Improvement of Contact Stress Distribution Between Work Roll and Backup Roll of a Hot Strip Mill

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Abstract—Contact state between work roll and backup roll has significant influence on surface fatigue and strip steel shape. In this work, the contact behaviours between work roll and backup roll of a hot strip mill were investigated. The contact stress distributions along the axial and radial direction were calculated. The effect of uneven contact stress distribution on strip steel profile was analysed. The risk of roll fatigue caused by contact stress concentration was pointed out. In order to improve the contact stress distribution, a design method of the backup roll profile was proposed. Both finite element calculation and industrial test have been carried out and showed that the new profile was excellent in reducing the peaks of the contact stress, homogenizing backup roll wear and improving strip profile.

1. Introduction
Strip steels provide basic raw materials to manufacturing industry. Hot rolling is a key process to produce strip steels. Hot strip mill is the essential equipment for strip steel hot rolling. There are two or four rolls in a hot strip mill, i.e., 2-hi mill and 4-hi mill are common forms in the strip mill. Generally speaking, the hot finishing tandem mill includes several stands of 4-high mill, while the roughing mill may includes one or two 2-hi or 4-hi mills. The 4-hi mill consists of 2 backup rolls and 2 work rolls, which can be seen from Fig.1. The backup roll contacts with the work roll during strip rolling process. Contact state is affected by many factors, among them roll profile is an important one. Rolling contact fatigue in the form of spalling may produce by uneven distribution and huge peaks of contact stress[1, 2]. Strip shape is a key aspect of the steel quality, which is also affected by contact state[3, 4]. In this paper, the contact stress distributions between work roll and backup roll with continuously variable crown (CVC) roll contour along the axial and radial directions are calculated. The effects of uneven contact stress distribution on roll fatigue and strip shape are pointed out. Ultimately, a design method of the backup roll profile was put forward and its performance is verified by finite element calculation and industrial test.
2. Contact stress analysis

This work is based on a hot strip production line, which consists of 2 roughing mills and a finishing tandem mill. The finishing tandem mill includes 7 stands of 4-high mill. In the finishing mill, work roll contour is set as CVC profile, while backup roll is the anti-symmetrical CVC profile in order to keep uniform contact with work roll. The contact stress along axial direction is calculated by a three dimensional finite element (FE) model [5], which is shown in Fig. 2(a). As shown in Fig.2(a), contact stress concentrations appear in the side areas during rolling process. Although the contact between two rolls is uniform before loading, huge stress peaks arise due to large flexural deformation of rolls when rolling force is imposed. The huge stress concentration accelerates the evolution of roll surface fatigue, which may lead to spalling (Fig.3) in the sides. Contact stress along radial direction is calculated according to Hertz theory, which is shown in Fig.2(b). The normal stress $\sigma_x$, $\sigma_y$, and $\sigma_z$ decrease with the depth from roll surface, while the shear stress $\tau$ increases to a maximum value in the subsurface and then decreases. The shear stress is considered to be closely related to roll fatigue. The fatigue crack originated in the subsurface where the shear stress is largest.

Harmful contact areas in the sides come into being because of the stress peaks, which is shown in Fig. 4. The work roll bending force cannot be effective enough to adjust the strip shape because of the harmful contact area. Side waves and other strip shape defects cannot be eliminated in this situation.
3. Design and Results

3.1. Design of the backup roll profile
The contact stress peaks in the sides should be cut down so as to reduce the risk of roll spalling and increase the adjust ability of work roll bending force. Varying contact roll (VCR) [6, 7] is an excellent backup roll profile, which can improve the contact state between work roll and backup roll. Harmful contact areas can be removed with the VCR backup roll. As shown in Fig. 5, an integrated backup roll profile is put forward, which is the sum of traditional VCR profile and CVC profile at each abscissa value. In this way, uniform contact in the central areas of rolls not only can be achieved, but also the compression of work roll against backup roll in the edges can be alleviated. The VCR profile is a six-order poly-nominal function, while the CVC is a three or five order parabola. The CVC backup roll profile is an anti-symmetrical work roll CVC profile. The difference in radius of VCR profile can be set from 0.2~1 mm. In the upper stands of the finishing mill, the difference in radius of the backup roll can be large, while it should be small in the lower stands. The effect of the VCR profile should be verified by FE simulation before industry test.

3.2. Results
Contact stress distributions are calculated by the FE model. Fig. 6(a) shows the comparison of contact stresses with the CVC backup roll profile and the integrated one in different work roll service period. Work roll wear takes place gradually during hot rolling process. In the early period of work roll, the contact stress peaks are relatively small because work roll wears slightly. As work roll wear aggravates, contact stress peaks increases and fatigue risk becomes high. However, contact stress peaks with the new backup roll profile is much lower than that of the the original one during the whole service period of work roll. At the same time, contact stress increase slightly with the new backup roll profile in different work roll periods. The stress peak values reduce by 10~20% with the new backup
The new backup roll profile is effective in reducing contact stress peaks. In this way, roll fatigue can be postponed or the service period can be prolonged due to the improvement of work roll wear and the reduction of the contact stress.

The integrated backup roll profile can remove the harmful contact area and increases the crown adjust ability of work roll bending force. As shown in Fig.6(b), the adjust range of roll gap crown with the new backup roll profile is large than that with the original one. The crown adjust ability of work roll bending force with the new profile is 0.12μm/kN, increasing by 28% compared to the original CVC backup roll profile. With the improvement of the bending force adjust ability, strip shape can be well controlled and many strip shape defects can be avoided. The new backup roll profile is applied to industry test afterwards and showed excellent performance both in alleviating roll wear (especially backup roll wear) and improving strip shape. The backup roll consumption can reduces by about 20% after continuous application. Backup roll service time can be prolonged to 15% without any spalling accidents.

![Graphs showing contact stress comparison and bending force adjust ability comparison](image)

(a) Contact stress comparison  (b) Bending force adjust ability comparison

Fig.6 Comparisons of the performance of the original backup roll profile and the new one

4. Conclusion
The main findings and contributions obtained from this investigation are as follows:

(1) Contact stress concentrations could appeared in the side areas of the work roll and backup roll during hot rolling process. The huge stress concentration accelerated the evolution of roll surface fatigue, produced the harmful contact area and restricted the work roll bending force adjust ability to strip shape.

(2) A backup roll profile design method was proposed by the superposition of VCR profile and the traditional CVC profile. The huge contact stress peaks can be cut down remarkably with the new backup roll profile during the whole work roll service period. At the same time, the crown adjust ability of work roll bending force was improved with the new profile. Industry test showed it being excellent in alleviating roll wear (especially backup roll wear) and improving strip shape.

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