JFE TECHNICAL REPORT
No. 9 (Mar. 2007)

Development of Surface Detector for No. 3 Tin Temper Mill (3TMP)†

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Abstract:

A newly-developed roll-surface defect detector which was installed at No. 3 tin temper mill (3TMP) at JFE Steel's West Japan Works (Fukuyama District) is introduced. In this system, defect images are detected by an all-purpose charge coupled device (CCD), and an original logic which was developed focusing on the periodic nature of roll defects is applied to judge defects. Although it was impossible to detect extremely small defects with the conventional technology, as such defects were below the noise level, the new system enables detection of these defects by defect recognition using only periodic signals.

1. Introduction

Production at the Tinplate Plant at JFE Steel's West Japan Works (Fukuyama District) centers on tinplate materials for use in beverage and food cans and tin mill black plate (TMBP).

In beverage and food can applications, in addition to the conventional requirements of corrosion resistance (compatibility with the can contents), strength, and formability, increasingly high quality requirements have been placed on surface properties (appearance and design properties) with each passing year. Further improvement in quality assurance (QA) is necessary and indispensable to satisfy these requirements.

2. Necessity of Roll Defect Detector

One important factor which is an obstacle to improved QA for tinplate and TMBP is roll marks. At No. 3 tin temper mill (3TMP) at West Japan Works (Fukuyama District), a product defect, called "roll marks" generated when foreign material adheres to the strip during rolling, is picked up by a work roll, and marks caused by this material are then transcribed back onto the strip each time the roll rotates. Thus, as shown in **Fig. 1**, a distinctive feature of rolls marks is the fact that they are transcribed onto the strip at a pitch corresponding to the diameter of the work roll. Because this is a high speed line, this defect is difficult to discover by flying inspection, and in many cases, it is only discovered in a succeeding process, resulting in rejection. In other words, roll marks occur along the full length of the steel strip with a regular periodicity corresponding to the roll diameter, and are an extremely harmful defect which can result in mass rejection once a defect occurs. In spite of this, discovery is exceedingly difficult by flying inspection under high speed operation. As a result, countermeasures to prevent roll defects by roll cleaning and roll exchanges are delayed, and by reducing the product acceptance rate, roll marks have become a main cause of late deliveries.

A roll-surface defect detector (hereinafter, surface detector) was installed at 3TMP to solve these problems, further improve QA, and at the same time, improve product quality by reducing the reject rate due to defects.

The target values in the installation of the surface detector were detection of more than 90% of roll marks with heavy defect grades and reduction of the defect reject rate by one-half.

This paper describes the content of development in

† Originally published in *JFE GIHO* No. 12 (May 2006), p. 17–21


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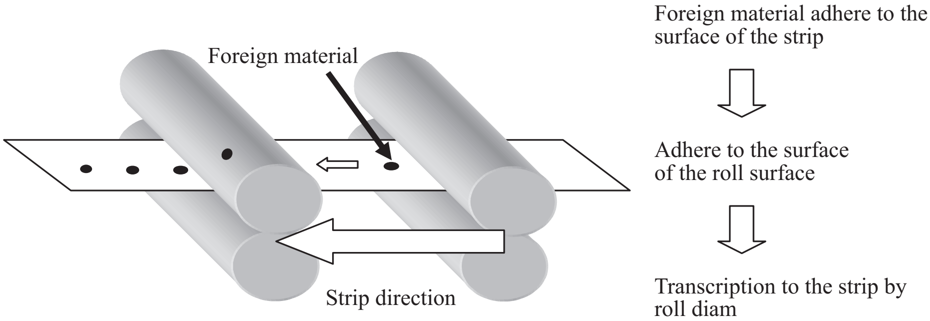

Fig. 1 Mechanism of roll mark

the introduction of the surface detector and the results after introduction.

3. Outline of Fukuyama 3TMP Equipment

Fukuyama 3TMP is a 4 High-2 Stands (4Hi-2Std) mill, in which a pair of work rolls and backup rolls are stacked in a straight line. The basic line specifications and product specifications are shown in **Tables 1** and **2**, respectively, and a schematic diagram of the line is shown in **Fig. 2**.

Table 1 Line specification

Capacity	50 000 t/mouth	
Line speed	1 500 m/min (maximum)	
Mill type	4 High-2 Stands	
Work roll	#1 Stand	500–414 × 1 425 mm
	#2 Stand	620–520 × 1 425 mm
Back-up roll	#1 Stand	1 420–1 320 × 1 425 mm
	#2 Stand	1 420–1 320 × 1 425 mm

Table 2 Products size

Strip thickness	0.08–1.2 mm	
Strip width	508–1 270 mm	
Coil weight	maximum 34 t	
Inside diameter	Entry	508, 610 mm
	Delivery	508, 610 mm
Outside diameter	Entry	maximum 2 340 mm
	Delivery	maximum 2 340 mm

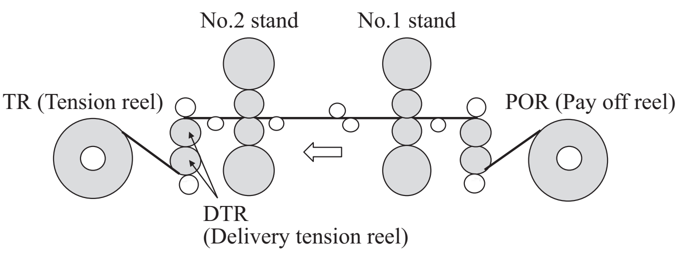

Fig. 2 Fukuyama No. 3 TMP

4. Necessary Performance in Roll Mark Detection and Content of Development

4.1 Realizing High Speed Processing/ High Resolution

As mentioned previously, 3TMP is a high speed line with a maximum line speed of 1 500 m/min. On the other hand, the size of roll marks, which are the defect to be detected, is on the order of 0.5 mmϕ. To enable surface inspection on this type of high speed line, high speed defect signal processing and, at the same time, improved camera resolution are necessary.

Because conventional defect detectors, represented by all-purpose CCD-type defect detectors, had a slow processing speed (frequency), conventional detectors could not satisfy resolution requirements in both the cross-web (strip width) and down-web (strip longitudinal direction), and therefore could not be applied to high speed lines. However, remarkable progress has been achieved in CCD-type defect detectors in recent years[1], and their processing speed has increased greatly. Although the conventional frequency was 10–20 MHz, the frequency of the most recent cameras is 40 MHz. This means that processing at a rate of 40×10^6 pixels/s is now possible.

For example, with a line-scan sensor camera (1-dimensional scanning) with 1 024 bit performance, scanning by 40×10^6 pixels/1 024 = 39 062 scans/s is possible. Because of 1 500 m/min equal to 25 m/s, one scan is equal to 0.64 mm. This is the down-web resolution.

Cross-web resolution is improved by increasing the number of camera units and the number of bits. Because the maximum strip width at 3TMP is 1 270 mm, the coverage per camera with a 4-camera system is 1 270 mm/4 cameras = 317.5 mm. If the number of camera bits is 1 024, 317.5 mm/1 024 = 0.31 mm as cross-web resolution. Considering the size of the roll marks which were the object of detection in this development project, a

Table 3 The suitable condition camera resolution

Case	Pixel	Amount	Resolution (Crossweb)	Resolution (Downweb)	Judgement
1	1 024	4	0.32 mm	0.64 mm	Adoption
2	2 048	2	0.32 mm	1.28 mm	Resolution: Less
3	2 048	4	0.16 mm	1.28 mm	Resolution: Less

Defect size: Minimum ϕ 0.5 mm
Camera frequency: 40 MHz
Inspection view: 1 290 mm (Production maximum + 20 mm)
Inspection speed: 1 500 m/min

decision was made to adopt four 1 024-bit cameras. A comparison of the respective cases is shown in **Table 3**.

4.2 Realizing High Accuracy

For application to a high speed line, separation of defect signals and noise is essential. Therefore, focusing on the periodicity which is a distinctive feature of roll marks, the authors (1) constructed a periodic defect judgment function and (2) optimized the defect threshold, and applied these features to the high speed line.

4.2.1 Periodic defect judgment function

A new periodic defect judgment function[2)] which is robust with respect to noise was constructed.

When the number of defects with the same period exceeds a set number in a certain judgment zone, the defect is judged to be a periodic defect. For example, assuming the judgment section has a period of X, and defining the number of defects for judgment of a periodic defect as Y individuals, when the X period is measured and the pitch of Y or more individuals is in agreement, a periodic defect (appearance of a roll mark) is judged. An outline is shown in **Fig. 3**. Assuming hypothetically that all pitches are in agreement at the timing of the Y period, a periodic defect is judged at that timing. If the number of defects with the same period is less than Y individuals, a periodic defect is not judged.

The values of X and Y can be set up at will, and 10 roll diameter settings are possible. These have been set in advance based on the diameters of the work rolls actually used at 3TMP.

This method not only simplified the computational function, but because a check of periodicity is performed, also made it possible to judge defects even if defect signals of a certain intensity do not occur continuously.

In contrast, with the conventional method, computational processing had been performed only after recording all signals in the cross-web direction, and it was not possible to judge periodicity if a certain signal intensity could not be obtained[3–5)].

4.2.2 Optimization of defect threshold

In cases where it is difficult to separate noise and defect signals, setting of a threshold exceeding these signal values was unavoidable from the viewpoint of preventing over-detection. However, this meant that it was extremely difficult to detect tiny defects with weak signals. With the newly-developed surface detector, it was possible to overcome this problem by constructing a logic which focuses on periodicity. Because defect recognition is not performed for signals without periodicity (including noise), over-detection can be prevented even if the threshold is reduced to near the extreme limit.

In other words, with conventional devices, it was difficult to detect defects below the noise level, but with the new surface detector, it was possible to separate these signals from noise by focusing on periodicity. This made it possible to detect tiny defects below the noise level. **Figure 4** shows an outline.

4.2.3 Image data storage function

As an additional feature of the surface detector, it is possible to store defect signals as image data irrespective of periodicity. This makes it possible to identify the

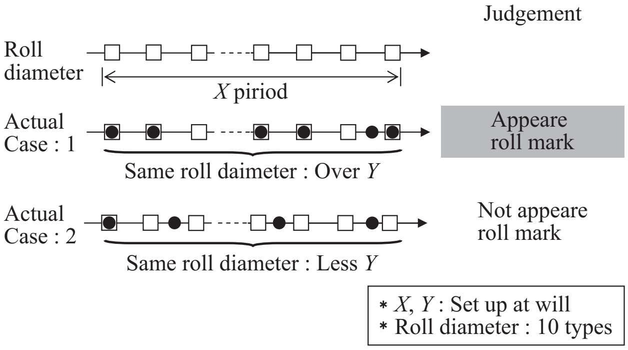

Fig.3 Judgement mechanism of roll mark

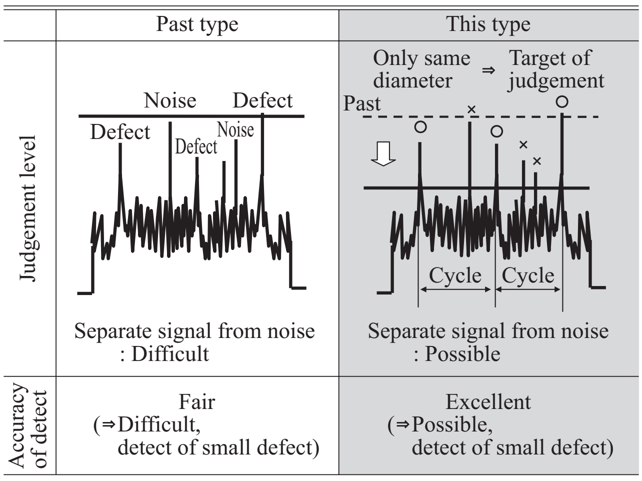

Fig.4 The most suitable condition of judgement level

type of defect in cases where a large transient signal without periodicity is detected.

5. Outline of Surface Detector

5.1 Detector Specification

The specifications of the surface detector installed at 3TPM are shown in **Tables 4**, **5**, and **Fig. 5**. Because this system performs inspections using high performance CCD cameras, it was installed above the delivery tension reel (DTR) in order to prevent external disturbance noise accompanying vibration of the steel strip. Moreover, considering the fact that approximately 90% of roll marks occur on the top side of the strip, the system was installed only on the top side. Stable inspection conditions were secured by hanging installation.

5.2 Defect Judgment Logic

Figure 6 shows the defect judgment logic.

As the defect judgment method, the judgment of the defect concerned is made through a sequence of two large processes comprising (1) defect recognition and (2) periodicity judgment.

As defect recognition, the system is equipped with functions for binarization processing, mura defect processing, and streak defect processing. The results of an advance study showed that roll marks are detected by binarization.

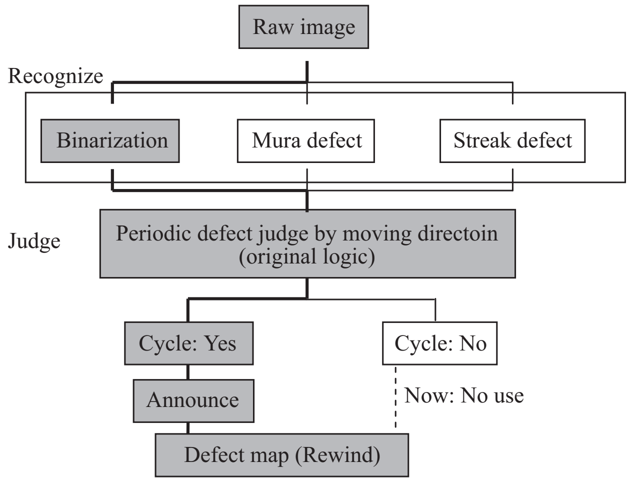

Fig. 6 Logic of defect recognition

Periodicity judgments are made for defects which exceed a set threshold by measuring the pitch of each signal (section 4.2.1). Defects which coincide with the periodicity judgment are judged to be periodic defects (i.e., roll marks). The system enables the operator to recognize this condition instantly by voice announcements and lighting of a rotary beacon light.

Table 4 Surface detecter specification

Camera	1 024 bits line sencer CCD × 4
Inspection field	1 290 mm (Production + 20 mm)
Resolution	0.3 mm × 0.7 mm
Overlap	10 mm
Light source	High frequency fluorescent light

Table 5 Inspection condition

Line speed	1 500 m/min
Rewind Length	99 999 m
Meander	± 10 mm
Thrash	± 1 mm

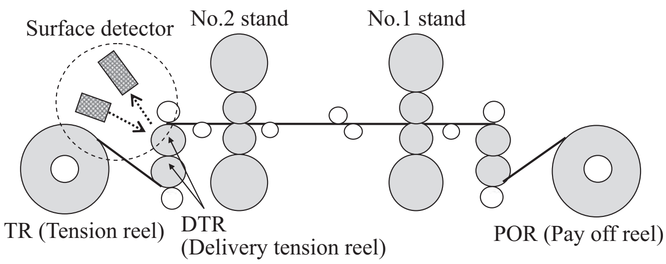

Fig. 5 Place of the “surface detector”

5.3 Recording of Inspection Results

To make it possible to grasp the position where a defect has occurred at a glance, the inspection result can be output as a 1-page A4 rewind defect map.

6. Condition of Application at Actual Line

6.1 Results of On-line Validity Test

The results of an on-line validity test are shown in **Fig. 7**. The object of this investigation was whether the surface detector detected roll marks which were discovered in the succeeding process or not.

When adjusted for the defect threshold and periodicity judgment logic by coil, the following results were

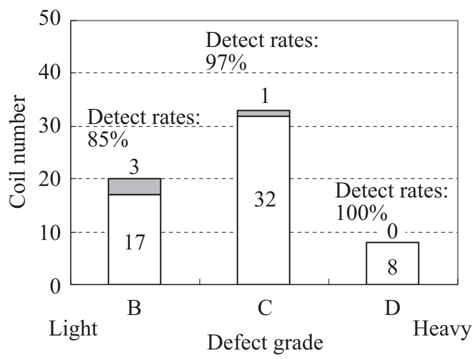

Fig. 7 Percentage of detect (Roll mark)

obtained.

For roll marks with heavy defect grades, the detection rate was 97% or higher, satisfying the development target. A detection rate of 85% was also secured for roll marks with light defect grades.

6.2 Transition of Reject Rate for Roll Marks

The introduction of this surface detector made it possible to take early countermeasures when a defect occurs, resulting in a large reduction in both the reject rate and reject amount (**Fig. 8**). Before installation, the reject rate was approximately 0.4%, but after installation, this was reduced by half, to 0.2%, amply demonstrating the effect of the surface detector.

As the background to this improvement, application of this device enabled early discovery of defects, and thus made it possible to obtain a quantitative grasp of the position of occurrence, line speed, and other factors at the time when the defect occurred, which had been impossible with the conventional technology. As a result, effective operating methods for preventing the occurrence of defects have been discovered.

Information is fed back not only to the 3TMP process itself, but also to upstream processes, depending on an analysis of the defect origin, and thus is also beneficial in concerted efforts to eliminate roll marks by all concerned.

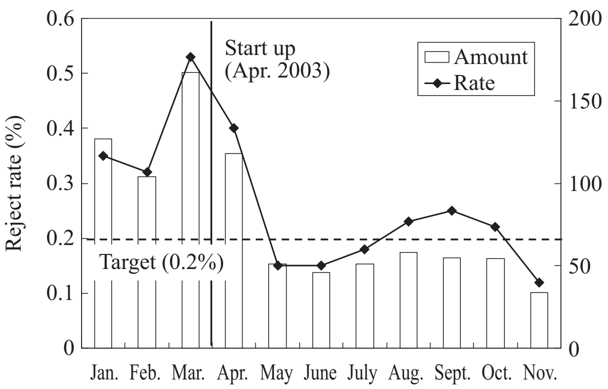

Fig. 8 Trainsition rate of out of grade

7. Conclusions

The content of this report may be summarized as follows.

(1) Separation of defect signals and noise was greatly improved by constructing a periodic defect judgment function. This has improved defect detection accuracy, making it possible to detect more than 97% of roll marks with heavy defect grades. As a result, it was possible to achieve the original development target for defect detection. Where the remaining 3% is concerned, a decision was made to maintain quality by the conventional method of visual inspection in the following process.

(2) Construction of an original defect judgment technology made it possible to apply all-purpose CCD-type surface defect detectors.

(3) Utilizing the above-mentioned effects, the newly-developed surface detector was successfully applied to a high speed line while maintaining high accuracy.

(4) Introduction of the surface detector enables early countermeasures when roll marks occur, and as a result, the defect reject rate has been reduced by half.

One of the features of the surface detector[6] is storage of defect images (section 4.2.3). The fact that this function is useful in analysis of the origin of periodic defects is considered extremely important effect.

For example, as a result of an investigation of defect images showing the origin of roll marks, it was possible to recognize the existence of scab (defect originating in steelmaking or hot rolling, which exists on the surface of the steel sheet). This case is shown in **Fig. 9**. In other words, it is possible to estimate that the cause of the roll mark in this case was passage of scab.

The authors intend to make effective use of the image data function to realize roll mark-less operation by utilizing this function in analysis of the origin of roll marks, including countermeasures not only at the 3TMP line, but also in upstream processes.

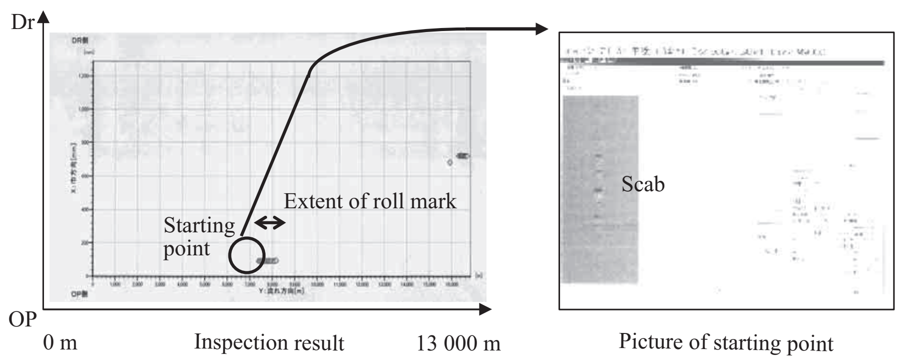

Fig. 9 The way of practical use by defect picture

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