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Development of Bar and Wire Rod Oval Gauge

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Abstract:

At the final rolling mill stand of the Bar and Wire Rod Mill at Steel Bar & Wire Rod Plant, Kurashiki Steel Bar & Wire Rod Dept., Steel Bar & Wire Rod Division, JFE Steel , operators perform a task where they press wooden pieces directly against the steel being rolled to visually assess the rolled shape of the product, which is affected by the height of the mill guide. This wooden piece check is a dangerous operation that poses a significant risk of serious accidents, as operators must enter the vicinity of the rolling stands. Therefore, there was a need to eliminate this task and stabilize the finishing rolled shape of the product through the "visual observation of the oval width." To achieve this, we developed an automatic measurement technique for the oval width using image processing and designed a camera box that includes durability considerations, successfully implementing it in actual operations. This report outlines the details of this achievement.

1. Introduction

The Steel Bar & Wire Rod Plant, Kurashiki Steel Bar & Wire Rod Dept., Steel Bar & Wire Rod Division, JFE Steel (hereinafter, Steel Bar & Wire Rod Plant) manufactures steel bars, Bar in Coil (BiC), wire rod material and related products by continuous rolling through a total of 20 stands, using round billets and square billets produced by the Billet Plant of the Kurashiki Steel Bar & Wire Rod Dept. as the starting materials. At the final rolling mill stand of the rolling line, operators perform inspections by directly pressing wooden pieces against the steel material being rolled and visually judge the non-deformed portion (oval width) of the steel material based on the condition of charring of the wooden pieces in order to assess the acceptability of the rolled shape, which is affected by the height of the guides. Since the operators must enter the line near the mill stands to perform this task, this wooden piece inspection is dangerous work with a significant risk of a serious accident.

With the aim of eliminating this dangerous task and stabilizing the finished rolling shape after elimination, JFE Steel developed an "oval gauge" device that automatically measures the oval width to enable visual observation of the oval width.

This paper introduces the background of the development of the oval gauge, its specifications and the results of verification of its accuracy.

2. Steel Bar & Wire Rod Plant and Round Cross Section Material Rolling Process

The Steel Bar & Wire Rod Plant comprises the material finishing line, heating line, rolling line, steel bar line and wire rod line. The rolling line is a continuous rolling process consisting of rough rolling (A, B, No. 1–6 stands), intermediate rolling (No. 7–12 stands) and finish rolling (No. 13–18 stands).

In finish rolling of materials with round cross sections, caliber rolls that alternately perform oval forming and round forming are used, and a substantially perfect circle cross section is obtained at the final stand. The term "perfect circle" is used here for purposes of explanation, but section formed in the finishing stand is actually circular shape in the process of forming a perfect circle from an elliptical shape.

Each stand is equipped with caliber rolls and guides to guide the steel material into the caliber. After adjusting the caliber center and the pass line center to the same height by moving the entire stand upward or downward, the operator prepares the mill for rolling by fine adjustment of the guide height.

An overview of the Steel Bar & Wire Rod Plant is shown in **Fig. 1**, and the appearance of a rolling stand is shown in **Photo 1**.

3. Definition of Oval Width

The caliber rolls of the finish rolling stands have a roll gap as an escape allowance for the steel filling part by rolling. This part, which is called an oval, includes the steel filling part and non-rolled part of the material which are not in contact with the rolls. **Figure 2** shows

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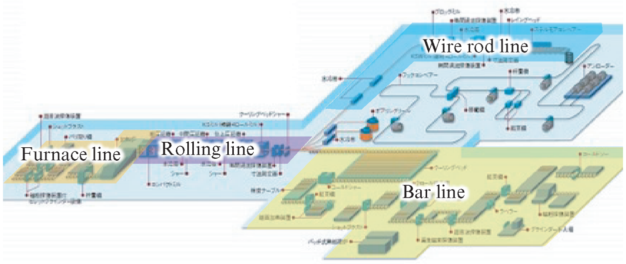

Fig. 1 Overview of bar and wire rod line plant

Photo 1 Overview of stand

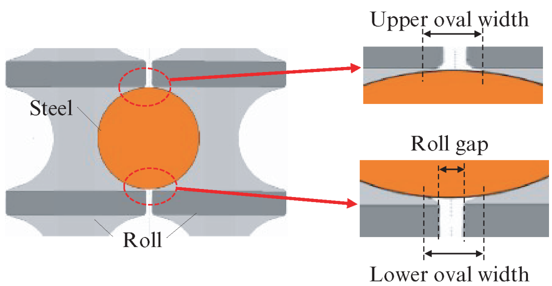

Fig. 2 Definition of roll skew and ovality in caliber rolls at even-numbered stands

the definition of roll gap and ovality in the even-numbered stands.

- Oval: Steel filling part and non-rolled part not in contact with the rolls
- Oval width: Oval length in the steel circumferential direction (at No. 16 finishing stand, about 3.0 to 5.0 mm)
- Oval width difference: Difference between the upper oval width and lower oval width

4. Factors Causing Oval Width Difference

A difference in the oval width is caused by deviations of the height adjustment of the guides, and is used as the criterion for pass/fail judgments of the rolled shape. In the following explanation, No. 16 stand is used as an example. When the material formed to an oval shape at No. 15 stand, which is the preceding odd-numbered stand, is passed through No. 16 stand, an even-numbered stand, the steel filling part of the oval is formed to a circular shape. Ideally, the upper

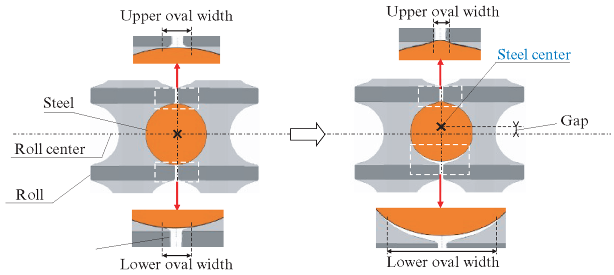

Fig. 3 Relationship between guide height adjustment due to differences in oval width and rolling product shape

and lower oval widths should be the same at this time, and in this case, the center of the oval steel filling part of the material being passed (height of the guides) coincides with the center of the caliber rolls. However, if the center of the oval steel filling part deviates from the center of the caliber rolls, the circular shape will collapse due to the deviation of the center of the steel filling part which is formed from the oval shape to a circle, resulting in a difference in the upper and lower oval widths. Therefore, at the final rolling stand, the rolling shape is stabilized by adjusting the guides of the first material in each rolling lot so that the center of the steel material is guided into the center of the caliber rolls.

Figure 3 shows the relationship between the guide height adjustment due to differences in the oval width and the rolling product shape.

5. Oval Width Adjustment by Wooden Piece Inspection Work

Pass/fail judgments of the shape (oval width) resulting from finish rolling are performed by visual judgment of the charring of the upper and lower wooden pieces which the operator presses directly against the steel from above and below during rolling at delivery side of final stand. This task is called wooden piece inspection work. The range where charring of the upper and lower wooden pieces is slight is judged to be the oval width. When the difference between the upper and lower oval widths is larger than the standard value, the guides are adjusted so that the center of the material being passed is guided into the center of the caliber rolls.

However, this manual wooden piece inspection work poses the risk of a serious accident because the operators must enter the area near the rolling line stands to perform this inspection.

Photo 2 shows the wooden pieces used in wooden piece inspections and the condition of charring of the pieces. **Photo 3** shows a scene of the wooden piece inspection work.

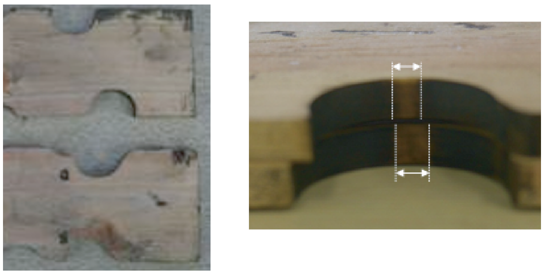

Photo 2 Use of wooden pieces in inspection tasks and conditions of charred wooden pieces

Photo 3 Inspection procedure using wooden pieces

6. Development of Oval Gauge

6.1 Key Points in Development and Study of Measurement Method

The key points in the development of the oval gauge were as follows:

① Feasibility: Stable observation (visualization) of the oval width under a poor environment must be possible.

② Reliability and high accuracy: Measurement of the oval width with at least the same accuracy as in wooden piece inspections must be possible. The target measurement accuracy was 0.2 mm or less.

As the candidate measurement methods, the 2D laser distance measurement method, temperature distribution measurement method using an infrared heat imaging device, and self-luminous CCD method were tested and studied in advance, and the self-luminous CCD camera method using the visible spectrum was adopted. **Table 1** shows a comparison of the measurement methods.

In the design of the optical system (camera), considering the dimensions of the intended installation place, depth of field, etc., the camera adopted was a model BG0303, 300K pixel CCD area camera manufactured by Toshiba Teli Corporation. The camera specification and installation environment are shown in **Table 2**.

6.2 Design of Camera Box Considering Resistance to Environment

Since the cameras are to be used under a poor environment with a large amount of roll cooling water and large scattering of scale, a stainless steel box structure was adopted, and the following measures were taken.

① Monitoring of the temperature in the box by temperature sensor

Table 2 Camera specification and installation environment

Bar diameter	φ16.0 to φ27.2 mm
Bar temperature	Approx. 900 to 1 100°C
Environment	Roll cooling water : large quantityScale scattering : large quantity
Installation space width	<150 mm

Table 1 Comparative results of measurement methods

Method	2D laser distance measurement method	Temperature distribution measurement method (infrared)	Self-illuminating CCD method (visible light)
Pre-test	Shape measurement of cold samples	Temperature distribution measurement of steel during rolling	Camera imaging of steel during rolling
Advantages	• Capable of high-precision measurement of steel shape • High-speed response	• Temperature distribution measurement possible	• Luminance distribution measurement possible • High sensitivity • High pixel resolution
Disadvantages	• Shape discrimination of the oval part is not possible • Significant influence of the measurement surface characteristics	• Temperature distribution has irregularities • Low pixel resolution • Low sensitivity	• Adjustment of lens, shutter speed, gain, and other parameters required
Evaluation	×	△	○

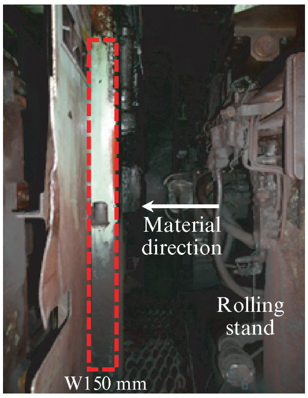

Photo 4 Installation space conditions

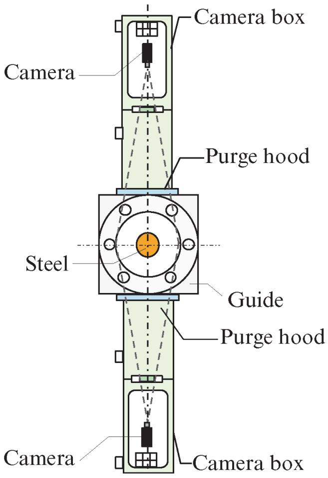

Fig. 4 Overview diagram of oval gauge

② Structure that enables exchanges of the protective glass
③ Dust-catching cover

Photo 4 shows the conditions of the installation space, and **Fig. 4** show a schematic overview of the oval gauge.

6.3 Oval Extraction Processing by Image Processing

Since an accurate grasp of the upper and lower oval widths is critical for accurate measurement of the oval width, the processing method was designed, focusing on width expansion/contraction processing considering pass line variations and lateral deviations as the key point.

Based on the principle of the camera, it is assumed that the size of the steel material in the image will change as a result of fluctuations in the distance between the camera and the steel due to vertical movement of the pass line, and the steel material may be displayed on the right or left side of the camera field of view due to movement to the right or left during lateral deviations. Measurement error occurs as a result of these fluctuations.

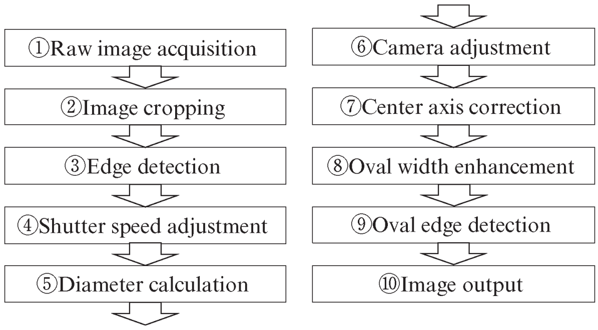

Fig. 5 Process flow for oval width detection using oval gauge

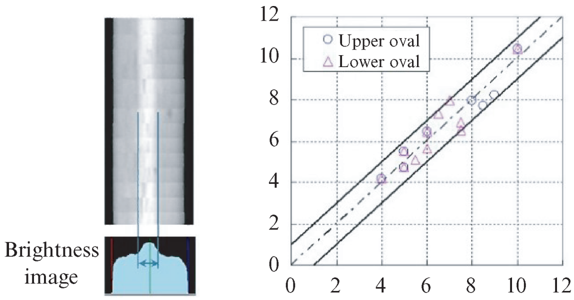

Fig. 6 Comparative results of oval width measurement using oval gauge and actual material

The following processing flow was adopted to solve these problems: After first performing steel edge detection processing by binarization of the observed images, followed by a series of processing operations that includes automatic shutter speed adjustment processing, steel diameter calculation processing, steel diameter vertical unification processing and steel lateral deviation processing, finally, luminance value maximization/minimization processing and luminance difference enhancement and luminance image differential value search processing are performed. **Figure 5** shows the process flow for oval width detection using the oval gauge.

7. Verification Results

To verify the accuracy of the developed oval gauge, the oval width of the verification target material measured by the developed oval gauge, and the oval width obtained by manual measurement of the oval part of the actual material after cooling and thermal dimension conversion were compared.

As a result of verification of the oval width in the range of 4–10 mm, the average error value was within±0.2 mm, achieving the target accuracy. The results of a wooden piece inspection were also confirmed at the time of this verification. Although there were variations in the oval width by the degree of charring, in this case as well, the values were almost the same when the oval width of the actual material after cooling was calculated by thermal dimension conversion. **Figure 6** shows the comparative results of the oval width measurements using the oval gauge and the actual material.

8. Conclusion

In-house development of a new oval gauge was carried out to eliminate dangerous work (wooden piece inspection work) and stabilize the condition of the finish rolled product shape at the Steel Bar & Wire Rod Plant at JFE Steel's Kurashiki Steel Bar & Wire Rod Dept., Steel Bar & Wire Rod Division.

In the developed oval gauge, stable measurement is achieved by installing a camera box to house the optical system in consideration of environmental resistance under the poor environment in the plant, and the oval width is detected by image processing to enhance feature values, contributing to stabilization of the finish rolled product shape.