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Study and application of crown feedback control in hot strip rolling

Xiaodong Wang[1), *Anrui He*[1), *Quan Yang*[1), *Zhi Xie*[2), *and Hongtao Yang*[2)

1) National Engineering Research Center for Advanced Rolling Technology, University of Science and Technology Beijing, Beijing 100083, China
2) Anshan Iron and Steel Corporation, Anshan 114002, China
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Abstract: Crown feedback control is one part of the automatic shape control (ASC) system. On the basis of large simulation researches conducted, a linear crown feedback control model was put forward and applied in actual strip rolling. According to its successful operation in the ASP1700 hot strip mill of Angang Group for one year and also from the statistical results of several crown measurements, it can be definitely said that this control model is highly effective and shows stable performance. The control effectiveness of different gauges of strips with the feedback control is found to increase by 10%-30% compared with that without feedback control.

Key words: hot rolled strip; crown; feedback control; automatic shape control; profiler

1. Introduction

Although there have been several researches related to strip shape control, yet most of those are concentrated on control methods and setup calculation, and no crown feedback control model that can be directly applied to hot rolling was put forward. R.M. Guo [1] stated that an online automatic shape control (ASC) system can be established through the deep understanding about strip rolling behavior based on shape theoretic models [2-9] suggested by predecessors. The simulation models can act as a bridge between theoretical and applicational models research, and it is used to prove the theoretical models. But these models did not involve a deep research with regard to the establishment of a close loop control system of crown feedback. The basic idea of strip shape control is that crown control is accomplished on upstream stands, whereas flatness control on downstream stands. X.L. Yao and Z.Y. Zhang *et al*. [10] put forward the strip crown prediction model, strip shape prediction model, and feedback control by simplifying and discretizing the models suggested by B. Cheng's elastic deformation theory of rolls. As no shape measuring apparatus was used, the real close loop control of strip shape was not achieved yet in the research mentioned above.

Therefore, the establishment of strip crown feedback control model (CFC) and its application to actual hot strip rolling have become one of the important tasks in ASC system research. One crown feedback control model that has been applied to the ASP1700 hot strip mill of Angang Group and its effectiveness are described in this article.

2. Principle of strip crown feedback control

Fig. 1 is the structural schematic graph of an online strip ASC system, which consists of a strip shape setup module, a bending force feed-forward control module, a crown feedback control module, and a flatness feedback control module. This system has been effectively applied to the ASP1700 hot strip mill. The strip crown value measured by a profiler is sent to the crown feedback control model, and then control variables are calculated based on certain arithmetic regulation. The aim of crown feedback control is to guarantee the strip crown within an economically reasonable range using the existing equipment. Hydraulic bending and shifting adaptors of work rolls were installed as the strip shape adjusting means from F3 to F6 in ASP1700. During crown feedback control, strips must be retained to be flat, that is, the difference value between the outlet and the inlet relative crown of every stand must be equal. The concept of relative crown is that strip crown is divided by strip thickness. The aim value of crown control is given at the exit of F6, the aim crowns at the exits of other stands can be calculated backward from F6 to F1. As the bending force adaptors were only installed on F3 to F6, bending of work rolls becomes the only controllable tool to control strip crown. The most ideal condition is that there is a profiler to measure the strip crown at the exit of every finishing stand and can achieve separate close loop control of each stand. But this situation is hardly realized for equipment layout because of the economic reason. Therefore, actual strip

Corresponding author: Xiaodong Wang, **E-mail:** x_d_wcumt@163.com

crown can only be measured by the profiler at the exit of F6, crown values at the exits of F3 to F5 can be calculated on the basis of the rule that relative crown should be retained as a constant. Thus the close loop control can be achieved. During strip shape setup calculations, the relative crown of every stand varies within a reasonable range, namely, satisfying Shohet discriminant [3], so that the flatness of a strip is not destroyed as shown in Fig. 2, in which CH/*H* and Ch/*h* represent the relative crowns at the entry and at the exit of the finishing stand, respectively. So this strategy is also used in crown feedback control. On the basis of Shohet rule, bending force is adjusted from F3 to F6. But the main adjusting values are loaded on F3 and F4, because the flatness of a strip is highly sensitive to the changes in the bending force of F5 and F6.

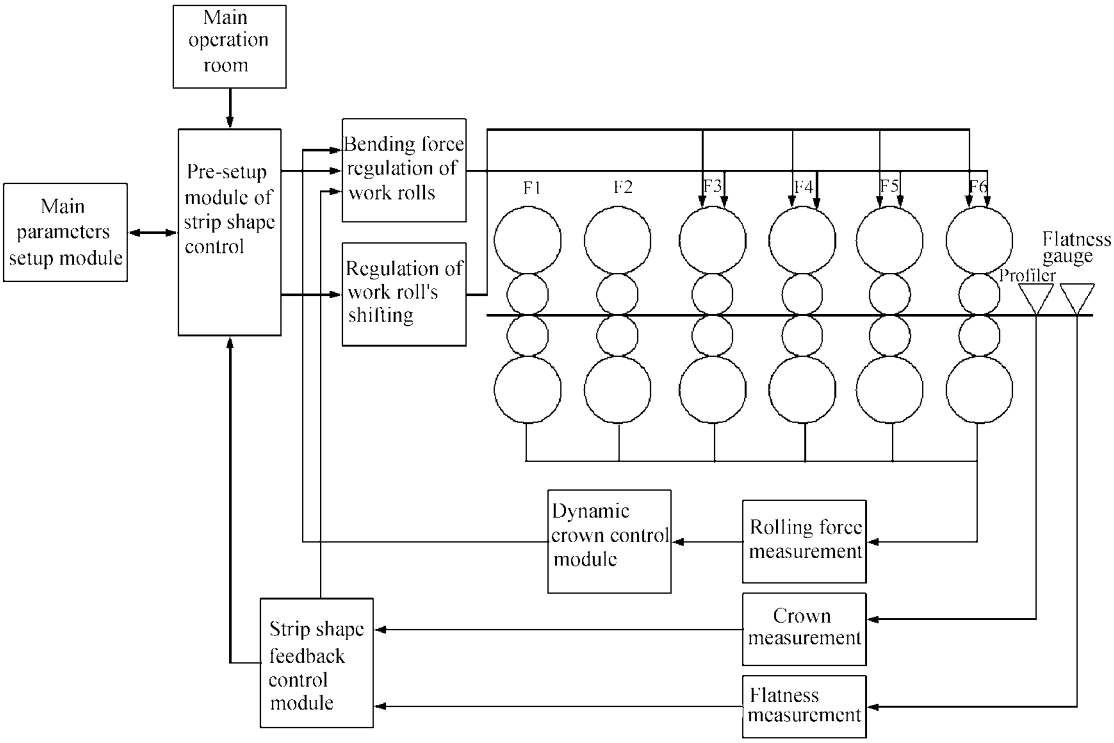

Fig. 1. Basic composition of automatic shape control system for hot rolled strip.

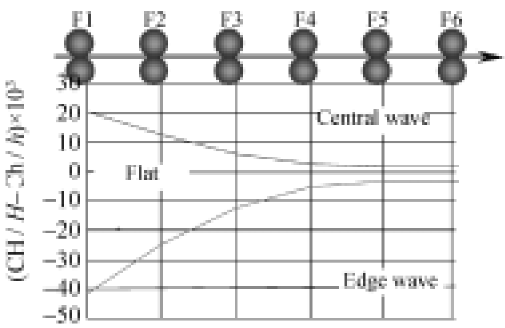

Fig. 2. Flatness dead area of strip shape control.

3. Profile measurement apparatus

One set X-ray profiler made by IMS Company was installed at the exit of the finishing train of an ASP1700 hot strip mill in Angang Group to measure the strip crown, and the schematic drawing is shown in Fig. 3. One or more X-ray sources were settled at the upper beam of the C frame, and a certain number of sensors were installed at the bottom beam. When the strip passes through the C frame, X-ray penetrates the strip and reaches the sensor. As the thickness is different at different width positions, the energy received by each sensor is different, and consequently, different electrical signals are produced and are sent to the signal-processing unit. So the thickness values at different positions on the cross section can be calculated using a computer, and then one crown value is given.

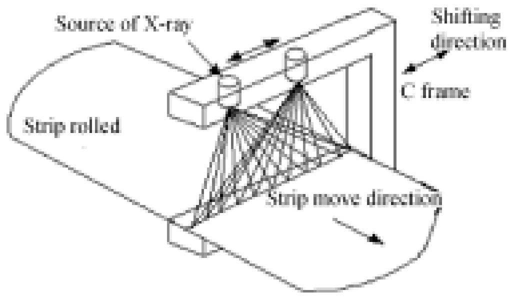

Fig. 3. Measurement scheme of the profiler.

As this profiler has only 28 measurement channels, one section profile cannot be measured one time, and the C frame must move along the direction of the strip width for obtaining the crown value during its measurement.

4. Crown feedback control model

On the basis of several product data, the deep research on the mathematical relationship between the strip crown and the bending force of the work roll was performed, in which the strip width factor was also considered. One simplified linear mathematical model was acquired as follows:

$$\mathrm{BF}_i = \mathrm{BFS}_i + K_t K_F \frac{\Delta \mathrm{CH}_i}{H_6} \qquad (i = 3, 4, 5, 6) \tag{1}$$

where BF_i is the bending force of the *i*th stand functioned by the crown feedback control; BFS_i the locked bending force value of the *i*th stand after T seconds time from the profiler ON; K_t the adjusting coefficient; K_F the adjusting characteristic of the bending force on the loaded roll gap, which is related to the rolling force, strip width, roll diameter *etc.*; H_i is the exit gauge of the *i*th stand and H_6 the exit gauge of the last stand (F6); ΔC is the difference value between the actual measured crown and the aim crown as follows:

$$\Delta C = \mathrm{C\_M} - \mathrm{C\_O} \tag{2}$$

where C_M is the measured crown value and C_O is the aim crown value. When $|\Delta C|<a$ or $|\Delta C|>b$, the crown feedback control function does not work. The crown difference is considered to be within the allowed tolerance in the formal situation, whereas the working condition of the profiler is considered to be abnormal in the latter situation. According to the production requirement, a and b are determined to be 18 and 300 μm, respectively.

To avoid a large fluctuation in bending force, the crown difference ΔC_1, which is obtained first, is not included in the crown feedback control momentarily. When the second crown difference ΔC_2 is in existence, the actual crown difference used in the feedback control is as follows:

$$\Delta C = p\Delta C_1 + q\Delta C_2 + r\Delta C' \tag{3}$$

where p and q are the two duty ratio coefficients of historical data, r is the crown prediction coefficient,

$$\Delta C' = 2\Delta C_2 - \Delta C_1 \tag{4}$$

Eq. (4) is the next crown difference value, which is determined according to the two crown differences obtained previously.

In the same manner, after the third crown difference ΔC_3 is obtained, another crown difference used in the feedback control is calculated as follows:

$$\Delta C = p\Delta C_2 + q\Delta C_3 + r\Delta C' \tag{5}$$

$$\Delta C' = 2\Delta C_3 - \Delta C_2 \tag{6}$$

This processing is sequentially performed until the end of crown measurement.

The bending force of every stand has its limit value. If its calculation value is beyond the limit, the limit is set as the bending force setup value. The absolute difference value $\Delta \mathrm{BF}_i$ between BF_i and BFS_i also has its limit of 200 kN. If it is beyond that range, the limit value is assigned as 200 kN or –200 kN. When one coil strip rolling is over, this value, $\Delta \mathrm{BF}_i$, is assigned as 0.

5. Application result of crown feedback control

Although during the throw-in and regulation stages of this control model, there had been several difficulties and problems such as the data communication problem, this crown feedback control model was formally introduced in an ASP1700 hot mill in March 2004. This model showed a stable performance and achieved a satisfied actual production result.

To control the strip crown within the aim range, the crown feedback model adjusts the bending forces operated on the work rolls. If the measured crown value is larger than the aim value, the bending force on the upper stream stands will be increased with a certain degree under the function of crown feedback; on the contrary, the bending force will be decreased if the measured crown value is less than the aim value. One example that can clearly illustrate the effectiveness of crown feedback control is presented in Fig. 4. The steel grade, gauge, and the width of this strip are Q235B, 2.48 mm, and 1060 mm, respectively. Variables in this graph are recorded using ibaAnalyzer software, curve 1 is the crown value measured by the profiler, and curves 2 and 3 are the bending force on F3 and F4, respectively. As there is no work roll bending apparatus on F1 and F2, adjustment of bending force can begin only from F3 and then from F4. In Fig. 4, the first two crown values of the strip are larger than the aim value of 20±18 μm, and then the bending forces on F3 and F4 have the increase of approximately 50 kN under the function of crown feedback. All the values for measured crowns except the head two are decreased and controlled within 20 to 30 μm. This demonstrates that the crown feedback control model has a good performance.

As one good control result cannot fully illustrate the model's performance, statistical result for its long-time application is required. The data were processed and recorded for nearly half year in 2005, and the statistical distribution of the sample is shown in Table 1. Table 2 shows the statistical results. The control work of the head shape of the strip including crown and flatness is achieved mainly *via* the strip shape setup level II program. Within the remaining length of the strip, the crown and flatness are controlled using the feedback control model. To fully demonstrate the effectiveness of the crown feedback control model, the average crown value in the whole length of the strip is considered for statistical studies. From the statistical result, effectiveness of crown feedback control can be seen. The percentage of average crown satisfying the aim value of the strip with the crown feedback control model has an increase by 10%-35% compared with that of the strip without crown feedback, especially with the increase of strip gauge. The improvement of crown control value is almost 12% when the strip gauge $h \le 5.0$ mm, and it is more than 30% when the strip gauge $h>5.0$ mm. When there is no function of crown feedback control and $h>5.0$ mm, the percentage of average crown satisfying the aim value is only about 50%-60%. When the feedback function is used, the percentage is approximately increased to 90%. When h is higher than 6.0 mm, this trend is more obvious, nearly having 35% improvement. From the statistical results of the standard average variance (SAV) related to the aim value, it can be seen that the percentage related to the aim crown less than 18 μm of the strip with feedback control has a more obvious increase than that of the strips without feedback function as shown in Table 2. Therefore, it is reasonable to assume that the crown feedback control also has a good stability.

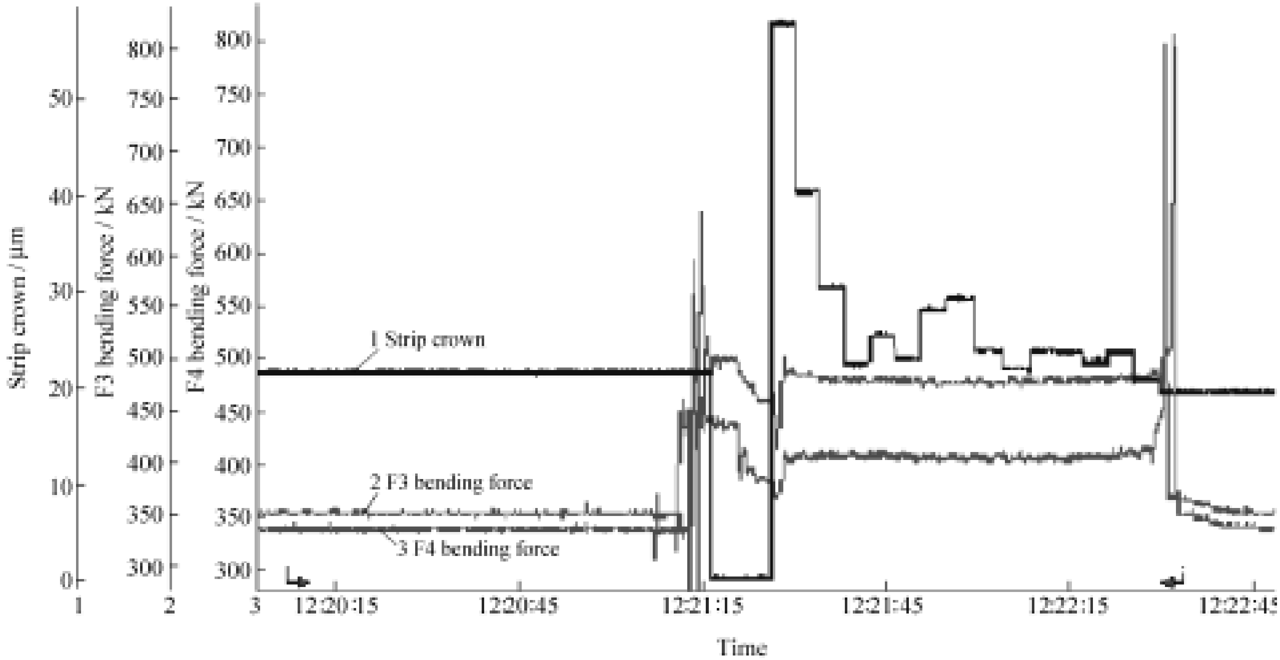

Fig. 4. Application effect of crown feedback control.

Table 1. Statistical number distribution of different strip gauges

Gauge, *h* / mm	Total strip number	Strip number with CFC	Strip number without CFC
$h \le 3.0$	1422	679	743
$3.0<h \le 4.0$	1473	592	881
$4.0<h \le 5.0$	715	288	427
$5.0<h \le 6.0$	877	485	392
$6.0<h$	606	221	385

Table 2. Aim crown control value of strips and the statistical results

Gauge, *h* / mm	Aim value of trip crown / μm	Percentage of average crown satisfying the aim value (with CFC model) / %	Percentage of average crown satisfying the aim value (without CFC model) / %	Percentage of SAV related to the aim crown less than 18 μm (with CFC model) / %	Percentage of SAV related to the aim crown less than 18 μm (without CFC model) / %
$h \le 3.0$	20±18	80.56	70.21	91.37	85.87
$3.0<h \le 4.0$	30±18	82.42	69.35	93.62	82.39
$4.0<h \le 5.0$	40±18	86.67	62.86	94.10	78.58
$5.0<h \le 6.0$	40±18	90.85	60.05	96.45	75.46
$6.0<h$	40±18	88.42	51.69	93.11	68.52

6. Conclusions

(1) The crown feedback control model is one of the important parts of a strip shape automatic control system.

(2) The close loop control model controls the strip crown in its whole length by adjusting the real-time bending force of the work roll based on the Shohet discriminant and the actual crown of the strip measured by the profiler.

(3) From the results of stable industrial application for a long time and the statistical results, it can be seen that this model has a good performance and is valuable to spread application.

(4) Establishment and application of this feedback control model helps to enhance the strip shape quality. This model can be referred as the basic of researches on strip shape close loop control.

(5) As there are only 28 measurement channels on the profiler, C frame must shift along the strip width to measure the crown. This has the adverse influence on the speed of crown feedback control. If there are enough channels, the movement of C frame is not required, and eventually the effectiveness of feedback control would be better.

References

[1] R.M. Guo, Development of an optimal crown/shape level-2 control model for rolling mills with multiple control devices, *Control Syst. Technol.*, 6(1998), p.172.

[2] M.D. Stone and R. Gray, Theory and practice aspects in crown control, *Iron Steel Eng.*, 42(1965), p.657.

[3] K.N. Shobet and N.A. Townsend, Roll bending methods of crown control in four-high plate mills, *JISI*, 1968, No.6, p.1088.

[4] R.M. Guo, Development of a mathematical model for strip thickness profile, *Iron Steel Eng.*, 67(1990), No.9, p.32.

[5] R.M. Guo, Prediction of strip profile in rolling process using influence coefficients and Boussinesq's equations, *Trans. ASME J. Manuf. Sci. Eng.*, 119(1997), No.2, p.220.

[6] A.R. He, J. Zhang, C. Zhang, Q.D. Zhang, *et al.*, Thermal behaviors of work roll in finishing trains of hot rolling, *J. Univ. Sci. Technol. Beijing*, 8(2001), No.1, p.59.

[7] A.R. He, Q. Yang, Q.D. Zhang, *et al*., Deformation character and analysis of stress and strain during stretching stage for cross wedge rolling, *J. Univ. Sci. Technol. Beijing* (in Chinese), 24(2002), No.3, p.306.

[8] Z.M. Xi, A.R. He, Q. Yang, *et al*., Roll wear on finishing trains of ASP1700 hot strip mills, *J. Univ. Sci. Technol. Beijing*, 11(2004), No.1, p.94.

[9] X.L. Zhang, J. Zhang, X.Y. Li, *et al.*, Analysis of the thermal profile of work rolls in the hot strip rolling process, *J. Univ. Sci. Technol. Beijing*, 11(2004), No.2, p.173.

[10] X.L. Yao, Z.Y. Zhang, J.F. Zhu, An application research on prediction and control of plate shape, *J. Beijing Inst. Technol.* (in Chinese), 21(2001), No.6, p.715.