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ORIGINAL ARTICLE

Research on ASR work roll contour suitable for all width electrical steel strip during hot rolling process

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Abstract

For high precision profile and flatness control ability of electrical steel strip with different width during schedule-free rolling (SFR) campaign, the asymmetry self-compensating work roll contour, which is suitable for all strip widths (ASR-C) is developed. The effect of strip width on work roll wear is analyzed through experimental data. By combining shifting strategy and initial shifting position, the new asymmetry self-compensating work roll (ASR) contour is designed. Compared with the ASR work roll for narrow strip (ASR-Y), ASR work roll for wide strip (ASR-N), and conventional work roll, ASR-C presents well profile and flatness control ability for all strip widths during entire rolling campaign. The characteristics of ASR work roll can be fully reflected when ASR-C and its shifting strategy are used. Experimental results show that the ratio of strip crown (C40) less than 45 μm is increased from 41.8 to 98.2% by using the ASR-C work roll of the ASR mill type, compared with conventional work roll of the K-WRS (Kawasaki-Work Roll Shifting) mill type.

Keywords Work roll contour · Wear · Hot strip rolling · Electrical steel · Schedule-free rolling

1 Introduction

The non-oriented electrical steel strip, which is used as electromagnetic core, has higher requirement on the profile and flatness quality. However, the work roll wear is serious because of the high rolling temperature and hardness of non-oriented electrical steel, which is the biggest challenge to profile and flatness control of non-oriented electrical steel strip [1–3]. In recent years, many research results have been obtained and applied for solving the problem of profile and flatness control of electrical steel strip [4–7]. The continuously variable crown (CVC) mill can increase the crown control ability by the periodic CVC work roll shifting strategy [8–10]. Pair cross (PC) mill can increase the control range of strip crown by crossing the conventional rolls. However, it does not have the ability for controlling the work roll wear, as proposed by John et al. [11]. The Kawasaki-Work Roll Shifting (K-WRS) mill can reduce the U-type work roll wear to some extend by the symmetrical work roll contour and periodic shifting [12–15]. However, K-WRS technology cannot fully eliminate the U-type work roll wear and meet the requirement of strip crown control. Therefore, lubricating rolling technology [16–18], high speed steel (HSS) roll [19], on-line roll grinder (ORG), and other devices are added to hot strip rolling mill for solving the problem of work roll wear. The work roll wear control ability is realized by adding equipment to reduce work roll wear. The addition of these technologies not only cannot achieve the requirement of profile and flatness control but also will cause more difficulties.

The asymmetry self-compensating work roll (ASR) mill to meet the requirements of SFR(schedule-free rolling) and the increasingly severe quality requirements of strip profile and flatness of electrical steel production in hot rolling was proposed by Cao et al. [20–22]. Its purpose is not to reduce but to utilize the law of work roll wear during hot rolling process. It changes the wear distribution form of work roll by special shifting strategy, which achieves both wear and flatness control ability. It can improve the profile and flatness quality of strip even if there is

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no lubricating rolling technology, HSS roll, ORG, and other devices. According to the working principle of ASR work roll, each strip width must correspond to a specific ASR work roll contour. The corresponding work roll shifting and bending strategy must be used in order to meet the high-quality requirement of strip. Otherwise, it not only cannot achieve the requirement of profile and flatness control ability, but also cause more difficulties for flatness control of strip. However, with the requirement of flexible production, low consumption and high efficiency, the strip width is more and more diversified. The existing ASR work roll cannot meet the requirement. The ASR work roll, which is suitable for all strip widths, needs to be designed.

In this paper, the work roll wear is analyzed based on actual situation of 1700 hot rolling mill when strips with different width are rolled. The ASR work roll, which is suitable for different strip width and combined shifting strategy, are designed.

2 Analysis of work roll wear

The work roll wear contours after an entire rolling campaign of two typical widths of non-oriented electrical steel strip are analyzed (as shown in Fig. 1). It can be seen that the difference of work roll wear along the axial direction of work roll is very small. The area of work roll wear along the axial direction of work roll is increased with strip width.

Statistics of the maximum work roll wear corresponding to different strip width of 14 rolling units are shown in Fig. 2. The relationship between the work roll wear volume and maximum number of coils is analyzed. The work roll wear is increased with the rolling quantity. The work roll wear is about 3.69 μm after rolling of each strip.

According to the above analysis, it can be seen that the work roll wear distribution has the same form, when the strips with different width are rolled. The width of work roll wear is increased with strip width. The design of the new ASR work roll is reasonable and feasible in coordination of work roll contour, flexibility initial shifting position, and shifting strategy.

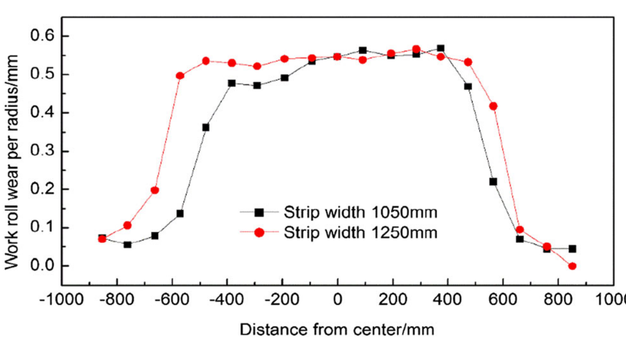

Fig. 1 The effect of strip width on work roll wear

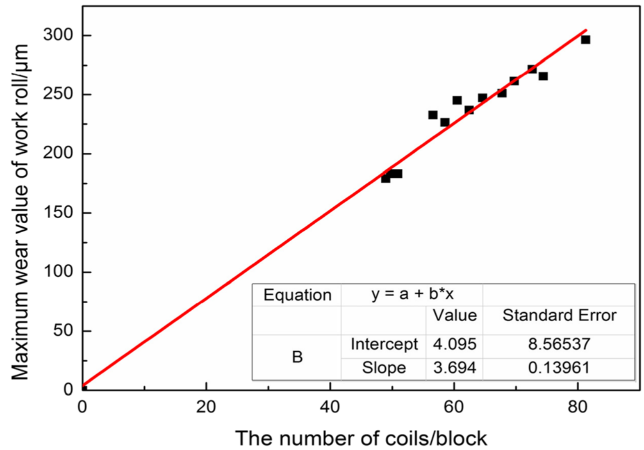

Fig. 2 The effect of the number of coils on work roll wear

3 The design of ASR-C work roll

The design of flexibility initial shifting position and shifting strategy is divided into three steps. First, the shifting range of work roll and width range of electric steel strip are determined. Second, the largest width of electrical steel strip is selected as the basis width. Third, the minimum shifting position is set as initial shifting position of the basis width strip (as shown in Eq. (1)). The initial shifting position of other width strip is set according to the difference between the strip width and basis width (as shown in Eq. (2)).

$$S_{so} = S_s = -150, \tag{1}$$

where, $S_{\rm so}$ is the initial shifting position of the strip with basis width, mm; S_s is the minimum shifting position, mm.

The initial shifting position of strip with other width is expressed as$S_{\rm sc}$

$$S_{\rm sc} = S_{\rm so} + \frac{B_0 - B}{2}, \tag{2}$$

where, $B_{\rm o}$ is the basis width of strip, mm; B is the width of strip, mm;

The roll shifting strategy includes shifting rhythm and shifting step. The number of total rolling coils is determined by roll shifting stroke and roll shifting strategy (as shown in Eq. (3)). According to the rolling factors, such as the unit of rolling campaign, range of roll shifting stroke and so on, the appropriate work roll shifting strategy is set to make full use of the roll shifting stroke for electrical steel strips with different width. In order to make the electric steel strip with different width meet the production need, the number of total rolling coils of electrical steel strip with largest width 1280 mm is set to 200.

$$n = \frac{(S_{\rm eo} - S_{\rm so}) \bullet R}{t}, \tag{3}$$

where,

R is shifting rhythm;
t is shifting step, mm;
S_{eo} is the last shifting position of basis width strip, mm; and
n is the number of total rolling coils, block.

In general, the shifting rhythm is $R = 1$, and the shifting step is expressed as

$$t = \frac{S_{eo} - S_{so}}{n} \quad (4)$$

The shifting step for electrical steel strip with width 1280 mm can be obtained by the upper calculation. The step length is 3 mm/step.

According to the basis width 1280 mm, the ASR-C work roll contour is designed. The ASR-C work roll contour includes convex adjustment section L_1, wear control section L_2, and structural process section L_3 (as shown in Fig. 3).

The design principle of the convex adjustment section length includes two parts: one is to make full use of the maximum stroke of work roll, the other is ensure that the starting part of the tapered section of work roll is aligned with the edge of electrical steel strip. The relative position between the work roll and start electrical steel strip is shown in Fig. 4.

Wear control section is the most important part of ASR-C work roll. The main function of wear control section roll contour is to counteract the work roll wear during hot rolling process. The work roll wear and thermal contour are the main factors that affect the work roll contour within the entire rolling campaign. Therefore, the wear control section of ASR-C work roll contour is designed considering the work roll wear and thermal contour within the entire rolling campaign. According to the actual situation, the number of total rolling coils of basis width is 200 volumes. During schedule-free rolling process, because of irreversible shifting strategy, the work roll wear is increased with the number of strip, the control point for the wear contour is determined by n/10 rolled electrical steel in the design of wear control section curve. The work roll contour of wear control section is determined by 11 wear control points. The thermal expansion of work roll in the middle is greater than that in the edge because the temperature in the middle of work roll is higher than that in the edge of work roll. Wherein, the thermal expansion compensation value of the work roll is the difference between the thermal expansion quantity at the part of the work roll and the thermal

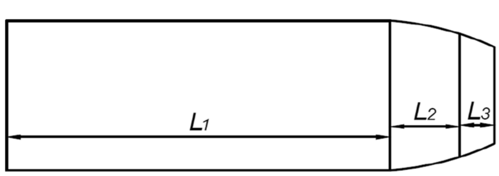

Fig. 3 The schematic diagram of ASR-C work roll contour

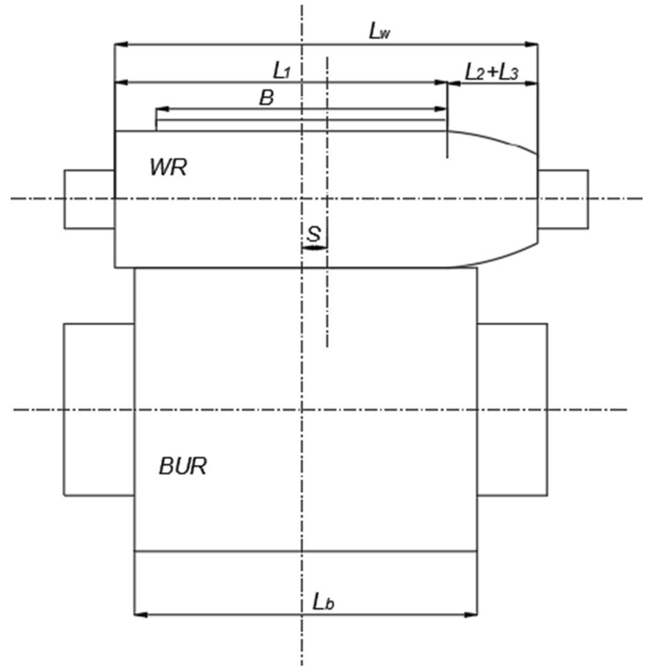

Fig. 4 The position relationship among strip, work roll, and backup roll

expansion at the origin. The wear control section curve of the work roll is obtained by adding the work roll wear value and thermal compensation value.

The structural process section L_3 cannot take flatness control, so it is smoothed according to the tangent way. The structural process section can not only ensure smooth of the work roll and enhance the control stability of wear control section, but also reduce the diameter difference. It is simple and easy for work roll contour grinding. The contour of the ASR-C work roll suitable for all strip width is shown in Fig. 5.

4 The profile and flatness control ability of different work roll contour

To analyze the profile and flatness control ability of ASR-C, a 3D finite element model for elastic deformation of rolls is built by the ANSYS software. The parameters for the model considering the actual condition are referred to Li et al. [22]. The work roll contour is composed by initial work roll contour, work roll wear contour, and thermal contour (as shown in Fig. 6). Where the work roll wear contour in different, the rolling stage is calculated by the work roll wear model, which is built by Cao et al. [20]. As shown in Fig. 6, the expected effect has been achieved by experiment. Serious U-type work roll wear is produced by conventional work roll. One side of the U-type work roll wear is partially opened when ASR-Y (work roll designed for narrow strip) and ASR-N (work roll designed for wide strip) are used. Only the new designed ASR-C work roll can open one side of the U-type work roll wear completely. The characteristics of ASR work roll can be

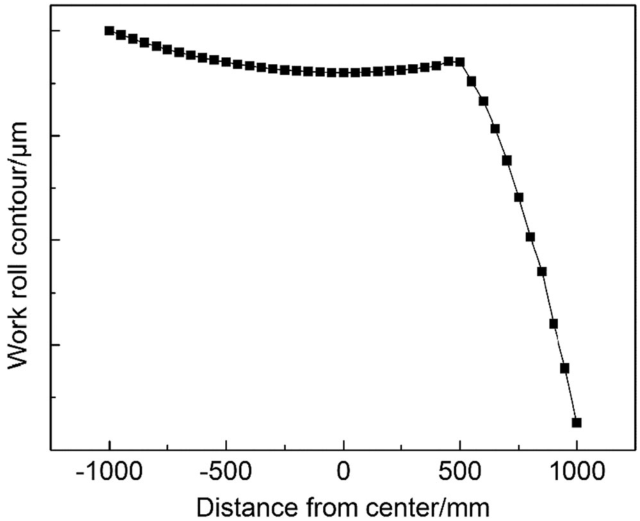

Fig. 5 The contour of the ASR-C work roll

fully reflected when the new designed ASR-C work roll and its shifting strategy are used. The work roll contour of the new designed ASR-C work roll is not changed during the whole rolling period, which keeps the flatness control ability in a steady state during the whole rolling period. As shown in Table 1, the effect of different work roll contour on strip crown is analyzed. When bending force is 500 kN, the flatness control abilities of different work rolls are compared during the early rolling stage (ES) and later rolling stage (LS). The work roll wear is not serious during the ES. The work roll wear is serious because of the increase of coil number during the LS. As shown in Table 1, when strips with width 1250 mm are rolled by work roll designed for narrow strip (ASR-Y), a larger strip edge bulge is formed during the LS, because the edge of strip is at the conical section of work roll. As shown in Table 1 when strips with width 1250 mm are rolled, the ASR-C and ASR-N both have profile and flatness control ability. However, when the width of strips is 1050 mm, the strip crown is 180 μm by using ASR-N and the strip crown is 125.4 by using ASR-C in the LS. It avoids the excessive bending force in the LS when ASR-C is used. When the new designed work roll (ASR-C) is used, regardless of the

Fig. 6 The FEM model for investigating the effects of roll shifting strategy on strip crown

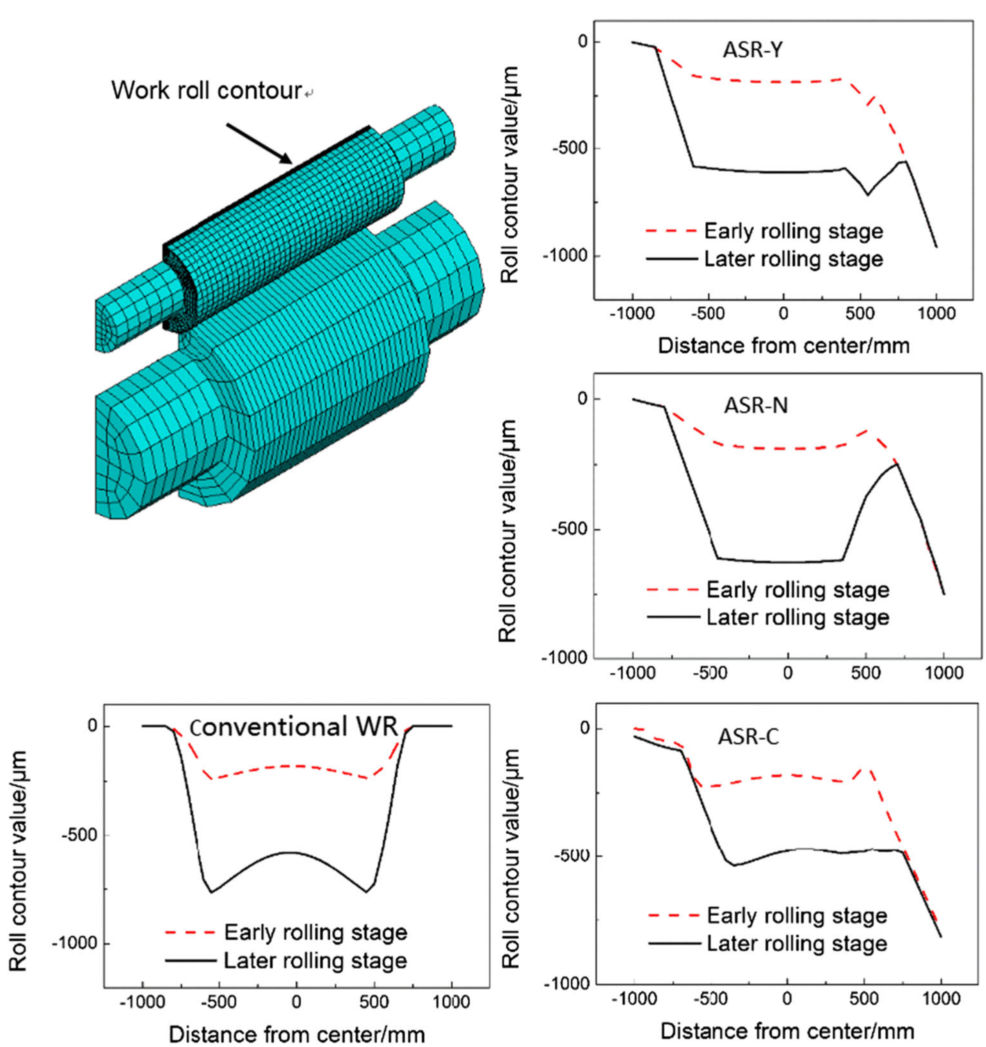

Table 1 The effects of different work roll contour on strip crown

Strip width	Strip crown/μm				
	Rolling stage	ASR-C	ASR-Y	ASR-N	Conventional WR
1050 mm	ES	150.5	152.5	150.5	161.5
	LS	125.4	126.4	180	193.8
1250 mm	ES	11.9	− 110.5	13.9	22.9
	LS	− 13.3	− 140.4	− 12.3	54.8

strip width, the strip crown can be controlled effectively in both the ES and LS.

5 Results of experiment and application

In order to verify the feasibility and effectiveness of the ASR-C work roll contour, the ASR-C work roll combined with the shifting strategy and hydraulic work roll heavy bending device has been applied in the production of electrical steel strip with different width.

The crowns of electrical steel strips are compared when conventional work roll, ASR experimental work roll, and new designed ASR-C work roll are used separately. As shown in Fig. 7, the ratio of strip crown (C40) less than 45 μm is 41.8, 94.9, 98.2% respectively when conventional work roll, ASR experimental work roll, and new designed ASR-C work roll are used separately. The ratio of strip crown between 46 and 52 μm is 24.3, 41, 0% respectively when conventional work roll, ASR experimental work roll, and new designed ASR-C work roll are used separately. The ratio of strip crown more than 53 μm is 33.9, 1, and 1.8% respectively when conventional work roll, ASR experimental work roll, and new designed ASR-C work roll are used separately. Compared with the values of conventional work roll, the new ASR work roll avoids the excessive bending force caused by serious U-type wear. It can be concluded that the ASR-C work roll can keep better strip profile and flatness ability.

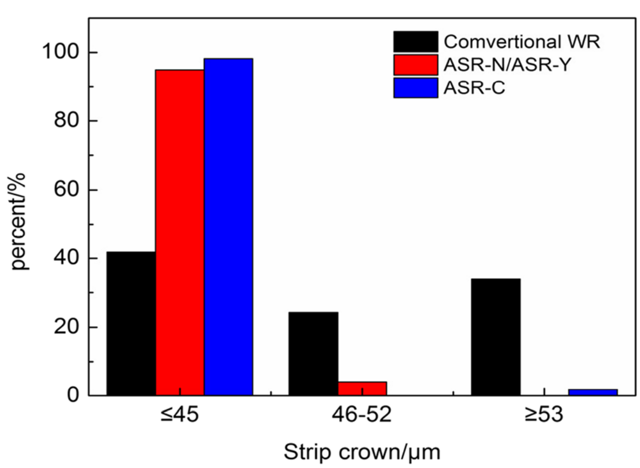

Fig. 7 The strip crown of different work roll contour

6 Conclusion

(1) The effect of strip width on work roll wear is analyzed through experimental data. The axial distribution of work roll wear amount along the roll has the same form, regardless of the strip width. The width of wear zone of work roll is increased with strip width. The wear amount of work roll is about 3.7 μm after rolling of each strip.

(2) By combining shifting strategy and initial shifting position, the new ASR work roll contour is designed. The characteristics of ASR work roll can be fully reflected when the new designed ASR-C work roll and its shifting strategy are used. The results of finite element simulation show that the flatness control ability of the entire rolling campaign is improved using the new ASR work roll contour. Experimental results show that the ratio of strip crown (C40) less than 45 μm is 41.8, 94.9, and 98.2% respectively when conventional work roll, ASR experimental work roll, and new designed ASR-C work roll are used separately.

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