International Journal of Multimedia and Ubiquitous Engineering
Vol.11, No.4 (2016), pp. 381-390
http://dx.doi.org/10.14257/ijmue.2016.11.4.38

# Design and Shape Control Ability Simulation of New Generation Varying Contact Length Backup Roll in Hot Rolling

Wenquan Sun, Jian Shao and Anrui He

*National Engineering Research Center of Advanced Rolling, University of Science and Technology Beijing, Beijing 100083, China*
*ustbshao@163.com*

***Abstract***

*Backup roll technology plays an important role in hot strip mill shape control. Varying contact length backup roll (VCR) technology in hot strip mill can increase transverse stiffness of loaded gap, heighten control effect of roll bending, and improve distribution of contact force between backup roll and work roll. However it appears to lack coordination with high-order curve work roll. A new objective function of new generation varying contact length backup roll (VCR plus) design curve is established with considering high-order work roll contour, and simulation is carried out to verify the effectiveness of VCR plus by a two dimensional variable thickness finite element method. The result shows that distribution of contact force between backup roll and work roll is more even in VCR plus technology, and which can extend the useful life of backup roll.*

***Keywords***: *Hot Rolling; Backup Roll; Shape Control Ability; FEM; Simulation*

## 1. Introduction

Hot rolling conditions are very complex and there are many interference factors in shape control. All the effects focus on rolling force fluctuation and roll profile diversity, including backup roll profile and work roll profile which are comprised of thermal and wear profile [1-2]. The diversity of roll profile not only disturbs the strip shape control, but also brings down the efficacy of bending force, then bending force will increase apparently and even exceed the limitation, as a result, the useful life of work roll will be declined rapidly. High shape control capability will eliminate or reduce the influences of rolling force fluctuation and roll profile diversity. For the purpose, Varying Contact Length Backup Roll (VCR) was independently developed [3], which can enhance the shape control efficacy of bending force, strengthen the transversal stiffness of loaded roll gap, smooth the roll wear, *etc*. The VCR technology has achieved significant effects through widely used on roughing mills and finishing mills in hot rolling. However it appears to lack coordination with high-order curve work roll, such as high performance variable crown (HVC) work roll or continues variable crown (CVC) work roll [4-8]. Based on VCR technology, a new generation varying contact length backup roll (VCR plus) is developed to improve the applicability in hot rolling which equipped with high-order curve work roll.

## 2. Design Theory and Method of VCR Plus

### 2.1 Polynomial and Optimized Parameters of VCR Plus Contour

In this section, VCR plus design method matching HVC is introduced. Polynomial is simple to be used and easily to be understood and grinded. So the VCR plus contour is also expressed by the form of polynomial, which is composed by VCR and HVC

ISSN: 1975-0080 IJMUE

polynomial. The polynomials of VCR and HVC are shown in equation (1) and (2), respectively.

$$g_1(x) = a_2x^2 + a_4x^4 + a_6x^6 \tag{1}$$

$$g_2(x) = b_0 + b_1x + b_2x^2 + b_3x^3 + b_4x^4 + b_5x^5 \tag{2}$$

Where $g_1(x)$ is VCR contour polynomial, $g_2(x)$ is HVC contour polynomial, $x$ is transverse regularization coordinates of roll length, $a_2$, $a_4$, $a_6$ are VCR contour polynomial parameters, $b_0$, $b_1$, $b_2$, $b_3$, $b_4$, $b_5$ are HVC contour polynomial parameters. In VCR plus design, $b_0$, $b_1$, $b_2$, $b_3$, $b_4$, $b_5$ are known parameters and $a_2$, $a_4$, $a_6$ are optimized parameters. The polynomial of VCR plus contour is shown in equation (3):

$$g_3(x) = \lambda g_1(x) + (1-\lambda) g_2(x) \tag{3}$$

Where, $g_3(x)$ is VCR plus contour polynomial, $\lambda$ is weight parameter which ranges from 0 to 1. If $a_2$, $a_4$, $a_6$ and λ are determined, the unique VCR plus contour is also fixed.

### 2.2 Objective Functions and Optimization Method for VCR Plus

The useful life of backup roll is long in hot rolling, in which the strip number is large and steel specification is various. It is unrealistic to develop an optimal backup roll contour for all kinds of strips. So the best way is to design a suitable contour for most strips. The basic idea of calculating VCR plus contour is closely related with strip shape control and backup roll consume.

The first propose is to reduce harmful contact area between work roll and backup roll. After optimizing, the backup roll contour should make contact length between rolls adapt to the width of the strip, in other words, the contact length and strip width is roughly equal for different strip width. To fully considering the influence of strip width and work roll wear on backup roll, four kinds of strip width and two kinds of work roll contour (no wear and badly wear) are given in the VCR plus design. The objective function is shown as equation (4):

$$T_1 = \sum_{n=1}^{k} \frac{d_n}{L_{mn} - B_n} \tag{4}$$

Where $T_1$ is the first objective function, $L_{mn}$ is rolls contact length in condition $n$, $B_n$ is strip width in condition $n$, $d_n$ is the proportion of the strip width for $B_n$ in the four kinds of strip width, $k$ is total condition number.

The second propose is to smooth the contact pressure between work roll and backup roll. The uniformity of the contact pressure between rolls affect the uniformity of the wear along roll body, the larger contact pressure value between rolls is, the easier rolls are spalling. If the total rolling force is constant and contact pressure between rolls is uniform, the maximum of the contact pressure is inevitable declined. Roll wear is an accumulation result and wear contour is changed seriously in a rolling unit. As the result, the roll gap is changed, which affects the contact pressure between rolls. To fully considering the influence of above factors on contact pressure between rolls, $q_d$ as the second goal is calculated under eight kinds of conditions, which is shown as follows:

$$T_2 = \frac{1}{q_d} \tag{5}$$

$$q_d = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left( q_a[i] - \frac{1}{N}\sum_{i=1}^{N} q_a[i] \right)^2} \tag{6}$$

$$q_a[i] = \frac{1}{k}\sum_{j=1}^{k} q[j][i] \tag{7}$$

 

Where $T_2$ is the second objective function, $q_a[i]$ is average value of contact pressure between rolls at point $i$ under different conditions, $q[j][i]$ is value of the contact pressure between rolls at point $i$ under condition $j$, $N$ is number of element calculated by backup roll length.

Contact length between the rolls cannot be less than the strip width, otherwise, it will make strip run off. So constraint condition is shown as follow:

$$L_{cn} \geq B_n \quad (n = 1 \sim k) \tag{8}$$

Where $L_{cn}$ is contact length between rolls under condition $n$.

The solution procedure is based on roll deformation and material plastic deformation model of four high mills [9]. The objective function is processed based on equation (9) which can calculate contact length and contact pressure between rolls of each unit under different conditions, and then the objective function $T$ is made to be maximum.

$$T = (1-\alpha)T_1 + \alpha T_2 \tag{9}$$

Where $\alpha$ is defined as weight coefficient of $T_1$ and $T_2$, $\alpha$=0.5. The calculation process of VCR plus is a nonlinear continuous optimization problem, and the mathematical expression between the objective function and the optimize parameters cannot be direct described, so the genetic algorithm is used in this optimization procedure. The optimized parameters of VCR plus backup roll contour contain $a_2$, $a_4$, $a_6$ and weight coefficient $\lambda$.

## 3. Shape Control Performance Simulation of VCR Plus

### 3.1 Configuration of Rolls in Hot Strip Mill

According to the data provided by hot strip mill as shown in Table 1, considering the different work roll contour and rolling conditions, corresponding VCR plus contour is designed to simulate the shape control performance.

Because each stand of finishing mill is different in rolling, so it is necessary to design different VCR plus profile for each stand. But considering the larger amount of roll profile is, the more difficult the management is, and there is interchange in backup rolls, hence, two or three VCR plus are designed for online application. In simulation performance, F1-F4 (finishing stand 1 to stand 4) work rolls use HVC1 contour which equivalent roll crown is [-0.7, 0.5] mm, and F5-F7 work rolls use HVC2 contour which equivalent roll crown is [-0.45, 0.35] mm, as shown in Figure1. For HVC work roll, shifting to positive direction equals to increasing bending force, and shifting to negative direction equals to reducing bending force.

**Table. 1 Data Provided by Hot Strip Mill**

| Stand | | | F1 | F2 | F3 | F4 | F5 | F6 | F7 |
|---|---|---|---|---|---|---|---|---|---|
| Work roll | Diameter of roll body, mm | Max. | 840 | | | | 680 | | |
| | | Min. | 765 | | | | 580 | | |
| | Roll body length, mm | | 2380 | | | | | | |
| | Diameter of roll neck, mm | | 509 | | | | 390 | | |
| | Distance between axial center of roll bear at operator side and drive side, mm | | 3620 | | | | 3720 | | |
| | Roll material | | HSS | | | | Ni-GR HSS | | |
| | Bending force per side, KN | | 1470 | | | | | | |

 

| | | | | |
|---|---|---|---|---|
| | Maximal axial shifting, mm | | ±150 | |
| Backup roll | Diameter of roll body, mm | Max. | 1600 | 1480 |
| | | Min. | 1450 | 1330 |
| | Roll body length, mm | | 2060 | |
| | Diameter of roll neck, mm | | 922 | |
| | Distance between axial center of roll bear at operator side and drive side, mm | | 3620 | |
| | Roll material | | Hi-Cr Forged Steel(5%Cr) | |
| Maximal rolling force of equipment limit, KN | | | 5000×9.8 | 4000×9.8 |

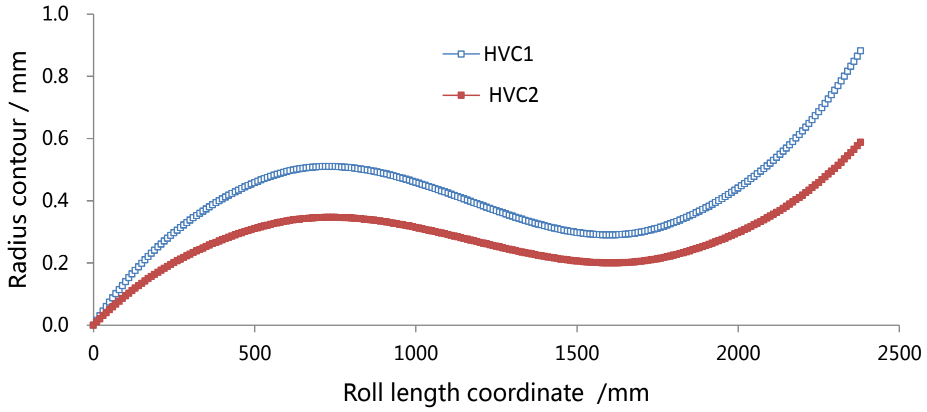


**Figure 1. Roll Contour of HVC1 and HVC2 Work Roll**

Considering the similarity of each stand, F2 is chosen as the simulation objects. According to the HVC1 work roll used in F2 stand, VCR2 plus backup roll is adopted as shown in Figure2.

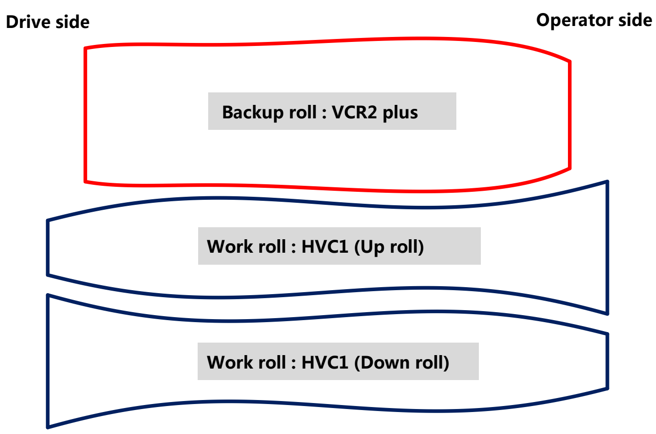


**Figure 2. Roll Configuration of HVC Work Roll and VCR Plus Backup Roll in F2**

### 3.2 Simulation Model

By a two dimensional variable thickness finite element method as shown in Figure 3 [10], shape control performance is simulated by equipped with conventional backup roll (CON), VCR2 and VCR2 plus, which is coupled with HVC1 work roll technology in F2 stand.

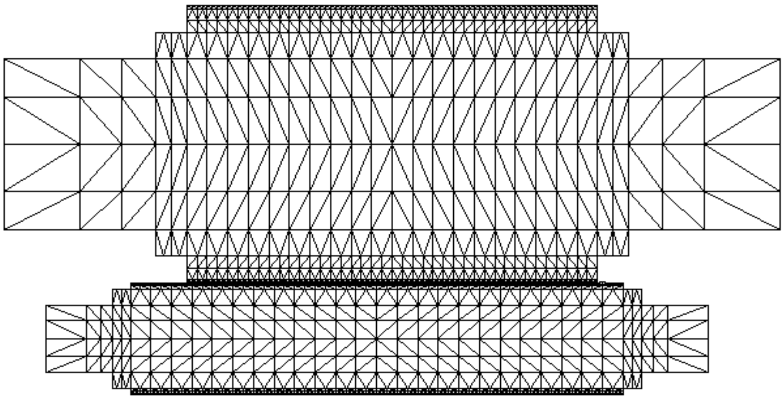

**Figure 3. Roll Deformation Computational Model of Shifting Condition**

Working condition parameters in the simulation model are shown in Table.2.

**Table 2. Parameters of Working Conditions in the Simulation in F2**

| | | | |
|---|---|---|---|
| Strip width, B2, mm | 1500 | | |
| Rolling force, Qs2, KN/mm | 15 | | |
| Bending force, Fb, KN | 0 (Fb1) | 750 (Fb2) | 1470 (Fb3) |
| Roll shifting, S, mm | -150 (S1) | 0 (S2) | -150 (S3) |
| Work roll | HVC1 | | |
| Backup roll crown | CON (Crown=0),VCR2,VCR2+ | | |

## 4. Simulation Result

### 4.1 Contact Force Distribution between Work Roll and Backup Roll

Contact force distribution reflects the contact status between work roll and backup roll. Homogeneous distribution in axis orientation is in favor of descending the maximum of contact force. Taking F2 for example, contact pressure distribution between rolls is calculated with different roll contours. Figure 4 shows comparison of contact force distribution in different conditions.

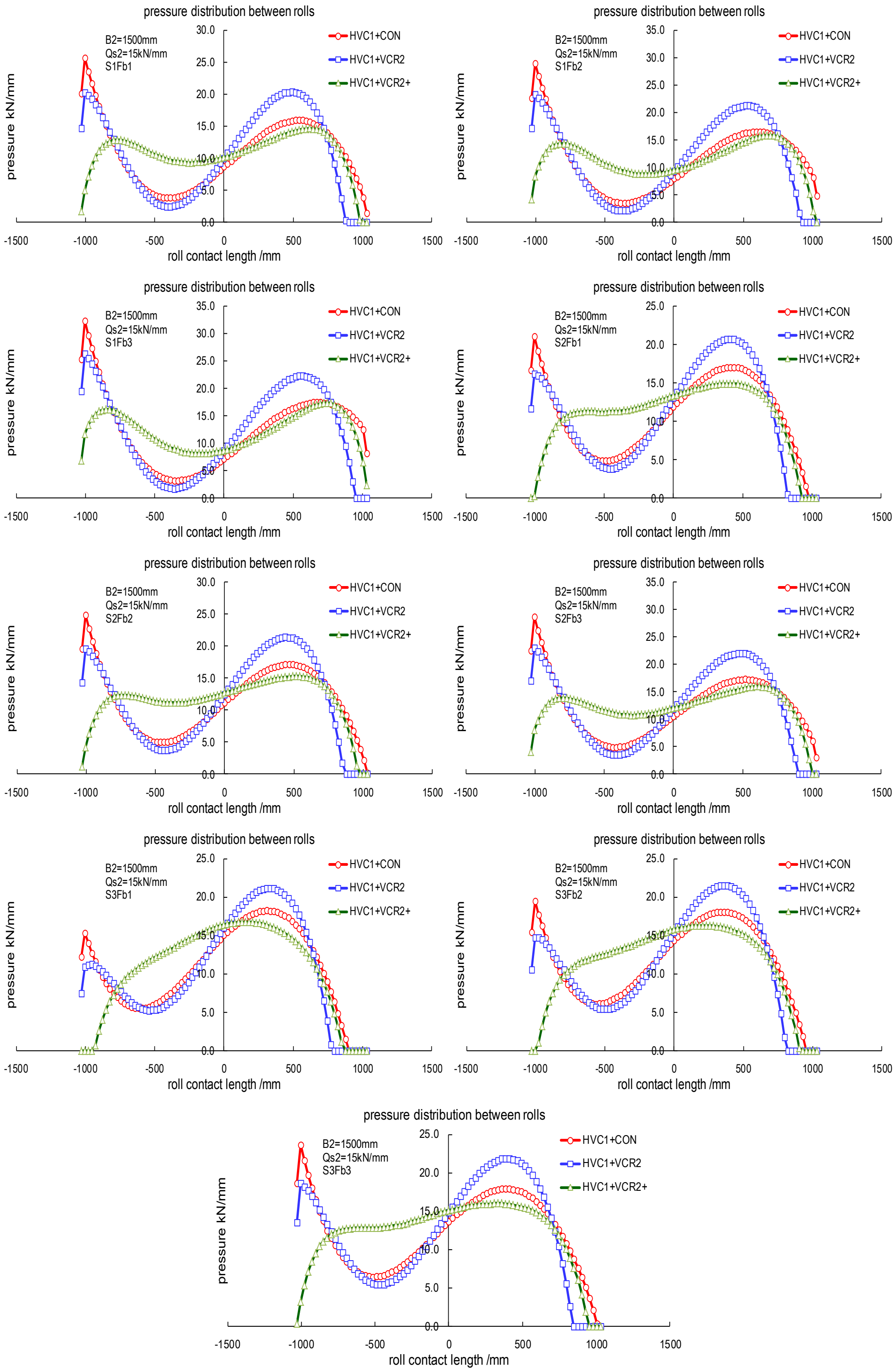


**Figure 4. Contact Force Distribution in Different Conditions**

It can be seen from Figure4 that VCR plus can descend the maximum contact force and cause even distribution compared with CON and VCR, which can prolong the useful life of work roll and backup roll, and get more even wear contour for better shape control conditions, also, work roll shifting has obvious influence on the contract pressure between rolls.

### 4.2 Transverse Stiffness of Loaded Roll Gap

Transverse stiffness of loaded roll gap reflects its ability of resisting the rolling force fluctuation. In other words, the greater transverse stiffness is, the influence of rolling force fluctuation in roll gap profile is smaller and the strip profile is more stable. Transverse stiffness of loaded roll gap can be represented as follows:

$$k_s = \Delta F_r / \Delta C_g \tag{10}$$

Where $k_s$ is transverse stiffness of loaded roll gap, $\Delta F_r$ is diversity of rolling force, $\Delta C_g$ is diversity of roll gap crown. Figure5 shows the comparison of the roll gap transverse stiffness on F2 in different conditions. The transverse stiffness of roll gap is increased by using VCR. However, for the VCR plus, the transverse stiffness of roll gap is better than CON but worse than VCR. In addition, after using VCR plus, the characteristics of roll gap are shown as follows: the wider of the strip, the greater stiffness is. Positive roll shift of HVC can increase the transverse stiffness of roll gap. The larger of bending force, the less transverse stiffness of roll gap is.

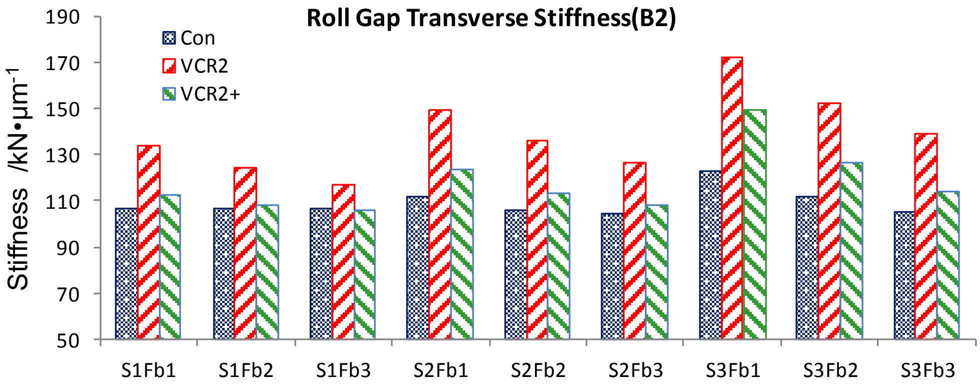


**Figure 5. Roll Gap Transverse Stiffness in Different Conditions**

### 4.3 Adjustment Efficacy of Bending Force

If bending force adjustment efficacy is better, the capability of bending force control is more forcibly, and shape defect can be eliminated more quickly and economically. At the same time, it is in favor of descending the maximum of bending force and increasing the useful life of work roll bearings. The efficacy can be represented as follows:

$$k_f = \Delta C_g / \Delta F_b \tag{11}$$

Where $k_f$ is the efficacy of control and adjustment of bending force, $\Delta F_b$ is the diversity of bending force, $\Delta C_g$ is the diversity of gap crown. Figure6 shows the comparison of adjustment efficacy of bending force on F2 in different conditions. The adjustment efficacy of bending force is increased by using VCR. However, for the VCR plus, adjustment efficacy of bending force is better than CON but worse than VCR. In addition, after using VCR plus, the characteristics of adjustment efficacy of bending force are shown as follows: the wider of the strip, the greater efficacy is. Positive roll shift of HVC can increase adjustment efficacy of bending force. With the increasing of unit width of rolling force, adjustment efficacy of bending force is decreased, but with increasing of the width, this trend is not obvious.

 

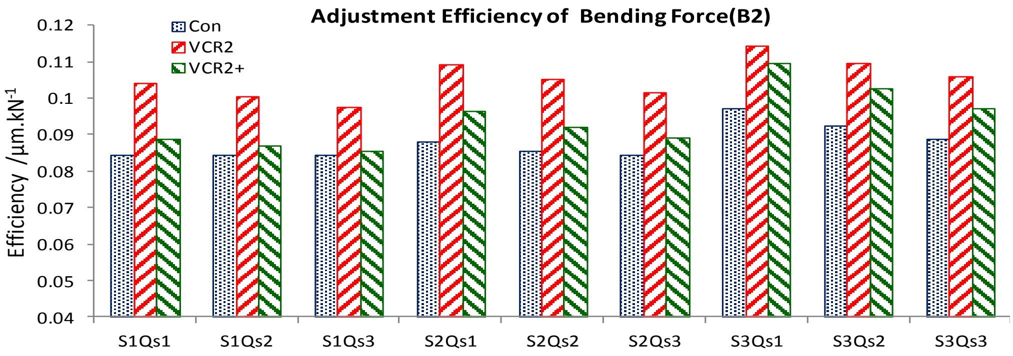


**Figure 6. Adjustment Efficacy of Bending Force in Different Conditions**

## 5. Conclusions

1) Based on VCR technology, a new generation varying contact length backup roll is developed to improve the applicability in hot rolling which equipped with high-order curve work roll and distribution of contact force between backup roll and work roll is more even in VCR plus technology.

2) By a two dimensional variable thickness finite element method, shape control performance is simulated by equipped with different backup roll, which is coupled with HVC work roll technology. VCR plus can descend the maximum contact force and cause even distribution compared with CON and VCR, which can prolong the useful life of work roll and backup roll. However, for VCR plus, either bending force adjustment efficacy or roll gap transverse stiffness is better than CON but worse than VCR.

## Acknowledgement

This work was supported in part by National Natural Science Funds of China (51404021), Beijing Higher Education Young Elite Teacher Project (YETP0413), Fundamental Research Funds for the Central Universities (FRF-TP-15-060A3) and Beijing Municipal Natural Science Foundation (3154035).

## References

[1] G. H. Yang, J. Zhang and Y. Z. Zhou, "Work roll non-uniform wear and shape control performance of the 2250 hot temper mill in WISCO", Journal of University of Science and Technology Beijing, vol. 31, no. 8, **(2009)**, pp. 1051-1056.

[2] X. D. Wang, Q. Yang and A. R. He, "Comprehensive contour prediction model of work rolls in hot wide strip mill", Journal of University of Science and Technology Beijing: Mineral Metallurgy Materials, vol.14, no. 3, **(2007)**, pp. 240-245.

[3] A. R. He and X. L., "Application of Varying Contact Rolling Technology on Hot Strip Mills", Iron and Steel, vol. 42, no. 2, **(2007)**, pp. 31-34.

[4] F. F. Kong, "Research on the Mixed Variable Crown Contour and Setup Models for Hot Strip Mills", Dissertation, University of Science and Technology Beijing, Beijing, (2012). [5] L. Cheng, A. K. Tieu, Z.Y. Jiang. A design of a third-order CVC roll profile. Journal of materials Processing Technology, vo1. 25, no. 9, **(2002)**, pp. 645-648.

[5] W. Bald, G. Beisemann and H. Feldmann, "Continuously variable crown (CVC) rolling", Iron and Steel Engineer, vol. 64, no. 3, **(1987)**, pp. 32-41.

[6] H. B. Ling, J. Zhang and J. G. Cao, "Roll contour and strip profile control characteristics for quintic CVC work roll", Journal of Mechanical Engineering, vol. 48, no. 12, **(2012)**, pp. 24-30.

[7] G. C. Wei, J. G. Cao and J. Zhang, "Optimization and application of CVC work roll contour on 2250 hot strip mills", Journal of Central South University, vol. 38, no. 5, **(2012)**, pp. 937-942.

[8] F. F. Kong, A. R. He and J. Shao, "Research on rapid online calculation methods of stack deformation", Journal of Mechanical Engineering, vol. 48, no. 2, **(2012)**, pp. 121-126.

[9] X. L. Chen and J. X. Zou, "A specialized finite element model for investigating controlling factors affecting behavior of rolls and strip flatness", Proceedings of 4th International Steel Rolling Conference, Deauville, France, vol. 6, no. 2, **(1987)**, pp. 41-43.

## Authors

**Wenquan Sun**, He received his M.Sc. (2005) and PhD (2010) in Mechanical Engineering from University of Science and Technology Beijing. Currently, he is an assistant researcher in National Engineering Research Center for Advanced Rolling Technology, University of Science and Technology Beijing. He has participated in 20 projects and published about 20 refereed journal and conference papers. His research interests include cold strip quality control, shape control model and automation.

**Jian Shao**, He received his M.Sc. (2003) and PhD (2009) in Mechanical Engineering from University of Science and Technology Beijing. Currently, he is an assistant researcher in National Engineering Research Center for Advanced Rolling Technology, University of Science and Technology Beijing. He has participated in 20 projects and published about 30 refereed journal and conference papers. His research interests include strip quality control, shape control model and automation.

**Anrui He**, He received his M.Sc. (1994) and PhD (2000) in Mechanical Engineering from University of Science and Technology Beijing. Currently, he is a research fellow in National Engineering Research Center for Advanced Rolling Technology, University of Science and Technology Beijing. He has authored and coauthored over 200 papers. He has been responsible for about 50 projects. He received over 20 state, province and university awards in science and technology. His research interests include mechanics behavior simulation and control, shape control model and automation.