PSO Algorithm Based PID Parameters Optimization of Hydraulic Screwdown System of Cold Strip Mill

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***Abstract*—Hydraulic screwdown system of cold strip mill is nonlinear, time-variant system and it is disturbed by many factors, so the turning quality of controller influences the accuracy of Automatic Gauge Control (AGC). In this paper an optimum design method based on particle swarm optimization (PSO) algorithm is presented for PID controller parameters optimization of hydraulic servo screwdown system of one cold strip mill. With PSO algorithm it is fast to calculate PID controller parameters through minimizing the fitness function and searching on the given controller parameter space. Simulation shows that the PID controller turned by PSO algorithm can achieve better control performance than Genetic Algorithm (GA) in AGC system of one single stand reversing cold rolling mill.**

***Keywords*—cold strip rolling mill, automatic gauge control, PID control, particle swarm optimization**

I. INTRODUCTION

In hydraulic screwdown system, PID method is often adopted as controller in industry. PID control is the most common control method used in industrial processes because the structure and algorithm of PID controller is easy [1-2]. Though the PID controller is widely used, its methods of parameter optimization are complicated. There are three methods widely used at present about parameter tuning of PID controllers which are trial-and-error method, experience and data method, and extension critical proportion degree method. There also have been some new artificial intelligent methods about parameter tuning of PID controllers. Neural network [3], fuzzy-genetic [4], and chaotic optimization [5] are just a few among the methods. PID regulator parameter optimization is determined by repeated calculation, and there exists problem of big calculation and it often can not obtain optimization resolution.

PSO algorithm is a new developed evolutionary computation method with simple bionics principle and excellent global optimization performance.

In PSO algorithm it doesn't need to establish a precise mathematical model of object and there are not many parameters to adjust. Using PSO algorithm to optimize PID parameters is a good direction of AGC system of cold strip mill.

II. PSO ALGORITHM

The particle swarm optimization is an evolutionary computation technique provided by Eberhart and Kennedy in 1995 [6]. Its development is based on the observation of animals' social behavior, such as bird flocking, fish schooling and swarm theory. Now the PSO has applied in many fields such as function optimization, neural network training, fuzzy control and so on [7-8].

The PSO algorithm works by initializing a flock of birds randomly over the searching space, where every bird is called as a "particle". These particles fly with a certain velocity and find the global best position after some iteration. At per iteration, each particle can adjust its velocity vector, based on its momentum and the influence of its best position *pbest* as well as the best position of its neighbors *gbest*, then compute a new position that the particle is to fly to.

Supposing x_k is the position value and v_k is the velocity value of particle, the PSO algorithm is described as following.

$$v_{k+1} = wv_k + c_1 r_1 (pbest_k - x_k) + c_2 r_2 (gbest_k - x_k), \quad (1)$$

$$x_{k+1} = x_k + v_{k+1}, \quad (2)$$

where, w is the inertia weight, c_1 and c_2 are two constants (i.e., the cognitive and social parameter, respectively), r_1 and r_2 is two random numbers between 0 and 1.

Position x denotes the solution of problem and can be designed as proper dimension corresponding demand. Velocity v is used to update position, which determines the move speed of particle to *pbest* and *gbest*. The velocity and the position is limited corresponding by $[-v_{\max}, v_{\max}]$ and $[x_{\min}, x_{\max}]$. The sketch map of movement rule of particles from one position to next position is shown as Fig. 1.

Inertial weight w is an important parameter which denotes the influence of velocity of last generation to current generation. In the beginning stages of algorithm, the inertial weight w should be reduced rapidly, when around optimum,

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the inertial weight w should be reduced slowly. So in this paper, the following selection strategy is adopted.

$$w = w_{\max} - \frac{w_{\max} - w_{\min}}{iter_{\max}} \times iter, \tag{3}$$

where, w is current weight, $w_{\max}$ is beginning weight, $w_{\min}$ is ending weight, $iter_{\max}$ is maximum generation of iteration, $iter$ is current generation of iteration.

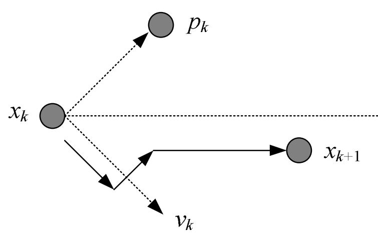

Figure 1. Sketch map of movement of particles

With the adjust function of parameter w, particle is more and more near the optimum and the speed is more and more slow with the increase of generation, which can avoid the oscillation.

III. PID CONTROLLER

A. Screwdown System Controller

Digital PID controller of screwdown system is adopted as the incremental form. Comparing with position PID algorithm, incremental PID algorithm can eliminate the integral saturation and can avoid the risk of computer disoperation. The increment PID can be expressed as following

$$\begin{aligned}\Delta u(kT) &= u(kT) - u(kT-T) \\ &= K_{\mathrm{p}}[e(kT) - e(kT-T)] + K_{\mathrm{i}} e(kT) \\ &\quad + K_{\mathrm{d}}[e(kT) - 2e(kT-T) + e(kT-2T)]\end{aligned}, \tag{4}$$

where, $\Delta u(kT)$ is increment of output of controller, $u(kT)$ is output of controller at the time of kT, $e(kT)$ is error between the reference value and actual value of control system at the time of kT, K_{p} is proportional coefficient, K_{i} is integral coefficient, K_{d} is Differential coefficient, and T is sampling period.

K_{i} and K_{d} meet the following equations

$$K_{\mathrm{i}} = \frac{K_{\mathrm{p}} T}{T_{\mathrm{i}}}, \tag{5}$$

$$K_{\mathrm{d}} = \frac{K_{\mathrm{p}} T_{\mathrm{d}}}{T}, \tag{6}$$

where, T_{i} and T_{d} are integral time constant and differential time constant.

B. PSO PID controller

Using PID controller based on PSO algorithm, the screwdown AGC computer control system is designed as Fig. 2 shown.

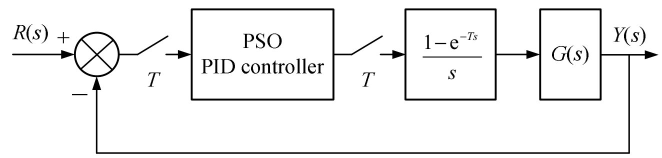

Figure 2. AGC control system based on PSO PID controller

By analyzing the parameter of one single stand reversing cold rolling mill, the transfer function of the closed loop of press which considers the rolling loads, hydraulic piston, electron-hydraulic servo valve, control pipeline and sensor can be simplified through model reduction as following equation

$$G(s) = \frac{14620(0.046s+1)}{s\left(\frac{s}{0.0297}+1\right)\left(\frac{s^2}{608^2}+\frac{0.422}{608}s+1\right)}. \tag{7}$$

The fitness function of PSO algorithm is set to consider the synthesis of rise time, steady-state error, output of controller and output of controlled plant. The fitness function can be expressed as following [9].

$$J = \int_0^t (w_1|e(t)| + w_2 u^2(t) + w_4|y(t) - y(t-1)|)\mathrm{d}t + w_3 t_{\mathrm{r}}, \tag{8}$$

where, $e(t)$ is error, $u(t)$ is output of controller, $y(t)$ is output of controlled plant, and t_{r} is rise time.

The discrete expression of the fitness function is as following

$$J = \sum_{k=0}^{n} (w_1|e(kT)| + w_2 u^2(kT) + w_4|y(kT) - y(k-1)T|) + w_3 t_{\mathrm{r}}, \tag{9}$$

where, $w_1 = 0.999$, $w_2 = 0.001$, $w_3 = 2$, $w_4 = 100$.

The three parameters of PID controller－K_{p}, K_{i}, K_{d} are set as the position variables of PSO algorithm. So position variable x [K_{p}, K_{i}, K_{d}] is a three-dimension variable.

PSO algorithm is based on iterative computing and the iterative flow chart of PID controller based on PSO algorithm is shown in Fig. 3.

The calculation parameters of PSO PID algorithm are shown in Table Ⅰ. The particle number is adopted as 80 and the maximal generation is 100.

TABLE I. CALCULATION PARAMETERS OF PSO ALGORITHM

c_1	c_2	$v_{\max}$	$x_{\max}$	$x_{\min}$	$w_{\max}$	$w_{\min}$
2	2	1	20	0.001	0.9	0.4

The convergence curve of PSO PID of different generation is shown in Fig. 4.

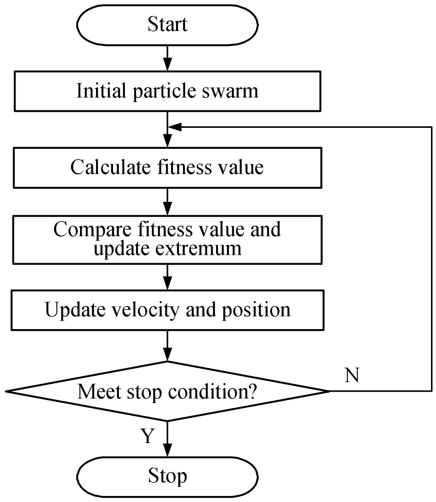

Figure 3. Flow chart of PSO algorithm

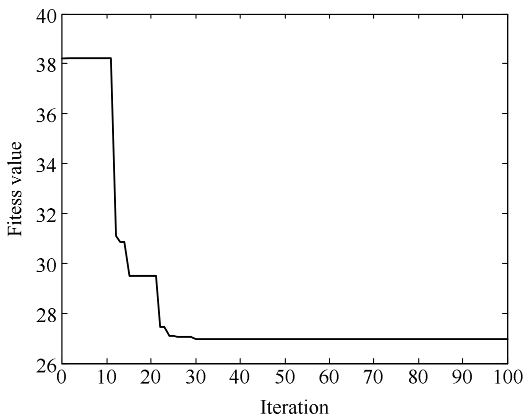

Figure 4. Convergence curve of PSO PID of different generation

From Fig. 4 it can be seen that the fitness value reaches the minimum fitness value after 30 times iteration.

The results of PID parameters optimization based on PSO are shown in Table Ⅱ.

TABLE II. RESULTS OF PSO OPTIMIZATION

K_p	$K_{i,}$	K_d	**Minimum fitness value**	**Convergence generation**
2.4281	0.0159	0.0010	26.9626	30

C. GA PID controller

In order to compare the optimization performance of PSO PID controller, genetic algorithm to optimize the PID controller is simulated with the same rolling mill mathematic model.

Genetic algorithm is a widely used optimization algorithm and has the global searching ability. The same with PSO algorithm GA is also based on iterative computing. Iterative flow chart of PID controller based on GA optimization is shown in Fig. 5.

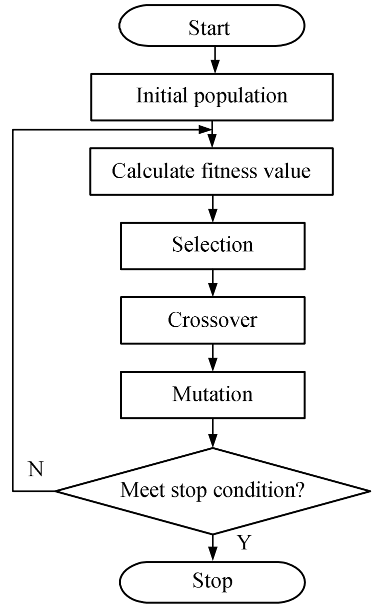

Figure 5. Flow chart of GA PID

The calculation parameters of GA PID are shown in Table Ⅲ. The population size is adopted as 80 and the maximal generation is 100.

TABLE III. CALCULATION PARAMETERS OF GA

n	p_c	p_{mmax}	p_{mmin}	x_{max}	x_{min}	***Maxiterarion***
80	0.9	0.1	0.001	20	0.001	100

The convergence curve of GA PID of different generation is shown in Fig. 6.

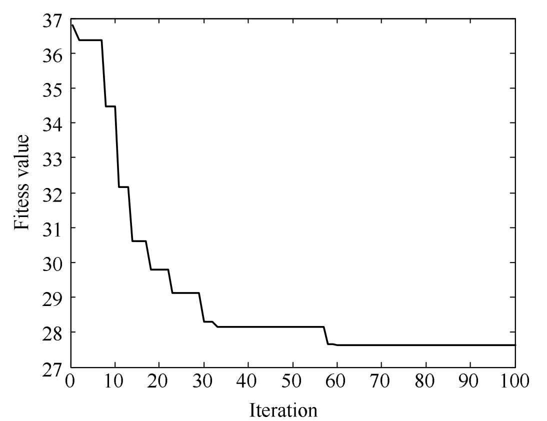

Figure 6. Convergence curve of GA PID of different generation

From Fig. 6 it can be seen that the fitness value reaches the minimum fitness value after 60 iterations.

The results of PID parameters optimization based on GA are shown in Table Ⅳ.

TABLE IV. RESULTS OF GA OPTIMIZATION

K_p	$K_{i,}$	K_d	**Minimum fitness value**	**Convergence generation**
2.0975	0.0168	0.1320	27.7092	60

The step respond curves of PSO PID and GA PID are shown in Fig. 7.

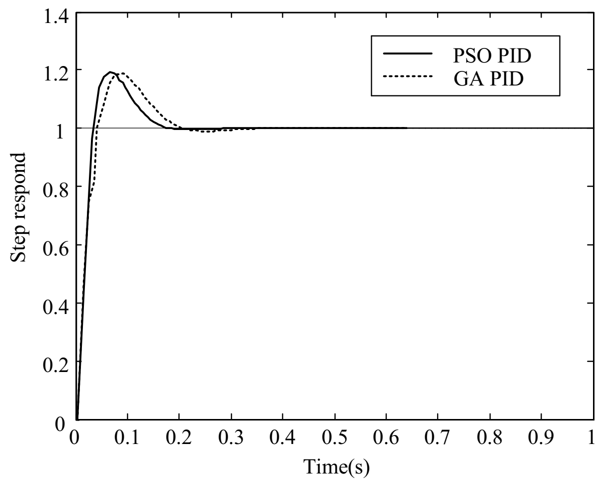

Figure 7. Step respond curve of GA PID

IV. CONCLUSION

From the simulation results, it can be seen that PID parameters optimization of the cold rolling mill using PSO algorithm is better than GA. PSO algorithm is a little faster than GA in settling time of step respond. From the minimum fitness value it can be seen that PSO algorithm is more precise than GA. The PSO algorithm has better convergence speed than GA, since minimum value of fitness function is reached after 30 iterations in PSO algorithm, where 60 iterations in GA.

The PID parameters optimization based on PSO can obtain better control effect and will improve the product quality of the cold strip mill.

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