Development of Pinch Rolls to Control Strip Wandering in Strip Processing Lines

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In strip processing lines, it is important to restrain strip wandering which obstructs operational reliability and makes productivity decline. To improve the stability of the strip conveyance at the existing facilities in addition to the new facilities, a compact guiding apparatus was able to be introduced easily and was valid. In this report, the structure of the unique bent roll covered with a rubber sleeve, which has a wandering restraint function, was examined and the effect was clarified using an experimental apparatus. A rubber sleeve that needs durability to endure expansion and contraction by rotation of the bent roll was also examined. Production machine size rolls were newly developed and evaluated as pinch rolls in processing lines. Under the general condition to set pinch forces identically on both sides of the roll, this roll always has the ability to restrain strip wandering. When put on deviation of pinch forces on both sides, the ability of the wandering correction was increased. It was proposed that the wandering correction system, which controls the pinch force using the output of width sensor, was useful in the processing line. It was also possible to use these pinch rolls as the wandering correction apparatus at the place where it is difficult to use a general guiding apparatus because there is no restriction of line tension.

KEY WORDS: rolling; strip wandering; flatness defect; camber; guiding apparatus; rubber sleeve roll; pinch rolls.

1. Introduction

In strip processing lines, such as a continuous annealing line (CAL), galvanizing line (CGL, EGL), and coating line, a strip is moved forward and processed through a long distance at high speed. If the strip wanders in a processing line because of strip shape defects, apparatus, operation or other factors, a stable operation is disturbed. Therefore, it is important to prevent the strip from wandering as running conditions of the strip change every second. In general, guiding apparatus are equipped in adequate positions and appropriate roll crown curve and line tension are adopted. Pinch rolls in processing lines also are effective to stabilize strip. But in case of increasing the productivity of existing lines, general guiding apparatus are not easily applied because space for the guide is tied up and facility cost becomes large. As compact guiding apparatus are useful to reduce strip wandering and are in much demand, new unique centering pinch rolls which control strip wandering, were developed. Newly developed rolls can be easily installed because ordinary type pinch rolls are used at many positions in processing lines. They can be applied to control wandering of the strip head and tail ends which are difficult to control because of no line tension.

First, using an experimental apparatus with 1/8 scale of an actual line, roll structure to control strip wandering was studied and the effect of the lateral force that the roll generates toward the strip was cleared.

Second, durability of the rubber sleeve that covers the roll was tested on condition that pinch force is loaded. Even thought, there were severe expansion and contraction by rotation of the bent roll, the newly developed rubber sleeve was not damaged and was not worn out unusually.

Third, using these results, production machine size rolls were manufactured and ability to control strip wandering in a processing line was examined. In order to improve the ability, it was very effective to change the pinch forces on both sides unequally, then larger wandering was adjusted. The wandering correcting system, which controls the balance of pinch force automatically was constructed, too.

Fourth, pinch rolls were also examined to control wandering of coil tail ends, for it is difficult to use the ordinary type guiding apparatus, because line tension is cut at this portion.

From these examinations, it is clear that newly developed pinch rolls have high ability to control strip wandering. Moreover they are easily installed on existing processing lines with minimum reconstruction of the facilities.

2. Model Roll Structure and Experimental Conditions

2.1. Structure of Newly Developed Roll

The structure of newly developed roll and the mechanism to control strip wandering are shown in Fig. 1. Steel sleeves
are set on self-aligning bearings, which are put on both sides of the straight arbor. Steel sleeves are covered with a rubber sleeve. Bending angle of the roll can be changed by rotating eccentric rings, those are set on both ends of the arbor and the rubber sleeve rotates with an inclination toward the arbor. If the strip moves forward while being pinched by bent rolls as shown in Fig. 1, the rolls incline to move the strip toward the direction of roll surface velocity. Then the rolls generate centering forces toward the lateral component of roll surface velocity on the strip surfaces. The difference of both centering forces works to diminish strip wandering. The larger the deviation of the strip lateral position from the center line is, the larger the difference of both centering forces becomes. The appearance of the test rolls (100 mm diameter×300 mm length) is shown in Fig. 2. The rubber sleeve is tightly fixed on steel sleeves. A strip is moved easily to lateral direction on the roll when the roll is declined a few degrees against the strip. Therefore, the roll bending angle \( \gamma \) is set optionally from 0 to 2.5 degrees.

2.2. Model Roll Experiments to Restrain Strip Wandering

The schematic diagram of the experimental apparatus with 1/8 scale of an actual line is shown in Fig. 3. Strip was moved from a pay-off reel to a tension reel with a strip loop. Tension was regulated by torque control of a pay-off reel motor. Line speed was regulated by rotating-speed control of a tension reel. In this apparatus a displacement guide roll (No. 4 roll) and a steering guide roll (No. 6 roll) were equipped, and E1 to E9 CCD cameras always measured strip wandering. Measured data were recorded to a personal computer and accumulated data were analyzed. The distance of top and bottom turning roll (100 mm diameter×300 mm length) was 2500 mm, and straight or convex crown rolls were used. Experimental standard speed was 25 m/min. SPCC-annealed strip (0.1 mm thick×112.5 mm wide) was used. The tested pinch rolls were set between No. 8 roll and No. 9 roll. Strip wandering which was generated using guide rolls, was corrected with changing pinch force, roll bending angle and tension \( T \).

2.3. Rubber Sleeve Tests to Estimate Endurance

By rolling the bent roll, the rubber sleeve expands and contracts and the rubber surface is worn down. This sleeve needs durability and strength during continual use of an actual line. The schematic diagram of the testing apparatus to estimate endurance of rubber sleeve is shown in Fig. 4. The test roll was pressed against the driven roll that corresponds to the strip. The driven roll was controlled to rotate at a constant rotating-speed. The press load of the test roll was given added weight to be suitable for general pinch force per unit length during a production size roll. In order to estimate the influence of strip edge to the test roll surface, and the partial load to the test roll, the contact width between test roll and driven roll was selected at 200 and 330 mm.

3. Experimental Results and Correcting Effects

3.1. Influence of Pinch Force

The relationship between pinch force and deviation of
strip lateral position from center line at the exiting position of the pinch rolls is shown in Fig. 5. The strip upstream deviation from center line was 25 mm. Tension $\sigma_t$ was 26 N/mm$^2$, roll bending angle $\gamma$ was 2.5 degrees and pinch force was changed from 196 to 784 N. The corrected value of strip wandering becomes larger in proportion to the pinch force.

3.2. Influence of Roll Bending Angle

The relationship between roll bending angle $\gamma$ and deviation of strip lateral position from center line at the exiting position of the pinch rolls is shown in Fig. 6. Pinch force was 784N, tension $\sigma_t$ was 26 N/mm$^2$ and $\gamma$ was changed from 0 to 2.5 degrees. The bigger the angle $\gamma$ is, the smaller the deviation from center line it becomes.

3.3. Influence of Entering Lateral Position

The relationship between deviation of strip lateral position from center line at the entering position of the pinch rolls and corrected value of strip deviation is shown in Fig. 7. Tension $\sigma_t$ were 7.8 and 26 N/mm$^2$, pinch force was 784 N, roll bending angle $\gamma$ was 2.5 degrees and the deviation of entering strip lateral position from center line was changed from 5 to 25 mm. The bigger the entering deviation is, the larger the corrected value of strip wandering becomes, because the deviation of both centering forces becomes larger. When the tension is smaller, the effect of correction also becomes larger. Figure 8 shows the relationship between line tension and centering force. As the lateral component of line tension is balanced with the centering force in a tension-applied line, deviation of strip lateral position from center line always remains a little. In a no tension line, larger correction effect is expected.

3.4. Endurance of Rubber Sleeve

As the rubber sleeve, which covers this bent roll, is extended and contracted with each rotation, it needs strength and durability; therefore, the inner layer of rubber was reinforced by synthetic fiber and rubber with high wear-resistance was applied to sleeve surface. 210 mm diameter×360 mm length model roll which had the same structure shown in Fig. 1, was used to estimate endurance of the rubber sleeve. The rubber sleeve was joined to the steel sleeve by vulcanization. Figure 9 shows the relationship between rolling time and temperature of the roll when roll bending angle $\gamma$ was 2.0 degrees, press force was 6.2 kN (18.7 N/mm) and roll surface tangential speed was 3.3 m/s. As the temperature of rubber sleeve raises about 20°C and is stabilized, repetition of expansion and contraction affects it very little. The temperature of the bearing stabilizes, too. The test lasted about 150 h (9 h per day). Rotating tests were practiced at the press force from 4.4 to 14.1 kN (21.9 to 70.4 N/mm) by narrowing the width of the contact between the rubber sleeve and the drive roll, too. Without damaging the rubber sleeve, it was secured to retain enough strength.
4. Wandering Correction Feature by the Production Size Test Roll 6–8)

4.1. Pinch Rolls Performance Evaluation in a Tension-applied Line

The experimental layout in a processing line is shown in Fig. 10. Figure 11 shows the production size test roll that was installed as pinch rolls. The experimental apparatus has a mechanism which can set the pinch force on either side of the pinch rolls independently. The strip (0.7–1.0 mm thick × 760–1 000 mm wide) lateral position was measured with the width sensor installed downstream of the pinch rolls. The strip wandering was generated using existing guiding apparatus that is situated on the upper stream of this layout. The specifications of the tested roll are shown in Table 1(a).

4.1.1. Influence of Pinch Force

The relationship between pinch force and deviation of the strip lateral position from center line is shown in Fig. 12. Line tension was 9.8 kN, γ was 2.8 degrees and pinch force was changed from 7.8 to 31.4 kN. In the figure, the upstream strip deviation is pointed at pinch force 5 0. The bigger the pinch force is, the smaller the deviation from the center line becomes under identical pinch forces on both sides of the roll.

4.1.2. Influence of Roll Bending Angle

The relationship between bending angle and deviation of strip lateral position from center line is shown in Fig. 13. Pinch force was 31.4 kN and line tension was 19.6 kN. In the figure, the upstream strip deviation is pointed at bending angle 5 0. The bigger the bend angle is, the smaller the deviation from the center line it becomes.

4.1.3. Influence of the Entering Strip Lateral Position

The relationship between deviation of entering strip lateral position from center line and corrected value of strip lateral position is shown in Fig. 14. Line tension was 19.6 kN, pinch force was 31.4 kN, γ was 2.8 degrees and the entering strip lateral position was changed from 10 to 40 mm. The bigger the entering deviation is, the larger the corrected value of strip wandering becomes. Approximately, proportional relation is seen.
4.1.4. Influence of Line Tension

The relationship between line tension and deviation of strip lateral position from center line is shown in Fig. 15. Pinch force was 31.4 kN, $\gamma$ were 2.0 and 2.8 degrees and line tension was changed from 9.8 to 26.5 kN. The smaller the line tension is, the smaller the deviation from the center line becomes. It was difficult to correct strip wandering exactly with identical pinch forces on both sides of the roll because of the restriction of the line tension. However, if the strip wandering becomes larger, the newly developed rolls can constrain strip wandering automatically. Therefore, they are sufficiently effective to be applied as a substitute for ordinary pinch rolls in order to restrain strip wandering constantly.

4.2. Correction Effect by Changing Pinch Force on Both sides of the Pinch Rolls

In order to correct strip wandering exactly, influence of unequal pinch forces on both sides of the roll was examined. When the upstream strip deviation was 40 mm and total pinch force was constant, then the pinch force of the side where the strip wandered was increased and the opposite pinch force was decreased simultaneously. The relationship between pinch force ratio of both actuators and deviation of strip lateral position from center line is shown in Fig. 16. Here, the following type defines the pinch force ratio.

$$\text{Pinch force ratio} = \frac{|F_d - F_w|}{(F_d + F_w)} \times 100 \, (\%)$$

$F_d$: Pinch force of drive-side actuator,
$F_w$: Pinch force of work-side actuator.

If both side pinch forces are equal, pinch force ratio is equal to zero. By increasing the deviation of both side pinch forces, the ability to correct wandering improves. It is possible to correct strip wandering to the center line. If the roll-bending angle is larger, then the pinch force ratio becomes smaller.

4.3. Effect of Pinch Force Ratio Control

When providing deviation of pinch forces on both sides, the force that drives a strip in the lateral direction rises and enough correction is achieved for larger lateral wandering. Since the actual lateral wandering changes every moment, it is necessary to adjust the pinch force ratio continuously. The output of width sensor was fed back and pinch force ratio was controlled. Correction of strip wandering is shown in Fig. 17. Line speed was 100 m/min, line tension was 19.5 kN and the upstream guiding apparatus was moved to generate strip wandering. The pinch force changes according to the lateral wandering. When the lateral wandering becomes zero, then the pinch forces are maintained. Strip lateral wandering is precisely corrected. It is possible to use these pinch rolls as a high-precision guiding apparatus.

4.4. Effect of Wandering Correction at Coil Tail End

An experimental layout of the entrance section in a processing line is shown in Fig. 18. The lateral wandering of the strip tail ends (0.7–1.2 mm thick×700–1400 mm wide), which were released from the restriction of line tension, was measured with the width sensor. Pinch force was 12.3 kN, $\gamma$ was 1.85 degrees and pinch forces on both sides of the roll were identical. The specifications of the test roll are shown in Table 1(b). An example that compared the change of strip lateral wandering when using test pinch rolls and when using ordinary pinch rolls is shown in Fig. 19. The shape defect and camber of a strip tail end sometimes causes wandering when restriction of line tension is released. But, strip wandering was corrected by test pinch rolls up to...
the time the line stopped. **Figure 20** shows the comparison of maximum strip lateral wandering when using test pinch rolls and when using ordinary pinch rolls. Strip wandering is substantially restrained by the use of the test pinch rolls and the deviation also decreases a degree and a half. It is possible to apply these pinch rolls with a wandering correction apparatus at the place where it is difficult to use a general guiding apparatus because there is no restriction of line tension.

### 5. Conclusions

In order to develop the compact apparatus to control strip wandering in processing lines, the pinch rolls that have a wandering restraint function was examined. Experiments by the model roll and facility verification by the production machine size test roll were accomplished. It was clear that the newly developed pinch rolls were effective to control strip wandering. The main results are summarized below.

1. This bent type roll secures sufficient stiffness with straight arbor and roll bending angle can be precisely set by using the mechanism of an eccentric ring. The newly developed rubber sleeve secures sufficient durability and strength to endure expansion and contraction by rotation of the bent roll.

2. This bent type roll is always generating centering force to restrain strip wandering. The larger the roll bending angle is, the bigger the pinch force is, and the smaller the line tension is, the larger the wandering correction effect becomes.

3. Newly developed pinch rolls are sufficiently effective to be applied as a substitute for ordinary pinch rolls in order to restrain strip wandering constantly. If the strip wandering becomes larger, the newly developed roll can constrain strip wandering automatically, though it is difficult to correct strip wandering exactly with identical pinch forces on both sides of the roll.

4. Applying the deviation of both side pinch forces, it is possible to correct strip wandering to the center line. Moreover, it is possible to correct strip wandering precisely by control of pinch force ratio.

5. It is possible to apply these pinch rolls as a wandering correction apparatus at the place where it is difficult to use a general guiding apparatus because there is no restriction of line tension.

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