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Development of Advanced Transverse Thickness Profile Control of Thin Hard Steel Strips at Tandem Cold Rolling Mill

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Development of Advanced Transverse Thickness Profile Control of Thin Hard Steel Strips at Tandem Cold Rolling Mill*



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1 Introduction

Recent years have seen a fresh recognition of the importance of resource and energy saving from the viewpoint of preservation of the global environment. Improvement of product yield is one of the most important themes for the steel industry. On the other hand, due to the stricter quality requirements of customers in recent years, gauge accuracy in longitudinal and transverse directions of strips has become an extremely important quality control item. Improvement in strip longitudinal and transverse gauge accuracy not only promotes the automation of customers' production lines (for example, automated stacking of silicon steel sheets), but also makes a major contribution to improving yield in steel production processes.

Under the foregoing situations this background, the one-side taper work roll shifting (K-WRS) method has been developed and introduced at the No. 2 cold tandem mill[1,2] at Mizushima Works and, accuracy of transverse thickness has been achieved within 0.5% in steady state, and within 0.8% in non-steady state for steel sheets, mainly of thin hard steel strips such as silicon steel. An outline of this accurate transverse thickness control system is presented in this paper.

2 Progress in the Development of Transverse Thickness Profile Control

Kawasaki Steel has historically been a pioneer in the development of crown and edge drop control technologies which apply the work roll shifting method using work rolls with one-side taper in the hot and cold rolling processes. First, the company showed that it was possible to reduce crown and edge drop by using tapered work rolls in the last stands of the hot rolling finishing train[3-5]. After further development of this method, the K-WRS method was developed and applied to actual equipment[6]. In hot rolling, the K-WRS method was applied to three stands (F3-F5) of the six-stand finishing mill train at the Chiba Works No. 1 hot strip mill (June 1983)[6]. This technology was also applied to three stands (F5-F7) of the seven-stand finishing mill train at the Chiba Works No. 2 hot strip mill. **Figure 1** shows the results of crown control obtained at Chiba Works No. 1 hot strip mill[7]. Conventionally, strip crown changes from 120 to 30 μm in a rolling campaign. The strip crown is improved to the range of 40 from 10 μm by the work roll shifting method using work rolls with one-side taper. At cold strip mills, on the other hand, the K-WRS method was applied to the No. 1 stand of the No. 1

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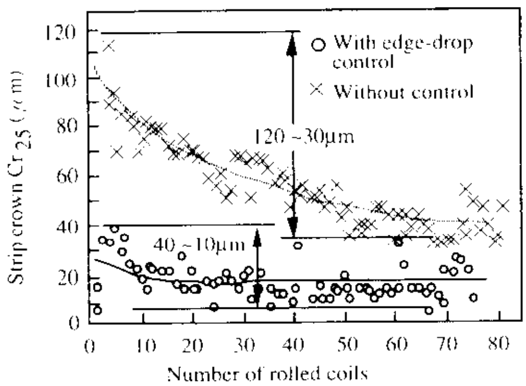

Fig. 1 Effect of one-side tapered work roll shifting method in hot rolling

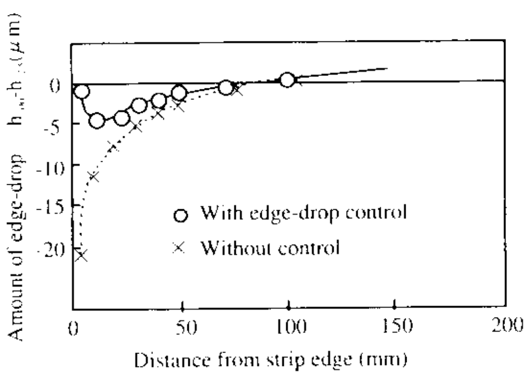

Fig. 2 Effect of one-side tapered work roll shifting method in cold rolling

tandem cold mill at Mizushima Works in December 1984[8-10], and later to all stands of the No. 2 tandem cold mill (four-stand mill) at Mizushima Works. As shown in **Fig. 2**, with cold-rolled strips of mild steel, it is possible to improve edge drop (h_{100}-$h_{12.5}$) greatly over that in conventional practice[11]. At present, the K-WRS method has been introduced into 29 stands of cold rolling mills for steel strips and non-ferrous strips around the world.

3 Establishment of the Transverse Thickness Profile Control System

It is comparatively easy to control the edge drop of cold-rolled strip by applying the K-WRS method because the crown of the hot-rolled strip is small in the case of mild steel. However, it has been difficult to achieve high accuracy transverse gauge control with thin hard strips, which have high flow stress, due to the large crown of the hot-rolled strips and the high rolling loads required even in cold rolling. This chapter will describe a method of transverse gauge control for thin hard strips having high flow stress. In particular, this method uses the K-WRS method not only to control the edge drop which occurs in conventional cold rolling, but also to expand the range of edge drop control to enable correction of the profile of hot-rolled strips in cold rolling to achieve a high target within 0.5% in steady state, and within 0.8% in non-steady state over the entire lenght of the thin hard steel product.

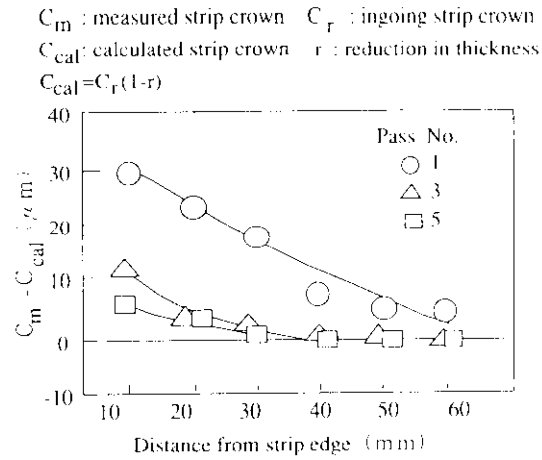

Fig. 3 Comparison of calculated and measured crown

3.1 Distribution of Transverse Thickness in Cold-Rolled Strips

The starting point of edge drop in cold rolling, as shown in **Fig. 3**[12], is approximately 50 mm from the strip edges at No. 1 stand, and about 30 mm from the edge at No. 3 and No. 5 stands. Thus, deformation is not consistent with the general crown ratio uniformity of the strip, and metal flow in the transverse direction is limited in the strip edge areas. Further, the fact that deformation of the crown ratio constant also occurs at points more than 50 mm from the edges indicates that, except at the edges, the strip profile in hot rolling has an important effect on the profile of cold-rolled strips.

3.2 Expansion of the Edge Drop Control Range in Cold Rolling

In order to investigate the edge drop control range in cold rolling, the control characteristics of the K-WRS method were studied using a laboratory mill. The experimental conditions are shown in **Table 1**.

The position of the work roll taper, as shown in **Fig. 4**, was varied in the range of EL = 50 to 80 mm (EL is the taper starting position relative to the transverse direction coordinate of the strip), with starting positions lying inside the strip edges as positive positions.

The profile after one-pass rolling, as seen in **Fig. 5**, shows a large amount of edge-up when the taper angle is large, at 1/375, and under all EL conditions, the shape of the taper is transferred to the strip basically up to the point where the taper begins. This fact shows that it is possible to control the profile of the strip at points further inside the strip than the point where edge drop

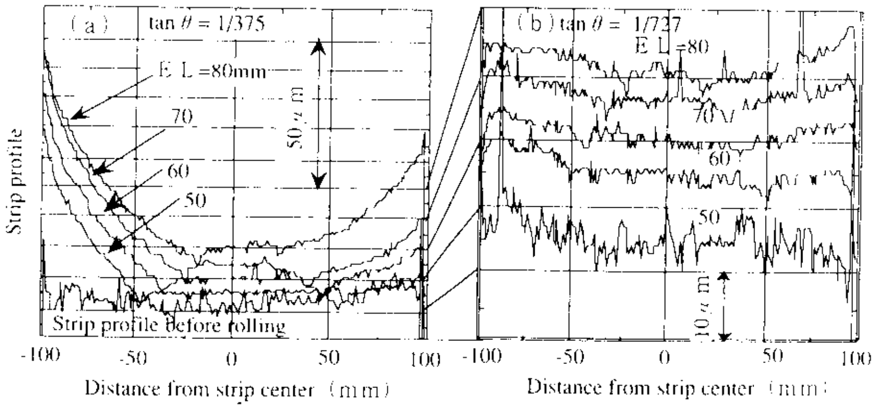

Fig. 5 Strip profile change by rolling with tapered roll, tan θ = (a) 1/375, (b) 1/727

Table 1 Experimental conditions

WR Dia. (mm)	310
Rolled material (mm)	Low carbon steel
Strip width (mm)	200
Strip thickness (mm)	Inlet/Outlet = 2.3/1.5
Tension (MPa)	Inlet/Outlet = 78/120
Taper angle tanθ	1/727, 1/600, 1/375, 1/188, 0(flat)
Shifting position EL (mm)	80, 70, 60, 50

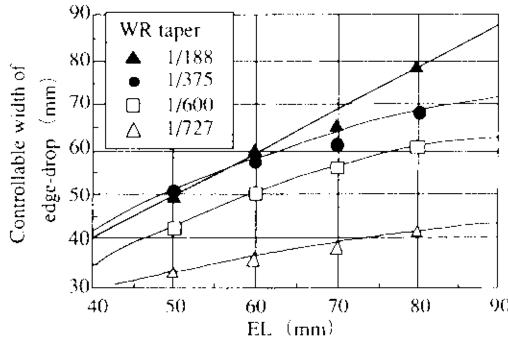

Fig. 6 Comparison of controllable range of edge-drop between taper angle

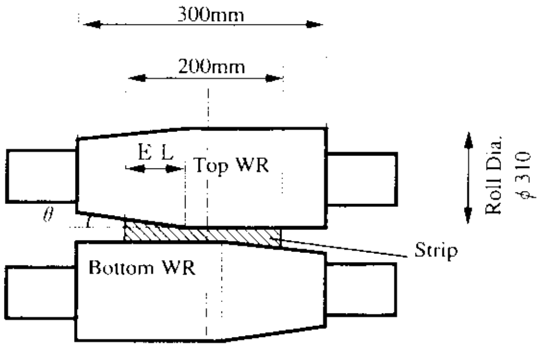

Fig. 4 Definition of WR taper θ and shifting position EL

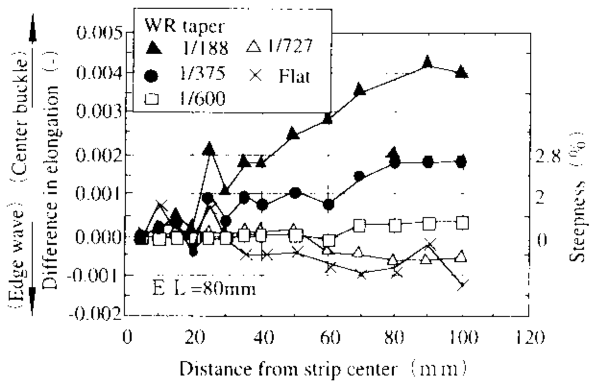

Fig. 7 Comparison of strip flatness after rolling

begins in cold rolling, as was shown in Fig. 3. As the control range when using tapered work rolls, **Fig. 6** indicates that roll taper can be used effectively at greater distances from the strip edge by increasing the taper angle, making it possible to expand the control range to the point where the profile begins to change. **Figure 7** shows the measured results of the elongation differential ratio with various angles of roll tapers in the case of EL = 80 mm. As the taper angle increases, the center elongation becomes more pronounced. With rolls having an angle of 1/375, the steepness of the center buckle is 2.8% or less, and with an angle of 1/188, the center buckle becomes considerably greater.

Based on the investigation with the laboratory mill, edge drop control was studied with an actual mill. As shown in **Fig. 8**, the cold rolling mill (No. 2 tandem cold mill) at Mizushima Works, which was started up in January 1987, is equipped with one-side tapered work roll shifting equipment at all stands in order to control edge drop, and as a means of profile control, is a fully continuous type cold rolling mill comprising four 6-high UC stands with intermediate roll shift, intermediate roll benders, and work roll benders at all stands. An edge drop

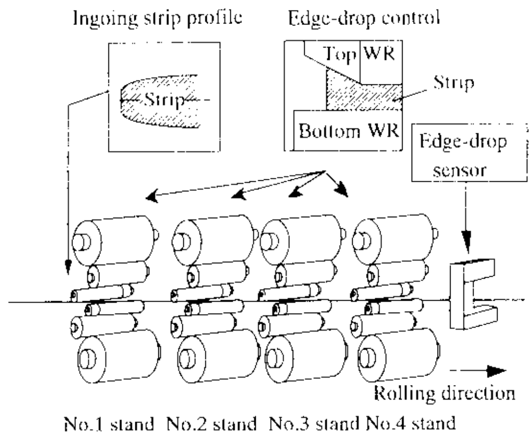

Fig. 8 Schematic diagram of Mizushima Works No. 2 TCM

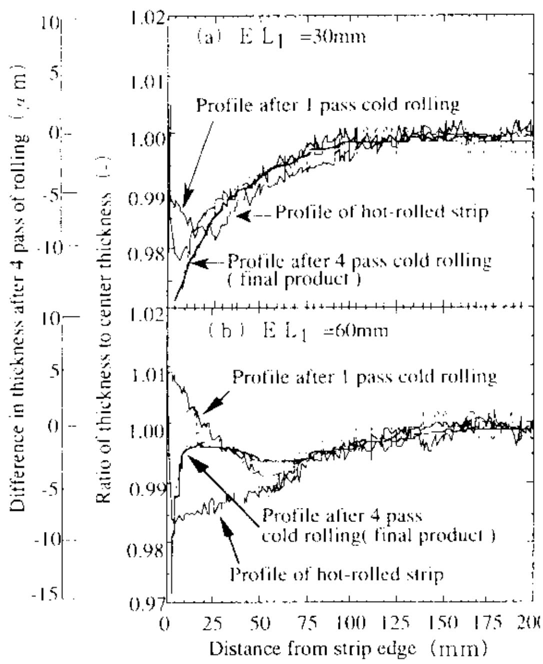

Fig. 9 Result of edge-drop control in Mizushima Works No. 2 TCM

sensor is installed at the delivery side of the final stand.

Figures 9 (a) and (b) show the strip profile when rolling hot-rolled strip with a relatively large crown using tapered work rolls with a 1/400 taper angle in a commercial cold rolling operation. The figure shows cases when EL_1 = 30 and 60 mm. In case (b), when EL_1 = 60, the crown ratio changes in an area about 60 mm from the strip edges, demonstrating that it is possible in the cold rolling process to control the profile of hot-rolled strip. With EL_1 = 60 mm in this example, edge drop in the product steel strip was almost completely eliminated by applying the K-WRS method.

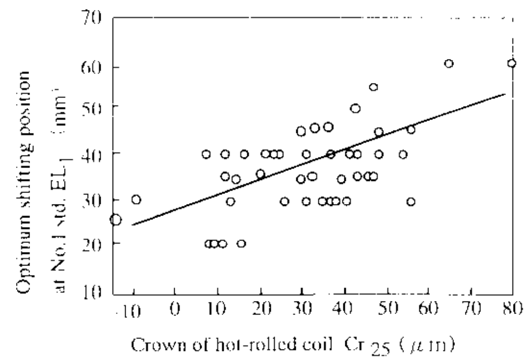

Fig. 10 Optimum shifting position at No. 1 stand depending on crown of hot-rolled strip

4 Development of Highly Accurate Profile Control System in the Whole Length of Cold-Rolled Strips

As indicated in the previous section, it has been found that variation of the hot-rolled strip crown is controllable in cold rolling by correcting the hot-rolled strip profile.

Furthermore, feed-forward edge drop control system, corresponding to the amount of crown of the hot-rolled strip, and feed-back edge drop control system using an edge drop sensor, have been established in the tandem cold mill. This technique corresponds to the in-coil crown variation of the hot-rolled strip and the difference in crown between the two edges of the steel sheet, so as to provide a uniform profile covering the entire length and width of the cold-rolled strip.

4.1 Edge Drop Control Corresponding to the Variation of Crown of the Hot-Rolled Strip

4.1.1 Feed-forward edge drop control system

Figure 10 shows the experimental results[13] for the EL_1 at which the edge drop at 20 mm from the strip edge became 0 μm after 4-pass cold rolling with hot-rolled strips having various crowns (Cr_{25}). Here, edge drop is defined as the difference between the strip thickness at 20 mm from the edge and that at a point 100 mm from the edge. It is confirmed that there is an optimal value of EL_1 corresponding to the amount of crown in the hot-rolled strip. Moreover, it is necessary to increase the amount of EL_1 substantially in proportion to the increasing size of the hot-rolled strip crown.

The feed-forward edge drop control system, by using the information from the profile sensor placed at the delivery side of the hot strip mill, controls work rolls shifting of No. 1 stand to obtain the target edge drop by using the relationship shown in Fig. 10.

4.1.2 Feed-back edge drop control system

The influence of the amount of work roll shifting at the first stand EL_1 on the change of strip thickness at

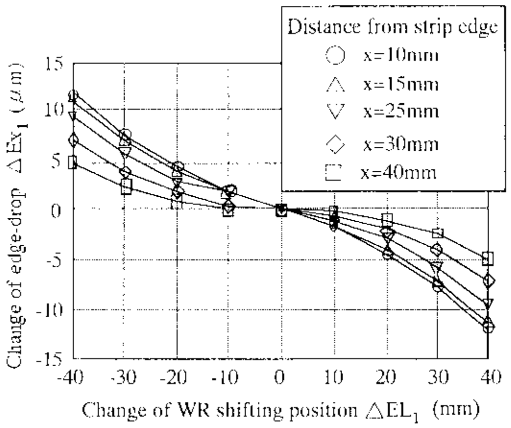

Fig. 11 Edge-drop change by changing WR shifting position (Experimental results)

each position after 4-pass rolling was evaluated. An experiment was conducted to measure the strip thickness value at each position on the strip edge by varying EL_1 within the same strip, and **Fig. 11** shows the results. The relationship between change of thickness and work roll shifting is represented by the following model formula.

$$\Delta E_x = f(\Delta EL_1) \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (1)$$

where ΔE_x: Strip thickness variation at x mm position (μm)

ΔEL_1: Changing value of EL for No. 1 stand (mm)

f: Function expressing the correlation between ΔE_x and ΔEL_1 at each position

The feed-back edge drop control system controls work rolls shifting of No. 1 stand to obtain the target edge drop by using the relationship.

4.2 Setting up the Edge Drop Control Target and Asymmetrical Work Roll Shifting

Figure 12 shows a schematic drawing of the produced strip profile which was controlled by using a work roll with a 1/400 taper angle. Strip thickness has a tendency to have a small edge-up in an area at 10 to 15 mm from the strip edge. The targets of controlled thickness deviation are conducted $\pm$ 5 μm at this area, and thickness deviation within $-$ 5 μm in an area at 25 to 30 mm from strip edge where the strip becomes thin. It is possible to achieve the accurate transverse thickness profile by this control.

There are cases in hot rolling where crown variance between the strip edges is caused by a difference in temperature, load, or off-centering of the strip. With the K-WRS method for cold rolling, the edge drop difference between the two edges must be reduced. The crown difference between both edges of hot-rolled strips is controlled by asymmetrical work roll shifting between the top and bottom work rolls. When asymmetric shifting control is applied, strip camber may occur. **Figure 13** shows the result of the strip camber calculated by an

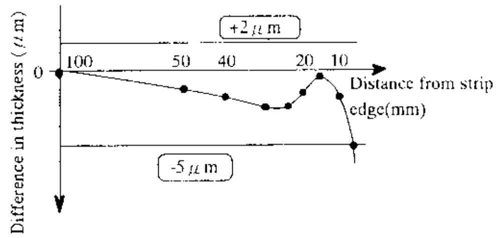

Fig. 12 Result of strip edge-profile by feedback control

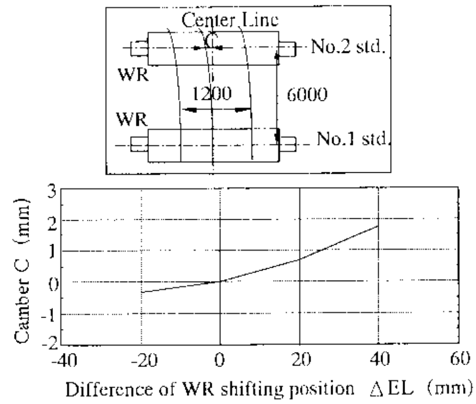

Fig. 13 Amount of strip camber

asymmetric roll deformation calculating model[14]. This result shows that even though asymmetrical shifting of the top and bottom work rolls would generate a small camber in cold rolling, as long as the difference in work roll shifting position is within 20 mm, camber value can be controlled within 1 mm. In fact, there is no problem in the practical operations by applying asymmetric shifting control.

4.3 Establishment of the Profile Control System

Figure 14 shows feed-forward and feed-back edge drop control systems which would maximize the effect of the K-WRS method established in the No. 2 tandem cold mill.

A result of the application of this profile control system applied to the No. 2 tandem cold mill at Mizushima Works is shown in **Table 2** and **Fig. 15**. A large improvement over the conventional control method using the fixed work roll shifting position and straight work roll has been achieved in transverse thickness profile accuracy, and for cold rolling thin hard steel strips with high flow stress, the development targets of $\pm$ 0.5% in steady state and $\pm$ 0.8% in non-steady state have been accomplished.

5 Conclusions

Transverse thickness profile control was applied by the one-side tapered work roll shifting (K-WRS) method

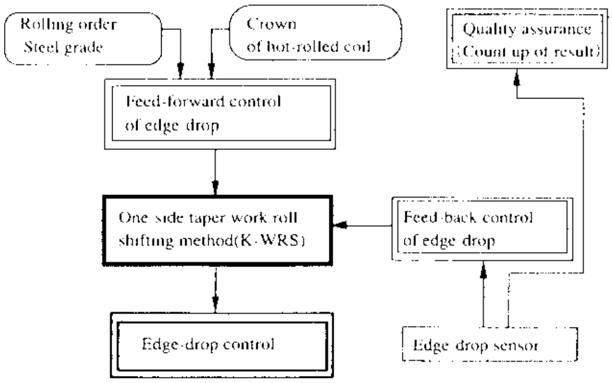

Fig. 14 System of transverse thickness control

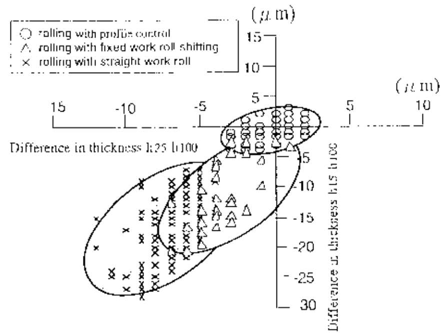

Fig. 15 Effect of transverse thickness profile control system

Table 2 Comparison of accuracy of transverse thickness ($h_{100} - h_{15}$) (%)

	Achievement ratio within ± 0.5% in steady state	Achievement ratio within ± 0.8% in non-steady state
Former	85.7	82.1
The present development	96.8	96.4

on all stands of the No. 2 cold tandem mill at Mizushima Works, with the following results:

(1) Accuracy of transverse thickness was achieved within 0.5% in steady state and within 0.8% in non-steady state over the full length of the thin hard steel product.

(2) A feed-forward edge drop control system corresponding to the amount of crown of the hot-rolled strip was established in the tandem cold mill.

(3) A feed-back edge control system using an edge drop sensor was established in the tandem cold mill.

(4) Optimization of the taper angle of the work roll expanded the edge drop control range during cold rolling.

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