

Comprehensive Shape Control Technology for CSP Hot Strip Mills

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Abstract: With the increasing demand on higher strip quality, the profile and flatness of hot rolling strips have become subjects of concern, particularly for compact strip product (CSP) hot strip mills. Based on the roll contour, control model, and rolling process, a comprehensive shape control technology is proposed and applied to CSP hot strip mill of Lianyuan steel, which includes optimization and design of the work roll contour and varying contact back-up roll (VCR) plus backup roll contour, analysis of the flatness feedback control model, as well as improvement of the rolling process control system. The application of the technology has significantly improved the shape control performance. The roll wear is improved and the general roll consumption of the finishing mill is reduced by 29.86%. The percentages that satisfy the control target ranges of the average strip flatness and crown are increased by approximately 15.40% and 14.82%, respectively. The rejection rate of grade Q235 due to shape quality problem is reduced monthly by 39.69%, which creates significant economic benefits for the plant.

Keywords: Compact strip product (CSP), hot strip mills, roll contour, control model, rolling process, shape control.

1 Introduction

The shape accuracy of hot rolling strips is a major quality index as well as an indispensable factor in determining its market competitiveness^[1,2]. With the increasing demand for higher strip dimensional tolerances, research on how to maintain a uniform strip crown and a flat shape during hot rolling has become one of the most challenging technical tasks in the steel industry, particularly for the continuous casting of thin slabs and the rolling line, such as the compact strip product (CSP) line. The shape control technologies that affect the shape quality of the thin strips fall into 3 aspects: the configuration and design of the work roll and backup roll, the accuracy of the shape control model, and the rolling process system. Shape control technology is also developing in the direction of integration^[3,4].

Significant research has been conducted on these 3 aspects of shape control technologies, and the results have been successfully applied to industrial production. Since continuously variable crown (CVC)^[5] technology began to emerge, new roll contour curves have been gradually developed. Chen et al.^[6] proposed two new types of rolls, including varying contact back-up roll (VCR) and asymmetric self-compensating work roll (ASR). Wang et al.^[7] came up with the linear variable crown (LVC) roll, which

achieves a linear ratio of the gap crown and strip width. The application of such rolls provides a better strip profile, flatness quality, and higher capability to produce thinner strips. At present, the sets of shape control systems in Chinese steel plants are mostly introduced by international companies, such as the profile, contour, and flatness control (PCFC) model of SMS, the profile and flatness control (PFC) model of Siemens, the shape setup (SSU) model of general motors (GE), and the global shape model (GSM) of TMEIC. Although the development of the profile, flatness, and edge control (PFEC) model from NERCAR has broken up the monopoly of these large, overseas companies on the domestic market^[8], technical privacy protection, particularly of the design principles and codes of the core technology, still put Chinese local enterprises at a disadvantage in the technological improvement process. For the rolling process, Flemming et al.^[9] discussed the basic principles of CSP technology, including the temperature distribution of the thin slabs and the energy balance of the overall process. Zhu et al.^[10] analyzed the influences of the process parameters on the strip shape, and rolling scheme as well as changing periods of work roll and backup roll, and they also provided their control strategies.

These studies enriched the shape control technologies, but almost always concentrated on one of aforementioned aspects. Due to the complex condition, the works might not be able to achieve good production performance. However, our work focuses on integrating the individual technologies for the 3 aspects together to form a cohesive whole. By analyzing a large amount of available production data^[11], the relationship between each shape control technology and shape quality is established. Then, the comprehensive shape control technology including the roll contour configu-

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ration, control model, and process system is depicted. This technology has been used in Liansteel CSP and achieved satisfactory results. By comparing the real data, the effectiveness of the comprehensive shape control technology is verified.

2 Shape control conditions of strips in CSP hot strip mills

The CSP technology was commissioned at Liansteel at the end of 2003, and its main product structure focuses on the thin strip. The proportions of the hot rolled strips with a thicknesses of less than 2.0 mm and 1.5 mm are over 40% and 15%, respectively. Thin strip rolling has greater demands on the mill state, process route, and accuracy of the control model because of its larger reduction ratio, higher rolling force, and higher rolling speed. The shape quality of the thin gauge strip is difficult to control and ensure. The shape control situations of Liansteel CSP are presented as follows:

1) Low qualified rate of strip shape. Table 1 shows the shape control performance for 3 consecutive months. The table indicates that the shape control performance is low, and that the average percentage of flatness is only 84.21%, whereas that of the crown is only 84.70%.

2) A large shape wave. Fig. 1 illustrates the flatness values of 9 measurement channels on the flatness meter along the strip width at a certain time. The symmetrical wave is large and the maximum value can reach up to 520 IU, which can easily cause shape quality rejection. Strips with shape quality rejection are feedback and disqualified from distribution.

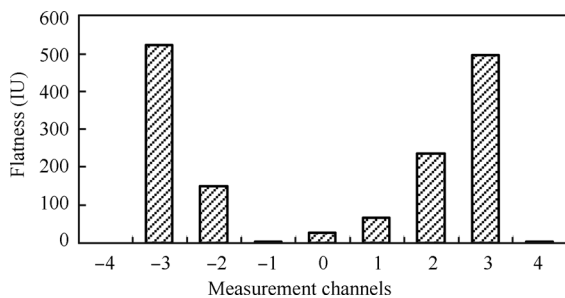


Fig. 1 Flatness values of 9 measurement channels on the flatness meter

3) Uneven roll wear. Fig. 2 shows the wear contour of the work roll and the backup roll of finisher 2 (F2). The wear

of the work roll is asymmetrical across the wear width and presents a box-like shape. Both ends are more serious, and exhibit local bulges and grooves. The uneven wear contour of the backup roll presents an S-shaped curve, and the wear value of the top roll is larger than that of the bottom roll. In addition, serious spalling is observed at the edge of the backup roll.

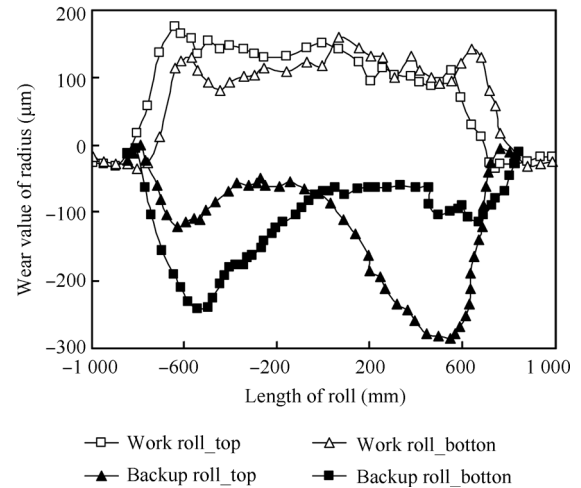


Fig. 2 Wear contours of wok roll and backup roll in F2

4) Uneven shifting distribution. Fig. 3 presents the shifting distribution of work rolls from Finisher 1 (F1) to Finisher 4 (F4) for 3 successive months. As Fig. 3 shows, the shifting positions of work rolls always stay at the negative limit position with the percentages of 74.98% for finisher 1 (F1), 61.21% for finisher 2 (F2), 42.35% for finisher 3 (F3), and 13.44% for finisher 4 (F4). The use of shifting means that the proportion of the actual shifting stroke compared with the overall shifting stroke is only 66%, which easily

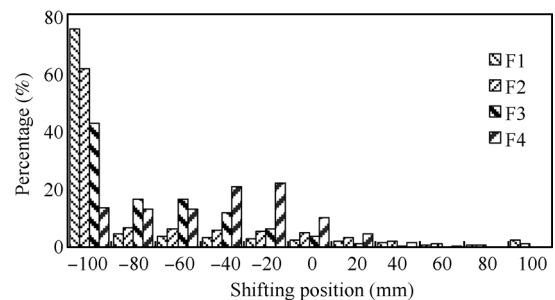


Fig. 3 Shifting distributions of work rolls of F1 to F4

Table 1 Shape control performance for consecutive three months

Gauge (mm)	Flatness		Crown	
	Tolerance (IU)	Percentage (%)	Tolerance (μm)	Percentage (%)
$h \leq 2.2$	±28	80.76	±17	87.39
$2.2 < h \leq 3.5$	±25	83.28	±20	86.01
$3.5 < h \leq 6.0$	±22	85.66	±22	84.11
$h > 6.0$	±18	87.15	±25	81.29

causes asymmetrical and uneven roll wear. At the same time, the use of shifting also shows that the contour of the work rolls lacks on shape control capabilities.

3 Configuration of work and backup roll contours in finishing mills

3.1 Configuration and design of work and backup roll contours

The proper configuration of the work roll and backup roll is the most direct and effective means to control and ensure shape control and shape quality.

The rational work roll contour can improve the starting point of strip shape control and increase rolling stability. The continuously variable crown (CVC) work roll is generally adopted and applied to whole stands of finishing mills in CSP hot strip mills because of its powerful shape control ability. According to the shifting distribution of the CVC work roll, the shape control ability and roll wear can be improved by modifying the adjustment range of the roll crown. The contour realizes the linear ratio of the gap crown to the shifting position, which is beneficial to achieve automatic control and simplify the application process.

Under the condition that the work roll contour is selected, the design of the backup roll contour determines whether the roll configuration is reasonable or not. The two most common contours of backup rolls are the conventional and VCR contours. Characterized by a varying contact length capacity, the VCR contour achieves better application effects than the conventional contour^[12]. However, because of the approximately flat roll at the center of the VCR contour, a harmful contact area exists between the CVC work roll and the backup roll. This condition leads to an “S” contact pressure shown as Fig. 4. The “S” contact pressure not only causes “S” wear on the backup roll, but also limits the varying contact ability accordingly. The shape control efficacy of the bending force is also affected. Meanwhile, the existence of the harmful contact area reduces the transversal stiffness of the loaded roll gap and self-maintenance of the backup roll. Thus, the roll gap is changed and the shape quality of the strip is affected.

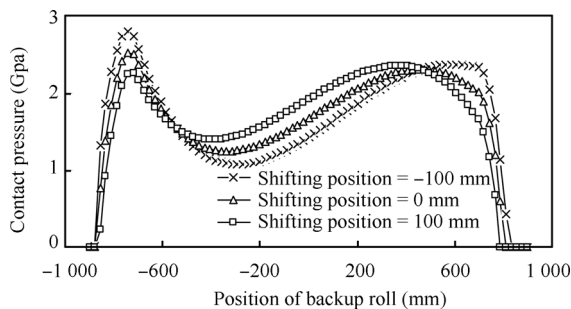


Fig. 4 Contact pressures between work roll and backup roll in F2

Based on VCR and CVC technologies, VCRplus backup roll contour was independently developed. And VCRplus

contour has 4 characters as follows: improving the contact pressure between the work roll and the backup roll (T_2), enhancing the shape control efficacy of the bending force (T_3), and enhancing the transversal stiffness of the loaded roll gap (T_4). The design principles are shown as

$$Target_1 = T_1 = \sum_{i=1}^{k_n} [L(i) - B(i)] \Rightarrow \min \quad (1)$$

$$Target_2 = T_2 = \sum_{i=1}^{k_n} \frac{q_m(i)}{q_a(i)} \Rightarrow \min \quad (2)$$

$$Target_3 = T_3 = \sum_{i=1}^{k_n} \frac{C_L(i) - C_U(i)}{F_U(i) - F_L(i)} \Rightarrow \max \quad (3)$$

$$Target_4 = T_4 = \sum_{i=1}^{k_n} \frac{p_u(i) - p_l(i)}{C_u(i) - C_l(i)} \Rightarrow \max \quad (4)$$

where $L(i)$ represents the contact length between the rolls under the i -th condition (mm), $B(i)$ is the strip width under the i -th condition (mm), k_n is the number of conditions, $q_m(i)$ is the maximum value of contact pressure under the i -th condition (GPa), $q_a(i)$ is the average value of the contact pressure under the i -th condition (GPa), $F_U(i)$ is the maximum value of the bending force under the i -th condition (kN), $F_L(i)$ is the minimum value of the bending force under the i -th condition (kN), $C_U(i)$ is the gap crown under the bending force of $F_U(i)$ (μ m), $C_L(i)$ is the gap crown under the bending force of $F_L(i)$ (μ m), $p_u(i)$ is the maximum value of the unit rolling force under the i -th condition (kN/mm), $p_l(i)$ is the minimum value of unit rolling force under the i -th condition (kN/mm), $C_u(i)$ is the gap crown under the rolling force of $p_u(i)$ (μ m), and $C_l(i)$ is the gap crown under the rolling force of $p_l(i)$ (μ m).

According to the aforementioned design principles, the weight coefficient method is used to transform multiple targets to simple targets, and the total objective function is presented in (5). The genetic algorithm^[13] is also used to modify the designed VCRplus contour. The optimization result is shown as

$$f(x) = w_1T_1 + w_2T_2 + \frac{w_3}{T_3} + \frac{w_4}{T_4} \Rightarrow \min \quad (5)$$

$$\lambda(x) = \eta(x) - k\delta(x) \quad (6)$$

where $f(x)$ is the total objective function, w_1, w_2, w_3 and w_4 are the weight coefficients, $\lambda(x)$ is the function of the VCRplus contour, $\delta(x)$ is the function of CVC contour, $\eta(x)$ is the function of the VCR contour, and k is the influence coefficient of the CVC contour obtained after optimization with the genetic algorithm method, $0 < k < 1$.

3.2 Performance analysis

Based on the preceding analysis, the contours of the CVC work roll were optimized and the corresponding contours of the VCRplus backup roll were designed for F1 to F4 of Liansteel CSP. Fig. 5 presents the new roll configuration. The body of the VCRplus backup roll presents a CVC curve, which makes the roll configuration more rational and

achieves a better varying contact ability.

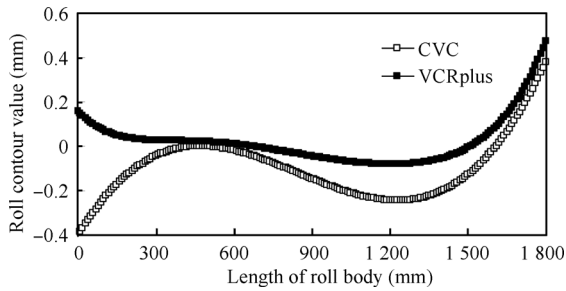


Fig. 5 Roll configurations of CVC work roll and VCRplus backup roll

Based on a finite element model with two-dimensional varying thickness and field data, the shape control capabilities for between the old and new roll configurations in F2 are fully analyzed and compared under the conditions that the strip width is 1250 mm, the unit width rolling force is 0.9 ton/mm, the shifting position is -100 mm, and the bending force is 1.0 MN. The comparison results shown in Table 2 prove the higher shape control capability of the new roll configuration. The increase in the transverse stiffness of the loaded roll gap improves the rigid characteristic, and the increase in the control efficacy of the bending force improves the flexibility characteristic. The reduction of the maximum value and unevenness of the contact pressure improves the contact state between rolls and enables the contact length to accommodate the strip width. This condition is beneficial for the decrease of “S” wear and prevents the backup roll from spalling. The shifting use of the work roll is increased by 36.36% and self-maintenance of the backup roll is increased by 10.31%, which improves the mill resistance to interfering factors and significantly improves the strip shape quality.

4 Flatness feedback control model

4.1 Description of flatness feedback control model

As a key element in the shape control system, the flatness feedback control system plays an irreplaceable role in improving the accuracy of the full-length strip flatness^[14,15]. The flatness feedback control system is responsible for eliminating the quadratic wave by periodically regulating the

bending force of each stand, which emphasizes the downstream stands, according to the difference between the measured flatness and target flatness. The control flow is summarized as follows:

- 1) When the flatness is measured, the fulfillment of the starting conditions of the control function is first considered. This process includes factors such as whether the flatness control switch is turned on, whether the effective number of measurements is greater than 1, etc. Only when all of the starting conditions are satisfied can symmetrical flatness and asymmetrical flatness be calculated.
- 2) After the calculation is completed, the reliability of the measured data in the flatness meter is verified. If the measured data is reliable, the regulation value of the bending force is calculated.
- 3) The calculated bending force of each stand is limited to ensure reliable regulation values.
- 4) The final regulation value of the bending force is calculated by an integral controller, and then the value is sent to the actuator in F7.
- 5) If the regulation value of the bending force in F7 is not enough to remove the quadratic wave, the bending force in F6 or F5 is regulated to bring the strip flatness closer to the target value.

The control model of the flatness feedback system is shown from (7) to (9), and its corresponding flowchart is presented in Fig. 6.

$$\Delta e(k) = \varepsilon_m(k) - \varepsilon_a(k) \tag{7}$$

$$F_{Bi}(k) = \begin{cases} \Delta e(k) \times \Delta F_{Bi}, & \text{if } F_{Bi}^L < \Delta e(k) \times \Delta F_{Bi} < F_{Bi}^U \\ F_{Bi}^U, & \text{if } \Delta e(k) \times \Delta F_{Bi} \geq F_{Bi}^U \\ F_{Bi}^L, & \text{if } \Delta e(k) \times \Delta F_{Bi} \leq F_{Bi}^L \end{cases} \tag{8}$$

$$F_{Ci}(k) = \begin{cases} G_i \sum_{j=0}^k F_{Bi}(j), & \text{if } F_{Ci}^L < G_i \sum_{j=0}^k F_{Bi}(j) < F_{Ci}^U \\ F_{Ci}^U, & \text{if } G_i \sum_{j=0}^k F_{Bi}(j) \geq F_{Ci}^U \\ F_{Ci}^L, & \text{if } G_i \sum_{j=0}^k F_{Bi}(j) \leq F_{Ci}^L \end{cases} \tag{9}$$

Table 2 Comparison of shape control capability between old and new roll configuration in F2

Indexes of shape control performance	Old roll configuration	New roll configuration	Increased proportion
Transversal stiffness of loaded roll gap (kN/μm)	179.2	191.23	6.71%
Shape control efficacy of bending force (μm/kN)	0.098	0.125	27.55%
Maximum value of contract pressure (GPa)	2.42	1.65	-31.82%
Unevenness of contract pressure	0.55	0.43	-21.82%
Shifting utilization of work roll (%)	66	90	36.36%
Self-maintenance of backup roll R_{tc} (%)	84.38	93.08	10.31%

(Note: $R_{tc} = 1 - 1000A/L_R$ (μm), A is the maximum value of backup roll wear in a roll changing period, L_R (mm) is the body length of backup roll)

where k is the number of control cycles, $k = 0, 1, 2, \dots$, and $\Delta e(k)$ is the difference between the measured symmetrical flatness and target symmetrical flatness of the k -th control cycle. If it is greater than zero, the wavy defect is considered as a double wave. Otherwise, it is considered as a middle wave (IU). $\varepsilon_m(k)$ is the measured symmetrical flatness value of the k -th control cycle (IU), $\varepsilon_a(k)$ is the target flatness value of the k -th control cycle (IU), i is the number of stands, $i = 1, 2, \dots, 7$, $F_{Bi}(k)$ is the calculated bending force of the k -th control cycle in the i -th stand (kN), ΔF_{Bi} is the influence coefficient related to the bending force and flatness (kN/IU), F_{Bi}^U is the upper limit value of the calculated bending force in the i -th stand (kN), F_{Bi}^L is the lower limit value of the calculated bending force in the i -th stand (kN), $F_{Ci}(k)$ is the regulation value of the bending force of the k -th control cycle in the i -th stand (kN), G_i is the integral coefficient of the flatness feedback system, F_{Ci}^U is the upper limit value of the regulation bending force in the i -th stand (kN), and F_{Ci}^L is the lower limit value of the regulation bending force in the i -th stand (kN).

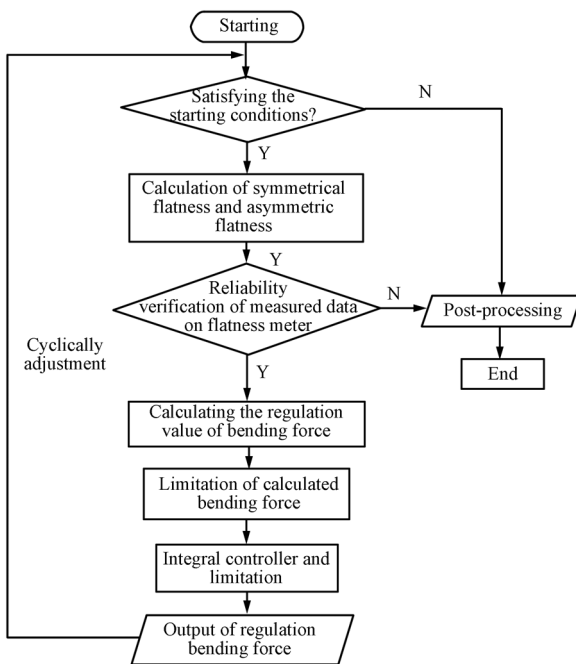


Fig. 6 Flowchart of flatness feedback control system

4.2 Research and improvement of flatness feedback control model

Liansteel CSP has the following differences from other steel plants in regard to achieving the control function of the flatness feedback system:

1) Generally, the control function of the flatness feedback control model is performed in the basic automation system (Level 1) to achieve a high response speed of 200 ms. Due to the restrict of shape control model and electrical system in Liansteel CSP, flatness feedback control model performs

the control calculation once in 1 s in the process control system (Level 2). However, the calculation results used to regulate the bending force are sent to Level 1 once in 2 s. Compared with 200 ms, the responsiveness of the system (with an adjustment cycle of 2 s) is extremely slow.

2) As shown in (9), the values of G_i , F_{Ci}^U and F_{Ci}^L have a direct effect on the final regulation value of the bending force $F_{Ci}(k)$. The production data show that the values of these parameters are so small that the control efficacy is influenced and the wavy defects are not eliminated in time.

Based on the research and an understanding of the model, certain parameters were modified so that the adjustment cycle was adjusted from 2 s to 1 s, the integral gain was altered from 0.2 to 0.5, and the limit value of the regulation bending force was changed from ± 50 kN to ± 150 kN. Fig. 7 illustrates the optimization effects when the head strip has a double wave. And we can see the following: First, the response speed is increased so that the bending force begins to be regulated after the strip is rolled 25 m rather than 38 m. Second, because of the small regulation bending force before optimization, the double wave is not removed and the flatness deviation was maintained within a field of 80 to 100 IU. However, after optimization, the double wave is eliminated and the flatness deviation is rapidly reduced from 120 to 0 IU. Consequently, the modified flatness feedback system has achieved a higher response speed and a better control performance on the bending force.

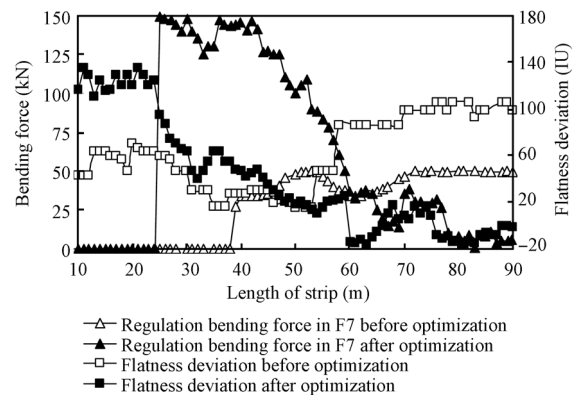


Fig. 7 Optimization effects of flatness feedback control model

5 Rolling process system

A reasonable rolling process system may provides favorable external conditions for shape control. The process system includes factors such as strip temperature, rolling speed, cooling water, etc. And it considers them to have multiple and nonlinear effects on the shape quality. Only by analyzing a large amount of production data can the relationship between the process system and shape control be established. However, with the lack of long-term field evaluation and analysis mechanisms for shape data, the influence of the rolling process on strip shape cannot be determined. As a result, the optimization of the process parameters dis-

plays blindness and limited actual impact. As the most visible and direct index reflecting the quality of strip shape, the mass data of shape quality objection were analyzed and compared with the online data in Liansteel CSP. Finally, the common characteristics of shape quality objection were identified and two process elements with serious problems were optimized in this study.

5.1 Entry temperature of finishing rolling

As one of the decisive factors in the production of thin strips, the entry temperature of finishing rolling (FET) has a direct relationship with the flatness quality^[16]. If the control level of FET is low, then the control accuracy of flatness is relatively poor. This conclusion is also reflected in the actual production. Generally, strips with an FET percentage of over 80% with a deviation of $\pm 20^\circ\text{C}$ along the slab length are considered as qualified. The statistic indicated that the FET qualifying rate of strips with shape quality objection was only 42.55% in Liansteel CSP.

Unreasonable control of gas flow in the tunnel furnace has a negative role in the uniformity control of slab temperature. As a result, an optimization control model of gas flow in the tunnel furnace based on fuzzy control strategy is proposed to improve the control performance of FET^[17]. On the basis of the difference between the actual and target temperatures, the gas flow of tunnel furnace is adjusted accurately using a 2-inputs-1-output fuzzy controller^[18] in order to enhance the stability of furnace temperature. The fuzzy controller including blurring input, fuzzy reasoning and ambiguity resolution is shown as Fig. 8, in which ΔT is the difference between the actual and target temperatures of the tunnel furnace, ΔT_c is the rate of change of ΔT , K_e , K_{ec} , K_u are factors of standard deviation, and $\Delta\lambda$ is the correction value of gas flow. Firstly, the process of blurring input converts the input of ΔT and ΔT_c into the matching linguistic values as its output. Secondly, according to the linguistic variables of input, the process of fuzzy reasoning activates the corresponding control rules which are given from the rule base in the form of linguistic rules or matrix tables, and then the linguistic variables are calculated. Finally, the process of ambiguity resolution transforms the linguistic variables into control variable, which converts fuzzy linguistic variables into the specific correction value of gas flow.

Based on a large amount of production data, the application of such an optimization control model achieved visible results in enhancing the stability of furnace and slab temperature. After optimization, the percentage of FET over each probability interval was improved and the mean hit rate satisfying the range from 80% to 100% was increased from 74.79% to 90.76%. Accordingly, the control level of flatness was also improved which is beneficial to prevent shape quality objection.

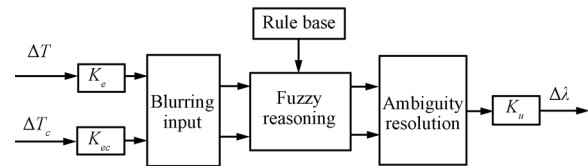


Fig. 8 Fuzzy controller of furnace temperature

5.2 Rolling schedule

The rolling schedule is a key to shape control^[19]. For the CSP hot strip mills, the rolling schedule is different from those of conventional hot strip mills because of the production organization characteristics of continuous casting and rolling. No strict limits are applied to steel grade, specification, and number of slab sheets in a rolling unit. However, statistical results showed that from the strips with shape quality rejection, approximately 35.6% were rolled at the end of the service period of the backup roll in F7 because of the serious uneven wear of the backup roll and the unstable rolling state of mills. Consequently, the service period of the backup roll in F7 must be considered as the standard when the rolling schedule is prepared. When the reasonable coordination between the rolling schedule and service period of the backup rolls is considered, production of strips with limited specifications can be prevented at the end of the service period of the backup roll.

Generally, rolling tonnage is considered as a standard for changing the backup roll^[18]. Strip shape quality is also considered. In Liansteel CSP, the rolls with different characteristics in the rolling process, such as F1 and F7, are often changed at the same time. This method is not conducive to shape control and rolling stability. Therefore, the change system of the backup roll is optimized. Based on the similarities of the process nature of each stand, the seven sets of backup rolls were classified into 3 categories: F1 to F2, F3 to F4, and F5 to F7. Each category is changed at the same time as much as possible.

6 Application effects of comprehensive shape control technology

The comprehensive shape control technology that includes roll configuration, shape control model, and rolling process system has been securely applied in Liansteel CSP for approximately two years, and the application effects are mainly evaluated based on the following indicators:

1) Roll wear. Fig. 9 shows the wear contours of the work roll and backup roll in F2. After the comprehensive shape control technology was used, the work roll wear was smoother across the wear width, and the bulge and groove at both ends were relieved. The “S” curve wear of the backup roll was improved, particularly at the bottom roll. Accordingly, after the project implementation, the general roll consumed by the finishing group was reduced from 0.653 to 0.458 kg/ton or by 29.86%. Compared with

the other CSPs built in China, where general roll consumption is mostly in the range of 0.60 to 0.90 kg/ton range, the comprehensive shape control technology has the advantage of reducing roll consumption.

2) Hit rates of the strip shape. The improvements in the hit rates of the average strip flatness and crown for the 3 successive months are presented in Fig. 10. After the application of the comprehensive shape control technology, the average hit rate of strip flatness was increased by 15.40% and the average hit rate of the crown was increased by 14.82%. This result is on the same advanced level as the rates achieved by world-famous electricity suppliers.

3) Shape quality objection. To fully illustrate the performance of the technology, we illustrate the improvements in the shape quality objection of steel Q235B in Table 3. Compared to the same month in 2011, which was before the optimization, the weight of the shape quality objection in 2012 decreased consecutively for 6 months, and the monthly average tonnage was reduced by 39.69%.

Table 3 Improvements of shape quality objection

Month	Weight of shape quality objection (ton)		Decreased proportion (%)
	2011	2012	
06	776.38	660.23	14.96
07	802.85	503.55	37.28
08	855.12	475.53	44.39
09	731.97	455.43	37.78
10	678.12	239.31	64.71
11	766.07	467.07	39.03
Average	768.42	466.85	39.69

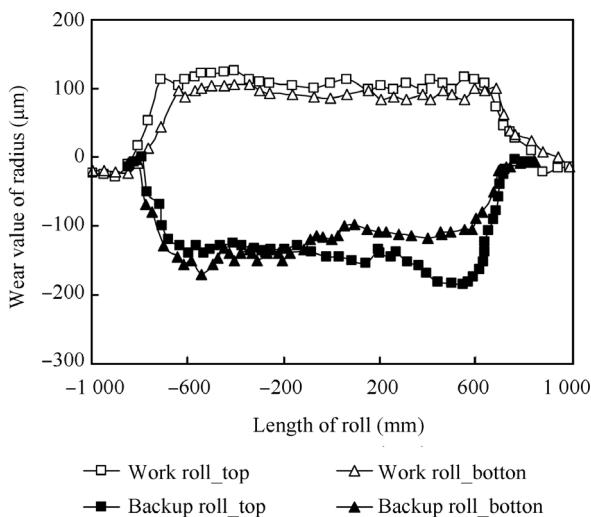


Fig. 9 Roll wear contours with comprehensive shape control technology in F2

7 Conclusions

1) The shape quality in CSP hot strip mills is determined by the roll configuration, control model, and rolling process

system. First, a reasonable roll configuration in finishing mills leads to good performance in enhancing the shape control ability. Second, a shape control system with a higher response speed and better control efficacy on the bending force can improve the shape control accuracy. Third, a perfect rolling process system provides favorable external conditions for shape control.

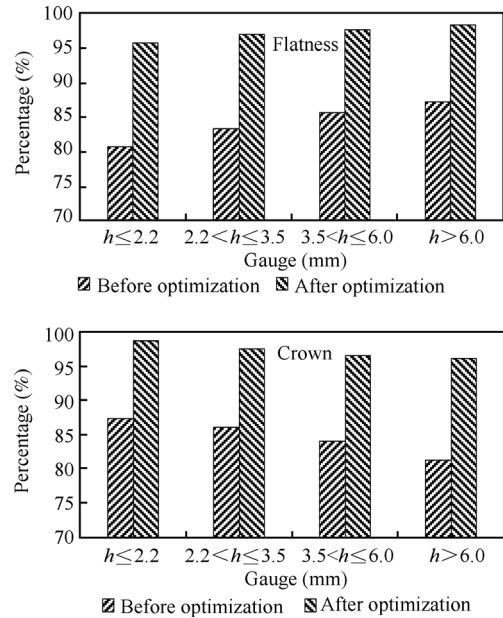


Fig. 10 Improvements of hit rates of strip average flatness and crown

2) The comprehensive shape control technology is proposed, including optimization of the work roll contour and design of the VCRplus backup roll contour, analysis of the flatness feedback control system, and improvement of the rolling process system. Taking Liansteel CSP for example, the comprehensive shape control technology was stably applied according to the control situations of strip shape.

3) The results show that after long-term application in CSP hot strip mills, the general roll consumption of the finishing group was reduced by 29.86%, and the flatness and crown of the strip were improved significantly, with an increased proportions of 15.40% and 14.82%, respectively. Furthermore, the monthly shape quality objection of the steel grade was reduced by 39.69%, which brought substantial financial benefits to the company. Therefore, applying the comprehensive shape control technology has significant implications on engineering practice and serves as a reference for other hot rolling mills in terms of improving the strip shape.

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