pressure of converter is first obtained and sent to the differential pressure transmitter through the pressure pipe on the pressure pickup hole installed at the bottom of converter port. After comparing with the external atmospheric pressure, the micro differential pressure transmitter is converted into the standard 4-20mA signal, and then connected to the converter DCS system. The DCS system reads the micro differential pressure signal and compares it with the set value to obtain the micro differential pressure deviation. Then calculated according to installation deviation algorithm used by the regulator 4-20mA output signal, through nonlinear compensation and two wen laryngeal orifice R-D valve position feedback signal after comparison on business value, and then input to the servo amplifier converts the signal to 0-±200mA signal to the electrohydraulic servo valve, the electro-hydraulic servo valve and two wen laryngeal orifice R-D valve of the hydraulic cylinder connections, is used to control two wen laryngeal orifice R-D valve opening, implementation of converter front micro differential pressure adjustment, throat opening pressure of converter and the outside air pressure difference control in a reasonable range. The principle of micro differential pressure control scheme of converter mouth is shown in Fig. 1.

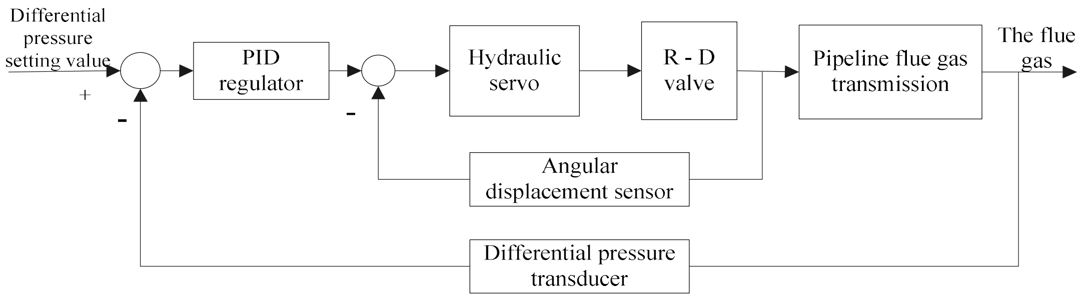

Figure 1. Flow chart of micro differential pressure control scheme of converter mouth

2.2. Study on PID variable parameter control

The converter differential pressure control system is composed of regulator, hydraulic servo device, R-D regulating valve at the second pipe, flue gas transmission pipeline, angular displacement sensor and differential pressure transmitter.

The parameters of conventional PID controller, kp, ki and kd are a set of fixed linear combinations, and the control quantity and output of the system are a mapping relationship [7], which is difficult to meet the requirements of tracking the given and suppressing the interference at the same time. When system characteristics change, the control quality will be reduced. Literature [8] describes a variable parameter PID control method using Gauss function as gain function. Its parameter adjusted Gauss function expression is

$$K_p = K_{p0}\left\{1 + K_p'[1 - \exp(-100e^2)]\right\} \tag{1}$$

$$K_i = K_{i0}\left[K_i' + K_i''\exp(-100e^2)\right] \tag{2}$$

$$K_d = K_{d0}\left[1 + K_d'\exp(-25e^2)\right] \tag{3}$$

For formula (1)-(3), kp, ki and kd are all functional relations of the absolute value of system deviation. In this way, the adjusted parameters only have good control effect on certain specific input changes, while in literature [8], the unit step signal is used as the setting value for simulation. Although the simulation results are good, they are not universal. In order to achieve satisfactory tracking control effect under different conditions and set values, the gain functions of kp, ki and kd are added with adjustable parameter factors, such as αp, αi and αd, so as to change the original fixed width into automatic adjustment and improve the adaptability and control quality of the system. In order to adapt to arbitrary condition and set value, the deviation term in the gain function is taken relative value. The improved function relation is

$$K_p = K_{p0}\left\{1 + K_p'\left[1 - \exp\left(-(e/R)^2/\alpha_p^2\right)\right]\right\} \tag{4}$$

$$K_i = K_{i0}\left\{1 + K_i'\exp\left[-(e/R)^2/\alpha_p^2\right]\right\} \tag{5}$$

$$K_d = K_{d0}\left\{1 + K_d'\exp\left[-(e/R)^2/\alpha_d^2\right]\right\} \tag{6}$$

Then the particle swarm optimization algorithm is used to optimize the undetermined coefficients αp, αi, αd in all gain functions kp, ki, kd.

3. PID parameter optimization based on improved particle swarm optimization

3.1. Simplified particle swarm optimization algorithm

The standard algorithm slows down in the late stage of evolutionary iteration, and it is easy to fall into local optimum. For this reason, many scholars have proposed an improved method. In [9], Hu Wang et al. analyzed the optimization rule of particle swarm optimization algorithm, removed the velocity term of particle optimization, proposed a simplified particle swarm optimization algorithm, and carried out a series of simulation experiments to obtain evolutionary process and particle velocity. Unrelated conclusions. The algorithm formula is as shown in equation (7):

$$x_{id}^{t+1} = wx_{id}^{t} + c_1 r_1 (p_{id}^{t} - x_{id}^{t}) + c_2 r_2 (p_{gd}^{t} - x_{id}^{t}) \tag{7}$$

Where is the inertia factor; the random number between obeying the uniform distribution; and the acceleration factor; the current position of the first-dimensional subspace of the particle for the first iteration. In the optimization and iterative process, the particles use the way of following the individual extremum and the group extremum to find a better position.

The first part on the right side of the equation (7) indicates the influence of the moment position on the time. The magnitude of the inertia factor can be adjusted to coordinate the global and local search ability. The second part is the particle “self-learning term”, and the particle passes the evaluation itself. The location of the experience is used to determine the influence of the historical trajectory on the current particle running trend; the third part is the “social learning item”, which means the search ability of the particle group, and the particles in the group share information with each other.

The simplified particle swarm optimization algorithm removes the velocity term of the standard particle swarm optimization algorithm. By updating the particle position and gradually reducing the optimal value of the weight optimization, the algorithm formula is simplified and the optimization efficiency is improved.

3.2. Improved Simplified PSO Algorithm

Analysis of the standard PSO algorithm shows that the global search ability of the algorithm is mainly related to the inertia weight w. When w is increased, the global search capability becomes stronger, but the search is not careful enough to easily miss the optimal solution. The decrease in w increases the local search ability, and the algorithm search is more careful but easily falls into local optimum [10, 11]. For the balance between local search ability and global search ability, foreign scholars Shi Y and Eberhart [12] proposed a strategy of decreasing the inertia weight w with the number of iterations. The inertia weight w is gradually decreasing linearly with the iteration parameter from the initial value of 0.9. To 0.4. In the early stage of PSO optimization, it has stronger global search ability, and in the later stage, it has stronger local search ability, which makes the optimization result more accurate. However, this simple strategy of linearly decreasing the inertia weight is difficult to find the optimal solution for different problems, and the search ability is limited. The optimization process by particle swarm optimization is itself a nonlinear process. Therefore, we use a nonlinear degressive strategy for inertia weight w. The formula is as follows:

$$w(k) = w_{start} - \left(w_{start} - w_{end}\right)\left(\frac{k}{K_{\mathrm{m}}}\right)^2 \tag{8}$$

Where k is the current number of iterations of the PSO algorithm; Km is the maximum number of iterations. According to the formula analysis, the inertia weight changes slowly when the previous k is small, and the w value is large. At this time, the algorithm has a strong global search ability; when the k is large, the inertia weight changes rapidly, and the w value is small. The time algorithm has strong local search ability, which has better optimization effect.

In addition, because the PSO algorithm will gradually make the particle position tend to be consistent or even the same situation of some individuals, the algorithm will stagnate. Therefore, we introduce the extreme value perturbation operator, set the evolutionary stagnation step t to the threshold value, and randomly perturb the individual and global extremum of the PSO by the extreme value perturbation operator, so that the system is always in an unbalanced state. That is, through the random disturbance adjustment of the extreme value perturbation operator, the particle position during the balance is disturbed to migrate to a new position, thereby avoiding the PSO algorithm from stagnation, generating a new search path and domain, and achieving optimality. The probability of solution is greatly increased. The extreme value perturbation operator is as follows:

$$p_{best} = r_3^{t_p > T_p} p_{best} \qquad g_{best} = r_4^{t_g > T_g} g_{best} \tag{9}$$

Where: respectively, the number of evolution steps of the PSO algorithm falling into the lag; and the threshold of the number of steps for generating the disturbance;

$$r_3^{t_0 > T_0} = \begin{cases} 1, t_0 \le T_0 \\ U(0,1), t_0 \ge T_0 \end{cases} \qquad r_4^{t_g > T_g} = \begin{cases} 1, t_g \le T_g \\ U(0,1), t_g \ge T_g \end{cases} \tag{10}$$

The equation after sPSO increases the extreme perturbation operator is:

$$x_{id}^{l+1} = wx_{id}^{l} + c_1 r_1 (r_3^{t_0 > T_0} p_{best} - x_{id}) + c_2 r_2 (r_4^{t_g > T_g} g_{best} - x_{id}) \tag{11}$$

3.3. Improved particle swarm optimization algorithm initial parameter optimization

The fitness function of the algorithm optimization is based on the differential pressure deviation of the converter object. The criterion is the absolute error value multiplied by the time integral criterion, and its calculation formula is

$$J = \int_0^t t|e(t)|dt \tag{12}$$

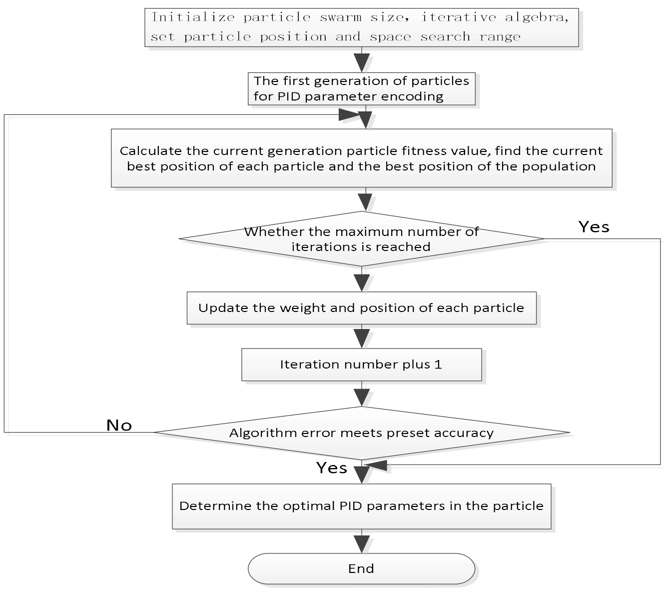

Figure 2. IPSO-PID flow chart

The ITAE criterion is easy to implement on a computer and is an objective function that can express system performance relatively accurately. The algorithm flow is as follows:

4. Simulation and analysis

Before applying to the actual converter gas recovery system,the variable parameter PID control scheme optimized by the IPSO algorithm proposed in this paper is computer simulated, to verify its control performance and compare its results with conventional PID control methods. To this end, this paper uses the identification model of the controlled object of the pressure difference control system of the converter at the second steel slab factory of Maanshan Iron and Steel Co., Ltd[13,14]. Its transfer function is as follows:

$$G(s)=\frac{0.822e^{-1.5s}}{(1+2.22s)\times(1+15.56s)} \tag{13}$$

The population size of the IPSO algorithm in the simulation is 30;particle dimension is set to 3;acceleration constant $c_1=c_2=2$;the maximum number of iterations is 100; $w_{start}=0.9$; $w_{end}=0.4$;particle position range [0,100].Figure 3 shows the evolution curve of the particle swarm using the $IPSO-PID$ algorithm,the optimal value was found around the 15th iteration, fitness value is $2.3333e^{-3}$.

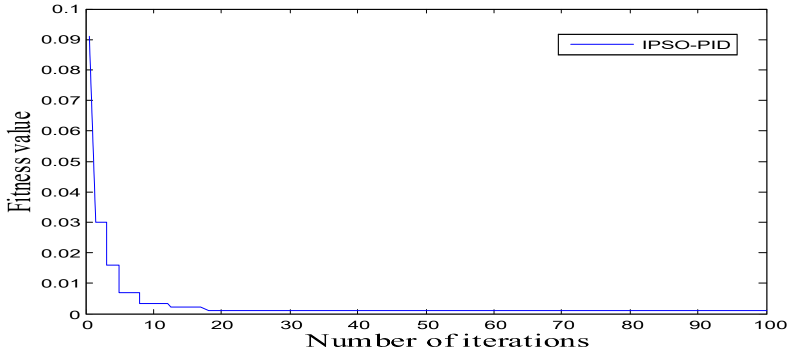

Figure 3. Particle swarm adaptive value evolution process curve

Comparing the $IPSO-PID$ based control method proposed in this paper with the conventional PID control method, in the $IPSO-PID$ control method, The optimal parameter value obtained by the improved particle swarm optimization algorithm is $k_p=0.05$,$k_i=0.03$,$k_d=0.03$,The step response curve of the system is shown in Figure 4:

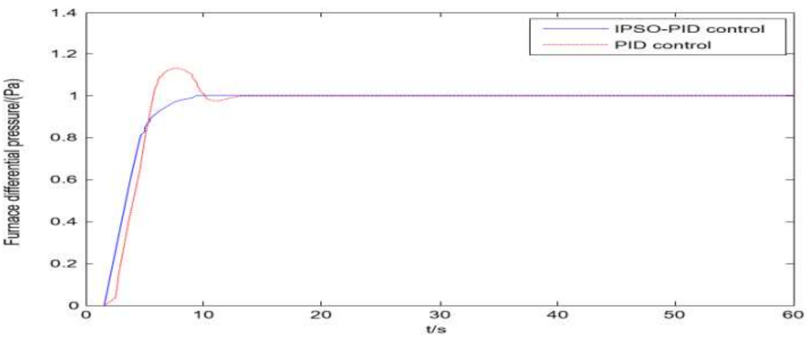

Figure 4. kinds of control method simulation curve

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Through analysis, the PID control has a large overshoot and a slow response speed, while the IPSO control method has a small overshoot, fast response, and good real-time performance.

In the process of steelmaking in the converter, variations in the flow rate of the flue gas, the rotational speed of the fan, and the calorific value can cause disturbance of the differential pressure at the furnace mouth. In order to compare the anti-interference of the $IPSO-PID$ and PID algorithms, add a 15% interference signal in the 30th sampling period, the simulation results are shown in Figure 5:

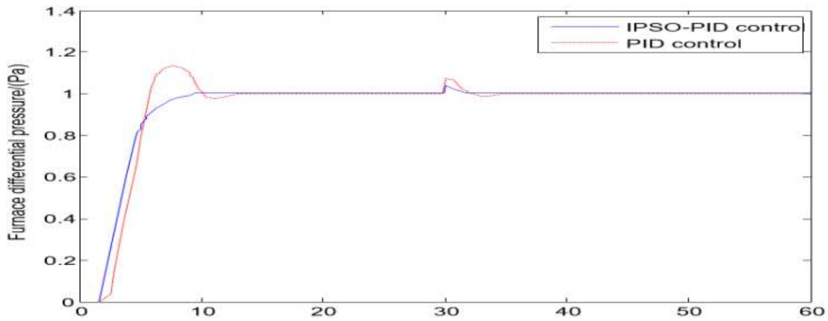

Figure 5. Simulation curve of two control methods under disturbance

As can be seen from the figure, the interference peaks of the $IPSO-PID$ control algorithm and the PID control algorithm are not much different. However, the $IPSO-PID$ control algorithm is robust and has a short time to reach steady state, from the perspective of pursuing system robustness, the $IPSO-PID$ control algorithm is significantly better than the PID algorithm.

5. Engineering Applications

In order to apply the algorithm proposed in this paper to the micro differential pressure control system of the converter at the second steel slab factory of Maanshan Iron and Steel Co., Ltd., the Siemens S7-300 PLC was used as the field controller for programming experiments. The Wincc configuration software is used as the host computer program development monitoring interface. Figure 6 is the PLC program flow chart of the converter furnace port differential pressure control system. Due to the hysteresis characteristics of the differential pressure regulating system of the converter and the life of the electric actuator, the cycle of adjusting the action of the electric valve by the regulator should not be too frequent, and it is set to 7~9 seconds here. Then build the project and program with Step7, the main function programs are: (1) PID controller FB1; (2) Calculate FC1 for three parameters kp, ki, kd. Among them, FC1 includes the improved simplified particle swarm algorithm described herein and the Gaussian gain function of variable parameters. The Wincc configuration screen is used to monitor changes in the differential pressure at the converter port and to set and modify some controller parameters. First, the initial values of some control parameters are determined by Matlab simulation, and then downloaded to the PLC for optimization. Fig. 7 and Fig. 8 are historical trend diagrams of converter differential pressure fluctuations of self-adjusting PID optimized by traditional PID and IPSO, respectively. It can be seen that the PID controller after adding IPSO has better tracking effect than the conventional parameterized PID control, and the anti-interference ability is stronger, which ensures the stability of the differential pressure control of the converter furnace mouth.

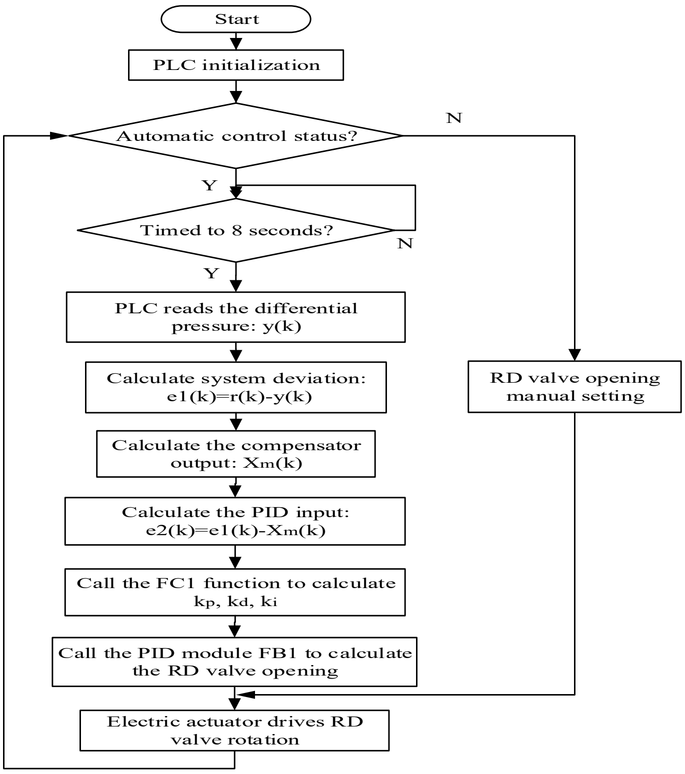

Figure 6. Flow chart of the furnace mouth differential pressure control program

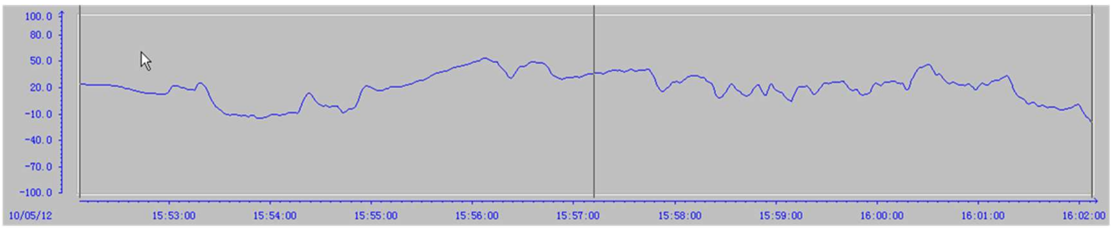

Figure 7. Traditional PID application curve

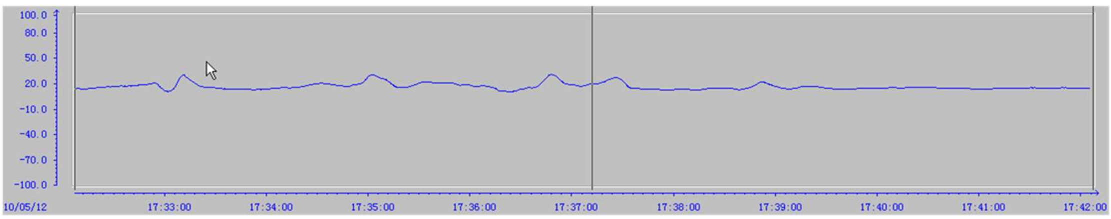

Figure 8. IPSO-PID application curve

6. Conclusion

This paper describes the influence of the differential pressure control technology of the converter mouth on the gas recovery, and analyzes the differential pressure control scheme of the converter mouth, taking the pressure difference control system of the furnace mouth as the research object, an improved simplified particle swarm optimization PID algorithm is proposed. The inertia weight factor is changed to the nonlinear inertia weight which gradually decreases with the number of evolution steps, and the mechanism disturbance factor is added to overcome the defect that the traditional PSO algorithm is easy to fall into a stagnant state. The global search capability of the IPSO algorithm is fully utilized, which

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greatly increases the probability of searching for the global optimal solution. The simulation experiment and engineering application show that the proposed algorithm exhibits good adaptability and anti-interference ability, enabling the control system to accurately and stably track the input. This method has important reference value for solving nonlinear, pure lag, uncertain and large interference problems such as temperature control systems.

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