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Automatic Surface Inspection System for Tin Mill Black Plate (TMBP)†

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Abstract:

This paper introduces an automatic surface inspection system applying a charge coupled device (CCD) line scan camera, which was installed at a continuous annealing line at JFE Steel. The line is the final product manufacturing line for tin mill black plate (TMBP) and has the world's highest operating speed. The resolution of the camera during surface inspections is 0.17 mm (cross-web) × 1.25 mm (down-web) at a strip speed of 1 400 m/min, and a defect detection ratio of 95.5% has been achieved. Since installation of this system, complaints related to strip surface quality have decreased to 1/20 of the former level. An adjustment method using artificial defects and a daily check method using the weld point, which is the joint between product coils, were also established, establishing a system for maintaining the accuracy of the inspection system.

1. Introduction

At JFE Steel's East Japan Works (Chiba District), final inspections of tin mill black plate (TMBP) are performed at the temper mill at the delivery side of the line or at the continuous annealing line (CAL), which has been integrated as a continuous process with the finishing line (trimmer and oiler). JFE Steel's No. 4 CAL operates at the world's highest line speed, with a maximum speed of 1 000 m/min in the furnace section[1)], and achieves a maximum speed of 1 400 m/min in the delivery section where inspections are performed, as shown in **Fig. 1**. Automated equipment was introduced at an early date for the thickness gauge, pinhole detector, and other devices used for quality assurance, but inspections of the strip surface were performed visually by an inspector. However, due to the high speed in the section where inspections are performed and the increasingly strict levels of surface quality required by customers, the limitations of visual inspections had become apparent. An automatic surface defect inspection system was therefore installed at the CAL in order to realize automation of strip surface inspections. As original JFE Steel functions, a pass-fail judgment function and a daily check function to secure the reliability of the equipment were added to the system, further strengthening the quality assurance system for the strip surface.

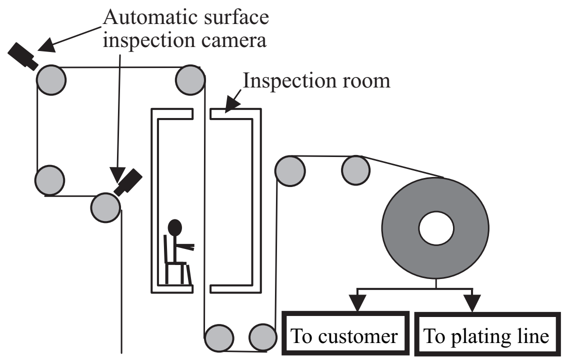

Fig. 1 Layout of delivery section of continuous annealing line

2. Outline of Surface Defect Inspection System

Various types of surface defect inspection devices are available, including laser-type devices and methods using the charge coupled device (CCD) line scan camera or CCD area scan camera[2–5)]. Among these, the laser type has conventionally been adopted in the steel indus-

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try, but as one problem with this method, adequate performance could not be obtained at high speed lines due to limitations on the laser spot diameter irradiated for inspections. Therefore, the CCD line scan method has been adopted, as this method provides sufficient resolution even at high speed lines, has a high defect detection capability which includes not only roughness-type defects, but also pattern-type defects, and offers more uniform detection performance in the detection field than the CCD area scan method[6–8].

In order to decide the specifications of the system, first, surface defects were divided based on defect type and level into defects which must be detected (MUST defects) and defects that the user wants to detect if possible (WANT defects), as shown in **Table 1**, and off-line tests were performed to determine whether the MUST defects could be detected or not. The camera angle and resolution were decided based on the results. The cameras consist of bright field cameras and dark field cameras. This configuration was adopted because detection capacity is improved by using two types of camera with different angles, and the accuracy of the defect type judgment function is improved by using the feature volumes of defects photographed by the respective cameras. In order to secure the necessary resolution in the cross-web (strip width direction), four cameras were installed in the cross-web direction, for a total of 16 cameras on the two sides of the strip. As shown in **Table 2**, this arrangement achieves a resolution of 0.17 mm (cross-web) × 1.25 mm (down-web).

Table 1 Classification of request for detect defect

Defect type	Pattern	Slight ← Level → Heavy				
		A	B	C	D	E
Defect A	Suddenly	W	M	M	M	M
Defect B	Cyclic	W	W	M	M	M
Defect C	Continuously	Z	Z	Z	Z	Z

Detect demand

M : Must W : Want Z : Needless

Table 2 Surface inspection machine specifications

CCD Camera type	CCD Line scan camera Resolution : 2 048 pixels Data rate : 40 MHz
Camera number	· Top 8 cameras bright/dark field · Bottom 8 cameras bright/dark field
Field of view	1 300 mm
Resolution	Cross-web : 0.17 mm Down-web : 1.25 mm
Light source	Halogen lamp

Figure 2 shows the system configuration. Among the features of the system, as described above, defect images are captured using two cameras (bright field and dark field), and feature volume calculations, judgments of the defect type, and over-detection prevention processing are performed by software. Six types of thresholds are used in extracting candidate defects. Examples are introduced below.

The automatic following threshold is applied to extraction of defects with comparatively slight roughness in the surface profile, while the differential threshold is effective for extraction of minute defects with roughness and the down-web integral threshold is effective for extraction of linear defects. These thresholds are set by reducing their values to a level where the defect which is the target of detection can be reliably extracted.

When thresholds are set in this manner, noise (harmless defect) is also identified as a candidate defect, but as a measure against this problem, reliable detection/judgment are possible by performing defect type judgment using the feature volume and separating harmless defects and harmful defects by the over-detection prevention function.

It may be noted that the defect feature actually used include 120 types. Inspection results are stored in a data-

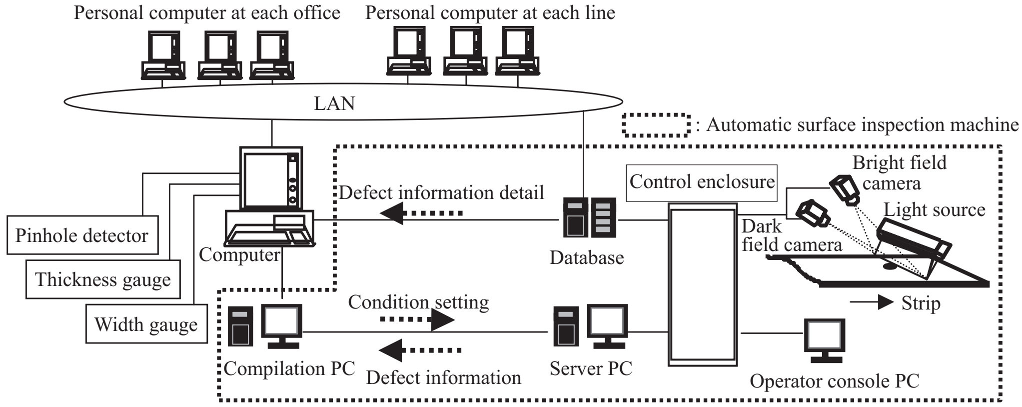

Fig. 2 System configuration of automatic surface inspection machine

Table 3 Judgement of the coil results

Defect ratio allowance	Slight ← Defect level → Heavy				
	A	B	C	D	E
① Level-A	Under percentage of X1		Under percentage of Y1		0%
② Level-B	Under percentage of X2		Under percentage of Y2		0%

base, and this defect data can be accessed and examined in the office and from personal computers at other lines via the steel works network.

As shown in **Table 3**, pass-fail judgments of product coils are made by an upper-level computer based on data on the defect inclusion ratio and the pass-fail judgment standards of each product specification.

3. Performance of Surface Defect Inspection System

The detection ability of the surface defect inspection system is shown in **Table 4**. In evaluating detection ability, first, a decision tree-type discrimination logic for defect types and defect classes was prepared off-line using sample defects. Next, multiple coils were actually passed on the line, and the defect type accord ratio (agreement of defect type) was evaluated by visual inspection in the following process[9,10]. The fact that the level would not cause the problem of over-detection was also confirmed by the same method.

The defect type accord ratio is shown in **Table 5**. The numbers in this table are the number of defects detected,

Table 4 Detection ability

Item	Result
Detection rate	95.5%
Defect type accord rate	92.9%
Defect level accord rate	93.3%

Table 5 Defect type accord

Machine \ Person	①	②	③	④	⑤	⑥	⑦
① Scab	26	0	0	0	0	0	0
② Sliver	3	30	2	0	0	0	0
③ Scale	1	1	45	1	1	0	0
④ Gauge	1	0	0	12	0	0	0
⑤ Scratch	0	0	2	0	20	0	0
⑥ Roll mark	0	0	0	0	0	28	1
⑦ Oil Spot	0	0	0	0	0	1	21

(shaded box): Defect type of machine detected was in accord with actual type.

and the shaded areas in the diagonal line represent the number of cases in which the type of defect detected by the surface inspection system and the actual defect type were in accord.

Examples of detected defect images are shown in **Photo 1**. The fact that images with a near-visual feeling can be obtained, as shown here, is an advantage of the system. These images are also stored in the database and are effectively utilized.

4. Maintenance Control of Inspection System

Because it is possible to use the detection results obtained with this system in pass-fail judgments of products, the system occupies a position as an indispensable device for quality assurance. Therefore, the maintenance control system is important to main tain the reliability of the system.

4.1 Establishment of Precision Inspection Method

As a key point for maintaining the accuracy of the inspection system, bright field and dark field cameras with different angles must be able to photograph identical positions with the prescribed sensitivity at all times.

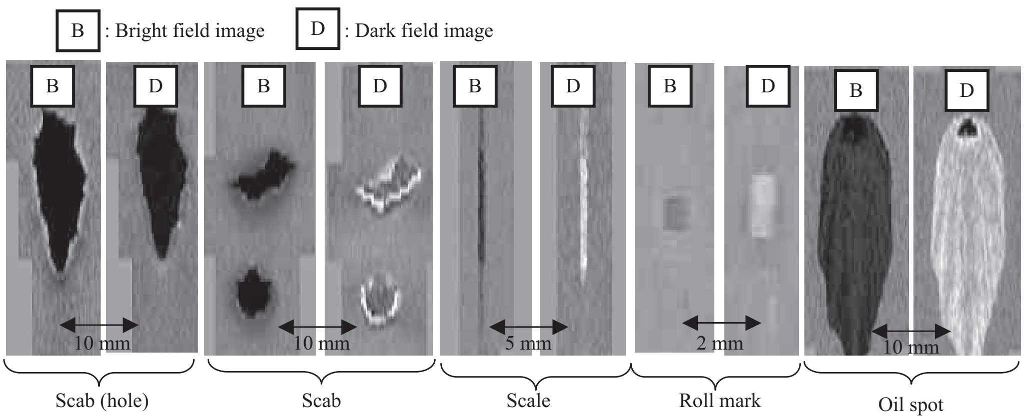

Photo 1 Example of the defect image

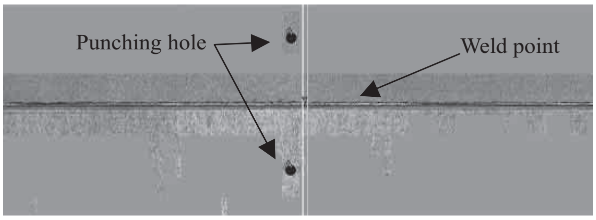

Photo 2 Weld point image for daily check

For this, original artificial defects have been prepared and are used when adjusting the system. These adjustments are performed when cameras are exchanged and when an abnormality is discovered in daily checks, as discussed in the following section. Maintenance of inspection accuracy is confirmed by periodically performing equipment inspections at intervals different from these.

4.2 Establishment of Daily Check Method

As a basic principle of the quality system, when equipment is being used as a quality assurance (QA) device and its accuracy in an equipment inspection is outside of the allowable range, it is necessary to trace the operation back to the last normal inspection and hold the product which was processed since that inspection as possible nonconforming product. For this reason, a simple equipment inspection method with a short cycle is necessary. An inspection method using the punching holes at strip weld points was established as such a method. At continuous lines, a weld point and punching holes exist in the strip width direction at the point where the succeeding strip was joined to the preceding strip. Using these, an on-line function for confirming the accuracy of the inspection system was provided.

Because the area around welds between strips is an unsteady part in temper rolling, this part is normally not treated as product and is therefore outside the inspection range. However, in the daily check method for the new automatic surface inspection system, this part is included in the inspection range, and images of the area around the weld (**Photo 2**) are used in daily checks. Daily checks are performed by (1) inspecting the diameters of the punching holes and length by checking the distance between the holes and (2) inspecting brightness by checking changes in the color density of the punching holes. This has made it possible to perform on-line daily checks of the new inspection system. All of this work has been standardized, and the accuracy of the new inspection system is now controlled by performing checks at a frequency of once/day or more often.

5. Effects

Introduction of the automatic surface inspection system has made it possible to contain defects, and as a result, complaints related to nonconforming strip surface quality have been reduced to approximately 1/20 of the former level. Automation of pass-fail judgments has eliminated deviations in judgments, achieving stabilization of product quality.

6. Conclusions

(1) An inspection system with resolution of 0.17 mm (cross-web) × 1.25 mm (down-web) under a high line speed environment of 1 400 m/min was introduced, and a defect detection rate of 95.5% was achieved.

(2) In order to improve the judgment function with respect to the defect type, in this system, two types of cameras (bright field, dark field) are used, and defect types are distinguished by the software. A defect type accord rate of 92.9% and the defect level accord rate of 93.3% were achieved.

(3) A control system for maintaining the accuracy of the new inspection system was created by establishing an equipment adjustment method using artificial defects and a daily check method using the weld points between coils.

(4) Introduction of the automatic surface inspection system has reduced complaints related to strip surface quality to 1/20 of the former level and stabilized product quality.

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