Superior Profile Control Technology With Edge-Oriented Shifting

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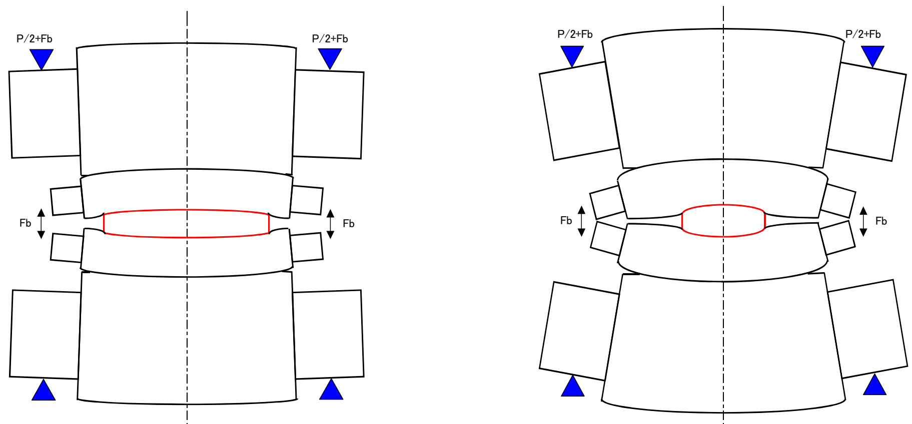
INTRODUCTION

The demand for minimizing any deviation in strip thickness in cross sectional width direction has grown recently in the field of cold strip rolling; as a result, the development of various types of crown control mill systems have made more precise control of the crown possible. On the other hand, edge-drops that are a phenomenon of drastically decreased thickness at the edge of strip have been addressed via several major solutions, including the implementation of relative shifting with hemi-taper contoured work rolls[1)], or a pair-cross-mill applied to cold rolling process[2)]. Suzuki[3)] asserts that the process of variable crown adjustment with the work rolls relative shifting each other in the axial direction cannot simultaneously be implemented when the edge-drop control and evening out the roll wear are being used. In fact the crown-control and edge-drop control functions have been separately being installed. Meanwhile, one major solution has been introduced, including the 6-Hi component consisting of work roll shifting for edge-drop control and intermediate-roll-shifting for crown control[4)]. Another solution is the combination of work-roll-cross and work roll shifting[5)].
This article presents a newly developed variable roll crown technology, named SPEOS™ (Superior Profile with Edge-Oriented Shifting) that can properly correct a strip crown and reduce the edge-drop at the same time by axial shifting a pair of rolls only.

SIMULTANEOUS CONTROL OF CROWN AND EDGE-DROP IN WORK ROLL SHIFT MILL

(1) As mentioned above it was reported to be possible to carry out both crown control and edge-drop control simultaneously in 4-Hi mill components, when the pair-cross mill is installed into a cold rolling mill. On the other hand, in the context of a work-roll-shift mill, Fukutake[6)] asserts that attaching a mechanical crown to the work roll with hemi-taper contour can be valid and feasible. Shihonmatsu[7)] asserts that attaching an in-curve (concave-crown) to the hemi-taper contoured roll is feasible. Although the former solution may address the problem of edge-drop via the convex mechanical crown, it was originally aimed at controlling edge-drop without achieving crown control at the same time. The latter also is aimed at controlling edge-drop, for the in-curve is determined secondarily in order to decrease the local tension force that is concentrated around the edge and gains stable threading.

(2) Figure 1 indicates where the distribution of unit load is the same. The narrower the subject strip, the bigger the deflection of the work roll converted to entire barrel length, and vice versa. The reason for the bending moment is as follows: The material is narrow, and bending occurs because the strip part comes close to concentrated summation. On the other hand, the load of distribution at the back-up roll remains wide. Meanwhile, the work roll deflection cannot be decreased according to the strip's decline of width, but can be contrarily increased from the perspective of the entire barrel length. Therefore, the necessary mechanical crown is smaller when the width of the strip is wider, and is bigger when the width is narrower. In the case that the variable crown contour is applied to the work rolls and shifted relatively each other in order to achieve crown control, the specific roll curve for the position of roll shift is originally set. When the strip is wide and the load per unit is low, it is minus 100%; when the strip is narrow and the load per unit is high, it is plus 100%.
The idea of whether this characteristic of the roll shift in the context of crown control can be utilized for edge-drop control by modifying the roll curve is examined, and the new type of roll crown is developed as follows.



(a) Rolling of wider strip (b) Rolling of narrower strip

Figure 1. Deflection of straight contoured roll

THE BASIC IDEA OF THE NEW, VARIABLE CROWN ROLL

(1) Component of Crown Roll

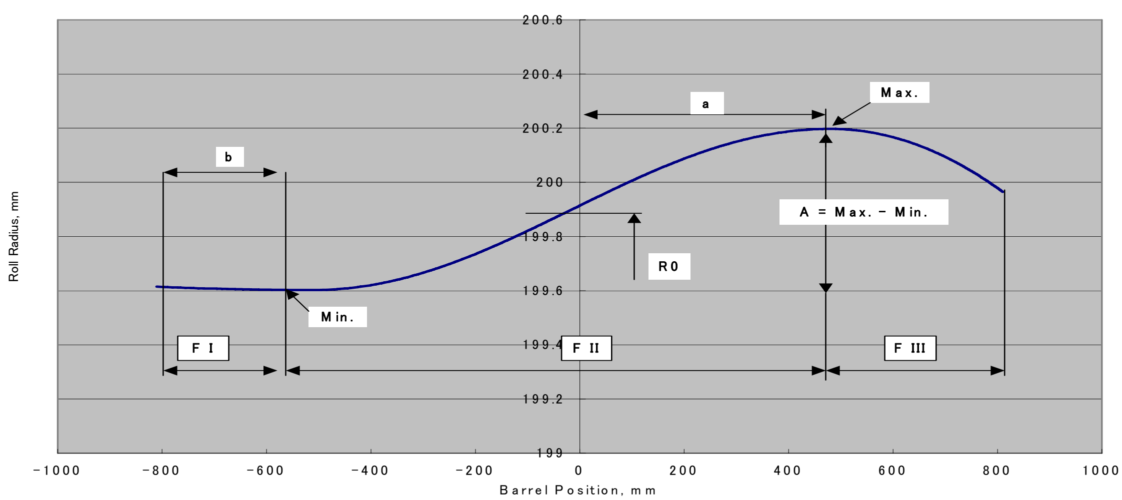


Figure 2. Outline of variable crown contour developed

As Figure 2 shows, the roll crown in this new, variable crown roll system (SPEOS™) has a continuous concave-convex curve having both a local maximum point and a local minimum point, and consists of three main mathematical functions.

The first function relates to the central region between those local maximum point and local minimum point; the second function is from local maximum point to the nearest edge of the roll, and it continues from the first function and it renders a steeper gradient than that of an extension of the first function; finally, the third function is from the local minimum point to the nearest edge of the roll, and it continues from the first function and it renders a gentler gradient than that of an extension of the first function.

(2) Characteristics of SPEOS™ crown roll

① When this crown roll is installed to top and bottom work rolls, the roll gap, which continuously transforms by the function between the local maximum point and the local minimum point, is generated around the central region of the roll. This fact can contribute to controlling the strip crown. On the other hand, the GETZ (Gap Expanding Transitional Zone) is generated around the edge of the roll gap mainly by the function from the local maximum point to the nearest edge of the roll; i.e., the second function mentioned in 3-(1).

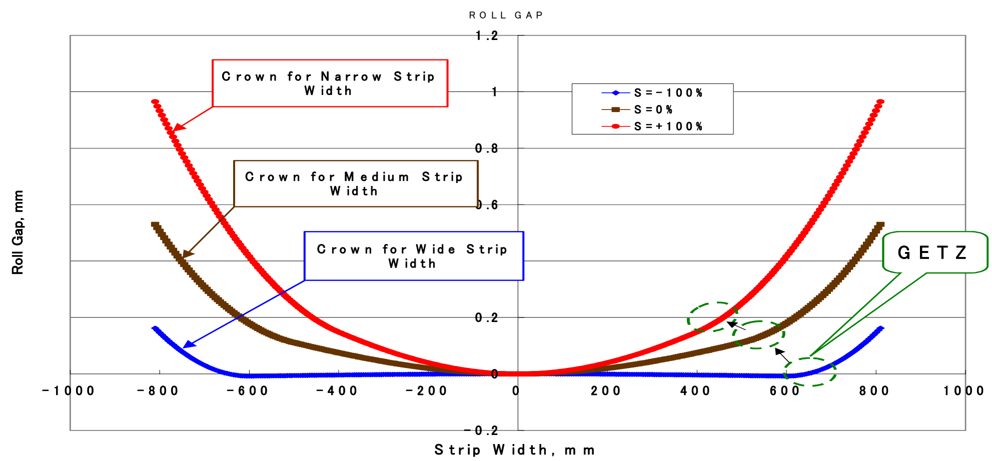


Figure 3. Roll gap of SPEOS™ crown at shifting position

② If the rolling unit load per width remains constant, the position of the roll shift, which corrects the roll deflection produced by the rolling load, shifts to the direction in which the crown becomes bigger (plus direction) as the width of the strip decreases.

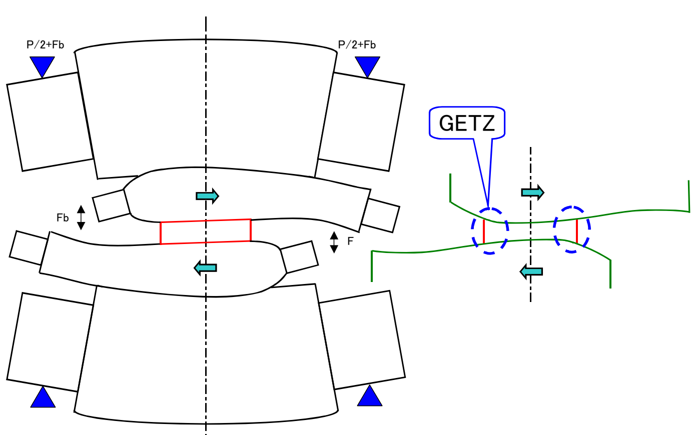


Figure 4. Deflection of SPEOS™ roll in narrower strip rolling

When SPEOS™ crown roll is set properly according to each strip width with unit rolling load, GETZ mentioned above is automatically located near the edge region of the strip. As shown in Figure 3, at the roll shifting position making a crown for wide width (S=-100%), GETZ is found near the edge of the strip of about 1200 mm width. Similarly, at the roll shifting position making a crown for small width (S=+100%), GETZ is also found near the edge of the strip of about 900 mm width.

Figure 4 shows that the constraint of work roll against back-up roll is loosened and sufficient work roll bending is exerted to correct the strip crown more properly when GETZ is located near the edge region.

(3) First SPEOS™ mill and its crown control characteristics

SPEOS™ was firstly applied to 4-Hi cold reversing mill for CSC Steel Malaysia and commercial operation started in 2007. Table 1 shows the main specification of the actual equipment at this mill. Figure 5 shows the roll gap distribution between top and bottom work roll along the strip width in each case of combination of shifting and bending of work roll, and Figure 6 shows the characteristics of crown control. Since one kind of crown roll covers not only for normal low carbon steel products but also for medium carbon steel products, the amount of crown control corresponding to the roll curve is relatively greater. Therefore, SPEOS™ has wide crown control ability even in rolling of a width of three feet strip.

Table Ⅰ. Main specifications of SPEOS™ mill

Work roll	φ 400 x 1,620 mm
Back-up roll	φ 1,220 x 1,420 mm
Work roll shifting stroke	＋－100 mm
Work roll bending/chock	－350 KN ～ ＋500 KN
Strip width at simulation	920 mm
Rolling force at simulation	736 ton (0.8 ton/mm)

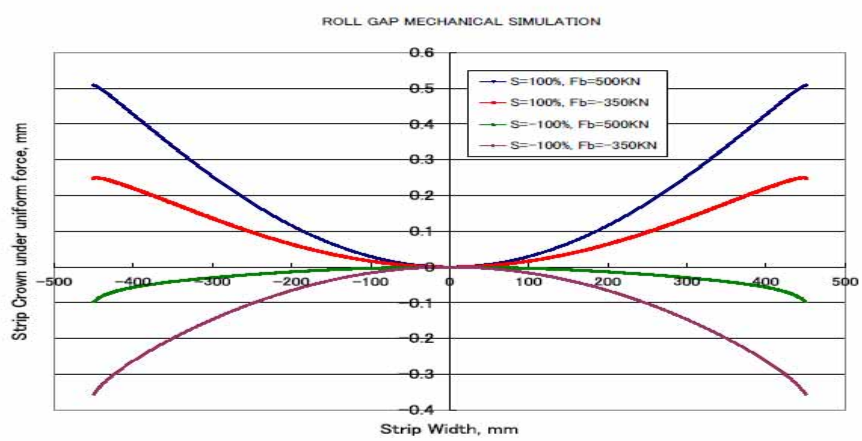


Figure 5. Roll gap distribution at each actuator conditions of SPEOS™ mill

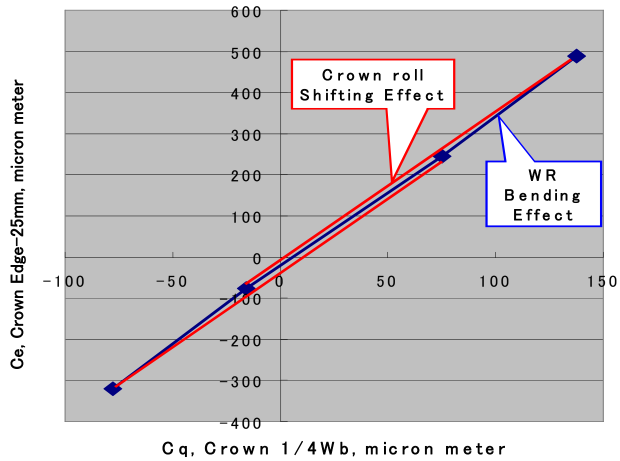


Figure 6. Crown characteristics of SPEOS^{TM} mill

(4) Edge-drop correction of first SPEOS^{TM} mill
The roll curve is mainly intended for crown control, for two reasons. The first is that the shift stroke is relatively small, and the second is that, as Figure 5 depicts, the region of the gap expanding is generated outside of the strip width, even when the shift stroke is at its maximum.
Next, characteristics of SPEOS^{TM} crown roll are presented when improvement both of crown and edge-drop is intended.

CHARACTERISTICS OF SPEOS^{TM} CROWN AS FOR EDGE-DROP CONTROL

(1) Mechanical Simulation
The characteristics of function for edge-drop improvement for SPEOS^{TM} crown roll are assessed by mechanical simulation. The method of calculation for roll deflection is mainly based on that of Ogawa[8)]. Flattening of work roll, which affects considerably on the edge-drop, is also simulated by the method suggested by Ogawa. The conditions of the mill in this simulation are the same as in Table Ⅰ, except for the amount of roll shift, which is 1.5 times longer. The radius difference between local maximum point and local minimum point of roll curve is, as Figure 7 shows, smaller than the one employed in section 3, while the curve from local maximum point to the nearest edge is steeper.

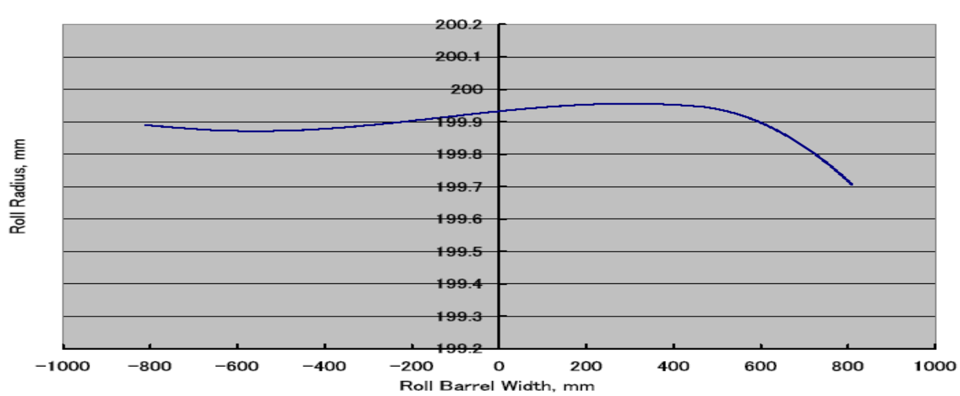


Figure 7. SPEOS^{TM} contour for mechanical simulation

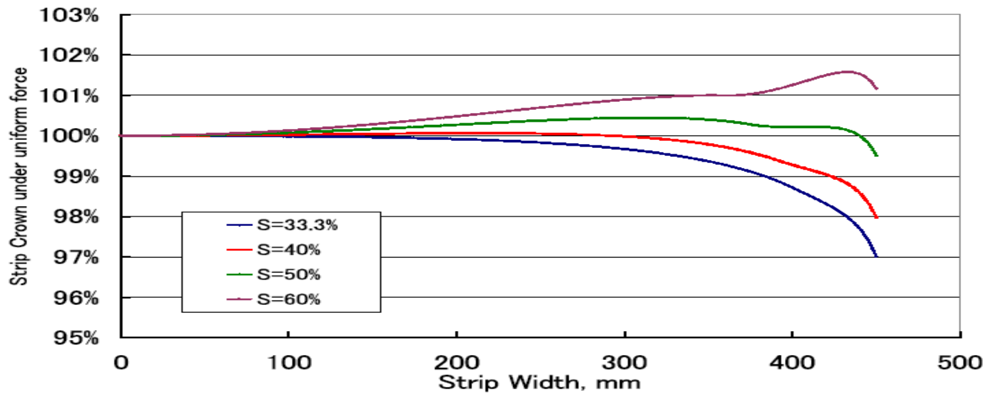


Figure 8. Strip crown variation by SPEOS™ work roll shifting

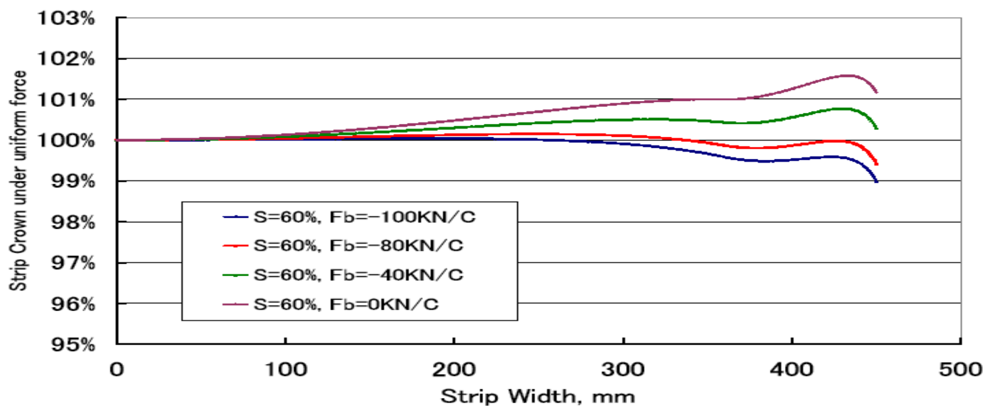


Figure 9. Strip crown variation by SPEOS™ work roll bending

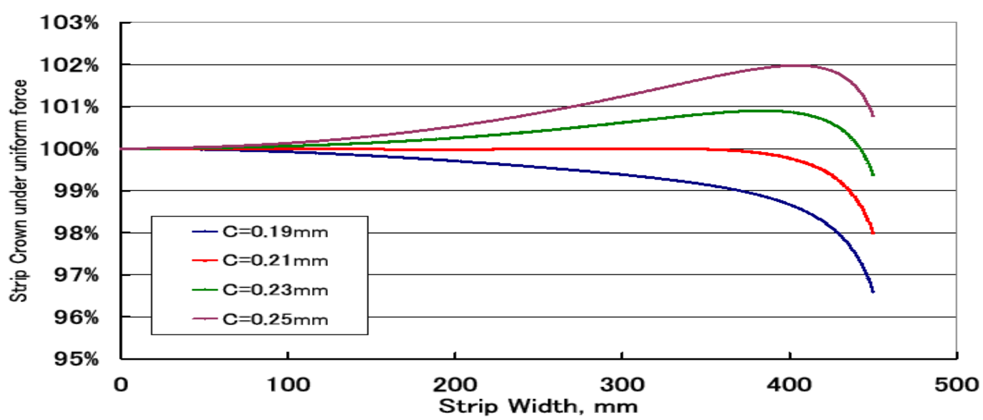


Figure 10. Strip crown variation by conventional work roll shifting

Figure 8 shows the change of the roll gap when the position of the shift is changed from +33.3% (ΔGE=0 mm) to +60.0% (ΔGE=40 mm). When the position of the shift gets close to +40.0 % (ΔGE=10 mm), a GETZ effect can be observed. When the position of shift reaches +50.0% (ΔGE=25 mm), the edge-drop is corrected by a large margin, because GETZ enters deeply into the edge of the strip at the same time as the crown adjustment occurs. When the position reaches +60.0% (ΔGE=40 mm), the edge-up starts. The result of the calculation for the conventional variable crown is shown in Figure 10 for comparison. The effect of improvement of the edge-drop by SPEOS™ crown roll is clearly identified, comparing both.

Figure 9 shows the result of the changes of the work roll bender, when the shift position is +60.0%. In case the roll shift is set mainly for edge-drop control, although it is easily thought that the central region of strip would be stretched, it is possible to correct the strip crown by a slight adjustment of the work roll bender.
SPEOS™ crown roll can properly correct the strip crown and reduce the edge drop at the same time by axial shifting a pair of work rolls with slight adjustment of work roll bending.

*ΔGE: The distance from the commencement point of the gap expanding to the strip edge.

(2) Consideration regarding setting up the position of shift in SPEOS™ crown roll
Figure 11 shows an example for setting up the position of the shift in SPEOS™ crown roll. Here, the appropriate position of the shift is calculated for every rolling force per unit width, so as to keep the same strip crown ratio of base material without using a roll bender. In order to acquire the best strip crown, the position of work roll moves to the plus direction from S=-100%, as roll campaign forwards from broad to narrow width. GETZ moves from a broad to a narrow width as much as the roll shifts from S=-100.0% to the plus direction. In the example of Figure 11, the inclination of set-up formula for roll shifting position relating to crown should be almost equal to that of GETZ geometrical position by roll shifting, the characteristics are derived as follows:

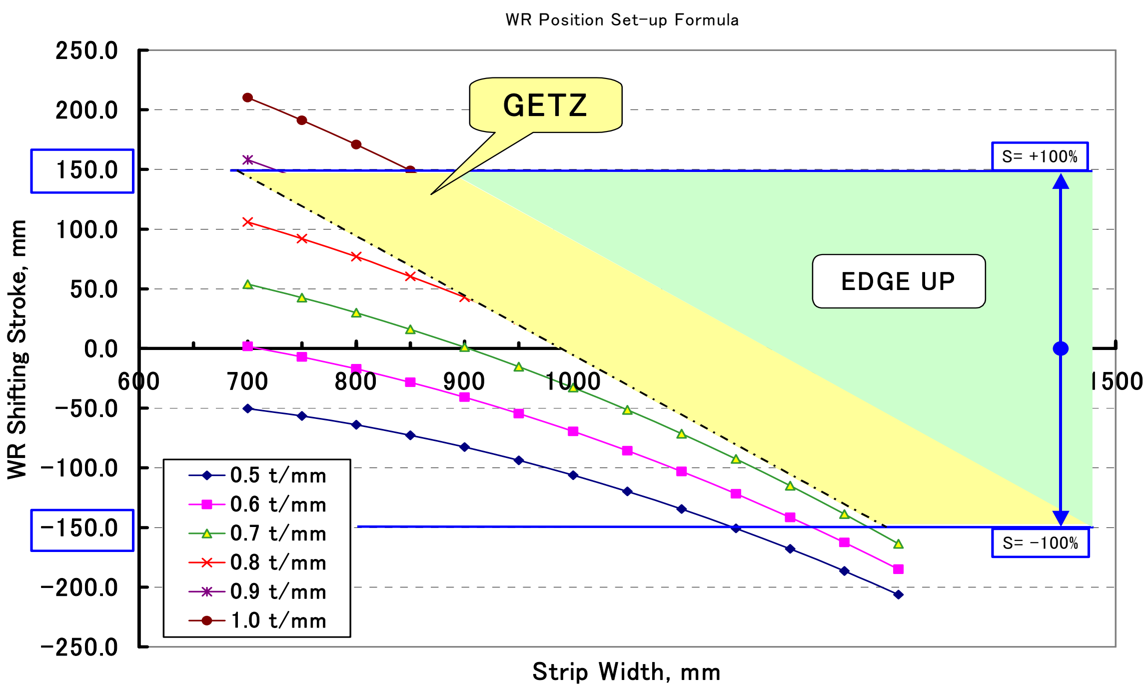


Figure 11. Set up concept of SPEOS™ crown roll

① Where rolling force per width of 0.7-0.8 ton/mm is provided to normal carbon steel in cold rolling, if the work roll shift is set in the appropriate strip crown position depending on its width, GETZ is automatically generated around at the edge of the strip and edge-drop is corrected.

② Where rolling force per width is larger or smaller than the above, it is also possible to achieve crown control. As shown in Figure 6, the slope of crown change of the roll shift and that of the work roll bender are similar, hence, utilizing such characteristics, crown is corrected by work roll in relatively small amount after shifting position of work roll is set by edge-drop requirement. Accordingly, setting up makes it possible to pursue both crown control and edge-drop control by comparable simple means.

③ Instead of this crown roll, as an alternative, discontinuous contour with a hemi-taper from the middle of the curve is thought to be expected same effect as SPEOS™ crown. Compared to that system, SPEOS™ crown roll is superior for two main reasons: The edge is corrected gradually and extensively in the area of GETZ. Second, it is possible to have options for the appropriate shape of the configuration, depending on the shape of the edge drop.

FEATURES AND REFERENCES OF SPEOS™ MILL

Thanks to above mentioned characteristics of crown and edge-drop control ability, following features are derived.

SPEOS™ 4-Hi Mill

☐ Higher yield in cross sectional width direction is expected
☐ Less investment cost compared to 6-Hi mill
☐ Less running cost and maintenance cost

SPEOS™ 6-Hi Mill

☐ Excellent crown and flatness control ability
☐ Bending effect is superior due to GETZ compared to conventional variable crown mill
☐ Flexible and stable operation compared to conventional 6-Hi mill

Typical examples of references of SPEOS™ mills are shown on Figure 12 and Figure 13.

Figure 12. SPEOS™ 4-Hi Mill in CSC Steel Malaysia

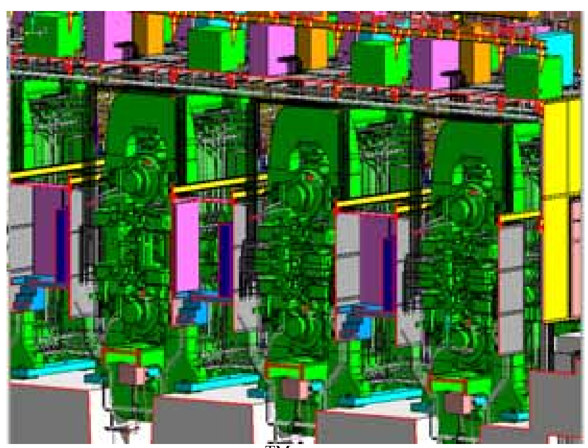


Figure 13. SPEOS™ 6-Hi Mills in CSVC

CONCLUSION

JP Steel Plantech Co. have developed the SPEOS™ crown roll that has the following features in the mill system with relative shifting of work rolls on comparably simple 4-Hi constitution.

(1) By relatively shifting a pair of work rolls, a gap between top and bottom rolls is generated around the middle part of the roll, which contributes to the strip crown control. In contrast, a Gap Expanding Transitional Zone (GETZ) also is generated around the edge of the roll gap.

(2) By relatively shifting this crown roll to the appropriate position of the crown depending on the width of the strip, GETZ is located automatically and simultaneously near the edge. This function makes crown control possible, which facilitates a decrease in edge-drop.

(3) Given that edge-drop is the main purpose of the control, crown control is made possible by the relatively small adjustment of the work roll bender after roll shifting to the adjustment position for the edge-drop correction. Therefore, this relatively simple means enables both crown and edge-drop control.

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