Intelligent optimization model of actuator adjustment based on feasible direction method and genetic algorithm

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Abstract. The strip flatness control in tandem cold rolling has the characteristics of fast response speed and many influencing factors. The calculation accuracy of the flatness control actuator adjustment directly affects the strip flatness quality. In order to further improve the flatness quality, an intelligent optimization model for actuator adjustment is established, and the model is solved based on the feasible direction method and genetic algorithm. The field test results show that the model proposed in this paper can significantly improve the strip flatness quality, and at the same time, the model has higher stability and can meet the requirements of online flatness adjustment.

1. Introduction
In recent years, due to the increasingly serious excess capacity of plate and strip in China's steel industry, how to produce high-quality cold-rolled strip has become an urgent problem to be solved. The cold-rolled flatness control technology is the core content of the cold-rolled technology field. The quality of the flatness reflects the technical level of the national iron and steel industry and is an important indicator for measuring the quality of cold-rolled strip[1,2]. With the structural upgrading of China's national economy, various industries have imposed stricter requirements on the flatness quality of cold-rolled plates and strips. The optimization of the flatness control system and the flatness core model will become a hot and difficult point of research[3].

The production process of tandem cold rolling is very complicated, and its control objects have the characteristics of multivariable, strong coupling, non-linearity, etc. Therefore, in this paper, a research is carried out on the influence of the flatness adjustment actuator on the strip flatness[4]. Based on the hybrid optimization algorithm, an intelligent optimization model of actuator adjustment is established to improve the control accuracy and flatness quality of the cold rolled strip.

2. Flatness actuator
In mainstream flatness control systems, the plate shape adjustment actuators are equipped with work roll bending, intermediate roll bending, work roll tilting, intermediate roll shifting[5]. In order to design a reasonable flatness adjustment strategy, it is necessary to analyse the adjustment efficiency characteristics of the flatness adjustment actuator, and then formulate the adjustment strategy according to the adjustment efficiency of the adjustment mechanism. The adjustment efficiency of each flatness adjustment actuator is shown in Figure 1.
3. Intelligent optimization algorithm

3.1 Feasible direction method

The main feature of the feasible direction method is to use the minimum points of a series of unconstrained problems to approximate the best advantage of a constrained problem. The typical strategy is to start from the feasible point, search along the feasible direction of decline, and find a new feasible point that reduces the value of the optimal evaluation function[6,7]. The main steps of the algorithm are selecting the search direction and determining the step size to move in this direction. The steps are as follows[8]:

Given the objective function \( J(\Delta u) \) and its gradient \( \nabla J(\Delta u) \), matrix \( A \) and vector \( b \) of inequality constraints, the limit of termination \( \varepsilon \).

1. Select the initial flatness adjustment amount feasible point \( \Delta u_0 \); Set \( k = 0 \).
2. Decompose \( A \) into \( A_k \) and \( A'_k \), and decompose \( b \) into \( b_k \) and \( b'_k \) accordingly. Make \( A_k \Delta u_k = b_k \), \( A'_k \Delta u_k > b'_k \). Set the dimension of \( b'_k \) is \( \tau \).
3. Solve a linear programming problem 
   \[
   \min \nabla J(\Delta u)^T p \\
   s.t. A p \geq 0 \\
   -\varepsilon \leq p \leq \varepsilon
   \]
   the optimal solution is \( p_k \).
4. If \( \nabla J(\Delta u_k)^T p_k < \varepsilon \), then output \( \Delta u_k \), jump out of the loop; Otherwise, calculate \( u = A_k \Delta u_k - b'_k \), \( v = A'_k p_k \).
5. If \( v \geq 0 \), then \( t = +\infty \). Otherwise, calculate \( t = \min \{ \frac{-u}{v} | v < 0 \} \), and solve 
   \[
   \min J(\Delta u_k + tp_k) \\
   s.t. 0 \leq t \leq t
   \]
   the optimal solution is \( t_k \); Calculate \( \Delta u_{k+1} = \Delta u_k + t_k p_k \).
6. Set \( k = k + 1 \), go back to (2).

3.2 Genetic algorithm

Genetic algorithm uses probabilistic search technique. Its selection, crossover, and mutation operations are all performed in a probabilistic manner. That is, multiple search information is used at the same time to select, cross, and mutate the groups to generate new groups. The steps are as follows:
(1) Given the maximum evolutionary algebra $T$, population number $M_{population}$, crossover probability $P_{cross}$, mutation probability $P_{mutation}$. Set $t = 0$, generate $M_{population}$ individuals randomly as initial population.

(2) Calculate the fitness value $F_{fitness}$ for each individual in the group.

(3) If the termination condition $t < T$ is met, go to (9).

(4) Calculate the selection probability $P_{select}$ for each individual in the population, calculate the cumulative probability $P_{accumulate}$, and generate a random number in the interval $[0,1]$. If the random number is less than $P_{accumulate}(1)$, the first individual is selected. If the random number is greater than $P_{accumulate}(k-1)$, and less than $P_{accumulate}(k)$, the $k$ individual is selected. The best individuals get multiple copies, the medium individuals stay flat, and the worst individuals die.

(5) According to the selection probability $P_{select}$, $M_{population}$ individuals are randomly selected from the population to obtain the population.

(6) According to the crossover probability $P_{cross}$, for each individual in the new population, a random number in the interval $[0,1]$ is generated. When the random number is less than $P_{cross}$, the individual is selected to cross. Individuals are selected from the population for mating, and the offspring after mating are selected to enter the new population. In the new population, the individuals who are not mated in the population are directly copied.

(7) According to the mutation probability $P_{mutation}$, each individual component has an equal chance to mutate. For each individual component in the group, a random number in the interval $[0,1]$ is generated. When the random number is less than $P_{mutation}$, the component of the individual is mutated. In the process of mutation, individuals are selected from the new population, and the original individuals in the population are replaced by the mutated individuals.

(8) Replace old groups with new ones. Set $t = t + 1$, go to (2).

(9) The individual with the largest fitness value $F_{fitness}$ in the evolution process, $x(t)$ is the optimal value after decoding and $x(t)$ is output.

4. Actuator optimization model

The optimal evaluation function for calculating the adjustment amount of each flatness adjustment mechanism is proposed based on the optimization method with constraints[9,10]. The flatness deviation eliminated by the adjustment mechanism is obtained by the flatness adjustment efficiency coefficient and the adjustment amount of the adjustment mechanism, and the optimal evaluation function is obtained from the total flatness deviation minus the square sum of the flatness deviation eliminated by each regulating mechanism:

$$J = \sum_{i=1}^{n} \left[ g_i ((mes_i - ref_i) - \sum_{j=1}^{m} \Delta u_j \cdot Eff_j) \right]^2$$  \hspace{1cm} (1)

Where, $J$ is the optimal evaluation function; $n$ and $m$ are the number of measuring sections and the number of adjusting mechanisms, respectively; $\Delta u_j$ is the adjustment amount of the jth flatness adjustment mechanism, kN; $Eff_j$ is the flatness adjustment efficiency coefficient of the jth flatness adjustment mechanism for the ith measurement segment; $mes_i$ is the flatness measurement value of the ith measurement segment, I; $ref_i$ is the flatness setting value of the ith measurement segment, I; $g_i$ is the weighting factor of each measuring point in the board width direction. The value is set between 0 and 1. It represents the degree of influence of the adjustment mechanism on the flatness of each measuring point in the board width direction. For general incoming materials, the weighting factor of the edge measurement points is larger than that of the middle area.
In order to obtain the optimal solution for the adjustment amount of the flatness adjustment mechanism, the mathematical model needs to consider the adjustment limit of the adjustment mechanism. When the optimal solution only satisfies the partial derivative of the mediation amount of all the adjustment mechanisms, that is, the optimal evaluation function reaches the ideal minimum value, but the optimal solution exceeds the mediation limit, obviously it cannot be used, so the optimal solution of the adjustment variable comes down to an optimization problem with constraints:

\[
\begin{align*}
\min & \quad J(\Delta u) \\
\text{s.t.} & \quad A\Delta u \geq b
\end{align*}
\]

Where, \( J \) is the evaluation function; \( \Delta u \) is the adjustment vector of the flatness adjustment mechanism, and its components are \( \Delta u_1, \Delta u_2, \cdots, \Delta u_n \), kN; \( A \) is an inequality constraint matrix, which is a matrix of \( m \times n \); \( b \) is an inequality constraint vector, which is an \( n \)-dimensional vector.

The feasible direction method is used to find equation (2), and the genetic algorithm is used to solve the linear programming problem.

5. Field test
The intelligent optimization model of the adjustment amount has been tested in the flatness control system of a 1450mm five-stand tandem cold rolling mill. The steel grade is SPCC, and the strip steel specification is 3.5×1250→0.88×1250. The flatness control effect of strip using conventional method is shown in Figure 2(a), and the flatness control effect of intelligent optimization model is shown in Figure 2(b).

![Figure 2. Flatness control effect diagram](a) Using conventional method; (b) Using intelligent optimization model)

In the flatness control system using the intelligent optimization model, the average flatness deviation of the entire rolling process is 6.25I. In the conventional flatness control system, the average flatness deviation of the entire rolling process is 7.27I. The average flatness deviation of the entire rolling process of the flatness control system using the intelligent optimization model is 1.02I less than the average flatness deviation of the entire rolling process of the conventional flatness control system, which indicates that the control accuracy of the entire rolling process is improved by 14.03%.

6. Conclusion
In this paper, an intelligent optimization model of flatness actuator adjustment in tandem cold rolling is proposed. The application results show that the optimized flatness control system shows good control results in the rolling phase and the flatness control accuracy has been improved to a certain extent, which is helpful to industrial production.
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