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Qiang Wang (wang_q@ntu.edu.cn)
Nantong University
Feng Zhang
Nantong University

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Research on Temperature Control System of Capacitor Hot Press Based on Improved Particle Swarm Optimization

Qiang Wang[1, *], Feng Zhang[1]

[1]School of Information Science and Technology, Nantong University, Nantong 226000, China

*Corresponding. wang_q@ntu.edu.cn

*these authors contributed equally to this work

Abstract

In the production of film capacitors, the temperature control of the capacitor hot press is very important. PID control algorithm is widely used in the capacitor hot press. However, traditional PID control algorithm often has difficulty setting parameters. It is not suitable for such a large hysteresis and nonlinear temperature control system. Through the research of traditional PID control algorithm, Particle Swarm Optimization (PSO) algorithm and fuzzy control algorithm, an improved particle swarm algorithm is proposed, and the Improved Particle Swarm Optimization (IPSO) algorithm is applied in the fuzzy PID temperature control system. The temperature control system is simulated by MATLAB. The research results show that the fuzzy PID temperature control system based on IPSO is superior to other temperature control system in terms of adjustment time, overshoot and anti-interference ability.

Introduction

As one of the most basic electronic components in electronic circuits, film capacitors are widely used in consumer electronics, electric vehicles, new energy grid connection, oil and gas exploration, aerospace and other fields. In the production process of film capacitors, the hot pressing process directly determines the quality and service life of film capacitors. If the film capacitor is not well pressed by heat, delamination will occur, so that the film capacitor will have voids, resulting in poor frequency characteristics, increased dielectric loss, and signal distortion. There are three important parameters in the hot pressing process: temperature, time, and pressure. Only under the condition of uniform heating and force, the performance and quality of the film capacitor obtained by hot pressing will be high. During hot pressing, the researchers designed an elastic connection device between the hot pressing plates to achieve uniform pressure on the film capacitor. Because the area of the hot-pressing plate of the capacitor hot-pressing machine is large, the heat balance will be destroyed when entering and leaving the raw materials, and the temperature recovery time of the hot-pressing plate is long. The hot-pressing efficiency and hot-pressing quality further improve the use efficiency of the capacitor hot-pressing machine.

The PID controller is often used in the temperature control system of the capacitor heat press. According to the difference between the given value and the measured value of the system, the PID controller realizes the temperature control through proportional integration and differentiation. For the industrial process with relatively simple production process and system structure, the traditional PID control algorithm has better control effect. However, more and more nonlinear and large hysteresis systems appear in modern industry, which requires higher and higher control precision of the system. The traditional PID control algorithm is difficult to meet its control requirements.

With the development of intelligent control technology, many scholars have done a lot of research on temperature intelligent control technology. In order to control the temperature during the transesterification process of edible oil into biodiesel, M F et al. [1] used PID algorithm [2] as the system controller to build a prototype of the biodiesel reactor control system. Lu H et al. [3] developed a multifunctional combined tumour therapy instrument based on improved PID algorithm, using improved PID temperature control algorithm to solve the problem of reduced accuracy due to changes in the process characteristics of different heaters, so as to ensure different The heater is uniformly and smoothly heated by radio frequency when treating tumours in the cavity. Li G [4] et al. used flue gas temperature and coal flue gas flow as the control parameters of the main loop and the secondary loop, and established a linear regression mathematical model of the top temperature of the regenerator and the temperature of the flue side of the machine using linear regression theory. According to the characteristics of the system, a compound fuzzy PID control strategy is proposed. Ye L et al. [5] adopted fuzzy PID control method and designed a self-tuning PID control system to keep the temperature of the honing coolant constant during the production process of the automobile engine. Liu X [6] et al. proposed a loop optimization method (PSO-RCO) based on particle swarm calculation and closed-loop simulation. This method is used to solve the problem of closed-loop optimization of controller parameters of a multi-controller single output thermal system. In order to effectively control the bed temperature of the boiler, Aygun H et al. [7] proposed a particle swarm optimization proportional integral derivative (PSO-PID) controller for the bed temperature of a circulating fluidized bed boiler.

In this paper, fuzzy control technology [8-10] and particle swarm optimization technology are combined, applied to the temperature control system of capacitive hot press, and a fuzzy PID temperature control system is constructed. The parameters of the fuzzy PID controller are optimized by particle swarm optimization [11-12], but particle swarm optimization is easy to be premature and fall into local optimization [13-14], which directly affects the performance of the algorithm and leads to inaccurate control accuracy. Aiming at this deficiency, this paper adopts a new method to improve the particle swarm algorithm. The improved particle swarm algorithm is applied to the fuzzy PID control system, and the simulation research is carried out. Compared with the PID temperature control system [15], the fuzzy PID temperature control system [16] and the PSO optimized fuzzy PID temperature control system [17], the IPSO optimized fuzzy PID temperature control system greatly reduces the over-shoot and adjustment time.

In Section 2, we introduce the temperature control system structure of the capacitor hot press and establish the mathematical model of the system. In Section 3, we introduce the basic concepts of the PSO algorithm and methods to improve the particle swarm algorithm. In Section 4, we carry out the design of the fuzzy logic of the system. In Section 5, we conduct a simulation study of a capacitor heat press temperature control system by MATLAB. Finally, the full text is summarized in Section 6.

The temperature Model of Capacitor Hot Press

This paper takes the capacitor hot press as the research object. Its temperature control system mainly includes electric heater, hot pressing plate and temperature sensor. The schematic diagram of the temperature control of the capacitor hot press is shown in Figure 1. The controller sends an instruction to the electric heater according to the desired temperature, the electric heater starts to heat. At the same time, the temperature sensor feeds back the difference between the real-time temperature value and the set value to the controller.

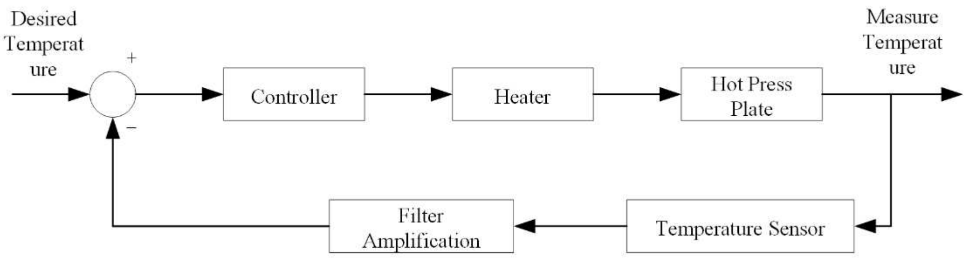


Figure 1. The schematic diagram of the temperature control of the capacitor hot press.

The structure of the temperature control system of the capacitor hot press is shown in Figure 2. The transfer function of the heater is:

$$G_R(s) = \frac{K_R}{1 + T_R s} \tag{1}$$

The transfer function of the hot press plate is:

$$G_H(s) = \frac{K_H}{1 + T_H s} e^{-\tau s} \tag{2}$$

Among them, KH and KR are the gain coefficients of the transfer function; TH and TR are the inertia time constants; τ is the pure delay time of the system.

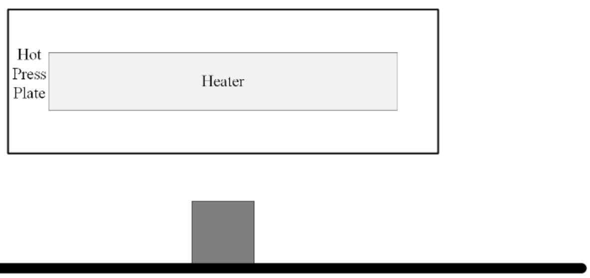


Figure 2. The structure of the temperature control system of the capacitor hot press.

Improved Particle Swarm Optimization

PSO is a random search algorithm with group collaboration as the core. It was proposed by Eberhart and Kennedy in 1995 on the basis of the study of bird predation behaviour. In this algorithm, the particles in the search space represent the solution of the problem, and these particles form a whole. The direction and distance of the particle's flight are determined by its speed. The particles fly in the solution space along the optimal solution. When a certain number of iterations is reached, the optimal position vector of the particle is the optimal approximate solution of the problem. Particle swarm optimization has the advantages of simple iteration and fast convergence speed, and is suitable for parameter optimization of PID algorithm.

Assuming that K particles are initialized in the D-dimensional solution space, each particle has its own spatial position $X_m=(X_{m1},X_{m2},\ldots,X_{mD})$ and its own flight speed $V_m=(V_{m1},V_{m2},\ldots,V_{mD})$. Among them, $m=1,2,3,\cdots,K$. In each iteration of the particle in the solution space, optimize its own speed through the optimal solution of the individual particle $Pbest_m=(P_{m1},P_{m2},\cdots,P_{mD})$ and the optimal solution of the particle population $Gbest_m=(G_1,G_2,\ldots,G_D)$ And location. The update formulas of particle velocity and position at the Nth iteration are can be determined on the basis of the following equations:

$$V_{mD}^{N} = V_{mD}^{N-1} + c_1 r_1 (P_{mD} - X_{mD}^{N-1}) + c_2 r_2 (G_{mD} - X_{mD}^{N-1}) \tag{3}$$

$$X_{mD}^{N} = X_{mD}^{N-1} + V_{mD}^{N-1} \tag{4}$$

Where, V_{mD}^{N} denotes the velocity of the m particle, X_{mD}^{N} denotes the position of the m particle, c_1 and c_2 denote the learning factor, r_1 and r_2 denote the learning factor random function within [0,1], and N denotes the number of iterations.

In the process of optimizing the parameters, the PSO algorithm is easily trapped in local optimization, which can directly affect the performance of the algorithm and result in inaccurate parameters. A new improved particle swarm optimization algorithm is proposed to avoid this. By introducing two inertia weights w_1 and w_2 in Eq. (3) to enhance the global search capability of the algorithm. The particle velocity of the Nth iteration after the algorithm is improved can be determined according to the following equation:

$$V_{mD}^{N} = w_1 V_{mD}^{N-1} + w_2 (c_1 r_1 (P_{mD} - X_{mD}^{N-1}) + c_2 r_2 (G_{mD} - X_{mD}^{N-1})) \tag{5}$$

Where,

$$w_1 = w_{max} + (w_{max} - w_{\min}) \times n/N_{max} \tag{6}$$

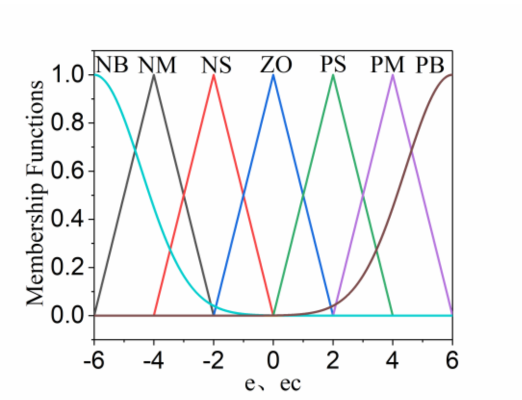
$$w_2 = w_{max} - (w_{max} - w_{\min}) \times n/N_{max} \tag{7}$$

Where, w_{max} is the maximum inertial weight and w_{min} is the minimum inertial weight, n is the current number of iterations, and N_{max} is the maximum number of iterations. As the number of iterations increases, the inertia weight w_1 increases, the flying speed of the particles becomes faster, and the global search capability of the particles is enhanced, which solves the problem that the PSO is easy to fall into local optimization. However, when the inertia weight w_1 is too large, the flying speed of the particles is too fast, and the algorithm will oscillate at the global optimal solution, leading to premature convergence. In order to constrain the flying speed of particles, an inertia weight w_2 is introduced. With the increase of the number of iterations, the inertia weight w_2 decreases, and the flying speed of the particles is balanced by the inertia weight w_1 and the inertia weight w_2, thereby obtaining the optimal correction amount of the PID parameters.

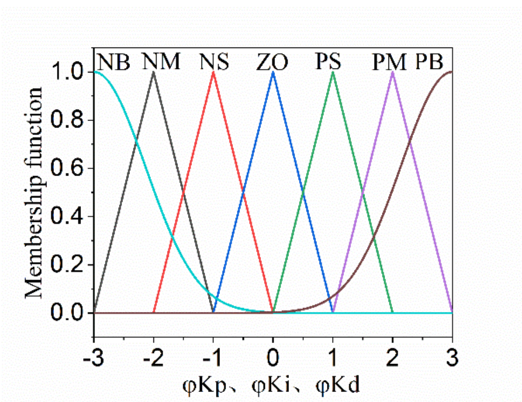
Fuzzy Logic Design

The deviation between the desired temperature and the measured temperature of the fuzzy temperature control system is set as e, and the deviation change rate is set as ec. Let e and ec be the input variables of the fuzzy particle swarm PID control system, and the corrections of the PID parameters K_p, K_i, and K_d, that is, φK_p, φK_i, and φK_d, are set as the output variables. It is assumed that the basic domains of e and ec are [-5, +5] and [-10, +10] respectively, and the basic domains of φK_p, φK_i, φK_d are [-1, +1], [-0.6, +0.6], [-0.8, +0.8]. Set the fuzzy universe of e and ec as [-6, 6], and the fuzzy universe of φK_p, φK_i, φK_d as [-3, 3]. A seven-segment fuzzy method is used to divide the input variables and output variables into seven language values: positive big (PB), positive middle (PM), positive small (PS), zero (ZO), negative small (NS), negative middle (NM), negative big (NB). The quantization factors for the input variables e and ec to transform from the basic domain to the corresponding fuzzy domain are k_e=6/5=1.2, k_{ec}=6/10=0.6. The scale factor for the output variables φK_p, φK_i, φK_d to transform from the corresponding fuzzy domain to the basic domain are k_p=1/3=0.33, k_i=0.6/3=0.2, and k_d=0.8/3=0.267.

The input variables of the fuzzy controller designed in this paper are Gaussian membership functions, and the output variables are triangular membership functions. The membership functions of the input variables are shown in Fig. 3, and the membership functions of the output variables is shown in Fig. 4.



(a)



(b)

Figure 3. Membership function: (a) Membership of input variables.; (b) Membership of output variables.

After analysing the relationship between e, ec and φK_p, φK_i, φK_d, combined with the knowledge and practical operating experience of experienced old employees, a fuzzy rule table is obtained. The fuzzy rule tables of φK_p, φK_i, φK_d are shown in Table. 1, Table. 2, and Table. 3.

Table 1. Fuzzy rule table of ϕK_p.

ec e	NB	NM	NS	ZO	PS	PM	PB
NB	PB	PB	PM	PM	PS	ZO	ZO
NM	PB	PB	PM	PS	PS	ZO	NS
NS	PM	PM	PM	PS	ZO	NS	NS
ZO	PM	PB	PS	ZO	NS	NM	NM
PS	PS	PS	ZO	NS	NS	NM	NM
PM	PS	ZO	NS	NM	NM	NM	NB
PB	ZO	ZO	NM	NM	NM	NB	NB

Table 2. Fuzzy rule table of ϕK_i.

ec e	NB	NM	NS	ZO	PS	PM	PB
NB	NB	NB	NM	NM	NS	ZO	ZO
NM	NB	NB	NM	NS	NS	ZO	ZO
NS	NB	NM	NS	NS	NS	PS	PS
ZO	NM	NM	NS	ZO	ZO	PM	PM
PS	NM	NS	ZO	PS	PS	PM	PB
PM	ZO	ZO	PS	PS	PS	PB	PB
PB	ZO	ZO	PS	PM	PM	PB	PB

Table 3. Fuzzy rule table of ϕK_d.

ec e	NB	NM	NS	ZO	PS	PM	PB
NB	PS	NS	NB	NB	NB	NM	PS
NM	PS	NS	NB	NM	NM	NS	ZO
NS	ZO	NS	NM	NM	NS	NS	ZO
ZO	NS	NS	NS	NS	NS	NS	ZO
PS	ZO	ZO	ZO	ZO	ZO	ZO	ZO
PM	PB	PS	PS	PS	PS	PS	PB
PB	PB	PM	PM	PM	PS	PS	PB

Simulation and Results Analysis

Algorithm test

In order to verify that IPSO algorithm is superior to PSO algorithm, a common standard test function is selected to compare the performance of the PSO and the IPSO. The expression of the test function Ackley is can be determined on the basis of the following equation:

$$\mathrm{f}(x) = -20exp\left[-\frac{1}{2}\sqrt{\frac{1}{n}\sum_{i=1}^{n}x_i^2}\right] - exp\left[\frac{1}{n}\sum_{i=1}^{n}cos(2\pi x_i)\right] \tag{8}$$

The number of selected particles is 20, and the maximum number of iterations is 400. Use MATLAB software to test the performance of PSO and IPSO, and get the curves of the two algorithms to optimize the Ackley function. The result is shown in Figure 4. For the test function Ackley, the convergence curve of the PSO begins to con-verge at the 173rd iteration, and the convergence curve of the IPSO begins to con-verge at the 73rd iteration. The IPSO is better than the PSO in terms of convergence speed and optimization accuracy.

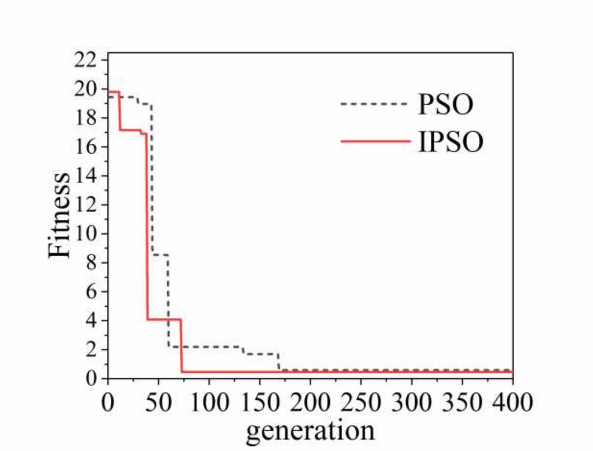


Figure 4. Ackley function optimization curve.

Control System Simulation

In order to verify the advantages of the IPSO algorithm, based on the thermal pressure model of the capacitor established, the simulation model of the system is established in MATLAB/Simulink, and the program of the particle swarm algorithm is written in the m file, through the m file and Simulink. Carry out simulation experiments. The control simulation model is shown in Figure 5 and Figure 6.

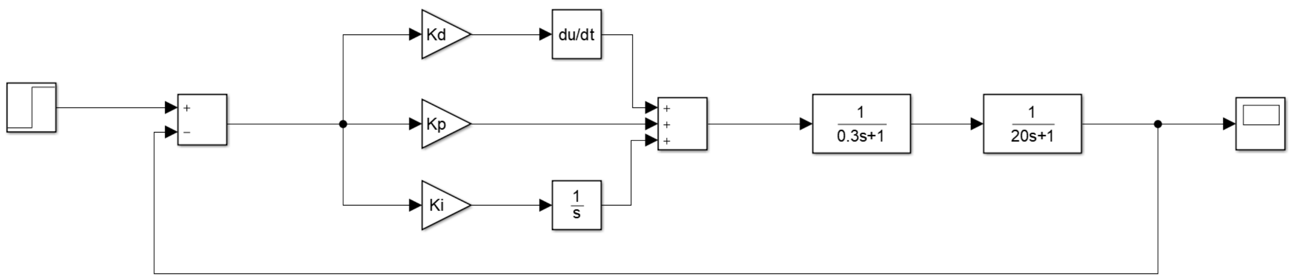


Figure 5. The simulation model of PID.

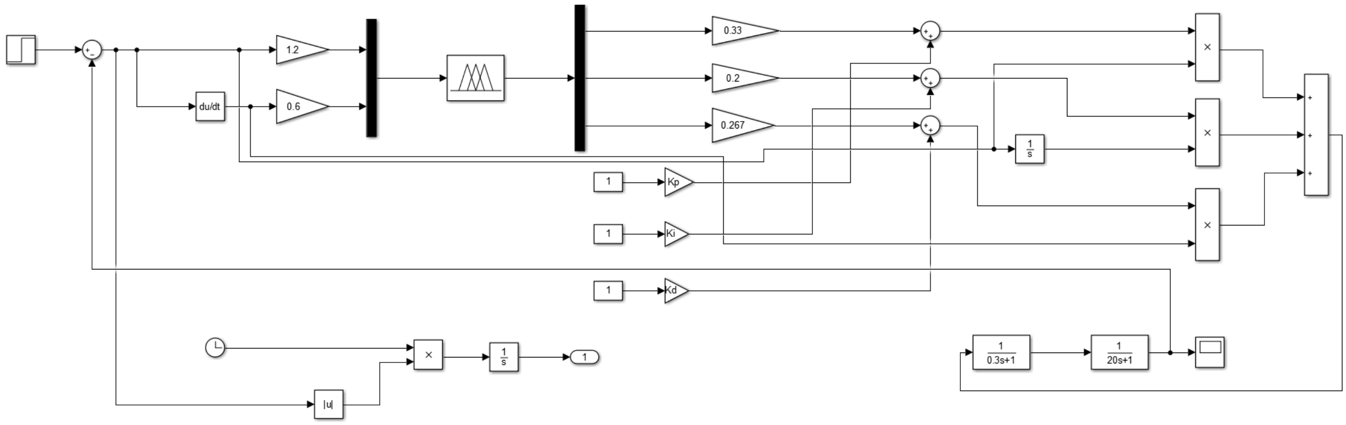


Figure 6. The simulation model of fuzzy PID controller system.

Firstly, the particle swarm algorithm is initialized, and the particle swarm size is 5, the number of iterations is 100, the learning factors c_1 and c_2 are both 2, and the inertia weight is 0.6. Then, ITAE is selected as the evaluation index of the controller performance. The expression of ITAE is shown in Equation 9.

$$J_{ITAE} = \int_0^{t_s} t|e(t)|\,dt \tag{9}$$

According to the transfer function of the established model, select the gain coefficients K_H and K_R as 1, and the inertia time constants T_H and T_R as 20 and 0.3. Select a conventional step signal as the input signal, and add a step interference signal of 20% amplitude at 125s. Comparing the performance of IPSO algorithm and other algorithms through the system's ability to adjust the step signal and the adjustment speed.

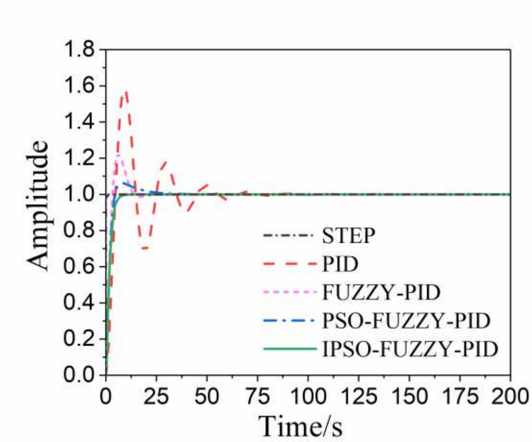


Figure 7. Simulation comparison of four control systems.

Table 4. Comparison of performance indicators of four control systems.

Control System	Overshoot	Adjustment time / s
PID	58.173%	66
FUZZY-PID	21.932%	40
PSO-FUZZY-PID	6.295%	34

IPSO-FUZZY-PID	0.001%	20

Figure 7 shows the step response signals corresponding to the four control systems. It can be seen from the simulation curve that the systems controlled by the four algorithms all return to a stable state within a certain period of time, which indicates that they have anti-interference capabilities. reach stability. At this time, the interference signal is added into the system, and the simulation result is shown in Figure 8. As can be seen from the simulation curves in Figure 8, these four control methods all exhibit different levelling abilities. The traditional PID control can suppress the system disturbance, but due to the fixed parameters, it is easy to fall into the empirical optimum. The fuzzy PID control optimized by PSO can make the system response faster and the anti-interference ability enhanced by optimizing the PID parameters, but the PSO algorithm is easy to fall into local optimization. The fuzzy PID control optimized by IPSO solves the problem that the PSO algorithm is prone to premature maturity, with faster response time and stronger anti-interference ability.

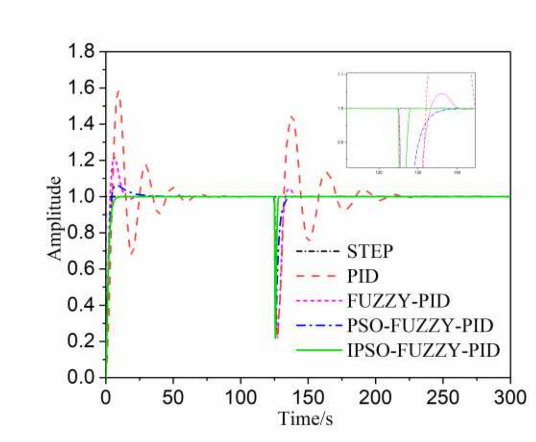


Figure 8. Simulation comparison after adding interference.

Table 5. Comparison of performance indicators after adding interference.

Control System	Overshoot	Adjustment time / s
PID	75.7%	103
FUZZY-PID	75.7%	26
PSO-FUZZY-PID	75.7%	14
IPSO-FUZZY-PID	75.7%	4

The performance indicators of the four control systems are shown in Table 4 and Table 5. It can be seen from Table 4 and Table 5 that under traditional PID control, the system overshoot is 58.173%, and the system reaches stability within 66s; under fuzzy PID control, the system overshoot is 21.932%, and the system reaches stability within 40s Stable; under the fuzzy PID control optimized by PSO, the overshoot of the system is 6.295%, and the system is stable within 34s; under the fuzzy PID control optimized by IPSO, the overshoot of the system is 0.001%, and the system is stable within 20s. After adding the disturbance, the system overshoot is 75.7%. Under traditional PID control, the system reaches stability within 103s; under fuzzy PID control, the system reaches stability within 26s; under PSO optimized fuzzy PID control, the system reaches stability within 14s; under IPSO optimized fuzzy PID control, the system reaches stability in Stable within 14s. Stable within 4s. Therefore, the temperature control system using the IPSO algorithm has a faster response speed and has great ad-vantages in anti-interference ability.

Conclusions

In this paper, an improved particle swarm algorithm is proposed through the re-search of particle swarm optimization. The IPSO algorithm is applied to the temperature control system of the capacitor heat press. The temperature control system based on IPSO algorithm can not only make PID parameters self-tuning, but also solve the problem that PSO algorithm is easy to fall into local optimization. The IPSO algorithm realizes the precise control of the temperature control system of the capacitor hot press. It can be seen from the simulation results that compared with the traditional control system, the control system based on IPSO algorithm has great advantages in overshoot and adjustment time. And the system has good adaptive ability and strong robustness and anti-interference ability. The application research of IPSO algorithm in the temperature control system of capacitor heat press provides a solution to the problem of poor temperature control effect of capacitor heat press, which is of great significance to the development of industrial control systems in the direction of intelligence.

Data Availability

Relevant supporting data has been embedded in the paper in the form of charts.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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