An Online Setup Strategy of Strip Shape Control for Tandem Hot Rolling Mills

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An online setup strategy of strip shape control for tandem hot rolling mills is proposed based on the crown control range concept. A 7-stand roll-shift type rolling mill equipped with roll benders is considered. Unsymmetrical work rolls are assumed to be used in the first 4 upstream stands and the symmetrical work rolls are assumed to be used in the last 3 downstream stands, respectively. The crown control ranges for stands with symmetrical and unsymmetrical work rolls were calculated respectively based on the limitations of work roll benders and work roll shifting devices. A setup strategy of strip shape control was adapted by comparing the crown control ranges of the exit side of F4 and the entry side of F5. For the conditions where two crown control ranges overlap, utilizing the crown control capability of the unsymmetrical work rolls efficiently was the priority of the model setup. On the other hand, for the conditions where no overlapping exists between two crown control ranges, the priority of the setup strategy was to keep the flatness of the strip. In these cases, the target crown might not be achieved. However, the rolling process was found to be stable and the error of the strip crown kept in minimum.

1. INTRODUCTION

Due to the demand for tighter dimensional tolerances of strip requested by customers, the strip profile and flatness have become important indices of strip quality. Therefore, the shape control has been one of the core techniques for hot strip mills. The development of work roll bending provides an efficient way to improve the strip shape. However, due to the capacity limitation of work roll benders, the working roll bending may not be sufficient in some critical cycles, especially for extremely thin products. More advanced mills have been proposed to utilize a second mechanical actuator, such as work roll shifting devices or work roll rotating devices, to enhance the strip shape control capability [1,2].

For strip shape control, it is important to utilize the work roll benders and the work roll shifting devices/ work roll rotating devices effectively to meet the requirements of the strip target profile and flatness. In this paper, the second strip shape controller is assumed to be the work roll shifting system incorporated with unsymmetrical work rolls. However, the same setup strategy of strip shape control can be applied to the work roll rotating system. The control ranges for stands with symmetrical and unsymmetrical work rolls are first determined based on the limitations of the work roll benders and work roll shifting devices. The effective crown control ranges are then determined based on the strip flatness limitations. Next, two crown control cones are established for stands with symmetrical and unsymmetrical work rolls, respectively. The strip profile allocation strategy is adapted based on the overlapping conditions of the two crown control cones. Finally, comparisons of the original strategy of shape control and the new strategy of shape control are discussed.

2. SETUP STRATEGY OF SHAPE CONTROL MODEL

For an easy explanation of the setup strategy of the shape control model, a 7-stand hot strip mill is assumed in this paper. Unsymmetrical work rolls are assumed to be used in the first 4 upstream stands, while symmetrical work rolls are assumed to be used in the last 3 downstream stands. All stands are equipped with work roll benders.

2.1 Crown Control Ranges for Symmetrical Work Rolls

First, evaluation of the crown control range for an individual stand consisting of symmetrical work rolls is carried out. In order to keep the strip flat, the crown ratio (defined as the ratio of the strip crown to the strip thickness) should be retained constant for each stand.

Therefore, the maximum strip entry crown (CrnEn_max) and the minimum strip entry crown (CrnEn_min) for the stands consisting of symmetrical work rolls (F5~F7) can be obtained based on the upper and lower limits of the product target crown. The crown control range then can be obtained based on the limitations of the work roll bending for each stand. Figure 1 shows the crown control range for an individual stand. As shown in the figure, the maximum strip exit crown can be obtained under the condition where the strip entry crown is maximum and the work roll bending is minimum. Conversely, the minimum strip exit crown can be obtained under the condition where the strip entry crown is minimum and the work roll bending is maximum.

However, the crown control range might exceed the flatness limitation of the stand. In order to satisfy the strip shape requirements, the effective crown control range is determined with consideration of the flatness restriction. In Fig. 1, “edwlmt” and “cbklmt” represent the edge wave limit and center buckle limit, respectively. The flatness restriction is assumed to be smaller than the flatness range (from Flat_U to Flat_L) for the maximum work roll bending (Bend_Max) case. In this case, the minimum strip exit crown is on Point B’ instead of Point B, and the corresponding minimum strip entry crown is on Point D’ instead of Point D. The maximum strip exit crown and the maximum strip entry crown can be obtained similarly for the minimum work roll bending (Bend_Min) case.

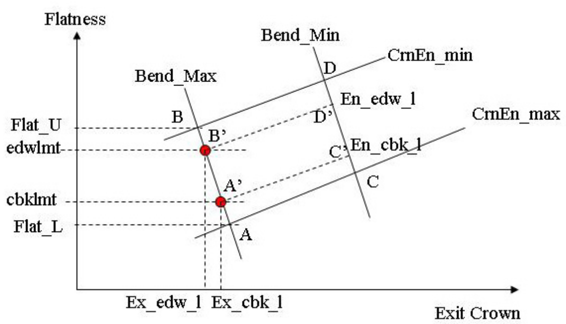

Fig. 1. Crown control range for F5~F7 cases.

In the above discussion, the determination of the effective crown control range provides a basis to understand the strip shape control capability of an individual stand. However, for shape control strategy, the effective crown control range should be evaluated from the view point of the entire mill system. In order to achieve the product target crown and satisfy the requirements of the strip flatness for all stands, only the overlap of the effective crown control range of each individual stand is considered, as shown in the dashed lines in Fig. 2.

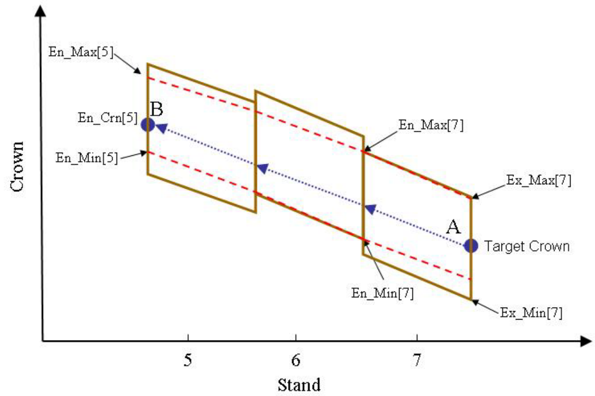

Fig. 2. Overlap of the crown control ranges for F5~F7.

When the strip exit crown at a stand is known, numerous possible settings of work roll bending can be selected to achieve the goal under the flatness limitation. As shown in Fig. 3, section EG represents the operating range of work roll bending that can satisfy both the strip exit crown and the flatness requirement. Since the work roll bending is recognized as the most convenient and fastest response crown control device, it is desirable that the setup value of the work roll bending remains within the operation adjustment range as much as possible. Therefore, the work roll bending is selected such that the value is kept in the medium of the operating range, as Point F shown in Fig. 3.

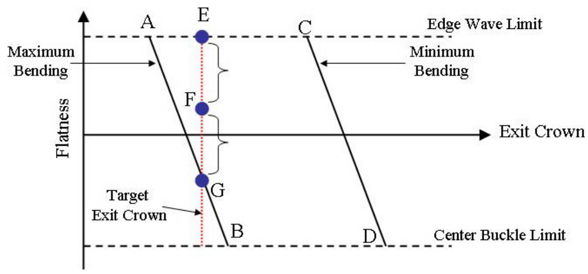

Fig. 3. Relationship between the exit crown and the work roll bending setup under flatness limitations.

The strip entry crown can then be determined based on the known exit crown and the work roll bending. Beginning at the last stand (F7) and moving in the reverse direction, the procedure is repeated such that the setting of the work roll bending and the corresponding entry and exit crowns from F7 to F5 are determined, as the path AB indicated in Fig. 2.

2.2 Crown Control Ranges for Unsymmetrical Work Rolls

For the stands consisting of unsymmetrical work rolls, two strip shape controllers, the work roll shifting devices and the work roll benders, are available. In this case, 5 different combinations of the work roll shifting and the work roll bending, defined as "maximum bending + maximum shifting", "medium bending + maximum shifting", "medium bending + medium shifting", "medium bending + minimum shifting", and "minimum bending + minimum shifting", are assumed to establish the basic relationship between the strip entry crown and the strip exit crown. With a pre-calculated transfer bar crown, the strip exit crown range at F1 can be determined. Similarly, the strip exit crown ranges from F2 to F4 can be determined based on the strip entry crown at the previous stand. The advantage of this procedure is that the crown control cone for the upstream stands can be obtained efficiently by the interpolation method. The schematic plot of the crown control cone for the upstream stands is shown in Fig. 4.

With the strip exit crown range at F4 and the crown path determined in Figure 2, two possible conditions can be observed. The first condition is that the strip entry crown at F5 is within the strip exit crown range at F4. In this case, the medium value of the strip entry crown range is assumed to be the strip entry crown, as shown in Fig. 4.

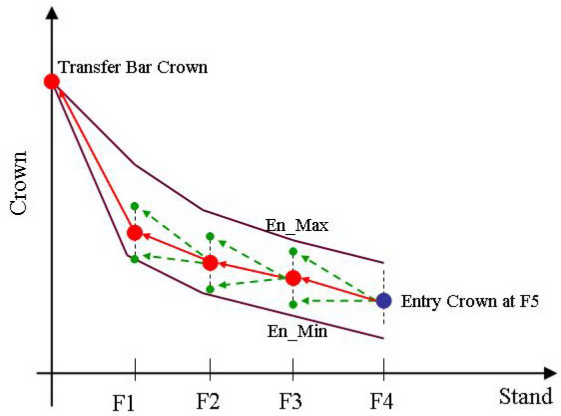

Fig. 4. Condition where the entry crown at F5 is within the strip exit crown range at F4.

The other condition is that the strip entry crown at F5 is not in the strip exit crown range at F4. In this case, the priority of the setup strategy is to keep flatness. The bender at F4 will be set such that the strip exit crown is in the limit of the crown control cone. The final strip crown is different from the target crown. However, the difference is kept to a minimum.

3. RESULTS

The new shape control setup strategy was evaluated in two aspects. One is the setup value of work roll bending, and the other is the quality of the strip flatness and crown. Figure 5 shows the comparison of the setup of work roll bending for F1~F7 by the original shape control strategy (used in CSC No.2 Hot Strip Mill) and new shape control strategy for 7983 coils. In the figure, the setup values of the work roll bending are divided into 5 ranges (from the minimum value to the maximum value). As can be seen in Fig. 5, the percentage of the work roll bending located in the middle range (1/4 ~ 3/4) based on the new shape control strategy is significantly higher than that based on the original shape control strategy. The result implies that the operator can have more control capability on the work roll bending with the new shape control strategy.

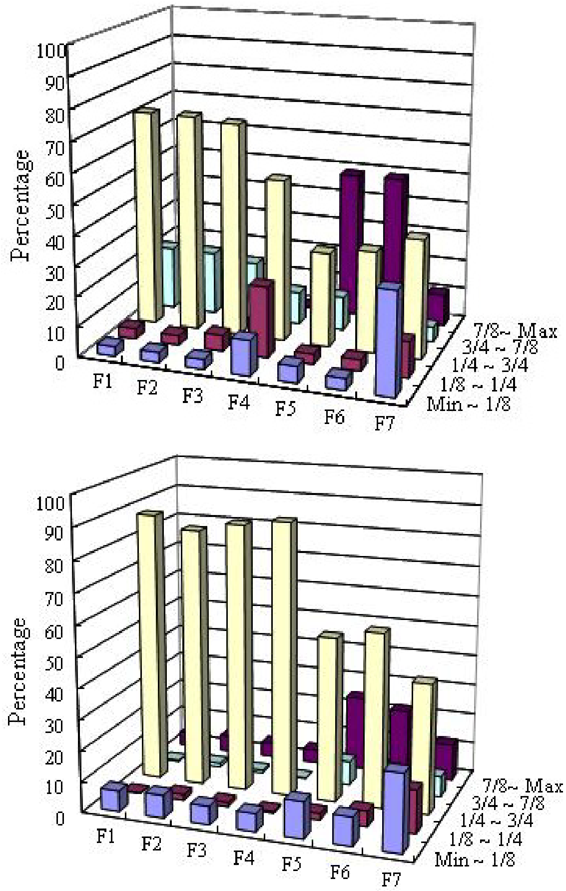

Fig. 5. Comparison of setup results based on the different shape control strategies (top: original, bottom: new).

Additionally, the quality of the strip shape by the original shape control strategy and the new shape control strategy was evaluated. Since the priority of the original shape control strategy is to satisfy the strip crown requirement instead of flatness, the results show that all products meet the target crown requirement. However, a significant amount of products (37%) can not satisfy the flatness requirements. On the other hand, for the new shape control strategy, 95.4% of the products can satisfy the flatness requirements. Only 4.6% of the products, such as 1.2mm thin gauge products and 850 mm width products, cannot satisfy the flatness requirements.

4. CONCLUSIONS

An online setting strategy of strip shape control for tandem hot rolling mills is proposed based on the crown control range concept. The advantage of the strategy is that the work roll bending for most of the product can be kept in the medium value of the operation range. The operator can have more flexibility to adjust the work roll bending to maintain a stable rolling. Furthermore, since the priority of the new shape control strategy is to keep the strip flat, the rolling process is more stable. The results indicate that the percentage of the work roll bending located in the middle range is significantly higher based on the new strategy than that based on the original strategy. For strip shape controllability, the results also indicate that the percentage of the products that satisfy the requirements of target crown and flatness increases significantly from 63% to 89% based on the simulation of 7983 coils.

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