Application of Particle Swarm Fuzzy-Smith PID in Temperature Control of Bag Filter

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Abstract—The temperature control of the bag filter is a non-linear control system with large time lag and too complicated environmental factors. Therefore, building an accurate model is very difficult and thus unable to perform precise control. Currently, fuzzy PID methods are mostly used. However, fuzzy PID relies too much on expert experience. After the parameter value is set, it cannot be adjusted with the change of the input error, and the dynamic performance is poor. In this article, optimizing the scale factors $K_p$, $K_i$, $K_d$ and quantization factors $K_e$, $K_{se}$ in fuzzy PID control by particle swarm optimization. Besides, smith control aimed to eliminate the effect of time lag and then using MATLAB to verify the effectiveness of the algorithm. Experiments show that particle swarm optimization fuzzy PID has faster response speed, smaller overshoot, and shorter time to reach a steady state.

1. Introduction

In recent years, the country's economy has developed rapidly, and various industries have risen quickly. The country pays more and more attention to environmental protection issues [1]. The most important one is the problem of air pollution control, the main factors are dust, particulate matter and other pollutants. The bag filter is an efficient dust removal equipment, mainly used to collect fine non-fibrous dust, and the dust removal efficiency is more than 99% [2]. At present, it has been widely used in cement, thermal power plants, fused magnesium production, chemical industry and other fields. Because these industries not only produce a lot of dust in the production process, but also cause great harm to the health of the workers on the scene, such as pneumoconiosis.

The bag filter often encounters high-temperature flue gas in practical industrial applications, such as industrial furnaces, cement production dust removal, fused magnesium dust removal [3]. The flue gas temperature is often greater than the maximum use temperature of the filter bag, which determines how to reduce the temperature to the acceptable range of the filter bag before the dust enters the dust collector, which has important significance and research value [4].

Because temperature control is a nonlinear, large time lag process and it is impossible to establish mathematical model, it is difficult for ordinary PID control to achieve good control effects. At present, some scholars combine fuzzy control with PID control to adjust common PID parameter [5]. However, there are errors in the process of artificial adjustment of parameters and excessive reliance on expert
experience. Under the multi-variable, strong coupling, and non-linear characteristics of temperature control, fixed parameters will lead to poor system adaptability and poor control effect [6-7].

This paper uses particle swarm optimization algorithm and adopts ITAE index as the fitness function to optimize the scale factors $K_p$, $K_i$, $K_d$ and the quantization factors $K_e$ and $K_{ec}$ in the fuzzy PID, so that the weight factor of the system can be adjusted. The problem of over-reliance on expert experience can realize the intelligent adjustment of controller parameters. Using smith control to eliminate the effect of time lag.

2. Parameters of dust removal efficiency of bag filter

2.1. Filter Wind Speed
The filter wind speed is too low, and the amount of dust processed per unit time decreases, and it needs to be increased. The large filter bag area causes a waste of resources; the filtering wind speed is too high, and the amount of dust processed per unit time is too much, resulting in excessive pressure of the filter bag and reduced service life. It is also related to factors such as dust concentration and cleaning methods.

2.2. Blowing Wear
If the blowing pressure is too high, the impact force of the cloth bag is too large, which will easily cause the cloth bag to wear and reduce the service life; if the blowing frequency is too fast, the cloth bag is easy to age.

2.3. Temperature Effect
Many industries will produce high-temperature flue gas during the production process, the temperature of which is even far greater than the acceptable temperature of the filter bag of the dust collector. Then its temperature control becomes a problem that cannot be ignored. The highest operating temperature of the high temperature flue gas filter bag material commonly used is generally 200 °C ~ 300 °C. The temperature of fused magnesium dust reaches above 400°C. Therefore, it will accelerate the chemical reaction rate, easy to deform and age, and the temperature may directly burn the filter bag; if the temperature is too low, the dust particles and water molecules will condense together in the filter bag. A paste bag is formed on the surface, which increases the pressure of the filter bag, shortens the life, and seriously affects the efficiency of dust removal.

3. Fuzzy PID-Smith Control

3.1. Normal PID Control

In formula (1), $e(t)$ is the deviation between the set value and the actual value. The proportional coefficient $K_p$ affects the strength of the control effect. The larger the $K_p$, the faster the system response and the higher the accuracy. However, if it is too large, it will easily cause overshoot and destabilize the system. Conversely, the adjustment accuracy will become worse, extend the adjustment time and damage system performance. If $K_i$ is too large, it is easy to saturate the initial integration and cause a large overshoot. Otherwise, the static error of the system is difficult to eliminate, which affects the adjustment accuracy. The differential coefficient $K_d$ is to restrain the deviation from changing in advance. However, if this value is not selected properly, the adjustment time will be very long and the anti-interference ability of the system is greatly damaged.

3.2. Fuzzy PID Control
Fuzzy PID control is a closed-loop control system composed of fuzzy control and ordinary PID control in series. Its principle is to fuzzify the actual detected deviation $e$ and the precise amount of deviation change rate $e_c$ to obtain the fuzzy controller input $E$, $EC$, and then assign it a fuzzy language value to
create a membership function. Fuzzy reasoning is carried out through fuzzy rules, and finally the obtained result is multiplied by a scale factor for defuzzification processing to obtain $\Delta K_p$, $\Delta K_i$, $\Delta K_d$, and then respectively added to the parameters before PID update to obtain the final control parameters. The control structure is shown in Figure 1.

![Figure 1 Fuzzy control structure diagram](image)

3.3. Fuzzy Controller Design

Taking the high-temperature smoke generated during the production of fused magnesium as the research background [8-9]. Selecting the dust temperature deviation ‘e’ and the dust temperature deviation change rate ‘ec’ as the input, and $\Delta K_p$, $\Delta K_i$, and $\Delta K_d$ as the output, The basic domain: e is [-120,120], ec is [-30,30], $\Delta K_p$ is [-2.4,2.4], $\Delta K_i$ is [-0.15,0.15], $\Delta K_d$ is [-6, 6]. The fuzzy domains are all [-6,6], then the quantization factor $K_e$ is 0.05, $K_{ec}$ is 0.2, the scale factor $K_p$ is 0.4, $K_i$ is 0.025, and $K_d$ is 1. The fuzzy language values are all taken as {NB, NM, NS, ZO, PS, PM, PB}, and the membership functions are all taken as triangular membership functions. Figure 2. shows the membership edit page.

![Figure 2 Membership function of edit.](image)

The control rule is shown in Figure3, 4, 5.

![Figure 3 Kp Control rules.](image)
3.4. Smith Control

Smith control is also called smith predictive compensation control. It is mainly for pure lag systems. As shown in Figure 6.

In fact, the smith predictive compensator is connected in reverse parallel to the controller, and the pure hysteresis link is moved outside the control loop, which will not adversely affect the system, and will not change the characteristics and waveform of the output. In the temperature control system designed in this paper, the air mixing valve is controlled to mix cold air into the pipe to achieve the effect of cooling the dust, but it takes a process to decrease the temperature until it stabilizes, so it is a typical pure lag process.

4. Particle Swarm Optimization Fuzzy-Smith PID

4.1. Principles of Algorithm

An intelligent optimization algorithm was proposed by Dr. Kennedy and Eberhart in 1995 based on the predatory behavior of birds [10]. The main idea is that each particle is regarded as a bird, which has two attributes: speed and position. Speed represents how fast the particles move to the optimal solution, and position represents the direction the particles move in the optimization process. The basic principle is to initialize a group of particles in a certain range, and the position and speed of the particles are random. Then optimize by continuously updating the position and speed of the particle itself. The best value of each particle in the historical search process called the individual extreme value. The entire group of particles is searched in history the best value obtained in the process is called the global extremum.

The update calculation formula for the position and velocity is
In formula (2), \( \omega \) is called the inertia weight, which is generally 0.8, \( c_1 \) and \( c_2 \) are called learning factors, and generally take 2.0. Generally, formula (2) can be understood as three parts: The first part is the inheritance of the velocity value, and the second part is the particle's cognition of itself, because at this time the particle compares and analyzes all the solutions it encounters in the search process. The third part is the particle's cognition of society, because at this time the particle has exchanged and updated information with other particles to further optimize the speed. Last but not least when the value of \( c_2 \) is large, the particles have strong social awareness, but they will converge to the global extreme prematurely and fall into precocity.

4.2. Inertial Weight \( \omega \) Optimization

The inertial weight \( \omega \) value is larger, which is conducive to enhancing the particle's global search ability and avoiding falling into the local optimum, while a smaller value is conducive to strengthening the particle's local search ability and algorithm convergence. Therefore, the value of \( \omega \) is not static. This article adopts the strategy of linearly decreasing inertia weight \[11\].

In general, \( \omega_{\text{max}}=0.9, \omega_{\text{min}}=0.1. \) The value of \( \omega \) is larger in the initial stage is beneficial to the global search, and the latter is carried out with the iteration, and the value of \( \omega \) decreases for local search.

4.3. Specific Optimization Process

For temperature control are non-linear, multi-variable, strongly coupled, and large time-delay systems, it is difficult for ordinary fuzzy PID control to quickly obtain the optimal parameters of PID. Therefore, the particle swarm optimization algorithm is used to optimize the five parameters of scale factors \( K_p, K_i, K_d \) and quantization factors \( K_{e}, K_{ec} \), and quickly tune the parameters. The control structure is shown in Figure 7.

4.4. The Control Steps

4.4.1. Set the Relevant Parameters of the Algorithm.

Initialize the population: the number of particles is 30, if the control system is larger, it can be 50 or 100. The dimension is 5, because the optimized parameters are 5, and the learning factor \( c_1=2, c_2=2 \). The particle velocity \( v_{\text{min}}=1, v_{\text{max}}=1 \), and iteration limit \( k_m=50, \omega_{\text{max}}=0.9, \omega_{\text{min}}=0.1 \).

4.4.2. Carry out Fitness Calculation

This article adopts the integrated index ITAE, which is the performance index, which can comprehensively evaluate the performance of the control system and is an index with very good practicality and selectivity. The calculation formula is
Using formula (5) is to calculate the fitness of the initial particle, compare the fitness value of a single particle with its own historical pbest, and if it is better, take it as the current optimal solution. The fitness value of all particles in the population is compared with the historical gbest, and if it is better, it is taken as the current global optimal solution. Updating these two optimal solution values through the fitness calculated in each iteration.

4.4.3. Update Particle Properties
The position and velocity of the particles are updated by formulas (2) and (3). Update its inertia weight $\omega$ by formula (4). If the updated particle speed is greater than the maximum particle speed $v_{\text{max}}$, then $v_{\text{max}}$ is used as the current particle speed, otherwise, $v_{\text{min}}$ is used as the current particle speed.

4.4.4. Check Whether the Termination Conditions are Met.
The termination condition is generally that the number of iterations reached the limit or less than the preset minimum fitness. If it is not satisfied, return to 3) to continue the operation.

5. Experimental simulation and analysis
The simulation is composed of three parts: Simulink model, improved particle swarm program, and program connecting algorithm and model. The improved particle swarm program randomly initializes the particles, and then uses the program connecting the algorithm and the model to pass the particles to the model to calculate their fitness, and then back to the algorithm program to achieve the goal of optimizing the weight factor. The linker is usually defined with the ‘assignin’ function or import the ‘.m’ file of the particle swarm program into the S-function model, and then encapsulate it into a two-input three-output subsystem.

5.1. Control System Model
By reading the literature, the model of the fused magnesium dust removal temperature control system is:

$$G(S) = \frac{0.66}{13s+1} e^{-5s} \quad (6)$$

5.2. Simulation System Model

5.2.1. The simulation models of fuzzy PID-Smith

![Figure 8 PSO optimized Fuzzy PID-Smith model.](image)
5.2.2. The particle swarm optimization fuzzy PID-Smith model

Figure 9 Fuzzy PID-Smith simulation model.

6. Conclusion
The simulation curves corresponding to the four control methods are shown in figure 10.

Figure 10 Simulation results of four control methods.

The control goal is to maintain the temperature at 100. Figure 7 shows clearly and intuitively that the use of ordinary PID has a large overshoot, a slow response speed and a long time to reach a steady state. After ordinary PID is added to smith control, the overshoot is significantly reduced and the response speed is accelerated. After further adding the fuzzy control, the response speed is accelerated again, the overshoot is slightly reduced, and the steady-state time is shortened. Finally, using particle swarm optimization with linearly decreasing inertia weight, it can be seen that there is no overshoot, the curve is smoother, and the steady-state time is shorter. To sum up, the particle swarm algorithm is used to optimize the fuzzy PID, and then the smith control is further added, the response speed, overshoot, and time required to reach a steady state are better than ordinary PID and fuzzy PID when controlling the temperature of the bag filter control.

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