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Information

Backup roll contour in finishing trains of hot rolling based on hybrid genetic algorithm

Anrui He[1), *Quan Yang*[1), *Jinwu Xu*[1), *Xianlin Chen*[1), *Gangcheng Wei*[2), *and Siqing Huang*[2)

1) National Engineering Research Center for Advanced Rolling Technology, University of Science and Technology Beijing, Beijing 100083, China
2) Wuhan Iron and Steel Group Corporation, Wuhan 430083, China
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Abstract: On the basis of integrating two-dimensional varying thickness finite element method with hybrid genetic algorithm, a precise model was developed to design ideal backup roll contour (Varying Contact Backup Roll, in short VCR) in finishing trains of hot rolling rapidly and efficaciously. Additionally, a lot of good actual effects of VCR, such as evident improvement of profile and flatness of strip, remarkable decrease of roll consume, excellent maneuverability and maintenance, and so on, were validated by long-term industrial tests in hot rolling strip plant of Wuhan Iron and Steel Group Corporation (WISCO).

Key words: hot rolling; backup roll; contour; profile and flatness control; genetic algorithm

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Violent market competition and downstream processes requirement put forward more and more rigorous demands on the profile and flatness of strip. Profile and flatness, sometimes named shape, is often expressed as crown, wedge, edge drop, local high spot and flatness. In hot rolling, crown and flatness are usually used to appraise the quality of strip shape.

In order to improve the profile and flatness of strip, many kinds of shape control technologies, such as CVC, HC, PC, DSR, SC, VC, and so on, were developed in the past several ten years. Roll contour, including backup roll contour, is one of the most active and directive factors that influence strip shape, on the other hand, it is also one of the most efficient means of shape control [1,2]. Additionally, reasonable roll contour can reduce production cost and increase yield output greatly. But the rolling condition is very complicated and it is difficult all along for producers and researchers to develop ideal backup roll contour. Varying Contact Backup Roll (VCR), one of the impactful profile and flatness control technologies, has been used in the seven-stand finishing trains of hot rolling in Wuhan Iron and Steel Group Corporation (WISCO) since 1997. The long-term outstanding production achievements indicate that VCR can not only improve strip shape remarkably, but also reduce production cost evidently.

1 Developing principles of VCR

Contrasting to cold rolling, hot rolling has many characteristics, for instance high temperature [3], severe roll wear [4]. In order to design ideal VCR, some conditions must be considered carefully.

1.1 Reducing bad contact area between rolls

In conventional four-high rolling mill, bad contact area, the contact line between rolls which is outside strip width, is the main factor that worsens strip shape and weakens mill ability to counteract disturbances. So it is the first thing to reduce the bad contact area between rolls when optimizing backup roll contour. In fact, the principle of many shape control technologies, such as BCM, TP, SC, comes from this [5]. But BCM, namely stepped backup roll, can only roll one width strip. Other technologies must change backup roll structure and the investment is high. VCR makes the length of contact line between rolls almost equal to strip width only by grinding ideal contour. This can be realized easily and its investment is very low. In addition, when using VCR, the length of contact line varies along with strip width change.

Considering the diversification of strip width and severity of work roll wear, the first principle of VCR can be expressed as following:

$$Obj_1 = \sum_{i=1}^{k} \frac{\gamma_i}{e^{|L_m - B|}} \Rightarrow \max \quad (1)$$

where L_m is the length of contact line between backup roll and work roll; B strip width; γ the proportion of

Corresponding author: Anrui He **E-mail**: harui@nercar.ustb.edu.cn

strip which its width is equal to B; i condition case; k_n sum number of condition cases, which include the case that work roll is worn seriously.

1.2 Uniforming contact pressure between rolls

Contact pressure between rolls is the most dominating factor that influences wear and spalling of backup roll. Thereinto, the uniformity of contact pressure along roll axis effects the uniformity of wear and the maximum of contact pressure influences roll spalling, especially backup roll spalling. In hot rolling, there are about 100 strips rolling continuously in one unit and work roll wear is very serious. This plays a great role in roll spalling. Consequently, ideal VCR can uniform contact pressure between rolls in whole rolling unit. It can be expressed as following:

$$\begin{cases} \mathrm{Ob}j_2 = \dfrac{1}{\mathrm{dev}} = \max \\ \mathrm{dev} = \sqrt{\dfrac{1}{N}\sum_{k=1}^{N}\left(\mathrm{avg}q[k] - \dfrac{1}{N}\sum_{j=1}^{N}\mathrm{avg}q[j]\right)^2} \\ \mathrm{avg}q[j] = \dfrac{1}{k_n}\sum_{i}^{k_n} q[j][i] \end{cases} \tag{2}$$

where $q[j][i]$ is contact pressure of i-th point of j-th condition case; N sum point divided along backup roll axis.

1.3 Constraint conditions

For the sake of stability of strip movement across stands during rolling, the length of contact line between rolls should be longer than strip width. Additionally, VCR must ensure good strip shape. Shohet empirical criterion [6] can be used to judge whether strip shape is good after rolling. Therefore, the constrain conditions can be integrated as following:

$$\begin{cases} L_{m,i} \geq B_i \\ \dfrac{C_{h_i}}{h_i} - \dfrac{C_{H_i}}{H_i} + 40\left(\dfrac{h_i}{B_i}\right)^{1.86} \geq 0 \quad i=1\sim k_n \\ \dfrac{C_{H_i}}{H_i} - \dfrac{C_{h_i}}{h_i} + 80\left(\dfrac{h_i}{B_i}\right)^{1.86} \geq 0 \end{cases} \tag{3}$$

where C_h, h is the crown and thickness of exit strip respectively; C_H, H those of entry strip.

2 Method of calculation

From developing principle of VCR, it is known that design of VCR is an optimizing problem that has two objectives and many constraint conditions. So a valid optimization method is needed. Additionally, in the objective or constraint conditions expressions, some variables, such as $q[j][i]$, C_h, is the results after rolls deformation. Consequently, method calculating rolls deformation is also required.

2.1 Two-dimensional finite element model

Among those methods calculating rolls deformation, finite element model is considered the most accurate. But three-dimensional finite element model need a lot of time and computer resource. By neglecting the effect of the third dimension, it is difficult to expect high precise in conventional two-dimensional analysis. This problem was solved consummately by two-dimensional varying thickness finite element model [7]. In this model, each element has its own thickness according to the ordinate distance from its roll axis and roll radius. Here this model is used to calculate distributed contact pressure and loaded roll gap, from which the crown can be gained. **Figure 1** is the analysis model used.

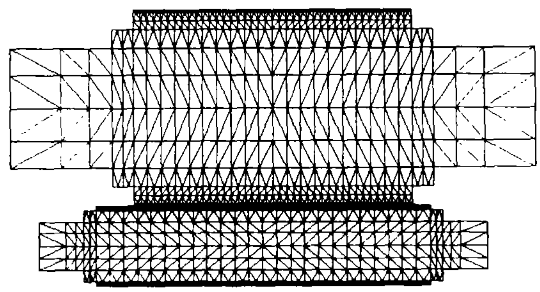

Figure 1 Two-dimensional varying thickness finite element analysis model.

2.2 Hybrid genetic algorithm

Calculation of backup roll contour is a high non-linear problem and the directive equation can not be erected between objective function and contour parameters. It is very difficult solving this problem using traditionary optimization method. By contraries, hybrid genetic algorithm is specially suitable [8].

Genetic algorithm (GA) is an advanced intelligent search algorithm based on the mechanics of natural selection. Because of its perfect characteristic, GA has been widely used in many fields, such as machine learning, signal process, adaptive control, artificial life, and so on. Compared with traditionary optimization method, although GA has many advantages, especially its global search ability, standard genetic algorithm (SGA) still has some shortcomings, such as bad local search ability and low convergence speed, *etc.* So it is the best solution to establish hybrid genetic algorithm (HGA), which integrates genetic algorithm with traditionary optimization method. The procedure of using HGA to solve the optimization of backup roll contour can be described as follows.

Step 1: Individuals are initialized in the appointed range of parameters by float type.

Step 2: Fitness function is erected according to objective function and its value of every individual is computed; Considering the difficulty of constraint conditions treatment, fitness function can be erected as following,

$$\begin{cases} \text{Fitness}=\begin{cases} \text{Ob}j & \text{case A} \\ d_{\min} & \text{case B} \end{cases} \\ \text{Ob}j=\text{Ob}j_1+\xi\cdot\text{Ob}j_2 \end{cases} \quad (4)$$

where $d_{\min}$ is a small positive value; ξ the transition coefficient between $\text{Ob}j_1$ and $\text{Ob}j_2$. Case A is when constraint conditions is satisfied while Case B is when constraint conditions is not satisfied.

Step 3: Individual with the best fitness value is reproduced straightway to the next generation.

Step 4: Local search algorithm, for example climb search method, is used to search better individual from the start point with the best fitness value. If a better individual is found, it is also reproduced straightway to the next generation.

Step 5: Other individuals are generated from the individuals of previous generation through genetic operators, which are selection, crossover, and mutation.

Step 6: The convergence condition or maximum generation is verified. If it is true, the procedure is finished, otherwise, go back to step 3.

During solving, the system parameters of HGA are chosen as followings,

Size of population: 80;

Crossover probability: 0.66;

Mutation probability: 0.12.

Figure 2 is the VCR contour calculated by two-dimensional varying thickness finite element model and hybrid genetic algorithm.

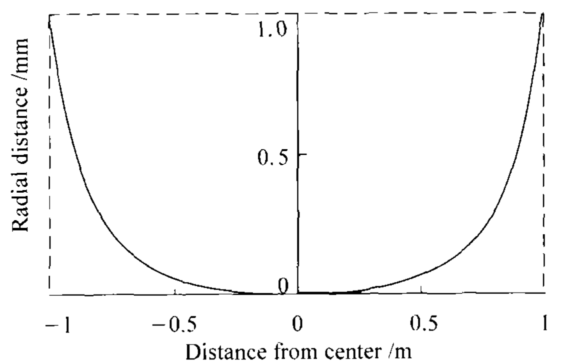

Figure 2 VCR contour calculated.

3 Actual effects of industrial tests

In order to validate the actual effects of VCR, the backup roll has been successfully used at the third stand in finishing trains of WISCO 1 700 mm hot rolling mills since October 1997. Because of its perfect performance, VCRs are extended to all seven stands now.

3.1 Improving strip profile and flatness evidently

By the engineering record, which collects a lot of production data and shape data of every strip of this industrial rolling mills, some statistical results can be achieved, as shown in **table 1**. Before using varying contact backup roll, the ratio which strip crown is beyond upper limit is 33.90%, but it reduced by 59.17% after using VCR. It is the same to flatness and dissymmetry, and the ratios that flatness and dissymmetry are beyond 7I-unit are reduced by 64.16% and by 99.36% respectively.

Table 1 Quality of profile and flatness before and after using VCR

Content	Before using VCR	After using VCR
Statistical number	51 000	45 000
Crown beyond limit/%	33.90	13.84
(Flatness>7Iu)/%	19.28	6.91
(Dissymmetry>7Iu)/%	18.61	0.12

3.2 Improving backup roll wear contour and prolonging its change cycle

Because of severe working conditions, such as high temperature and heavy load, conventional backup roll is worn rapidly and unevenly along roll axis. The most frequently observed wear pattern is a box-shaped depression with sloping walls, as shown in **figure 3**. Solid triangle expresses wear contour of top backup roll while solid circle is that of bottom. Such serious irregular box-like wear contour is not favorable in wide strip rolling. It not only reduces mill transverse rigidity, increases the instability of loaded roll gap and weakens the efficiency of bending force of work roll, but also engenders contact pressure peak between backup roll and work roll, which causes roll spalling frequently.

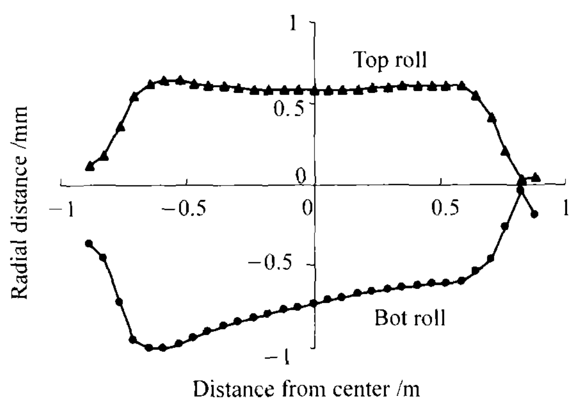

Figure 3 Wear contour of conventional backup roll.

VCR makes contact situation between rolls better, so as to improve wear contour of backup roll, as shown in **figure 4**. The wear contour is maintained almost as the same of grind contour, although the backup rolls have been used for 36 days. Because of good maintenance of

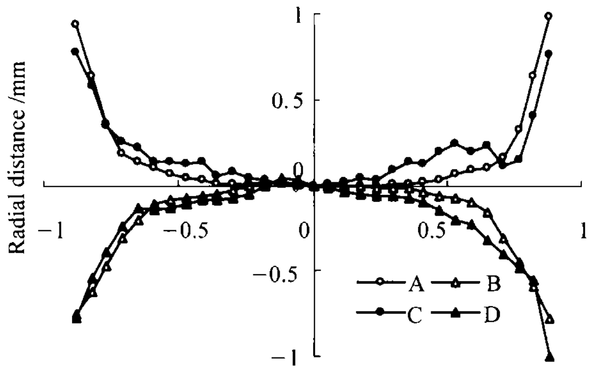

Figure 4 Wear contour of VCRs, A, B—grind contour of top and bottom backup roll respectively, C, D—wear contour of top and bottom backup roll respectively, used for 36 days.

contour, VCRs can be employed continuously for 3 or 4 weeks, even 5 weeks every time, while the change cycle of conventional backup roll is only 2 or 3 weeks. VCR decreases the number of backup roll changes evidently. Accordingly, the productivity is increased and the roll grind time is reduced largely.

3.3 Eliminating roll spalling and decreasing the production cost

Before using VCR, every time when backup rolls changed, some spalling rolls can be found. This shortens the life of backup roll greatly and augments operational difficulties consumedly. VCR makes the contact pressure between rolls uniform and avoids the emergence of stress pinnacle, so it can prevent backup roll from fatigue destroy, which often result in roll spalling. In fact, roll spalling was not emerged any more since VCRs was used.

4 Conclusions

This thesis expounds fully the developing principles of VCR; And a systemic method, which can be used to calculate VCR contour in finishing trains of hot rolling rapidly and precisely, is developed; Additionally, industrial application achievements of VCR are introduced in the last.

Finally, it is worthy of indication that VCR is designed to replace a conventional backup roll and is specially suitable for modification of existing mills.

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