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## APPLIED RESEARCH

# Research on the Control Strategy of Battery Roller Press Deflection Device by Introducing Genetic Algorithm to Optimize Integral Separation PID

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**ABSTRACT** At the site of continuous rolling of lithium battery electrode, most of its correction units use traditional PID control algorithms, coupled with the complex structure of the rolling equipment and the large number of control system actuators, result in the deviation of the pole piece position being controlled within 10mm only. In order to avoid the undesirable industrial problems caused by untimely correction and insufficient control accuracy, this paper proposes a control strategy for lithium battery roll press deflection device with the introduction of GA(Genetic Algorithm) optimized integral separation PID. For the problems of poor self-adaptive capability of deflection control and interference with equipment and environment during the rolling process. Analyze the causes of runout of the pole piece and the structure of the deflection correction system, establish a mathematical model and an integral separation fuzzy PID controller to realize the deflection control. Optimize the key parameters of the controller using GA to improve the control accuracy and performance of the deflection control. Simulations and experiments show that the deviation control strategy proposed in this paper can reduce the position deviation of the polar strip to within 4mm, which can effectively improve the deviation correction accuracy and the anti-interference capability of equipment operation, and also provide a good solution for the deviation control of other large and complex mechanical equipment.

**INDEX TERMS** Battery roller press, deviation control, genetic optimization, fuzzy PID.

## I. INTRODUCTION

During the operation of the roller press, the pole piece runs fast on the drive roll. However, due to the bending and deformation of the pole piece itself or the influence of roller press operation technology, it will cause the deviation of the lithium battery pole piece on the drive roll, thus causing damage to the rolling unit and other mechanical units of the roller press [1].

The deviation correction system mainly has the following functions in the smooth rolling of the pole piece [2], [3], [4]:

1. Avoid the deviation of the pole piece during the production process and ensure the smooth running of the pole piece on the main roll and drive roll.
2. Realizing the stable winding of the pole piece, avoiding the folding or wrinkling of the pole piece during the winding process;
3. Making the traction force of the pole piece parallel to the center line of the driving roller, and ensuring uniform tension of the winding and unwinding pole piece.

The current correction control strategy is more traditional, not only the accuracy method is not high, but also the ability of adaptive adjustment, and the anti-interference ability is

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slightly insufficient. Therefore, it is of great significance to study the new high-precision and strong anti-interference ability correction control method for the deviation control of rolling mill.

In the field of corrective control, many scholars have carried out research on the corrective control methods of various mechanical equipment, which is of great significance for this paper. Kou X Q aimed at the steel strip deviation, an improved PID control method based on RBF neural network is proposed. According to Jacobian information identification of RBF neural network combined with incremental PID algorithm, the self-tuning of parameters is implemented so that the performance of the system can achieve the designed requirements [5]. Wang based on the actual running deviation data of some aluminum strip rolling industry, we analyzed their chaos and fractal character, proposed one improved pattern classification based on the fuzzy c-average clustering, on basis of this method classified running deviation pattern, constructed adding weight zero-order local prediction method of strip turning deviation signal [6]. Hui found that the nonlinearity and time-variance of electrical-hydraulic servo system for steel strip deviation make traditional PID control hard to achieve the ideal control effect it. The combination of neural networks control and general PID can form neural network self-adjusting PID control strategy to realize good control of electrical-hydraulic servo system for steel strip deviation. To improve the dynamic response speed and performance of the system, RBF neural network is adopted to indentify and predict the system [5]. The dual-chip control system of “ARM+DSP” proposed by Xiao and Deng, etc., using the dual-chip architecture and fuzzy PID to improve the anti-interference capability of pole piece deflection and tension control [7]. However, the control method in the overall amplitude of the equipment is too large or failure, the traditional PID control will produce the integral accumulation phenomenon, resistance to large interference signal when the control accuracy and speed is not enough. Among them, the initial parameters in the fuzzy PID and the selection of fuzzy rules mostly rely on experience, while the correction control in the polar piece rolling process is a nonlinear system that changes in real time, and the improper selection of initial parameters can also affect the control accuracy. Deviation between the selected initial parameters and the optimal parameters by relying only on experience and not in relation to the actual operating conditions of the equipment. To improve the performance of the PID controller for a steel strip deviation control system, an enhanced artificial bee colony algorithm is proposed to optimize PID controller gains [8]. However, an accurate mathematical model was not established in this paper.

It can be seen that although the authors have adopted a lot of different rectification control methods in the rectification control of pole piece, there are still certain deficiencies in them in combination with the deflection accuracy and the deflection effect described in the paper, for the following reasons:

1. Most rectification control strategies are relatively simple and lack good adaptive ability;
2. In addition to the position of the pole piece belt, the deviation correction part of the pole piece rolling mill also has a certain coupling relationship with various parameters such as guide rollers, tension and vibration. The existing control method is difficult to solve the interference of the equipment itself and the external environment when the pole piece is rolled, and needs to be further optimized and upgraded;
3. Most of the above methods are for the analysis and research of strip steel.

The existing deviation control methods are robust control, adaptive control, fuzzy control, neural network and PID control. The PID control method is simple and widely used in industry. With the fuzzy algorithm which does not need to establish an accurate mathematical model and has excellent anti-interference ability, it can be well applied to the tension control process of rolling mill. Therefore, this paper studies and analyzes the rectification mechanism and improvement method of the pole piece in the pole piece rolling mill, and on this basis, designs a kind of rectifying control method suitable for the pole piece rolling mill, that is, the fuzzy PID control method based on genetic algorithm(GA) optimization. On the basis of integral separation PID control algorithm, fuzzy algorithm is introduced to realize on-line adjustment of  $K_P$ ,  $K_I$  and  $K_D$  parameters in PID control by using relevant expert knowledge, which can effectively improve the accuracy and anti-interference ability of the control link. In order to avoid the problem that the traditional optimization method is easy to fall into the local optimal solution, the GA is introduced to optimize the PID initial parameters and fuzzy rules.

The robust control has good performance against the interference of the internal and external environment of the system, but its control accuracy is slightly lower than that of other methods. Adaptive control has good performance in dealing with external random interference and lag response method of mechanical equipment, but the lag of mill deviation control is not high, and the interference is not particularly strong in the process of stability control, so this method is not selected in this paper. Neural network has strong performance in self-learning and self optimization, and has good adaptability in rolling mill tension control, but it is not convenient to write the algorithm of the control system. Compared with robust control and adaptive control, the control strategy proposed in this paper can guarantee the control accuracy while countering the internal and environmental interference, and is more suitable for the deviation control of the pole piece.

This article takes the pole piece rolling machine's deviation correction system and deviation correction flow as the starting point, on this basis, it focuses on the genetically optimized fuzzy PID control method [9].

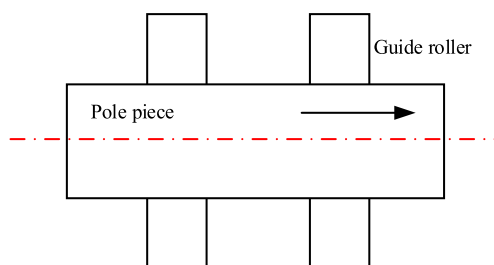
The novelty of this paper lies in the establishment of the model of the deviation correction system and the optimization of the initial parameters and fuzzy rules in the integral separation fuzzy PID. In the process of genetic optimization, the

initial parameters are optimized first. When the fuzzy rules are optimized, the initial parameters of the optimization are introduced to obtain the final optimization results. Through the establishment of the model and the optimization of the parameters, a deviation correction system suitable for the pole piece rolling equipment is constructed, which solves the problems of low control accuracy and poor anti-interference ability in the field of pole strip deviation correction. Aiming at the nonlinearity of the rolling mill control system, the mathematical model of the deviation correction system is established, and the transfer function of the deviation correction control is introduced to simulate the real-time deviation correction effect, so as to feed back the fitness value under different initial parameters to improve the adaptability of the genetic algorithm.

Firstly, the establishment of fuzzy PID controller is achieved by establishing the method of correcting fuzzy, membership function and related fuzzy rules, combined with PID control algorithm [10]. Then the genetic iterative optimization principle is used to optimize the basic parameters of PID and the fuzzy rules in the fuzzy controller to improve the accuracy and anti-interference ability of the control method [11]; Finally, the performance of the algorithm is verified by means of simulation analysis, experimental verification and comparative analysis. In the industrial field, the position deviation of the pole piece is less than 10mm in the traditional PID control algorithm used in the rewinding and correcting unit of the polar strip rolling mill. The fuzzy PID control algorithm proposed in this paper can reduce the position deviation of the polar strip from 10mm to 4mm, which greatly improves the accuracy and effect of the rectification.

**II. CAUSES OF THE DEVIATION OF POLE PIECE**

In the ideal environment of lithium battery pole sheet rolling, the running direction of the pole piece is completely perpendicular to the center line of the guide roll of the production line. At this time, the pole piece runs smoothly without position deviation, as shown in Fig.1.

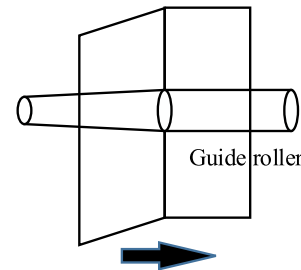


**FIGURE 1.** Structure diagram of pole piece without offset phenomenon.

However, in the actual rolling process, due to the complex structure of mechanical equipment, more actuators of control system and external uncertain interference factors, the pole piece will produce a certain degree of offset, and this offset is often difficult to avoid. The main factors are as follows.

**A. INFLUENCE OF GUIDE ROLL GEOMETRY**

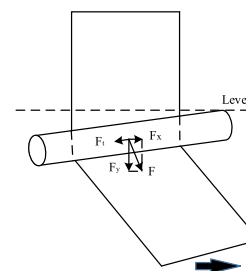
In the process of polar strip conveying, the cylindrical guide roll is commonly used, but in the actual production process, the shape of the guide roll may not be standard. Or in the long-term conveying process of the polar strip, the guide roller is worn due to the friction with the polar strip. These factors will lead to the change of the shape of the guide roll, such as bending, bulging or the change of the roll body structure into cone roll. Taking the cone roll as an example, this paper analyzes the impression of the guide roll geometry on the offset of the polar strip: assuming that the roll shape is intact, the polar strip is only subject to the traction force perpendicular to the center line of the guide roll. When the roll shape is conical, as shown in Fig.2, due to the uneven force on both sides of the polar strip, a transverse offset force will be generated on the polar strip from the place with the smaller roll diameter to the place with the larger roll diameter. When the lateral offset force is greater than the maximum static friction between the roll surface and the pole piece, the pole piece will shift to the larger roll diameter.



**FIGURE 2.** Schematic diagram of the influence of guide roll shape on polar plate offset.

**B. INFLUENCE OF INSTALLATION ERROR OF GUIDE ROLLER**

During the installation of the guide roll, due to the operator's error, the guide roll and the horizontal line may no longer be parallel, as shown in Fig.3. In this case, compared with the above analysis method of cone roll, a lateral offset force  $F_x$  will be generated. The offset force points to the higher side of both sides of the conductor roll, which will cause the pole piece to offset to this side.



**FIGURE 3.** Schematic diagram of the influence of guide roll installation error on pole piece offset.

**C. THE WAVE EDGE LEADS TO UNEVEN TENSION DISTRIBUTION**

When the wave edge phenomenon occurs in the rolling process of the pole piece, the force analysis is shown in Fig. 4.

When the pole piece is under constant tension, the force on the left and right sides of the pole piece is unbalanced due to the wave edge phenomenon, and there will be both longitudinal traction force and a transverse deflection force pointing to the wave edge on the pole piece, which will cause the pole piece to shift to the side with wave edge phenomenon.

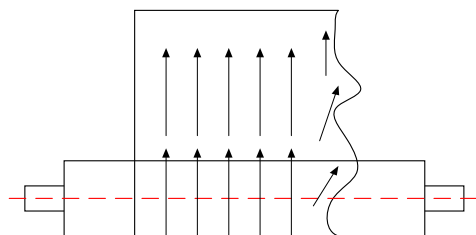


FIGURE 4. Schematic diagram of the influence of wave edge phenomenon on polar plate migration.

**D. THE AXES OF GUIDE ROLLERS ARE NOT PARALLEL**

Sometimes, two or more guide rollers need to be installed to realize the stable transmission of polar strip. At this time, if the axes of different guide rollers are not parallel, as shown in Fig.5, there is a certain angle between the axis of guide roller and the transmission direction of polar plate, which will lead to the uneven tension received by polar plate belt. At this time, the polar plate belt will tilt to one side due to the friction component perpendicular to the roller direction.

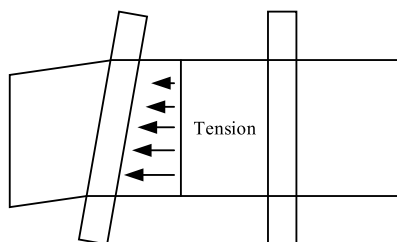


FIGURE 5. Schematic diagram of influence of non parallel guide roller axis on polar plate offset.

**E. SECTION THICKNESS OF POLAR STRIP**

After the pole piece is rolled by the rolling mill, the section thickness will be compacted to the same thickness. However, before rolling, there may be a certain section thickness difference in the coarse material of the pole piece discharged from the unwinding air expansion shaft. When passing through the guide roll in the unwinding device, due to the different transverse thickness difference, the force on both sides of the pole piece on the guide roll is uneven. The section of the guide roll is shown in Fig.6, At this time, there will be a traction force on the strip from the thinned part to the thicker part, resulting in the offset of the strip before it enters the roll.

Under the influence of the above factors, the pole piece tape will be shifted during the transmission process. These pole piece shift phenomena continue to interact and accumulate, and may produce tower-shaped rolls, overflow edges and roll

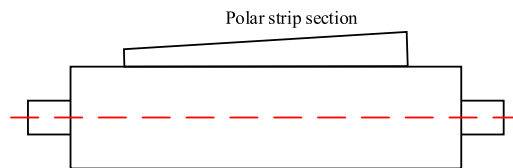
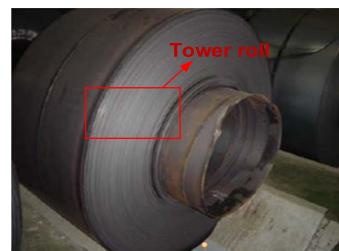


FIGURE 6. Schematic diagram of the influence of the section thickness of the polar plate on the polar plate offset.

layer disorder etc. Where the tower roll and roll layer disorder are shown in Fig. 7.



(a) Tower roll phenomenon



(b) Disorder phenomenon of polar convolution

FIGURE 7. Adverse phenomena caused by pole displacement.

In addition, during the operation of the equipment, the uneven tension distribution of the pole piece belt has an adverse effect on the deviation correction control of the pole piece belt to a certain extent, which is mostly caused by mechanical structure problems. However, with the use of equipment, the change of mechanical structure is inevitable, so the influence of tension is not considered in the process of rectification.

**F. STRUCTURE OF DEVIATION CORRECTION SYSTEM**

In order to avoid the above-mentioned adverse effects, and to ensure that the pole piece strip can accurately pass through the roll when unwinding, and can be neatly passed through the rectification mechanism during rewinding, the edge correction system is often used in pole piece rolling mills to achieve the pole piece. The correction is shown in Fig. 8.

The electrode strip rectification system is mainly composed of rectification detection device, main control system, rectification control device and electric actuator [12]. The photoelectric or ultrasonic sensor is installed on one side of the electrode strip as the reference. When the polar strip is offset, the detection device will measure the offset distance and angle of the strip edge, determine the degree of the strip offset, and transmit the collected information to the main control system. After analysis and processing, the main control

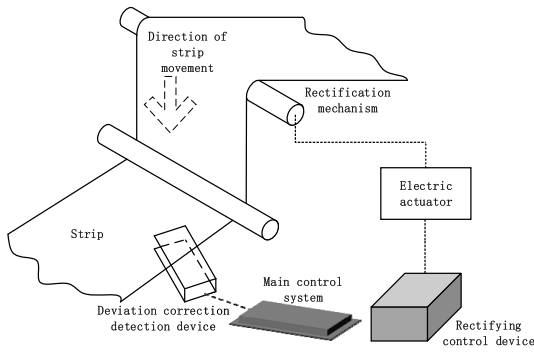


FIGURE 8. Structure diagram of pole piece correction system.

system determines the control strategy, outputs the signal to the rectification control device, and then drives the electric actuator to drive the rectification mechanism to realize the pole piece rectification. When the offset distance of the pole piece returns to the set value after correction, the action of the electric actuator shall be stopped. During the operation of the rolling mill, the above operations shall be continuously cycled to make the strip run stably within the set offset range. The rectification process of pole piece is shown in Fig.9

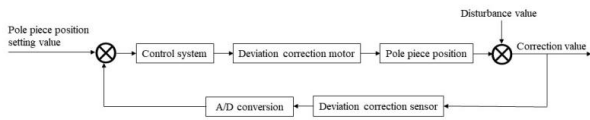


FIGURE 9. Schematic diagram of pole piece correction process.

### III. THE ESTABLISHMENT OF MATHEMATICAL MODEL OF DEVIATION CORRECTION SYSTEM

Before the research on the control method of deviation correction, it is necessary to confirm the system model of the execution and transmission part of the deviation correction system, and complete the correct drive signal output. Therefore, this section combines the drive motor with the mechanical actuator to derive the transfer function of the pole piece rectification system.

According to the functional requirements of the model, the model can be divided into three parts: detection and comparison, motor drive and mechanical drive. In the detection and comparison part, the strength of the collected sensing signal is detected and converted into the offset distance of the actual electrode strip by calculation, and the offset information of the electrode strip is calculated by comparing the measured value with the set offset value; In the motor driving part, the driving motor is transformed into a mathematical model, and its transfer function is obtained by analyzing its motion equation for subsequent analysis. The mechanical transmission link drives the mechanical structure through the motor to realize the action of the guide roller, which is the last link to complete the deviation correction control. Here, the transmission model is established for analysis to replace the corresponding mechanical structure.

1. The detection and comparison link mainly involves position detection. Because the detected signal is an analog signal, the analog signal  $L$  and the corresponding position information  $H_L$  can be converted into a proportional link through the proportional coefficient  $K_L$ . The specific transfer function is shown in (1). Then, by comparing the collected position information  $L_f$  with the set value  $L_c$  and making a difference, the position deviation information  $L_e$  is obtained, as shown in (2).

$$H_L(s) = K_L l \tag{1}$$

$$L_e = L_c - L_f \tag{2}$$

2. Motor drive link. In order to facilitate the subsequent simulation model building and simulation analysis, this paper simplifies the motor model and adopts a simple DC motor model:

$$L_a \frac{di_a}{dt} + R_a i_a = U_a - E_a \tag{3}$$

$$E_a = K_e \omega_a = K_e \frac{d\theta}{dt} \tag{4}$$

In the equation,  $U_a$  is the armature voltage,  $\theta$ ,  $L_a$  and  $R_a$  are inductance and resistance of armature winding,  $E_a$  is motor back EMF,  $K_e$  is motor back EMF coefficient,  $\omega_a$  is the motor speed.

The electromagnetic torque of the motor is:

$$M_d = K_m i_a \tag{5}$$

In the Equation:  $K_m$  is the torque coefficient of the motor. The torque balance equation of the motor is as follows:

$$M_d = J \frac{d^2\theta}{dt^2} + f_0 \frac{d\theta}{dt} \tag{6}$$

In the Equation,  $J$  is the moment of inertia of the motor shaft and  $f_0$  is the damping coefficient.

In combination with the above (3) - (6),  $i_a$  is eliminated by transformation, and Laplace transformation is carried out to obtain (7)

$$\frac{\theta(s)}{U_a(s)} = \frac{K_m}{s[JL_a s^2 + (JR_a + f_0 L_a)s + (R_a f_0 + K_e K_m)]} \tag{7}$$

In the Equation,  $K_d = \frac{K_m}{R_a f_0 + K_e K_m}$

$$T_m = \frac{JL_a}{R_a f_0 + K_e K_m} \quad T_d = \frac{JR_a + f_0 L_a}{R_a f_0 + K_e K_m}$$

The transfer function of voltage angle can be obtained by simplification:

$$G_m(s) = \frac{\theta(s)}{U_a(s)} = \frac{K_d}{s(T_m s^2 + T_d s + 1)} \tag{8}$$

Since the motor speed can be regarded as the differential  $\omega_a = \frac{d\theta}{dt}$  of the motor angle,  $\omega_a(s) = s\theta(s)$  can be obtained by Laplace transform of the Equation. When  $y$  is brought into the motor transfer function obtained above, the voltage speed transfer function  $G_v(s)$  as shown in (9) can be obtained. The



obtained transfer function is a typical second-order oscillation link.

$$G_v(s) = \frac{\omega_a(s)}{U_a(s)} = \frac{s\theta(s)}{U_a(s)} = \frac{K_d}{T_m s^2 + T_d s + 1} \quad (9)$$

[3.] The mechanical transmission link is the action link of the mechanical equipment from the output of the servo motor to the completion of the deviation correction. In this part, with the servo motor driving, the action equipment completes the adjustment of the offset distance synchronously. Therefore, the adjustment of the motor output and the offset distance can be regarded as a proportional link, and the proportional coefficient can be set to  $K_s$ . However, in the process of the mechanical equipment transmission and control, the adjustment of the motor output and the offset distance can be regarded as a proportional link. It is necessary to add a delay link in addition to the proportional link because of the inherent property of the equipment. According to the delay theorem of pull transform, we can get that:

$$G_d(s) = e^{-\tau_0 s} = \frac{1}{e^{\tau_0 s}} \quad (10)$$

In the equation:  $\tau_0$  is the pure delay time.

By expanding  $e^{\tau_0 s}$  according to Taylor series, we can get the following results:

$$e^{\tau_0 s} = 1 + \tau_0 s + \frac{\tau_0^2 s^2}{2!} + \frac{\tau_0^3 s^3}{3!} + \dots \quad (11)$$

Because  $\tau_0$  is smaller, so only the first two terms are retained for subsequent calculation, that is  $e^{\tau_0 s} \approx 1 + \tau_0 s$ . In this case, combined with the proportional coefficient  $K_s$ , the simplified transfer function  $G_s(s)$  of the whole mechanical transmission link can be obtained as follows:

$$G_s(s) = \frac{K_s}{\tau_0 s + 1} \quad (12)$$

The closed-loop transfer function of the rectifying system of the lithium battery plate rolling mill can be obtained by combining the above three parts of the transfer function:

$$G(s) = K_L \times \frac{K_d}{T_m s^2 + T_d s + 1}$$

$$G_s(s) = \frac{K_L K_d K_s}{(T_m s^2 + T_d s + 1)(\tau_0 s + 1)} \quad (13)$$

## IV. RESEARCH ON CORRECTION FUZZY PID CONTROL METHOD

### A. OVERALL SCHEME DESIGN

In the traditional deflection control of the pole piece rolling mill, in order to improve the accuracy of the rectification control of the unwinding and unwinding and reduce the interference of the equipment or the environment on the industrial site, the PID control method with strong adaptability is mostly used. The position deviation information is obtained by making the difference between the collected pole piece belt position information and the set value of the pole piece belt position, which is used as a deviation signal as an input amount in PID control. Then through proportional,

integral and differential calculation of the deviation signal to output the control signal to control the motor drive device to complete the position correction of the pole piece [13]. When setting the three parameters of the PID controller  $K_P$ ,  $K_I$ ,  $K_D$ , a lot of relevant expert knowledge is needed, but most of these parameter setting knowledge is a vague experience, which is not conducive to the formation of clear parameters. The fuzzy control is to express the experience of the expert's ambiguity through the computer, which can effectively optimize the three parameters in the PID controller [14].

In order to avoid the phenomenon that the position deviation signal of the pole piece belt is too large during the start, stable operation and stop of the pole piece rolling mill, it will have a greater impact on the integral link of the PID control and produce an integral accumulation phenomenon. This article introduces the integral separation control method in the PID control process. When the position deviation signal of the pole piece is large, the stability of the system is improved by removing the integral link in the PID control; When the deviation signal decreases and is closer to the set value, the integration link is re-introduced to eliminate the static error in the correction control. At this time, the overall flow of the integral separation fuzzy PID algorithm as shown in Fig.10 is obtained [15].

### B. INTEGRAL SEPARATION PID CONTROLLER

During the start-up, stable operation and stopping of the lithium mill, the position information of the pole piece is not stable and constant, and there may be excessive deviation of the pole piece position signal. At this time, the position signal of the polar strip will produce a large change in a short period of time, in the process of PID control, this situation will have a large impact on the integration link, resulting in the accumulation of integration phenomenon. Without changing the control strategy, it will cause the corrective control accuracy and speed to be reduced, and even the execution equipment may oscillate under the influence of the output signal, which in turn threatens the mechanical structure of the mill. In order to avoid the possible bad consequences of the above problems, this paper introduces the integral separation control method in the PID control process. Improving the stability of the system by removing the integral link in the PID control when the deviation signal of the pole piece position is large, When the deviation signal decreases and is closer to the set value, the integration link is reintroduced to eliminate the static error in the correction control. The operation flow is shown in Fig.11.

When making a judgment on whether to introduce the principle of integral separation, it is first necessary to set the deviation threshold  $\omega$  according to the actual control object. When the controlled quantity exceeds the set value too much and is greater than the set  $\omega$ , the integral link in the PID control is eliminated, and conversely when the controlled quantity is close to the set value and is less than the set  $\omega$ , the integral link is reintroduced to complete the proportional integral differential control. By bringing the parameter  $\beta$

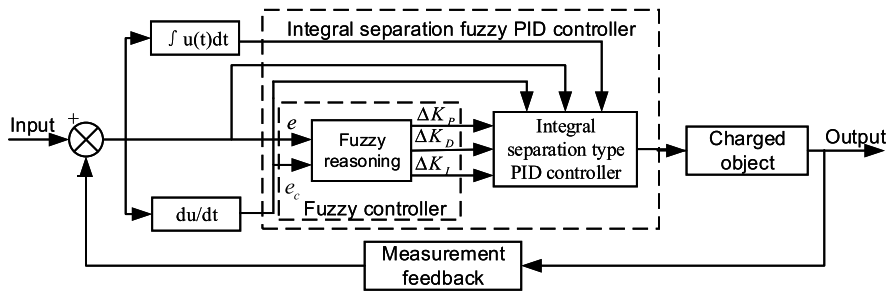


FIGURE 10. Schematic diagram of application flow of integral separation fuzzy PID algorithm.

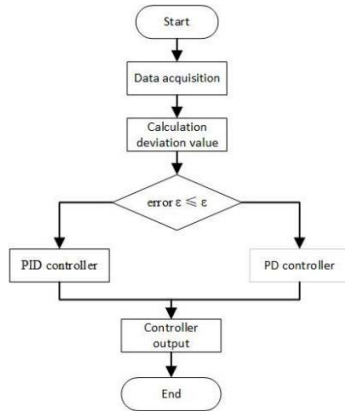


FIGURE 11. Schematic diagram of operation flow of integral separation.

obtained from the judgment into the above equation, the calculation of integral separation PID control can be obtained. The method is as in (14) (15).

$$\beta = \begin{cases} 1 & |\text{error}(t)| \leq \omega \\ 0 & |\text{error}(t)| > \omega \end{cases} \quad (14)$$

$$u(t) = k_p \text{error}(t) + \beta k_i \int_0^t \text{error}(t) dt + k_d \frac{d\text{error}(t)}{dt} \quad (15)$$

C. ESTABLISHMENT OF FUZZY CONTROLLER

Fuzzy control refers to converting the actual operation or control experience of experts in related fields into a fuzzy language control rule, and using the established database and rule base to complete the association of input and output through the inference engine [16]. The main components and structural block diagram of fuzzy control are shown in Fig.12.

In the application process of fuzzy algorithm, the fuzzy interface is used to realize the transformation from input parameters to fuzzy universe, and the proportion relationship between input parameters and universe is established through quantitative factors, and the output accurate parameter value is transformed into fuzzy language value; the knowledge base can be divided into a fuzzy database and a fuzzy rule base according to different internal functions: the database contains the membership functions of all fuzzy subsets of the input and output parameters that have been set in advance. The rule base expresses expert knowledge as language rules in the form of if-then, and establishes the mapping relationship between different quantization levels of input and output parameters for subsequent fuzzy reasoning;

the inference engine performs fuzzy inference on the input parameters through the established knowledge base to obtain the fuzzy output; the de-fuzzification interface completes the conversion of the fuzzy parameters to the precise output through the de-fuzzification operations such as the center of gravity method [17].

When constructing a fuzzy correction controller, first of all, the basic domain of input and output parameters in fuzzy inference should be divided, and combined with appropriate quantization factors, the basic domain should be converted into a fuzzy domain that is convenient for fuzzy inference operations.

First, we determine the fuzzy subsets of *e* and *e<sub>c</sub>*. For PID control, we choose seven language variables: Negative Big [NB], Negative Medium [NM], Negative Small [NS], Zero [ZO], Positive Small [PS], Positive Medium [PM], and Positive Big [PB] to express their fuzzy subsets with sufficient accuracy. So we define the fuzzy subset of *e* and *e<sub>c</sub>* as {NB, NM, NS, ZO, PS, PM, PB}. Its actual variation range is [-12,12], so its basic domain is determined to be [-12,12].

Increasing the number of elements in the universe can improve the control accuracy, but it increases the amount of calculation, and the improvement of fuzzy control effect is not obvious. When the above fuzzy subset is selected, the universe of *e* and *e<sub>c</sub>* can be selected as {-6, -4, -2,0,2,4,6}.

In actual control, the values of input and output are generally not elements in the universe. In this case, it is necessary to transform the universe through quantization factor and scale factor. Generally speaking, the basic universe of the system input is: the error *e*(*t*) is [-*e*, *e*], the error change rate *e<sub>c</sub>*(*t*) is [-*e<sub>c</sub>*, *e<sub>c</sub>*], and the basic universe of the output variable is [-*u*, *u*]. According to the basic domain and calculation formula of input and output, the quantization factors *k<sub>e</sub>*, *k<sub>ec</sub>* and scale factor *k<sub>u</sub>* can be obtained:

$$\begin{cases} k_e = \frac{n}{e_m} \\ k_{ec} = \frac{n}{e_c} \\ k_u = \frac{u}{l} \end{cases} \quad (16)$$

where:

- n*-*e*(*t*) maximum value of basic domain
- m*-*e<sub>c</sub>* (*t*) maximum value of basic domain
- l*-Δ*K<sub>P</sub>*, Δ*K<sub>I</sub>*, Δ*K<sub>D</sub>* maximum value of basic domain

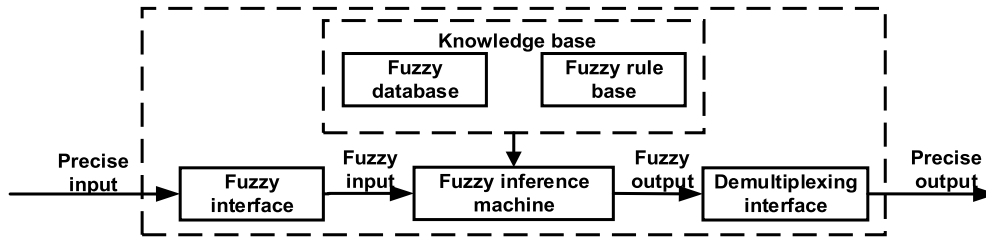


FIGURE 12. Schematic diagram of application process of fuzzy algorithm.

TABLE 1. The fuzzy theory field and quantitative factors of rectifying deviation.

Input and Output Parameters	Fuzzy Domain	Quantization Factor	Basic Discourse
Pole position deviation $e$	[-6, -4, -2, 0, 2, 4, 6]	1/2	[-12, 12]
Deviation rate $e_c$	[-6, -4, -2, 0, 2, 4, 6]	1/2	[-12, 12]
$\Delta K_P$	[-6, -4, -2, 0, 2, 4, 6]	1/3	[-2, 2]
$\Delta K_I$	[-3, -2, -1, 0, 1, 2, 3]	1/3	[-1, 1]
$\Delta K_D$	[-3, -2, -1, 0, 1, 2, 3]	1/6	[-0.5, 0.5]

This article combines the actual change range of each parameter in the correction control, and selects some quantization factors to achieve the transformation of the control parameter from the basic domain to the fuzzy domain, as shown in Table 1.

In this paper, the five parameters are divided into 7 parts according to the selection range of the fuzzy universe, which corresponds to the 7 fuzzy subsets of the fuzzy universe. In the selection of the membership function of the rectification control, if the rectification control cannot be completed quickly, it may cause edge cutting errors or edge folding during the winding and unwinding of the pole piece tape. Therefore, when the position deviation of the pole piece belt is large, the resolution of the fuzzy set of the membership function can be set lower to achieve a fast response to correction; and when the position deviation is small, the control accuracy needs to be improved. At this time, the resolution of the fuzzy set should be adjusted appropriately to meet the precise control. According to the above analysis, the corresponding membership function is established. Taking the pole piece position deviation as an example, the established membership function is shown in Fig. 13, where the left and right boundary parts use semi-trapezoid membership functions, and the middle five quantization levels use triangular membership functions [18].

When establishing fuzzy rules in the correction control, it is necessary to fully consider the overall operation of the pole piece rolling mill and the correction control of the winding and unwinding. Combined with the experience of on-site correction operation, the relationship between the input pole piece deviation signal and its rate of change and the three parameters in the integral separation PID are given under different working conditions. The specific principles are as follows:

1. In the process of rectification control, when the deviation value  $e$  of the pole piece position is large, in order to quickly reduce the deviation value, a larger value of

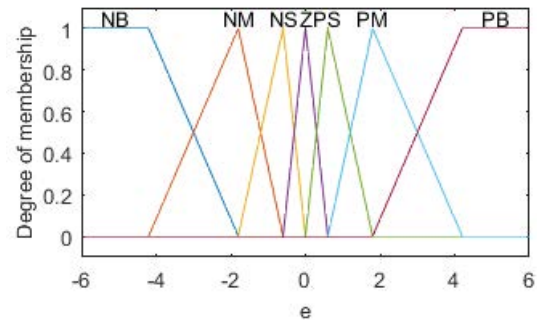


FIGURE 13. The membership function of the deviation of pole piece correction.

$\Delta K_P$  should be selected so that the deviation correction system can respond quickly; at this time, if the rate of change of the deviation value  $e_c$  is too large, the  $\Delta K_D$  is appropriately reduced to weaken the influence of the differential link [19].

- When the pole piece deviation  $e$  is centered, the value of  $\Delta K_P$  can be increased appropriately to increase the effect of the integration link; the value of  $\Delta K_D$  should be appropriately reduced to avoid overshoot and oscillation;  $\Delta K_I$  should be a small value to avoid excessive static errors.
- When the pole piece deviation  $e$  is small, in order to avoid the overshoot and oscillation effect caused by the integration link, the value of  $\Delta K_P$  should be appropriately reduced. At the same time, the value of  $\Delta K_I$  should be appropriately increased to eliminate static errors; at this time, if the error change rate  $e_c$  of the correction system is small, in order to reach a stable state as soon as possible, the value of the integration coefficient  $\Delta K_I$  should also be appropriately reduced. If the value of  $e_c$  is medium or large,  $\Delta K_D$  takes a moderate value to stabilize the differential link.



TABLE 2. Fuzzy control rules table of  $\Delta K_P$ ,  $\Delta K_I$  and  $\Delta K_D$  for deviation correction.

$e_c$	$e$						
	-6	-4	-2	0	2	4	6
-6	6/-3/1	6/-3/-1	4/-3/-3	4/-2/-3	4/-2/-3	2/0/-2	0/0/1
-4	6/-3/1	4/-3/-1	4/-2/-3	4/-2/-2	2/-1/-3	0/0/-1	-2/0/0
-2	4/-2/0	4/-2/-1	4/-1/-2	2/-1/-2	0/0/-1	-2/1/-1	-4/1/0
0	4/-2/0	2/-1/-1	2/-1/-1	0/0/-1	-2/1/-1	-4/1/-1	-4/2/0
2	4/-1/0	2/-1/0	0/0/0	-2/1/0	-4/1/0	-4/2/0	-4/2/0
4	2/0/3	0/0/-1	-2/1/1	-4/2/1	-4/2/1	-4/3/1	-6/3/3
6	0/0/3	-2/0/2	-4/1/2	-4/2/2	-4/3/1	-6/3/1	-6/3/3

Based on the above principles, combined with reference materials and on-site correction and debugging experience, the fuzzy rules shown in Table 2 can be established.

Through MATLAB simulation, the fuzzy relationship surfaces of the pole piece position deviation  $e$  and deviation change rate  $e_c$  and  $\Delta K_P$ ,  $\Delta K_I$ ,  $\Delta K_D$  can be obtained, as shown in Fig.14

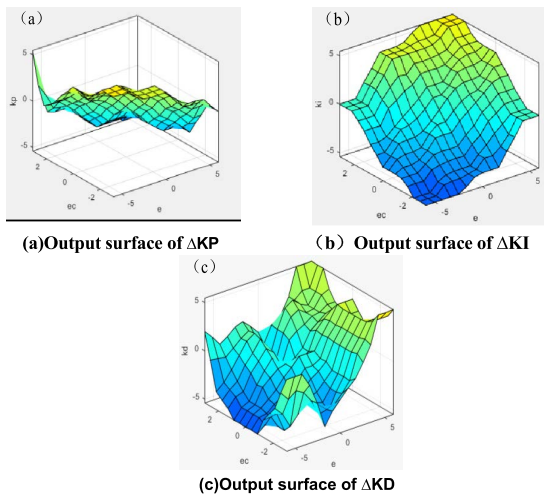


FIGURE 14. Fuzzy relation surface.

**D. THE CONSTRUCTION OF THE INTEGRAL SEPARATION FUZZY PID SIMULATION MODEL FOR DEVIATION CORRECTION CONTROL**

In the subsequent analysis and verification of the integral separation fuzzy PID correction control method, it is necessary to introduce a pole piece correction control model. By referring to the relevant data and combining the related models of motor drive and mechanical transmission in the correction control, the transfer model of the correction system for the lithium battery pole piece rolling mill shown in (17) can be obtained.

$$G(s) = K_L \times \frac{K_d}{T_m s^2 + T_d s + 1} \times G_s(s) = \frac{K_L K_d}{T_m s^2 + T_d s + 1} \times e^{-\tau_0 s} \quad (17)$$

Combined with actual drive motor parameters, sensor parameters and mechanical structure parameters, appropriate selection of some parameters can convert the second-order correction transfer model with delay link into the mathematical model shown in (18), which is convenient for subsequent algorithm model construction and simulation analysis.

$$G(s) = \frac{3.5}{5s^2 + 0.8s + 1} \times e^{-0.1s} \quad (18)$$

Combined with the transfer function model of the correction structure obtained by the analysis, the integral separation fuzzy PID simulation model shown in Fig.15 is constructed in Simulink. In the figure, the simulated step signal is used as the input, and the performance of the controller is analyzed by analyzing the response parameters such as the response rate and overshoot of the output waveform.

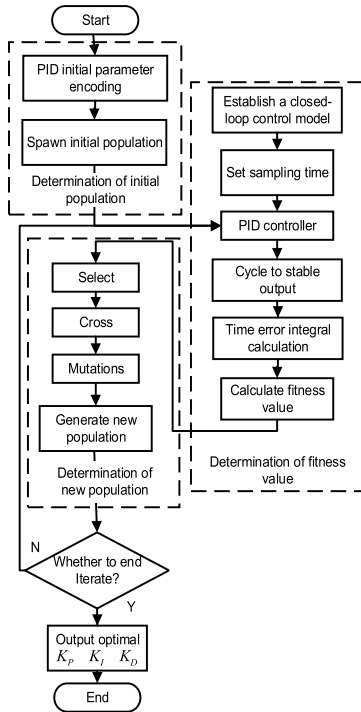
**V. GENETIC ALGORITHM OPTIMIZING CORRECTION FUZZY PID PARAMETERS**

The previous research on the correction control algorithm involved the selection of PID initial parameters and the construction of fuzzy rules. However, in the selection process of these parameters, most of the application is expert experience combined with simulation debugging, PID initial parameters and fuzzy rules may have certain deviations. Genetic algorithms do not rely on specific inference functions, but rather improve the adaptive capacity of their own populations from the perspective of probabilistic and genetic properties by simulating the evolutionary alternation of natural populations [20]. Therefore, in this paper, GA is added to optimize a large number of the above parameters and improve the selection accuracy of PID initial parameters and fuzzy rules.

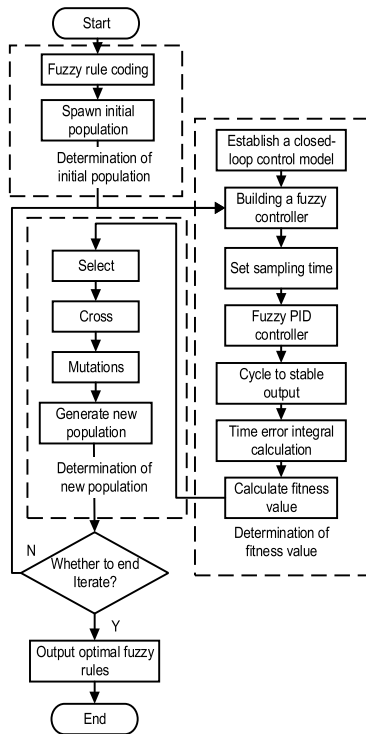
**A. OPTIMIZATION SCHEME DESIGN**

In the application process of GA, first of all, we must determine the problem to be solved, and then build a basic population by randomly generating individuals; after that, the fitness function is constructed to analyze and evaluate the number of codes in the population, to identify excellent individuals and eliminate the inferior individuals with insufficient fitness; finally, by selecting, crossing and mutating the remaining





(a) Schematic diagram of optimization of PID initial parameter flow



(b) Schematic diagram of optimization of fuzzy rule flow

FIGURE 16. Diagram of key parameters for GA optimization.

$P_m$  need to be set, usually  $P_c$  is set higher, taking values between 0.5 and 1, and  $P_m$  is set lower, taking values between 0.001 and 0.1. Some adjustments were made to  $P_m$  and  $P_c$  within a certain range for different individual fitness values, which helped to retain genes from quality individuals.

The specific calculation method is as follows.

$$P_c = \begin{cases} \frac{k_1(f_{max} - f)}{f_{max} - f_{avg}}, & f \geq f_{avg} \\ k_2, & f < f_{avg} \end{cases} \quad (22)$$

$$P_m = \begin{cases} \frac{k_3(f_{max} - f')}{f_{max} - f_{avg}}, & f' \geq f_{avg} \\ k_4, & f' < f_{avg} \end{cases} \quad (23)$$

where:  $f_{max}$  is the maximum value of population fitness;  $f_{avg}$  is the mean value of population fitness,  $f$  is the larger value of fitness for the two individuals in the crossover,  $f'$  is the value of fitness for the individual performing the mutation operation,  $k_1, k_2, k_3$  and  $k_4$  are constants, and  $k_2 > k_1$  and  $k_4 > k_3$  are guaranteed. We set the parameters to  $k_1 = 0.66, k_2 = 0.99, k_3 = 0.001, k_4 = 0.1$ .

#### 4) ESTABLISHMENT AND SUBSTITUTION OF CLOSED LOOP TRANSFER FUNCTION

In order to ensure the accuracy of the optimization parameters, each individual in the population needs to be introduced into the PID control model of the deviation correction system established in the previous paper.

#### B. OPTIMIZATION OF PID CORRECTION PARAMETERS AND FUZZY RULES

The transfer function was established in MATLAB and Z-transformation was carried out. The sampling time was set as 0.005s, and the discretized molecular coefficient is  $1.0e-05 * \{0, 0.874, 8, 0.874, 5\}$ , and the discretized denominator coefficient is  $\{1.000, 0, -1.999, 2, 0.999, 2\}$ . It is substituted into the winding PID control, and the response condition within 2.5s can be obtained through cyclic iteration for 500 times. According to the output of the PID closed-loop control model and the closed-loop control error in the loop, the fitness values of different individuals are obtained. In MATLAB, the genetic operation is carried out through the operation flow described above. In the course of 100 genetic iterations, the change curve of the optimal individual fitness value of each generation is shown in Fig.17.

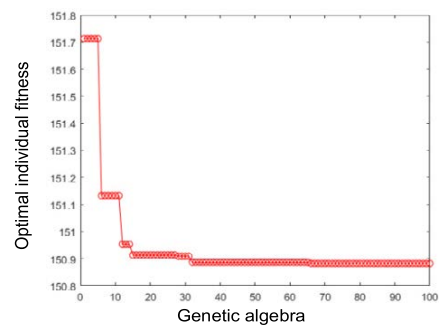


FIGURE 17. Optimal individual fitness of 100 generations of heredity corresponding to pole rectification.

From the figure we can see that the fitness value reaches stability around 30 generations. Therefore, in order to ensure the output of the optimal PID initial parameters, the optimal

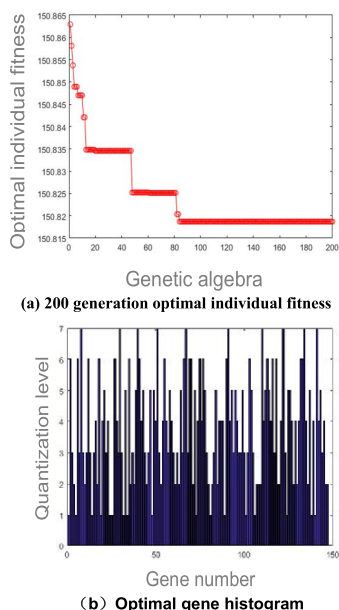
**TABLE 3.** The optimal solution of PID parameters for pole rectification after 100 genetic iterations.

	Population Number									
	1	2	3	4	5	6	7	8	9	10
$K_P$	13.361	13.167	13.692	13.181	12.776	13.608	13.710	13.418	13.185	12.914
$K_I$	2.479	2.817	2.861	2.521	2.558	2.796	2.763	2.325	2.818	2.353
$K_D$	4.699	4.635	4.807	4.640	4.507	4.778	4.815	4.716	4.638	4.548
Adaptation Value	150.47	150.51	150.60	150.50	150.69	150.56	150.61	150.51	150.57	150.66

individual after the population is inherited for 100 generations is selected as the initial PID parameter. The initial parameters of PID optimized by GA are accurate to 3 decimal places, so there will be some differences in the initial parameters after the optimization is completed. In this paper, 10 different populations are constructed. After multiple iterations of optimization, 10 sets of  $K_P$ ,  $K_I$ , and  $K_D$  parameters are obtained. The specific values are shown in Table 3.

By averaging the values in Table 3, the initial PID parameters  $K_P$ ,  $K_D$  and  $K_I$  of the correction control can be obtained as follows: 13.301, 4.678 and 2.629.

In the genetic optimization of fuzzy rules, the optimized PID initial parameters are introduced, and the fuzzy rules of the correction control are optimized and iterated after 200 generations. The fitness value of the best individual in each generation is shown in Fig.18(a). The obtained optimal individual genome is extracted to obtain the optimized fuzzy rule code, and Fig.18(b) is a histogram representation of the optimal fuzzy rule code.



**FIGURE 18.** Fuzzy rule optimization results.

By extracting the genes in Fig.18(b), it is divided into 3 groups in sequence, each group contains 49 fuzzy rule data, corresponding to the fuzzy rules in the cases where the output of the fuzzy controller is  $K_P$ ,  $K_I$ ,  $K_D$ . By classifying and

combining the genes represented by the histogram, the fuzzy rules shown in Table 4 can be obtained.

## VI. SIMULATION ANALYSIS AND EXPERIMENTAL VERIFICATION

### A. SIMULATION ANALYSIS OF FUZZY CORRECTION PID CONTROL METHOD

Before the simulation, we need to confirm the initial parameter settings of PID control. In this paper, the three initial parameters of PID,  $K_P$ ,  $K_I$  and  $K_D$  are obtained by test and comparison. They are 7, 1 and 2 respectively. The parameters of the PID controller were obtained using an intelligent soft computing technique, but are omitted in the paper for typographical and other reasons. In the simulation analysis, the parameters of the PID controller were determined based on the Ziegler-Nichols critical scale factor method using the root trajectory function rlocus as well as the rlocfind command on the basis of the MATLAB platform. Based on this, we carry out the comparative study of the three methods. Taking step signal as input signal, sinusoidal signal and smaller step signal as interference, and setting threshold value to 5, the integral part in PID is eliminated.

In this paper, the traditional PID, integral separation PID and integral separation fuzzy PID control methods are compared and simulated, as shown in Fig.19. In the simulation comparison of the different control methods, the three initial parameters of the PID are set to be the same. The input signal, the value of the disturbance signal and the time of joining are all the same. Simulation analysis is performed under the premise of ensuring the same conditions. And there is no environmental interference in the simulation analysis, which can ensure the fairness of simulation analysis comparison. At the same time, in the simulation process, a small step signal is introduced at 10ms to simulate the small interference in the process of deviation correction control. In the actual correction process, large signal interference may occur, so this paper introduces a sinusoidal signal to simulate the large interference that may occur in the correction control process. At this time, Fig.20 is obtained.

By comparing and analyzing Fig.19 and Fig.20, we can see that under the same control signal, the response rates of the three methods are relatively close. However, by analyzing the subsequent overshoot oscillations and the time to finally reach steady state, we can see that the effect of integral

TABLE 4. The fuzzy control rule table of GA optimization.

e <sub>c</sub>	e						
	-6	-4	-2	0	2	4	6
-6	1/4/5	6/7/3	3/3/1	2/2/3	1/4/6	6/6/5	3/4/3
-4	7/3/1	3/5/2	2/4/2	3/3/2	6/2/7	3/3/4	1/2/5
-2	3/5/6	4/3/5	2/6/4	6/7/6	1/3/3	4/6/6	5/6/2
0	3/2/2	4/5/4	1/1/7	1/4/3	1/6/1	6/4/5	4/6/5
2	3/5/4	7/3/2	3/2/4	1/1/2	5/2/4	1/3/6	6/5/6
4	2/2/7	3/4/4	2/4/2	5/4/5	7/1/1	6/6/4	4/7/1
6	5/4/7	3/5/4	2/3/5	3/5/3	5/4/4	1/3/2	5/3/2

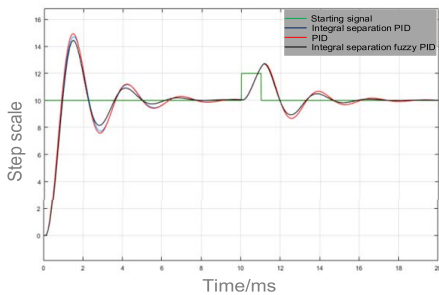


FIGURE 19. Simulation curve of small interference signal.

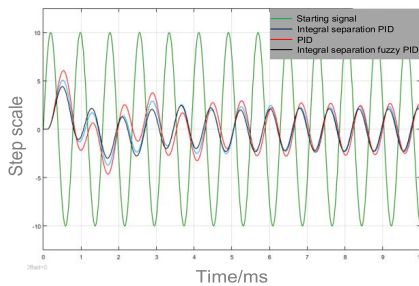


FIGURE 20. Simulation curve of large interference signal.

separation fuzzy PID is the best. Through the simulation analysis and research on the interference signal, we can see that the three methods have certain anti-interference ability, but in the face of the interference of large and small signals, the integral separation fuzzy PID shows more excellent anti-interference performance

**B. SIMULATION ANALYSIS OF WINDING TENSION CONTROL**

The PID initial parameters obtained after optimization are brought into the constructed pole piece belt correction simulation model, and the response curves before and after PID initial parameter optimization can be obtained, as shown in Fig.21. At the same time, in order to verify the anti-interference ability of the optimized parameters, a small disturbance link is introduced at 15ms.

By analyzing the above figure, we can see that after the optimization of PID parameters is introduced, the corresponding slope of the curve is larger, and the response rate

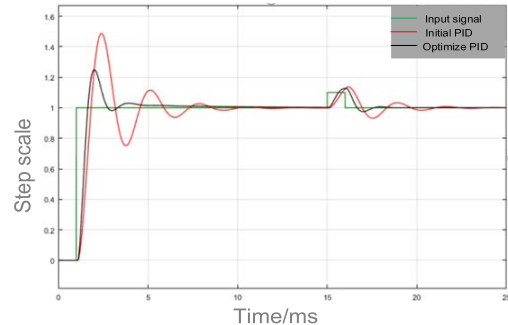


FIGURE 21. Comparison simulation diagram of PID parameters before and after optimization.

to the initial step signal will be faster, at the same time, its overshoot is much smaller than the curve corresponding to the original setting parameters, and it also reaches a stable state more quickly; after the disturbance is introduced, the curve obtained after optimization can also return to the set step signal value more quickly, which has stronger anti-interference ability.

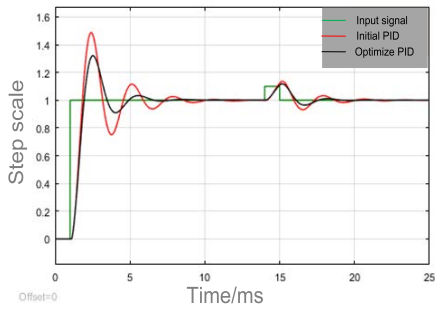
In order to verify the performance of optimizing fuzzy rules, the old and new fuzzy rules are substituted into the pole piece correction simulation model, respectively, and Fig.22 is obtained. Fig.22(a) is the response curve corresponding to the two rules under the original PID parameters, and Fig.22(b) is the response curve under the optimized PID parameters. It can be seen from the information in the figure that the initial response rates of the two curves are approximately the same, but in the process of subsequent curves returning to stability, the response curve corresponding to the optimization rule has a smaller overshoot and the curve state is stable faster. Under the two PID parameters, the simulation performance of the optimized fuzzy rules is better than the original fuzzy rules. It can be seen that the optimized fuzzy rules have good adaptability to the changes of PID parameters.

**VII. EXPERIMENTAL VERIFICATION**

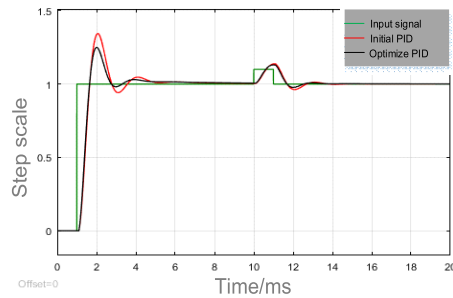
**A. CONSTRUCTION AND TEST OF EXPERIMENTAL PLATFORM**

The experimental platform adopts the embedded integrated measurement and control system, uses the self-designed embedded control motherboard as the main controller, and





(a) Performance verification of fuzzy rules under original PID parameters



(b) Performance verification of fuzzy rules under optimized PID parameters

FIGURE 22. Simulation model comparison.

combines the signal acquisition board, motor drive board and other main circuit structures, as well as various sensors, drivers, transformers and some low-voltage appliances. The overall hardware control scheme is shown in Fig.23.

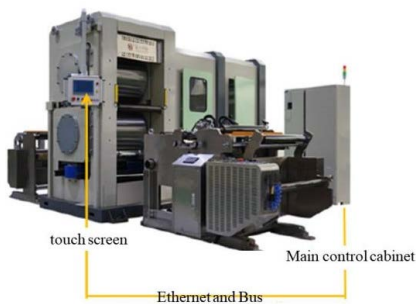


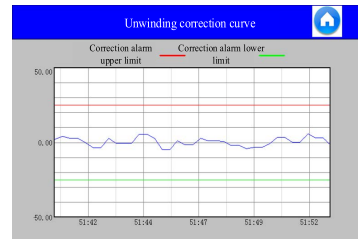
FIGURE 23. Overall hardware control scheme.

In the process of deviation correction control, the parameter accuracy of information acquisition is very important, so the multi-channel real-time information acquisition test is carried out on the information acquisition module before the experiment. Set the input voltages of the 8 ports of the information acquisition module to 3.3V and 1.8V alternately, and print the collected voltage values through the serial port. The data collected by the 8 channels are shown in Fig.24.

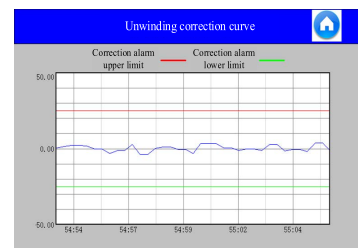
The 10 groups of measured data are averaged and sorted to obtain the data shown in Table v. It can be seen from the table that the measured voltage value is basically consistent with the original input voltage value. The error of 8 channels can be stable within 0.15%, and the accuracy can reach four decimal places, which can fully meet the high-precision collection of pole piece position information.

AD1: +3.3021	AD2: +1.8005	AD3: +3.3031	AD4: +1.7982	AD5: +3.3045	AD6: +1.8020	AD7: +3.2982	AD8: +1.8013
AD1: +3.3021	AD2: +1.8005	AD3: +3.3030	AD4: +1.7982	AD5: +3.3045	AD6: +1.8020	AD7: +3.2983	AD8: +1.8014
AD1: +3.3024	AD2: +1.8003	AD3: +3.3028	AD4: +1.7982	AD5: +3.3043	AD6: +1.8021	AD7: +3.2983	AD8: +1.8014
AD1: +3.3022	AD2: +1.8004	AD3: +3.3030	AD4: +1.7984	AD5: +3.3043	AD6: +1.8022	AD7: +3.2984	AD8: +1.8014
AD1: +3.3021	AD2: +1.8005	AD3: +3.3030	AD4: +1.7983	AD5: +3.3041	AD6: +1.8020	AD7: +3.2982	AD8: +1.8013
AD1: +3.3019	AD2: +1.8004	AD3: +3.3030	AD4: +1.7982	AD5: +3.3045	AD6: +1.8020	AD7: +3.2982	AD8: +1.8014
AD1: +3.3020	AD2: +1.8007	AD3: +3.3031	AD4: +1.7979	AD5: +3.3045	AD6: +1.8021	AD7: +3.2980	AD8: +1.8014
AD1: +3.3021	AD2: +1.8004	AD3: +3.3029	AD4: +1.7979	AD5: +3.3044	AD6: +1.8020	AD7: +3.2982	AD8: +1.8017
AD1: +3.3022	AD2: +1.8005	AD3: +3.3030	AD4: +1.7980	AD5: +3.3044	AD6: +1.8019	AD7: +3.2979	AD8: +1.8015
AD1: +3.3021	AD2: +1.8005	AD3: +3.3029	AD4: +1.7981	AD5: +3.3044	AD6: +1.8020	AD7: +3.2982	AD8: +1.8015

FIGURE 24. Information collection test.



(a) Traditional PID correction curve



(b) Fuzzy PID correction curve

FIGURE 25. Pole piece location information.

**B. SENSITIVITY TEST**

When the main roll speed is set at 30m/min, the experimental equipment can run stably. When the roll speed is more than 40 m/min, the electrode strip will break and shake due to the excessive tension, which makes it impossible to control the tension accurately. When the roll speed is lower than 10m/min, the strip will be relaxed and wrinkled due to the low tension, and the tension cannot be controlled accurately. Now in the actual industrial environment, the rolling speed of lithium battery is 15~30m/min, which can fully meet the experimental requirements.

**C. CONTROL TEST OF UNWINDING AND DEVIATION CORRECTION**

In the experimental verification, the unwinding correction structure was taken as an example for analysis. In the experiment, the position of the correction sensor was aligned, and the alignment position at this time was set as the standard value of the pole piece position, corresponding to the value 0. When the position of the pole piece belt changes, the corresponding standard value is taken to be positive or negative. After the equipment runs stably, collect the edge information of the pole piece in the rectification control and obtain the traditional PID control algorithm. The position information of the unwinding pole piece is shown in Fig.25(a). After introducing this algorithm, the pole piece position information is shown in Fig.25(b).

TABLE 5. Information collection data sheet.

	channel sequence number							
	1	2	3	4	5	6	7	8
Input Voltage/V	3.3	1.8	3.3	1.8	3.3	1.8	3.3	1.8
Voltage collected/V	3.302 1	1.800 4	3.303 0	1.798 1	3.304 4	1.802 0	3.298 2	1.801 4
Relative Error/%	0.063 6	0.022 2	0.090 9	0.105 5	0.133 3	0.111 1	0.054 5	0.077 7

From the unwinding correction curve graphs corresponding to the two methods, it can be seen that the collected edge information of the pole piece fluctuates around the standard value 0. In the traditional PID algorithm, the adjustment speed is slower and the degree of fluctuation is more severe when the position of the pole piece belt fluctuates; in the integral separation fuzzy PID algorithm, the adjustment speed is faster after the position of the pole piece deviates from the set value, and the position information fluctuation is small. In the sample data collected by the position information of the pole piece, the sampling points are randomly selected, and the two methods select 10 sets of position sampling information, respectively, to obtain Fig.26. “+” and “-” in the table indicate the direction in which the edge of the pole piece is shifted relative to the set value.

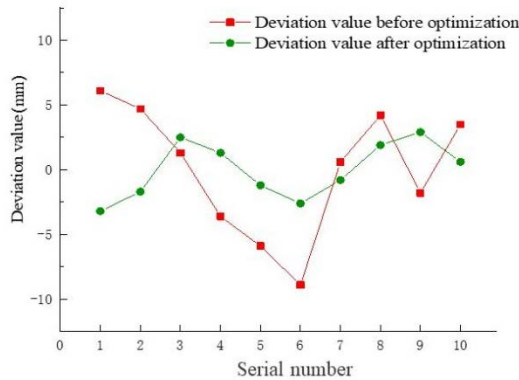


FIGURE 26. Unwinding correction error comparison.

By comparing the data in the table, it can be seen that the deviation value of the pole piece corresponding to the integral separation fuzzy PID algorithm is generally smaller than the deviation value corresponding to the traditional PID algorithm. Comparing the collected data with the preset correction range, it can be seen that the position deviation of the pole piece band is within 10mm in the traditional PID algorithm, while the position deviation of the pole piece band is within 4mm in the integral separation fuzzy PID algorithm. It can be seen from the above that during the rectification control of the algorithm in this paper, the position of the pole piece is more stable, the rectification control is stable and reliable, and the adverse effects caused by the deviation of the pole piece are reduced.

D. CONTROL TEST OF WINDING AND DEVIATION CORRECTION

The initial reference value is also set to 0, and the range of lithium battery pole piece correction is set within  $\pm 50$ mm. Under the two control algorithms, 10 groups of tension values are collected respectively, and the measured value of pole position and its error comparison are shown in Fig.27.

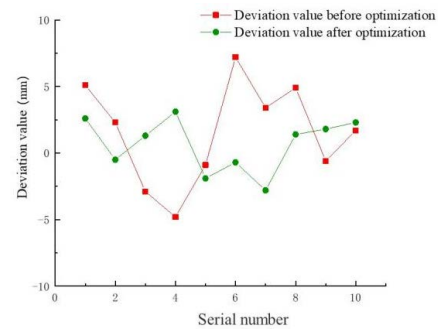


FIGURE 27. Winding correction error comparison.

Compared with the collected position information of the winding pole piece, it can be seen that the position of the pole piece belt fluctuates greatly in the traditional PID algorithm, so the pole piece position may shift too much in the operation process, thus causing an alarm; In contrast, the position of the pole piece corresponding to this algorithm fluctuates less, there is no sampling point approaching the limit value of the rectification range, and the average position deviation is less than that of the traditional PID algorithm, so the stability and control accuracy are significantly higher.

E. DISCUSSION

The genetic optimization integral separation fuzzy PID control strategy can greatly improve the stability and anti-interference ability of the system. Compared with the dual chip architecture of ‘ARM+DSP’, the control strategy can achieve the requirements of high accuracy on the premise of using only one main control board for control through the optimization design of the control algorithm, and save more economic costs. While the deviation prediction error proposed by G. Wang was basically maintained at  $\pm 15$ mm. In contrast, the control strategy proposed in this paper can control the deviation within  $\pm 4$ mm. Therefore, it has significant advantages in control cost and control accuracy.

If the control strategy is applied to the stability control of the tension in the rolling process, according to the control results of this paper, the stability and control accuracy of the tension can also be improved. And the optimization strategy proposed in this paper provides a good solution to the parameter optimization problems involved in the field of automatic control, especially the application of PID control method and fuzzy control strategy optimization.

However, due to the experimental conditions, the following problems and areas for further improvement still exist:

1. In the experimental part of this paper, only a small number of rolling situations are selected for analysis, while in the actual rolling process, the operating state of the mill may change to a certain extent, so the actual industrial field experiments can be extended to introduce a variety of pole piece of different materials and widths for experimental verification of the deflection control.
2. In order to expand the application scope of the algorithm, reduce the operation time and improve the quality of the solution, the idea of parallel computing can be introduced to combine the genetic algorithm with other algorithms to accelerate the evolution speed.
3. IOT technology and operating system can be added to the hardware system built in this paper to achieve efficient reading and analysis of production data. It provides an important technical support for the realization of the intelligence of the control system.

## VIII. CONCLUSION

This paper researches and analyzes the correction control method of pole piece rolling mill, combines multiple algorithms, designs the genetically optimized integral separation fuzzy PID correction control method, and verifies the performance of the algorithm through simulation analysis and experimental verification. The following conclusions are drawn:

1. This paper studies and analyzes the rectification control system and rectification process of the pole piece rolling mill, establishes the mathematical model of the deflection system, proposes the integral separation fuzzy PID rectification control method, and completes the construction of the rectification fuzzy controller and the rectification simulation model.
2. Aiming at the possible problems in PID parameters and fuzzy rules in the fuzzy PID correction control method, a genetic algorithm is introduced. Different genetic optimization processes were established, different types of initial populations were constructed, and the time error integration function was selected as the fitness function, combined with the correction function model, and genetic optimization was completed through selection, crossover, and mutation operations. After the initial PID parameters and fuzzy rules are optimized, the deviation of the pole strip position is

reduced from 10mm to within 4mm. The control accuracy has been improved by 60%.

3. Through simulation analysis and experimental verification, it is proved that the integral separation fuzzy PID correction control method has good response rate, control accuracy and anti-interference ability, so that the pole piece offset can be stabilized around the set value and has certain practical application value. It can ensure that the equipment is rolled in a stable state and has a certain practical application value, and at the same time provides a good solution to the problem of deviation correction for large and complex equipment.

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