Basic Examination on Strip Wandering in Processing Plants

Takeshi MASUI, Yoshiyuki KASEDA and Kazumi ISAKA

Corporate Research and Development Laboratories, Sumitomo Metal Industries, Ltd., Fuso-cho, Amagasaki, Hyogo-ken, 660-0891 Japan.

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1. Introduction

In strip processing plants, such as a continuous annealing line (CAL), galvanizing line (CGL) and coating line, there are from 100 to 200 turning rolls (deflector rolls, hearth rolls, sink rolls, steering rolls, etc.) where the strip is processed through long distance at high speed. If the strip wanders in the line because of strip shape, thermal effect or other factors, stable plant operation is disturbed. This report is concerned with strip lateral wandering. The cause of strip wandering is clarified by using a model processing plant. Strip camber and welded joint angle, that is a non-straight form of the strip, mainly gives rise to wandering. The effects of misalignment on the equipment are small. Tension leveler that corrects not only shape defects but also camber and welded joint angle is very effective to depress wandering. Pinch roll to prevent strip wandering, the hearth roll and the quenching roll to prevent a thermal crown have been newly developed to hold good strip tracking.

KEY WORDS: rolling; strip wandering; bending; flatness; thermal crown; cooling; pinch roll; hearth roll; quenching roll.

2. Experimental Apparatus

Figure 1 shows the schematic diagram of the experimental apparatus with 1/8 scale of an actual plant. Strip is processed from a pay off reel to a tension reel or endless traveling with a strip loop. Tension is regulated by torque leveler. Tension leveler that corrects not only shape defects but also camber and welded joint angle is very effective to depress wandering. Pinch roll to prevent strip wandering, the hearth roll and the quenching roll to prevent a thermal crown have been newly developed to hold good strip tracking.

Basic technology for high speed stable traveling of the strip was achieved by combining these new methods.
control of a pay-off reel motor in case of reel to reel traveling and by weight hanging in case of endless traveling.

Line speed is 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 the steering guide roll was usually used.

Table 1. Experimental conditions.

| Line speed | 0 ~ 250 m/min |
|------------|---------------|
| Tension    | 8.8 ~ 44.1 N/mm² |
| Strip      | Material: SPCC-annealed |
|            | Thickness: t = 0.1 mm |
|            | Width: w = 112.5, 150.0 mm |
| Tested factors | Misalignment of the welded joint |
|            | Operation: Tension, Speed |

Table 2. Standard roll crown.

| Roll No. | diameter of barrel (mm) | A (mm) | B (mm) | C (mm) | Ra (μ m) |
|----------|-------------------------|--------|--------|--------|----------|
| 1        | 120×320                 | —      | —      | F      | —        |
| 2        | 100×300                 | —      | —      | F      | 2.5      |
| 3        | 100×300                 | 100    | 250    | 0.06   | 1        |
| 4        | 100×300                 | 120    | 280    | 0.06   | 1.1      |
| 5        | 100×300                 | 70     | 220    | 0.12   | 2.5      |
| 6        | 100×300                 | 70     | 220    | 0.12   | 2.5      |
| 7        | 100×300                 | 70     | 220    | 0.12   | 1        |
| 8        | 100×300                 | —      | —      | F      | 3.5      |
| 9        | 100×300                 | —      | —      | F      | 1.7      |
| 10       | 100×300                 | 70     | 120    | 0.12   | 1        |
| 11       | 100×300                 | 70     | 220    | 0.24   | 2.5      |
| 12       | 100×300                 | 70     | 120    | 0.06   | 1        |
| 13       | 100×300                 | 70     | 120    | 0.24   | 1.8      |
| 14       | 120×320                 | —      | —      | F      | —        |

(*) F: Flat Roll

3. Experimental Results to Make Clear the Cause of Strip Wandering

3.1. Effect of Line Tension

The strip was set at 30 mm distance from the center line of experimental apparatus and processed with \( V = 12.5 \) m/min to change tension level. Guiding equipment was fixed. Figure 2 shows the effect of line tension. Strip moves toward center line. The higher the tension, the shorter the recovery time to center line it becomes. In case of low tension, strip sometimes remained in a steady position with a small distance from center line.

3.2. Effect of Line Speed

Line speed was changed from 12.5 m/min to 250 m/min, but strip positions at \( E_6 \), \( E_7 \) and \( E_8 \) hardly moved as shown in Fig. 3. In the case of a higher speed over 250 m/min, the friction coefficient between strip and turning roll decreases somewhat and it may affect strip wandering.

3.3. Effect of Roll Misalignments

If one side of a turning roll is pushed up, strip moves to a lower side. Figure 4 shows the relationship between lateral wandering (\( \delta \)) and inclination of the roll (\( \alpha \)). \( \delta \) becomes larger in proportion to \( \alpha \) even under several combined conditions of line tensions and strip cambers (C).

In the case of roll parallel misalignment between top and bottom rolls, strip moves from entry side to exit side of the
twisted turning roll in proportion to the twisted angle, but the value of deviation from line center is smaller compared with horizontal misalignment $\alpha$.

3.4. Effect of Strip Camber

If the strip has a camber, much wandering occurs. Figure 5 shows the definition of a camber and the relationship between the value of camber $C$ and strip wandering $d$. The bigger the camber $C$, the larger the wandering $d$ becomes and that lateral wandering on each roll is added toward downstream. When the line tension is lower, $d$ becomes larger.

3.5. Effect of Angle on the Welded Joint

Figure 6 shows the definition of angle $\theta$ on a welded joint and the relationship between $\theta$ and lateral wandering $d$. In the case of small $\theta$, $d$ is in proportion to $\theta$, but in the case of large $\theta$, $d$ has a tendency toward saturation.

The direction of wandering is on the convex side of the strip same as camber, as shown in Fig. 5 and Fig. 6.

3.6. Effect of Discrepancy on Welded Joint

Figure 7 shows the strip wandering when a welded joint with discrepancy passes through measuring points. $d$ is nearly equal to sifted value $d$. Strip moves only in the welded joint area and its effects are small on strip wandering.

3.7. Effect of Strip Shape Defects

Figure 8 shows the relationship between strip shape defects and lateral wandering. Longitudinal straight strip with symmetrical shape defects (center buckle, quarter buckle, wavy edge) has a small influence on strip wandering. Asymmetrical shape defects cause camber and there is a strong influence on strip wandering. Longitudinal straightness of the strip is the most important factor to restrain strip wandering.

3.8. Effect of Combined Factor

Strip wandering, based on strip factors written in Secs. 3.4 to 3.7, must be put one upon another, but it is not affected by changing line speed.

4. Studies on Control Strip Wandering

4.1. Camber Correction of the Strip by Tension Leveler

Main causes of strip wandering are strip camber and unstraightening on welded joints. A tension leveler (15×9 rolls) was installed in the model apparatus and strip with shape defects was corrected by tension leveler, after which the strip was processed again. Test results before and after tension leveling were compared. Figure 9 shows the effect of tension leveler on camber correction. The horizontal axis is the extension deviation (difference of both edge length of the strip) calculated from camber before tension leveling and the vertical axis is the plastic elongation $\varepsilon_p$ by tension leveler.

When the strip was stretched over the value of extension deviation (hollow circle), strip camber and shape defects were corrected. In this case, strip wandering did not occur. When the strip was stretched under the value of extension deviation (solid circle), strip camber was not corrected or did asymmetrical shape defects remain. In that case, strip wandering was not depressed. Figure 10 shows the effect of tension leveling on depressing strip wandering.
4.2. Correction of Welded Angle Defect $\theta$ by Tension Leveler

Figure 11 shows the relationship between welded angle defect $\theta$ and plastic elongation $\varepsilon_p$. $\theta$ decreases in proportion to elongation. In the case of large $\theta$ ($\theta > 1^\circ$), $\theta$ remains with a small value even under large $\varepsilon_p$, but this part was very localized and hardly effected strip wandering.

4.3. Development of Pinch Rolls to Control Strip Wandering$^4$

Pinch rolls are installed at various positions in CAL and EGL in order to move the strip forward and stabilize strip tension, etc., but do not have enough ability to reduce strip wandering. Strip wandering near the welder in CAL or CGL when coils have no tension, disturbs welding alignment and also influences strip wandering.

The newly developed centering pinch rolls have a unique structure that the roll can bend at its center portion by the eccentric ring, and ability of centering the strip. The physical force to line center works when the bent rolls pinch the strip and rotate, and the strip moves toward the line center naturally, as shown in Fig. 12.

The bending angle of the roll can be adjusted between $0^\circ$ to $2.5^\circ$. The larger the angle of the roll, the bigger the physical force becomes, as shown in Fig. 13. Therefore, the appropriate force is given according to the angle of the roll.

The roll surface is covered completely with neo-plain rubber, so there is no concern about the bent roll being in contact with the strip.

4.4. Development of Hearth Roll to Reduce Thermal Crown$^5$

Various kinds of problems happen in CAL and CGL due to an unexpected thermal crown, which can cause strip buckling or lateral wandering and affect productivity. In order to solve these problems, reducing the thermal crown is necessary.

A newly developed “non-thermal crown hearth roll” has high thermal conductivity material inside its barrel, shown in Fig. 14. Therefore, the roll can disperse the heat from the strip with high temperature and prevent an excessive thermal crown on its barrel. High thermal conductivity material is bonded with its barrel metallurgically, so there is no con-
cern about its separation.

Figure 15 shows the results of the off-line test comparing a conventional hearth roll and a “non-thermal crown hearth roll” which were both heated to 120°C for two hours by an electric heater.

The “non-thermal crown hearth roll” reduces thermal crown remarkably and the appropriate mechanical roll crown is sustained, this prevents operation trouble.

4.5. Development of a Quenching Roll to Reduce the Thermal Crown

Roll quenching is one of the strip cooling methods in CAL. The strip is cooled by contact with the roll that is cooled by a coolant (usually water) from the inside. In applying this method, it is important to unify the temperature of the strip transversely and to prevent shape defects and wandering of the strip when the strip is in contact with the roll.

In order to prevent non-uniform contact between the strip and the roll, a newly developed quenching roll is structured so that the outer sleeve with screw-shaped waterways inside is put on the inner sleeve using a shrink fit method as shown in Fig. 16. Figure 17 shows the effect of this roll compared with a conventional roll in a 1/5 scale model test. Thermal expansion of the roll sleeve which is heated by the strip (0.15 mm thick × 280 mm wide, 300°C × 10 min) is canceled by the initial strain of the shrink fitting.

5. Conclusions

The principal results obtained from the present experimental investigation relating to strip wandering are summarized below:

(1) The main cause of strip wandering is a non-straight form of the strip such as camber and welded joint angle, and the direction of wandering is on the convex side of the strip. Misalignments of the plant have small effect on strip wandering if there is suitable maintenance.

(2) Tension leveling of the strip corrects not only shape defects but also camber and welded joint angle, which effectively depress strip wandering.

(3) Newly developed centering pinch rolls which can be bent at its center portion by the eccentric ring, generate centering force continuously to reduce strip wandering. They are also effective to prevent irregular weld which may have unexpected gap or unexpected angles.

(4) Newly developed “non-thermal crown hearth roll” has a special barrel to which high thermal conductivity material is bonded. It can reduce thermal crown dramatically to keep an adequate mechanical convex crown that is effective in depressing strip buckling and strip wandering.

(5) Newly developed quenching roll is structured so that the outer sleeve with screw-shaped waterways inside is put on the inner sleeve using the shrink fit method. It can reduce thermal crown dramatically to keep adequate mechanical crown that is effective in preventing shape defects and strip wandering.

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