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RESEARCH ARTICLE

Research and Application of Improved Particle Swarm Fuzzy PID Algorithm Based on Self-Disturbance Rejection in Temperature Control System of Plastic Extruder

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ABSTRACT Plastic profiles are mainly processed by plastic extruders. In order to better solve the problems of hysteresis, high overshoot and low anti-interference ability of the extruder temperature system. First, the process flow and working principle of the extruder are analyzed, and the extruder temperature control system is developed on this basis. The step response curve identification method is used to obtain the system model parameters and establish the mathematical model of the temperature control system. On the basis of previous research on Fuzzy PID control, for the problem of empirical priority of Fuzzy control, a control method based on the improved particle swarm algorithm iteratively solves the key parameters in the Fuzzy PID variational domain algorithm is proposed, and the improved particle swarm Fuzzy PID controller is designed, and the control model is constructed, and the writing and debugging of the control algorithm is completed. Finally, step and interference simulation experiments are designed to simulate and analyze the temperature control effect of traditional PID, Fuzzy PID and improved particle swarm Fuzzy PID on the temperature control system. The results show that: the improved particle swarm Fuzzy PID significantly reduces the maximum overshooting amount, greatly shortens the restoration of steady state time, and at the same time meets the requirements of the system to control the process overshooting amount, has a strong resistance to dryness, and is able to better adapt to the changes in the system control output, which meets the system's demand for temperature control accuracy, stability and rapidity.

INDEX TERMS Plastics extrusion machine, temperature accuracy, particle swarm optimization, stability control.

I. INTRODUCTION

As we all know, Plastic profiles are widely used in our daily life and work.and has a very good development prospect in the chemical industry, construction industry, medical and health industry, household and other fields. Plastic extruder as the core equipment for the production of plastic profiles, its production of polyethylene, polyethylene terephthalate, polyvinyl chloride and other plastic products in the market share is growing. In the actual processing of plastic profiles, the control of the temperature of the plastic extruder is extremely important to the molding quality of the product. If the temperature is too low [1], the molten material will be difficult to melt, affecting product quality and damaging the internal components; if the temperature is too high, the plastic will decompose and damage the internal structure of the plastic [2], and the decomposed material will be attached to the wall of the internal cylinder of the extruder, which will affect the normal operation.

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At present, the plastic profile processing enterprises use plastic extruder barrel temperature control basically using PID (Proportional Integral Derivative) control mode. Due to the PID control mode of plastic extruder is vulnerable to the workshop environment, equipment structure and poor parameter calibration and other factors, it is difficult to meet the quality requirements of precision extruded products [3], but also cause waste. Therefore, In order to better improve the quality of profile products, some scholars have used Fuzzy PID control strategy to optimize the performance parameter indicators of the temperature control system of the extruder [4], which to a certain extent reduces the overshooting of the temperature control system and stability [5], and improve the quality of the product. In the face of strong uncertainty of the controlled object, fuzzy control can better adjust the PID parameters in real time in response to environmental changes, but in the design of the corresponding fuzzy control rules, often based on personal experience to select the database parameters, the performance of the fuzzy controller is strongly correlated with the personal factors, which results in the system performance is difficult to reach the optimal. Therefore, this project proposes to use the improved particle swarm algorithm to optimally adjust the scaling factor and quantization factor of the fuzzy PID in order to overcome the influence of human factors in the design of fuzzy control as much as possible, so that the system can be controlled more accurately and faster. The particle swarm algorithm finds the optimal solution by updating the position and speed of the particles [6], which has the advantages of easy implementation and fast convergence, and is suitable for parameter optimization of temperature control system. The algorithm can be applied to the optimization of multi-dimensional problems, and it has good adaptability to the parameter selection of fuzzy PID [7]. Optimizing the temperature system design of plastic extruder through this algorithm can further improve the quality of plastic profiles, reduce the consumption of various types of resources, shorten the production cycle of plastic profiles, and then make the plastic profile processing enterprises more competitive in the market.

II. ANALYSIS AND SCHEME DESIGN OF TEMPERATURE CONTROL SYSTEM FOR PLASTIC EXTRUDER

A. COMPOSITION OF EXTRUDER EQUIPMENT

The composition of extruder equipment mainly includes extrusion system, transmission system, heating and cooling system. The equipment structure diagram is shown in Figure 1.

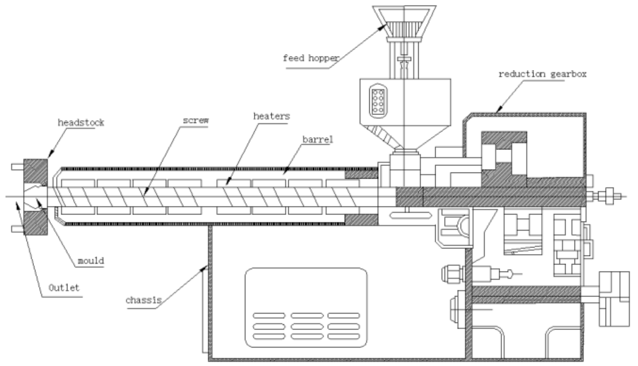

FIGURE 1. Structure diagram of extruder equipment.

1) EXTRUSION SYSTEM

Extruder temperature control system mainly consists of three parts: screw, barrel and head. Firstly, By setting pressure and a certain speed on the machine head, then the material is formed into a uniform melt by extrusion plasticization, and is extruded from the head in quantitative quantity under the set temperature and pressure.

2) DRIVE SYSTEM

The transmission system is driven by a motor to make the screw rotate at a constant speed according to the set torque, completes the plasticizing and melting of the material and gradually extrudes the material in a certain shape from the barrel.

3) HEATING AND COOLING SYSTEM

Plasticizing plastic through a heater to achieve its own viscous flow temperature, ensuring the smooth extrusion process of plastic profiles [8]. The cooling device ensures that the temperature range required for the plastic melting and plasticizing process is within the required temperature range, The waste heat generated during the profile forming process has been removed, and high temperatures have been avoided, which may generate small bubbles on the surface of the product and even lead to the decomposition of raw materials [9].

B. OVERALL SCHEME DESIGN OF EXTRUDER TEMPERATURE CONTROL SYSTEM

According to the control requirements of the plastic extruder, the system is divided into two levels of control: an upper computer PC and a lower computer PLC(Programmable Logic Controller). The upper computer is implemented by a PC and mainly completes functions such as equipment operation, data display, human-machine interaction and device parameterization. The lower computer is controlled by PLC and mainly completes functions such as data acquisition, command input and output, and program control for the extruder. This system mainly consists of two parts: hardware and software design [10]. The system hardware mainly includes power module, Ethernet communication module, upper computer PC control computer, and lower computer SIMATIC S7-1200 PLC; The system software mainly includes writing main programs, configuring monitoring screens, and communication programs between upper and lower computers. The scheme design is shown in Figure 2.

The working process involves thermocouple sensors detecting the current temperature of the material barrel and machine head, converting it into electrical quantity and

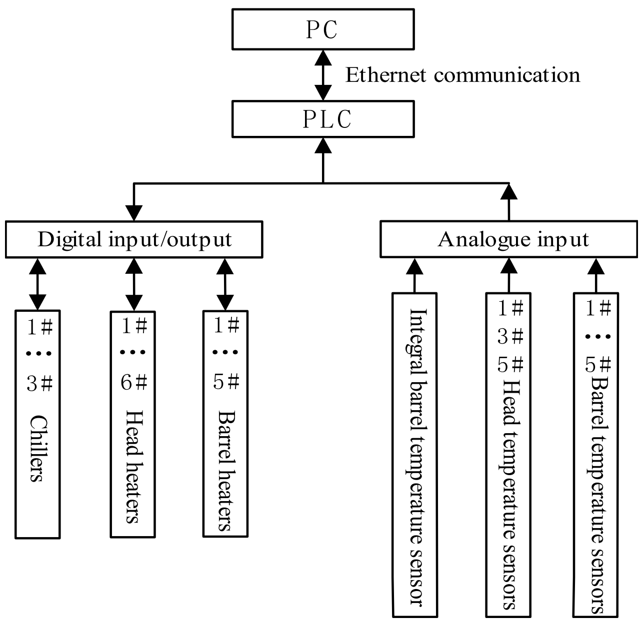

FIGURE 2. **Overall design of temperature control system scheme.**

transmitting it to the PLC main controller. The digital quantity template integrated into the PLC then converts the electrical quantity into a digital quantity that can be recognized by the PLC. The PLC processes the temperature digital quantity and the set temperature value through the IPSO Fuzzy PID(Improved Particle Swarm Optimization Fuzzy PID) control strategy [11], and outputs the obtained control quantity to the PLC digital quantity template. The digital quantity output achieves a signal level of 0 or 1 to control the on/off of the solid-state relay SSR(Solid state relay), achieving control over the heating coil and cooling fan, thereby controlling the temperature of the extruder barrel and head.

C. PRODUCTION PROCESS REQUIREMENTS FOR EXTRUDER

The main process parameters that affect extrusion molding include temperature, pressure, and extrusion rate. Temperature control plays a decisive role and is an important aspect of the extrusion process. If the temperature changes during the extrusion process, the melt pressure of the extruder, the degree of plasticization of the material, and the residual stress of the product will all undergo certain changes, leading to a decrease in the stability of the control system and difficulty in ensuring the quality and productivity of plastic profiles. In the setting of extrusion temperature, it is not only necessary to determine a temperature level, but also to control the temperature in segments according to the specific extrusion process. The material is plasticized inside the barrel, and further heated and melted by the heater to reach a certain viscous flow temperature. Otherwise, the smooth extrusion process cannot be guaranteed. Excessive or prolonged exposure of the barrel to relatively high temperatures can exacerbate plastic decomposition, causing discoloration and foaming of plastic products, seriously affecting product quality. The temperature control system of the extruder barrel, as a nonlinear and large inertia multivariable system, has the following requirements:

1) TEMPERATURE CONTROL ACCURACY

During the processing of plastic profiles, the temperature value is dynamically changing, and its fluctuation range is generally required to be ± 2 °C.

2) OVERSHOOT

plastic extruder temperature zones are distributed next to each other, in the heating stage is likely to lead to the temperature fluctuations of each temperature zone interferes with the temperature overshooting amount is too large will lead to the profile product bubbles and burnt discoloration and other problems.

D. MATHEMATICAL MODELING OF EXTRUDER TEMPERATURE CONTROL SYSTEM

Due to the complexity of the temperature system of the plastic extruder [12], there are a large number of uncertain factors affecting the temperature change, such as the raw material temperature, the extrusion stress between the screw and the raw material, the coupling of the temperature zones, the head temperature, shear heat and other factors. Therefore, It is difficult to build a mathematical model of the temperature system of an extruder [12], and the corresponding parameters of the extruder temperature control system can only be analyzed and calculated through the parameter identification method, which leads to the transfer function model [13].

This experiment adopts the step response method to model identification of the system, in the operation of the system [7], to provide a step signal to the input variable, then the output variable will also change, but through a single change can not find out the law of the response, at this time, adjusting the temperature power switch, the output variable will get a step response curve, then through this response curve, the relationship between the output and the input can be found, so as to establish the relevant model. Figure 3 for the extruder barrel heating process barrel change curve, through the first-order system response curve method for identification, the transfer function $\boldsymbol{G}(s)$ formula as equation (1).

$$G(s) = \frac{K}{Ts+1}e^{-\tau s} \tag{1}$$

1) AMPLIFICATION FACTOR K

The step response curve generated by the material cylinder when inputting a step signal to the system is shown in Figure 4. In the figure, Δm stand for the amplitude of the step signal [14], and Δn stand for the output amplitude of the system after entering steady state.

2) AMPLIFICATION FACTOR K

$$K = \frac{\Delta n}{\Delta m} \tag{2}$$

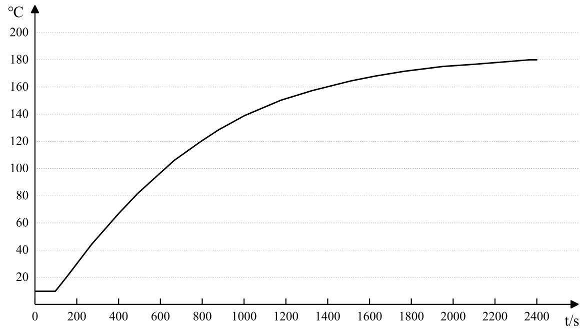

FIGURE 3. Heating response curve of extruder barrel.

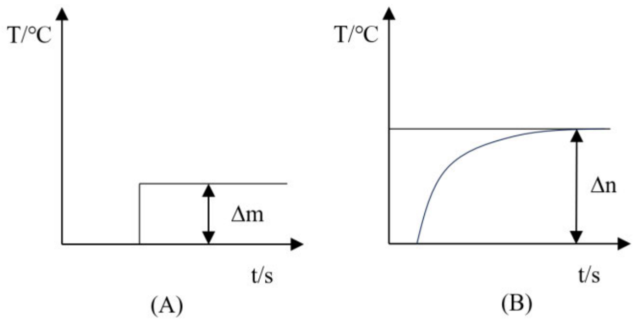

FIGURE 4. Temperature step response curve of material barrel.

3) CALCULATE T AND τ

Convert the experimental step response curve into a nominal step response curve.

$$\acute{y}\,(t) = \frac{y\,(t)}{y\,(\infty)} \tag{3}$$

To determine T, τ Select two coordinate values of $\acute{y}\,(t)$ and establish a simultaneous equation. If t_1 and t_2 are selected, there are:

$$\begin{cases} \acute{y}\,(t_1) = 1 - e^{\frac{t_1-\tau}{T}} \\ \acute{y}\,(t_2) = 1 - e^{\frac{t_2-\tau}{T}} \end{cases} \tag{4}$$

After calculation, it can be concluded that:

$$\begin{cases} T = \dfrac{t_1 - t_2}{\ln\left(1-\acute{y}\,(t_1)\right) - \ln\left(1-\acute{y}\,(t_2)\right)} \\ \tau = \dfrac{t_2 \ln\left(1-\acute{y}\,(t_1)\right) - t_2 \ln\left(1-\acute{y}\,(t_2)\right)}{\ln\left(1-\acute{y}\,(t_1)\right) - \ln\left(1-\acute{y}\,(t_2)\right)} \end{cases} \tag{5}$$

The mathematical model of the plastic extruder is analyzed by calculating the transfer The function is equation (6)

$$G\,(s) = \frac{16}{126s+1} e^{-48s} \tag{6}$$

III. FUZZY CONTROL METHOD FOR EXTRUDER

A. FUZZY PID CONTROL SYSTEM STRUCTURE COMPOSITION

Fuzzy PID control uses the output of the Fuzzy control as the input of the PID control [15], effectively combining the advantages of the two algorithms. The introduction of Fuzzy control allows the controller to adaptively adjust the three parameters kp, ki, kd [16], so as to obtain the best combination of parameters and effectively improve the control effect [17]. Figure 5 shows the structure of the Fuzzy PID temperature control system for an extruder.

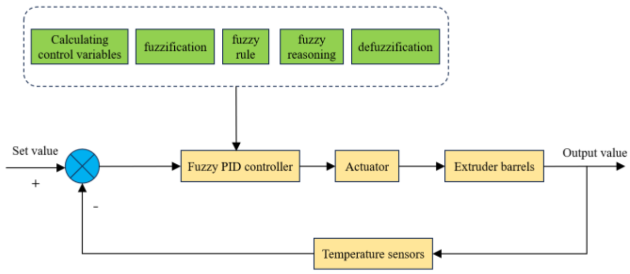

FIGURE 5. Fuzzy PID temperature control system block diagram.

B. CONSTRUCTION OF FUZZY PID CONTROLLER

This design is based on Mamdani Fuzzy controller. where the two input variables are the difference e and the rate of change of the difference ec between the actual temperature and the set value of the system temperature [18], and the three output variables are set to be Δkp, Δki, and Δkd, respectively.Therefore, the system is designed as a two-dimensional, three-output system with the amount of deviation and the rate of change of the deviation and the PID with the three parameter integer values [19].

Extruder temperature control system of Fuzzy PID control process is as follows: before the operation [20], it is necessary to summarize the experience and knowledge of the experts or operators, to develop the control rules for the inputs and the correction value of three PID parameters, and these rules are compiled into the Fuzzy rule base; in the operation of the controller, the feedback device will be the physical signals collected by the sensors are converted into electrical signals to send to the temperature controller, and the temperature controller and the set value of the temperature after the comparison of the difference, to obtain the deviation e and the rate of change of the deviation ec [21]. The control signal is adjusted by the quantization factors ke and kec, matched with the Fuzzy control rules to get the Fuzzy quantity [22], and the Fuzzy quantity is adjusted by the proportionality factors kpu, kiu, and kdu to get Δkp, Δki, and Δkd, and then passed to the PID controller to complete the adjustment of kp, ki, and kd; finally, the output signals are applied to the actuator to complete the whole control process. The schematic of the Fuzzy controller is shown in Figure. 6.

C. FUZZY DISTRIBUTION OF INPUTS AND OUTPUTS

Fuzzy controller is the most important module of control system, the first step is to set the Fuzzy set; the second step is to select the domain of the parameter variables; The third step is to set the two variables temperature error e and its rate of change of temperature error ec as inputs to the system [23],

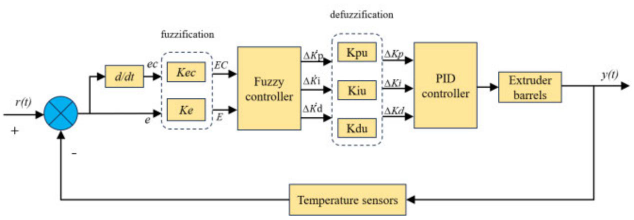

FIGURE 6. Fuzzy PID controller schematic.

and the value of the on-line correction as the output variable, and the range of the input and output variables are [−6,6], [−6,6], respectively. The center of gravity method is chosen as the defuzzification link [7], due to the use of offline way to query the control rule table calculation is small, does not affect the operation speed of the PLC, and can meet the requirements of its temperature control system [24].

D. FORMULATION OF FUZZY RULES

In the process of extruder barrel temperature control, this topic summarizes, organizes and analyzes the actual operating experience of the operators, and summarizes the specific experience as follows: in the heating stage, when $|e|$ is large, the difference between the actual temperature and the set target temperature is large [25], in order to make the temperature respond quickly, the kp value should be taken as a larger value; in order to prevent overshooting phenomenon caused by the saturation of integrals, the ki should be set to a smaller amount. In the transition process stage, $|e|$ and $|ec|$ size moderate, the actual temperature and the set target temperature difference is large, in order to reduce the amount of overshooting, Kp should be taken as the smaller value [26]; in order to ensure that the response rate of the system, should be taken as a moderate ki and kd value. In the normal constant temperature working stage of the extruder, $|e|$ is small, the difference between the actual temperature of the barrel and the set target temperature is small, and larger values of kp and ki should be taken in order to improve the steady state performance of the system; in order to avoid oscillations, when $|ec|$ is large, kd should be taken as a smaller value, when $|ec|$ is small, kd should be taken as a larger value [27].

The Fuzzy subsets are defined as NB, NM, NS, Z0, PS, PM, PB [28], The Fuzzy sets are always finally expressed by the affiliation function, in order to quickly recognize the Fuzzy domain and improve the matching accuracy, and at the same time to meet the controller performance requirements, the temperature control system in this project uses the triangular affiliation function to define the Fuzzy subsets. In this study, 49 Fuzzy conditional statements were summarized, and Fuzzy rule tables for the output variables ΔKp, ΔKi and ΔKd applicable to the extruder at different values of e and ec were defined and written into the Fuzzy rule base as shown in Tables 1, 2 and 3.

Opening the surface observation window for the output quantities kp, ki and kd. it can be seen that the shape of the control rule surface is smoother, with no inflection points, and the correspondence between the input and output variables is normal, as shown in Figure 7.

TABLE 1. Δkp fuzzy rules table.

Δ Kp	NB	NM	NS	ZO	PS	PM	PB
NB	NB	NB	NS	PM	PB	PS	PM
NM	NB	NS	PM	PB	PB	NB	NS
NS	PB	PS	ZO	ZO	NM	NS	PM
ZO	NM	ZO	NM	NM	PS	PM	PB
PS	ZO	NS	PS	PM	NB	NS	PB
PM	NS	PS	PM	PB	NS	NS	PM
PB	PS	PB	PM	PM	NM	PM	PB

TABLE 2. Δki fuzzy rules table.

Δ Ki	NB	NM	NS	ZO	PS	PM	PB
NB	PB	PB	NS	PS	PM	PS	NM
NM	PB	NM	NS	NB	NS	NB	NS
NS	PB	PS	PM	NS	NS	NS	PM
ZO	NM	NM	PS	PM	PS	PM	PB
PS	PS	PM	NB	NS	NM	NM	PB
PM	PM	PB	NS	NS	PS	PM	PM
PB	PS	PB	PM	PM	PM	PB	PB

TABLE 3. Δkd fuzzy rules table.

Δ Kd	NB	NM	NS	ZO	PS	PM	PB
NB	PB	PB	NS	PS	PM	PS	NM
NM	PM	NS	ZO	PM	NS	PM	NS
NS	ZO	PM	PB	PB	PM	PB	PM
ZO	NM	NS	PB	PB	ZO	ZO	PB
PS	PS	NS	PM	PM	NM	NM	PB
PM	PM	PM	PB	PB	PS	PM	PM
PB	PS	PM	PB	NS	NS	NB	NS

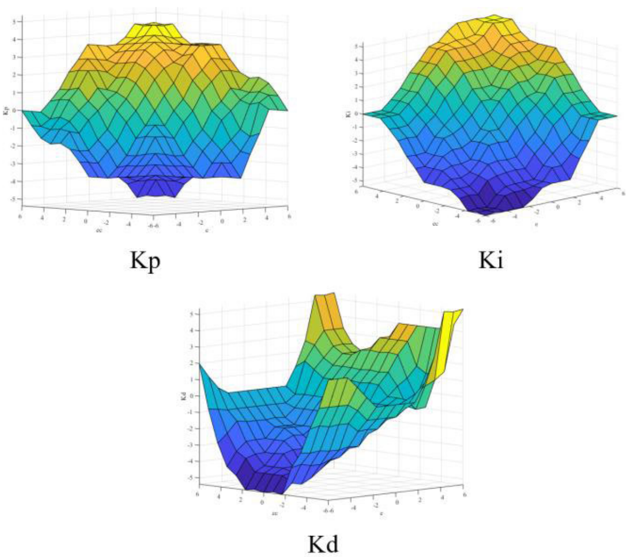

FIGURE 7. kp, ki, kd value output curve observation window.

The Simulink simulation diagram of the Fuzzy PID controller is created in the MATLAB/Simulink simulation software, as shown in Figure 8.

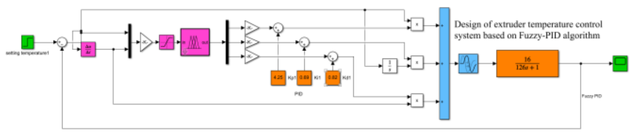

FIGURE 8. Simulation model diagram of fuzzy PID controller.

IV. IMPROVED IPSO FUZZY PID CONTROLLER IMPLEMENTATION

A. PARTICLE SWARM ALGORITHMS

The particle swarm algorithm searches for the optimal solution by updating the position and velocity of the particles [29], which has the advantages of easy implementation and fast convergence speed, and is suitable for parameter optimization of temperature control systems [30]. The algorithm can be applied to the optimization of multi-dimensional problems, and it is well adapted to the parameter selection of Fuzzy PID. In the particle swarm algorithm, the particles represent the solution of the problem and fly along the optimal solution in the solution space, after a certain number of iterations, the optimal position vector of the particles is the optimal approximate solution of the problem [30].

In the particle swarm Fuzzy PID algorithm, the proportionality factors kp, ki, kd and quantization factors ke, kec are represented as particles, and each particle has a certain position and velocity. The algorithm makes the particles move towards the global optimal solution by continuously updating their positions and velocities, and gradually converge to the optimal solution.

Assume that the scaling and quantization factors of the Fuzzy PID controller are in an N-dimensional solution space with an initial population of K particles. Where the spatial position of the ith particle is denoted as $X_i \in [X_{min}, X_{max}]$, which determines the search direction of the particle; the flight speed is denoted as $V_i \in [V_{min}, V_{max}]$, which determines the search speed of the particle. When the particle keeps iteratively searching for the optimum in the N-dimensional solution space, it is possible to find the optimum value of the particle through the individual particle's optimal extreme value $Pbest_i = (P_{i1}, P_{i2}, P_{i3}, \ldots, P_{iN})$ and the global particle's optimal extreme value $Sbest_i = (S_{i1}, S_{i2}, S_{i3}, \ldots, PS_{iN})$ to iteratively optimize their velocity and position.

The velocity and position iteration formula is shown in Equation 7 and 8 as follows:

$$V_{i+1} = \omega v + a_1 b_1 (P_i - x_i) + a_2 b_2 (S_i - x_i) \tag{7}$$

$$x_{i+1} = x_i + v_{i+1} \tag{8}$$

where ω denotes the inertia weight, a_1, a_2 are learning factors, and b_1, b_2 are random numbers belonging to the range [0, 1].

The algorithm optimization process is as follows:

(1) Setting of Particle Parameters: The number of particles in the initial population is set to 40, the maximum number of iterations is set to 30 [31], the inertia factor ω=0.6, learning factor $a_1 = a_2 = 2$, and dimension n=3.

(2) Operate on the Fitness Value: Compare the output of the controller with the desired output to calculate the tracking of the control system error and calculate the area value of the tracking error according to the ITAE criterion. The area value of the tracking error is taken as the fitness value of the particle. The area value of the tracking error is used as the fitness value of the particle [32]. As can be seen in Figure 9, the optimal adaptation value is 1300 after 20 iterations.

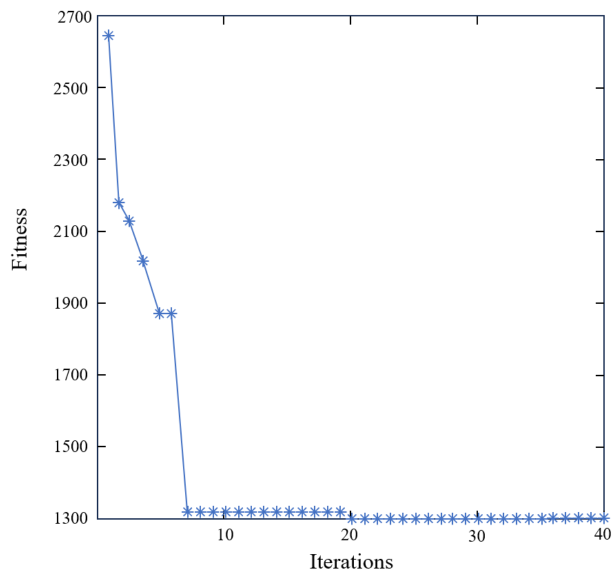

FIGURE 9. Particle swarm optimization curve.

B. IMPROVEMENT OF PARTICLE SWARM ALGORITHM

The particle swarm algorithm, in the process of optimizing the Fuzzy PID controller parameters of the barrel temperature control system of the extruder, has a strong local search capability, which will lead to a greater chance of falling into the local optimum, resulting in a poorer ability to find the globally optimal solution; and when the global optimal search capability is strengthened, it may lead to the inaccuracy of the optimized parameters. Therefore, in order to avoid this phenomenon, this subsection further investigates this defect of the algorithm and proposes the method of introducing the compression factor and dynamic inertia weights for algorithm improvement.

1) INTRODUCING A COMPRESSION FACTOR

By introducing the compression factor can limit the size of the particle speed and prevent the particles from moving too fast during the search process, thus avoiding the oscillation and dispersion phenomenon during the optimization process and improving the search accuracy and stability of the particle swarm algorithm. The compression factor will gradually decrease with the increase of iteration times [33], so that the particles gradually tend to a stable state during the optimization process, thus making it easier to find the global optimal solution. The velocity update equation is given by

Equation 9.

$$V_{id}(t+1) = \gamma * V_{id}(t) + a_1 b_1 (P_{id}(t) - x_{id}(t)) + a_2 b_2 \left(P_{gd}(t) - d(t)\right) \quad (9)$$

In the formula, γ Is the compression factor;

$$\gamma = \frac{2}{\left|2 - \delta - \sqrt{(\delta^2 - 4\delta)}\right|} \quad (10)$$

$$\delta = a_1 + a_2 \quad (11)$$

The final convergence of the temperature control system behavior is achieved using a compression factor γ, which decreases as the number of iterations increases [34]. In the early stages, the value of γ is large and the particles can explore the search space quickly; in the later stage of the optimization process, the value of γ gradually becomes smaller, and the speed of the particle gradually decreases to achieve more accurate search results, which improves the search efficiency and precision of the system. The search efficiency and precision of the system are improved.

2) DYNAMICALLY ADJUSTING INERTIA WEIGHTS

The inertia weights directly affect the inheritance speed of the particles, which in turn has an impact on the global and local search results. When the inertia weights are too large, the particles have strong exploration ability but weak exploitation ability, resulting in difficulty in obtaining optimal solutions and slow convergence. On the contrary, when the inertia weights are too small, the particles are weak in exploration but strong in exploitation, This can easily lead to a bad situation of falling into a locally optimal solution, but has the advantage of converging faster than before.

The improvement strategy in this topic uses an exponential function to control the change of inertia weight ω. As the number of iterations increases $e^{\frac{-t}{t_{max}}}$ decreases in a nonlinear manner. The random number generator betarnd in MATLAB is used to generate random numbers conforming to the (Beta)distribution to increase the global search capability of the algorithm and reduce the possibility of falling into local optimal solutions [35]. Specific improvements The inertia weight expression is given as:

$$\omega = \omega_{\min} + (\omega_{\max} - \omega_{\min}) e^{\frac{-t}{t_{max}}} + \partial \text{betarnd}(p, q) \quad (12)$$

In Equation 13. t refers to the number of iterations, $t_{\max}$ stands for the maximum number of iterations [36], σ inertia adjustment factor is usually taken as 0.1; the initial inertia weight $\omega_{\max} = 0.9$, the inertia weight at maximum iteration number $\omega_{\min} = 0.3$, p=1, q=3. The initial inertia weight $\omega_{\max} = 0.8$, the inertia weight at the maximum number of iterations $\omega_{\min} = 0.5$, p=1, q=3.

To avoid iteration into local optimal solutions, the diversity of population size is maintained, this study introduces a differential evolutionary algorithm to operate on particles. The differential evolutionary algorithm is divided into four steps: initialization, mutation, crossover and selection. In this project, mutation and crossover operations are used to update the position of particles [37]. The specific position update formula is as follows:

$$\begin{cases} X_{r1,j} + F\left(X_{r2,j}\right), & \text{rand} < CR \\ X_{r3,j}, & \text{rand} \geq CR \end{cases} \quad (13)$$

In the above equation, $X_{r1,j}$, $X_{r2,j}$, $X_{r3,j}$, represent the values of three random individuals in the jth dimension, respectively. F is the scaling factor, which is taken as 0.5; rand generates a random number of [0, 1], and CR refers to the crossover probability, which is taken as 0.1. When rand is smaller than CR, the particle position is updated; when rand is larger than CR, the position remains unchanged. Through the above two operation methods, the diversity of the population is effectively improved, the algorithm's global search capability is optimized, and the algorithm's iteration into local optimum is reduced.

C. IMPROVED PARTICLE SWARM FUZZY PID CONTROLLER IMPLEMENTATION

Combined with the requirements of IPSO related rules, the optimization steps of Fuzzy PID control algorithm mainly include the following steps:

(1) Initialization Parameters: determine the number of particles, iteration times, inertia weights, acceleration coefficients, etc. of the improved particle swarm algorithm, and randomly initialize the position and velocity of each particle;

(2) Particle Adaptation Evaluation: according to the current particle position and velocity information, take it as the parameter input of the PID controller, run the control system and get the adaptation evaluation value of the particle;

(3) Updating the Optimal Position: by comparing the current and historical fitness values of a particle, the best fitness value is used and the optimal position of that particle is updated;

(4) Update the Global Optimal Position: select the position information with the optimal fitness value from the individual optimal positions of all particles as the current global optimal position;

(5) Judge the Termination Condition: if the condition of optimal fitness evaluation value is reached or the preset number of iterations is reached, end the calculation. Otherwise, return to step (2) for the next round of iteration;

The process of particle algorithm optimization for Fuzzy PID controller is shown in Figure 10.

D. SIMULATION MODEL OF IPSO FUZZY PID CONTROL SYSTEM

The Simulink module in MATLAB establishes the simulation diagram of the IPSO Fuzzy PID controller as shown in Figure 11.

The simulation diagram consists of three main parts:

(1) PID Control Section: The Fuzzy control section contains a table of Fuzzy control rules for extruder barrel

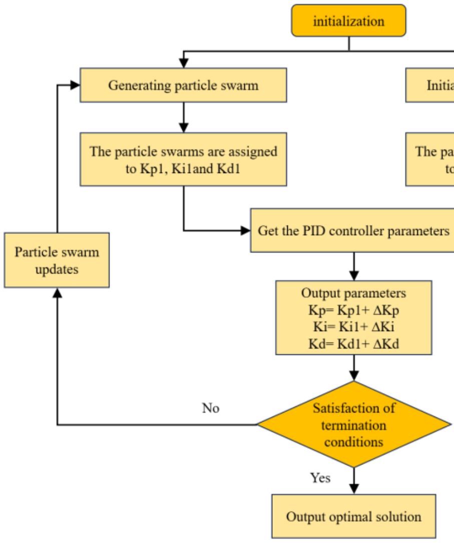

FIGURE 10. Particle algorithm optimized fuzzy PID controller process.

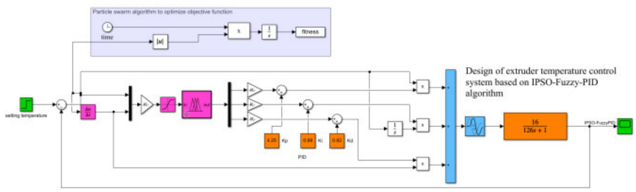

FIGURE 11. Simulation model of IPSO fuzzy PID control system.

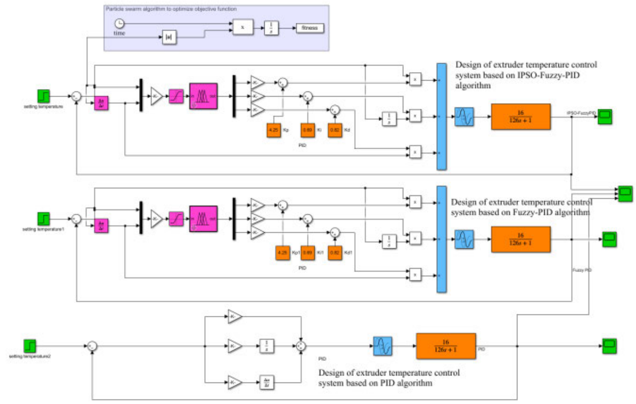

FIGURE 12. Simulation model of extruder temperature control system.

temperature control characteristics. The Fuzzy control module is used to output Fuzzy quantities for defuzzification, correct kp, ki and kd, and pass the optimized parameters to the simulation model for control.

(2) Improve the Output Part of the Particle Swarm Program: Assign the optimal parameters to the kp, ki, kd, Δkp, Δki, Δkd assignment module block to connect the simulation model with the particle swarm optimization algorithm.

(3) Output Component: This is the objective function calculated by the ITAE evaluation.

V. SIMULATION AND EXPERIMENTAL VERIFICATION

To test whether the plastic extruder barrel temperature control system meets the production requirements, it is also necessary to verify and analyze its actual temperature overshooting, steady-state deviation, anti-interference ability and other properties.

A. SIMULATION MODELING

The simulation model diagram is shown in Figure 12. In order to ensure the smooth progress of the simulation experiment, it is necessary to first establish a simulation model of the temperature control system. Use the Simulink module in MATLAB to model three sets of control methods.

B. STEP SIMULATION AND PERFORMANCE ANALYSIS

Extruder barrel temperature in normal operating conditions, to be heated from room temperature to the set temperature, due to the hope that the temperature can quickly reach the set temperature, so the control system in this case is easy to overshoot the phenomenon, and the system to reach the stability of the longer time, so the need for step simulation to verify the amount of overshooting of the system and the rapidity of reaching a stable state.

To verify the effectiveness of the IPSO Fuzzy PID algorithm in temperature control, the following IPSO Fuzzy PID control model is constructed, the Fuzzy PID model and the traditional PID model are simulated in MATLAB software. The simulation time is set to 350s, the initial parameters are kp=4.25, ki=0.69, kd=0.82, and the target value of the given signal is 1. Running the simulation model and comparing the simulation results under the control of the three algorithms, we get the curve comparison graph as shown in Figure13, and the comparison table of the results of the performance parameters is shown in Table 4.

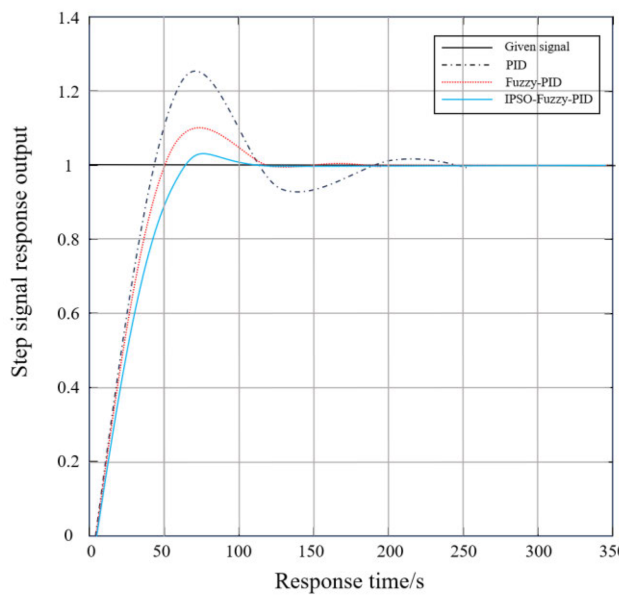

FIGURE 13. Comparison diagram of step simulation.

Simulation results display: the maximum overshoot of the traditional PID is 22%, the rise time is 60s, and the

TABLE 4. Comparison table of performance parameters under three control methods.

Control method	Stabilization time(s)	overshoot	rising time (s)
PID	252	22%	60
Fuzzy PID	138	6%	48
IPSO Fuzzy PID	108	2%	42

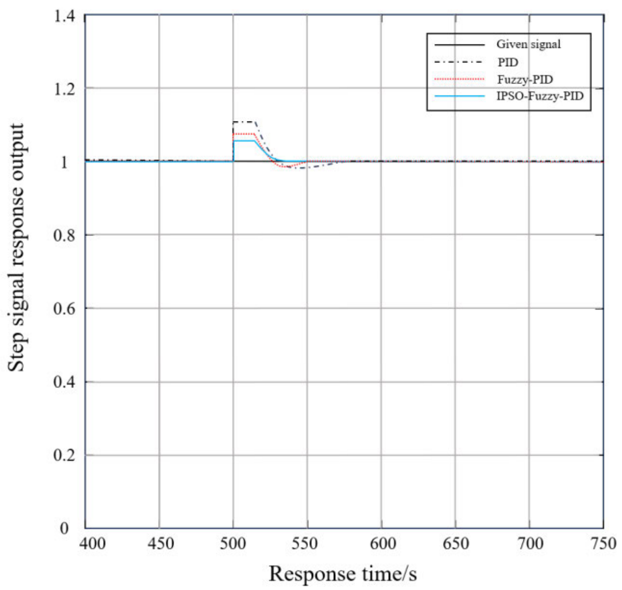

FIGURE 14. Simulation comparison chart under interference conditions.

stabilization time is 252s; the Fuzzy PID control in the whole control process, the maximum overshoot is 6%, the rise time is 48s, and the stabilization time is 138s; the maximum overshoot of the IPSO Fuzzy PID control method is 2%, the rise time is The overshoot is 2%, the rise time is 42s, which is close to the set value, and when reaching the stable state, the stabilization time of the system is 108s, which is more rapid. Through comparison, it can be clearly seen that, under the same control object and control conditions, the system adopts the improved particle swarm Fuzzy PID control with shorter regulation time, smaller overshooting amount and lower steady state error. The performance of the system is obviously improved and has better effect.

C. ANTI-INTERFERENCE SIMULATION AND ANALYSIS

To verify the anti-jamming ability of the extruder temperature system under the control of PID algorithm, the anti-jamming test was carried out on the extruder barrel temperature control model. The simulation in this case is to add a disturbance when the designed temperature control system reaches the steady state for a period of time. After the temperature region is stabilized, a disturbance signal is applied at 500s to ensure the reliability of the data. The simulation curve comparison of the anti-interference test is shown in Figure14

As can be seen in the simulation waveform in Figure13, After adding the interference signal, the deviation of the improved particle swarm Fuzzy PID control is relatively small, and the time taken to restore the steady state again is also shorter, and the anti-interference ability is obviously stronger. According to the above simulation results analysis shows that the improved particle swarm Fuzzy PID controller for plastic extruder designed in this project has better control performance than the traditional PID controller and Fuzzy PID controller, the temperature deviation is obviously smaller, the temperature control speed is faster, and the anti-jamming ability is relatively good, which is inferred from this that the improved particle swarm Fuzzy PID temperature control system's anti-jamming performance meets the overall design requirements.

TABLE 5. Control effect comparison of temperature 90°.

Control method	Stabilization time(s)	overshoot	state error
PID	356	<5℃	<4℃
Fuzzy PID	275	<3℃	<2℃
IPSO Fuzzy PID	238	<1.2℃	<1.3℃

TABLE 6. Control effect comparison of temperature 110°.

Control method	Stabilization time(s)	overshoot	state error
PID	421	<5℃	<4.8℃
Fuzzy PID	324	<3.9℃	<3℃
IPSO Fuzzy PID	269	<1.6℃	<1℃

TABLE 7. Control effect comparison of temperature 130°.

Control method	Stabilization time(s)	overshoot	state error
PID	489	<6℃	<6℃
Fuzzy PID	375	<4℃	<4℃
IPSO Fuzzy PID	304	<1.8℃	<1℃

TABLE 8. Control effect comparison of temperature 150°.

Control method	Stabilization time(s)	overshoot	state error
PID	528	<6.6℃	<5.8℃
Fuzzy PID	402	<4.6℃	<3.6℃
IPSO Fuzzy PID	342	<1.6℃	<1℃

TABLE 9. Control effect comparison of temperature 160°.

Control method	Stabilization time(s)	overshoot	state error
PID	716	<6.8℃	<5.6℃
Fuzzy PID	432	<5℃	<3℃
IPSO Fuzzy PID	398	<1.5℃	<1℃

TABLE 10. Control effect comparison of temperature 180°.

Control method	Stabilization time(s)	overshoot	state error
PID	832	<6.6℃	<5℃
Fuzzy PID	502	<5.4℃	<3℃
IPSO Fuzzy PID	428	<1.6℃	<1℃

D. COMPARATIVE ANALYSIS OF EXPERIMENTS

To verify whether the extruder temperature control system and IPSO Fuzzy PID control algorithm designed in this paper can meet the various functional and performance requirements of the enterprise, so that the defects and problems in the design of the system can be detected in time, solved and optimized. In the experiment, we set the target barrel temperature as 90°, 110°, 130°, 150°, 160°and180°, loaded the PID control method, Fuzzy PID method and IPSO Fuzzy PID control method respectively, The performance of the temperature control system was verified by comparing the control effects of several methods and analyzing the experimental results. When the target temperatures were set to 90°, 110°, 130°, 150°, 160°and180°, The control effects of the experiment are shown in the following 6 sets of data.

By analyzing the experimental data in the three sets of tables, it is concluded that compared with the PID and Fuzzy PID control method, the IPSO Fuzzy PID control method reduces the system stabilization time and system overshooting under the target temperatures of 90°, 110°, 130°, 150°, 160°and180°, and at the same time controls the steady state error to about 1°. IPSO Fuzzy PID control method has good self-resilience in extruder temperature control system.

VI. CONCLUSION

(1) Analyzed the characteristics and process requirements of the extruder temperature control system, based on the working principle of the extruder Based on the process requirements, the overall scheme of the temperature control system for the plastic extruder has been determined.

(2) The extruder temperature control object is analyzed, the step response curve identification method is used to obtain the system model parameters, and the barrel temperature control system mathematical model is established. The PID controller, Fuzzy PID controller and IPSO Fuzzy PID temperature controller were designed, and the system simulation of the three control methods was carried out by MATLAB/Simulink software. At the same time, To verify the anti-interference ability of the system, a disturbance is added to simulate the Fuzzy PID and IPSO Fuzzy PID control methods, and the simulation results show that the IPSO Fuzzy PID temperature controller designed in this paper has smaller overshooting, higher steady-state accuracy and stronger adaptive ability and anti-interference ability in the large hysteresis system compared with the conventional PID and Fuzzy PID.

(3) In the extruder barrel experimental platform, using different control algorithms for experimental verification, through three sets of experimental data show that the temperature control system designed in this paper and the IPSO Fuzzy PID control algorithm in the barrel heating experiments, the system overshooting amount of 1.5% or so, the steady state error is controlled at 1.1 ° or so, showing a high degree of control accuracy and strong adaptive ability.

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