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An On-line Measurement of Hot Strip Profile

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Synopsis :
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The body can be viewed from the next page.

An On-line Measurement of Hot Strip Profile*

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Two sets of hot strip profilemeter installed at Chiba Works; a No. 1 for No. 2 mill in March, 1979, a No. 2 for No. 1 mill in March, 1980; feature a combination of two high-precision X-ray thickness gages—the fixed type and the scanning type. The measuring system has been operating smoothly, contributing greatly to a high-precision measuring of strip crown and 'high spot'. The results of tests on this development are summarized as follows:

(1) The profilemeter can detect 'high spots' of more than 4 μm in height and 5 mm in width in off-line tests and those of more than 5 μm in height and 10 mm in width during rolling.

(2) It can measure the strip crown and wedges at an accuracy of within ±10 μm.

(3) Regardless of strip profile changes during the scanning of the gage, the profilemeter output shows good correspondence to values measured by the γ-ray thickness gage in the subsequent line.

1 Introduction

Two profilemeters were introduced into hot strip mills of Chiba Works; the one for its No. 2 mill in March, 1979 and the other for its No. 1 mill in March, 1980. They measure the thickness and profile of the strip on-line as an important quality control measuring system.

This report centers on the following features of this system.

(1) Specifications of X-ray thickness gage and profile measuring system.
(2) Precision of thickness gage.
(3) Detectability of strip crown and 'high spot' (abnormal projection) in off-line and on-line tests.
(4) Profilemeter operating method.

2 Specifications of X-ray Thickness Gage and Profile Measuring System

2.1 Constitution of Profilemeter System

2.1.1 Constitution of profilemeter

Fig. 1 shows the layout of the profilemeter and **Fig. 2** the constitution of the system.

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The profilemeter is composed of three main components: a 'fixed' thickness gage that measures the center thickness of the strip, a 'scanning' gage that measures strip thickness while moving in the widthwise and a profile calculator. The difference between the two measured values obtained by the fixed gage and by the scanning gage is calculated by the profile calculator and its result is fed to a mill control computer and a recorder.

2.1.2 Features of profilemeter constitution

The features of this system are as follows:

(1) It is equipped with an exclusive micro-computer for profile calculation which is performed in real time. The computer can display the results of calculation with respect to crown and wedge and output the calculated results to the mill control.
(2) Since the fixed gage (named No. 1 detector unit) and the scanning gage (named No. 2 detector unit) are installed at different positions, the point measured by the fixed gage must be measured by the scanning gage when it arrives directly under the scanning gage. This system is equipped with a device that matches the two measuring points in the rolling direction of the strip (This matching will be described as the 'correction of the measuring point', hereafter). The accuracy of the correction of the measuring position affects the 'high spot' detecting ability, coupled with the measure-

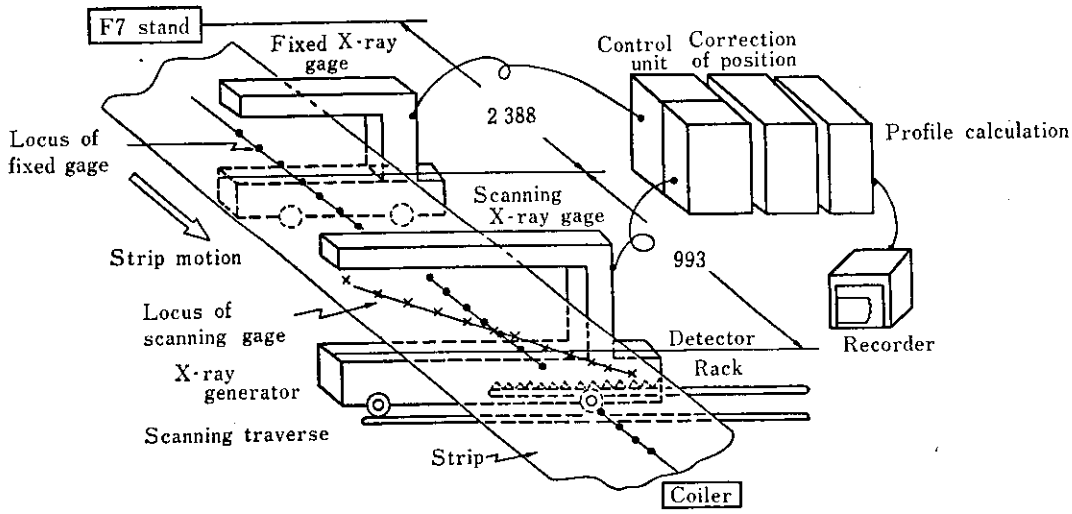


Fig. 1 Outline of profilemeter

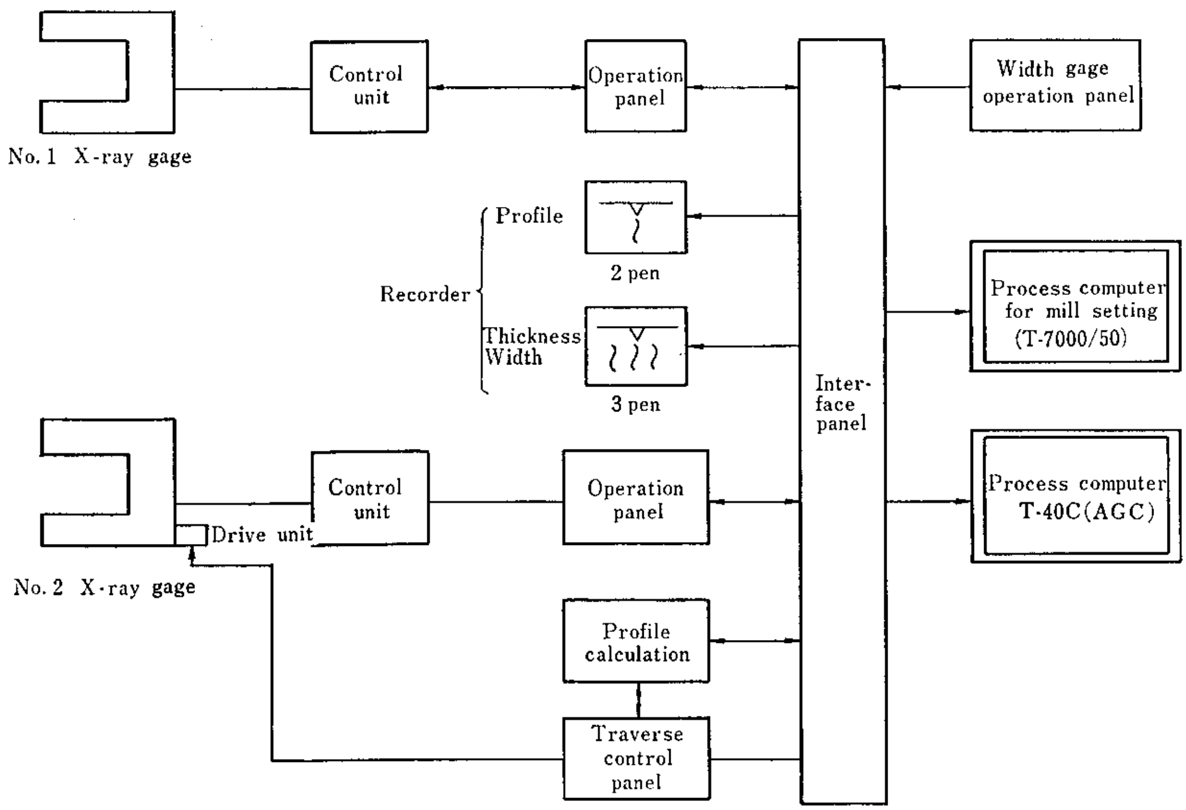


Fig. 2 Constitution of profilemeter at No. 2 hot strip mill

ment output interval of the thickness gage. This equipment adopts a shift register of 16 steps and the correction of the measuring position is performed at an accuracy of 56.3 mm/step in No. 1 mill, and 61.9 mm/step in No. 2 mill.

(3) The carriage speed of the scanning gage is altered in accordance with the following:
   (a) Precision of profile detection
   (b) Number of reciprocating scanning per strip

The carriage speed is set at 30–50 mm/s for the section of 100 mm from the strip edge and 50–150 mm/s for the center section to improve the precision of profile detection.

If the carriage speed is increased over 150 mm/s, it will eventually increase the noise level in the thickness measurement signals, which results in the deterioration of precision of profile detection.

Should the number of reciprocating scanning per strip in motion be increased, the traverse speed at the center section will be increased while the traverse speed at the strip edges is kept within the above-mentioned range.

2.2 Specifications of Profilemeter

Table 1 shows the specifications of the X-ray thickness gage and **Table 2** the specifications of the control unit of the profilemeter.

The dimension of the X-ray beam on the pass line, when the slit is set, is 30 mm in the rolling direction of coil, and 6 mm in the width direction of the coil. The X-ray beam is narrowed in the width direction by slit in the scanning thickness gage. The slit is necessary for the following reasons:

(1) The strip thickness varies greatly at the position 40–50 mm from the edge. The slit gage can perform a measurement of thickness with high precision in this section.
(2) The slit gage accurately detect 'high spots' of very small dimensions in the width direction of the strip.

2.3 Method of Profile Measurement

The method of profile traversing in No. 2 mill is shown in **Fig. 3**. The scanning gage moves to the point

Table 1 Main specification of X-ray thickness gage[1] (Common to fixed and scanning gage)

Item	Specification		
Thickness range	With slit 1 - 13.00 mm Without slit 1 - 25.99 mm		
Alloy compensation range	± 0 - 9.99% (0.01% step) of setting thickness		
Setting accuracy	Slit	Setting thickness (mm)	Setting accuracy
	On	1 - 10.00 mm 10.00 - 13.00 〃	±0.1% of setting thickness ±10 μm
	Off	1 - 10.00 mm 10.01 - 15.99 〃 16.00 - 25.99 〃	±0.1% of setting thickness ±10 μm ±0.1% of setting thickness
Noise	Slit	Setting thickness (mm)	Noise for setting thickness
	On	1 - 9.99 mm 10.00 - 13.00 〃	±0.07% ±0.12%
	Off	1 - 9.99 mm 10.00 - 15.99 〃 16.00 - 19.99 〃 20.00 - 25.99 〃	±0.05% ±0.08% ±0.10% ±0.12%
Deviation range	±500 μm/±100 μm (No. 1 hot strip mill), ±250 μm (No. 2 hot strip mill)		
Effective beam diameter	At pass line 30 mmφ (Without slit) 6×30 mm (With slit)		
Carriage traverse	Fixed gage		Scanning gage
Motor Drive Traverse speed	AC motor Wheel drive Constant speed of 9 m/min		DC motor with variable speed Rack and pinion Variable speed of 1.8 - 18 m/min

Table 2 Main specification of carriage traversing and profile calculation

Item	Specification
Traverse speed mode	(1) Selection from 4 speeds according to strip width (2) Direct setting by dial switch
Traverse speed range	30 mm/s - 300 mm/s 1 mm/s step (set by operator)
Start timing	Mode 1: X-ray on, Mode 2: Coiler on Mode 3: Manual, Mode 4: Computer
Position detection	Pulse generator Resolution: 0.1 mm, Display unit: 1 mm
Correction of distance between two gages	Correction by 16 bit-shift register
Profile calculation	(1) Real-time profile calculation (2) Calculation of crown and wedge value
Record of strip profile	Syncronizing with carriage position
Stand-by position of carriage	Stand-by at the drive side of the line

100 mm from the edge of the strip, stands there and waits for a command from the mill control computer. It moves automatically from the point C and advances to D, E and F points as the strip passes. It stops at F for one second, inverts and retracts to G, H, I and J to complete one cycle of scanning. The values of crown and wedge are gained from the profile calculator system at this point.

2.4 Method of Crown and Wedge Calculation

The crown and wedge calculation is performed in the following.

(1) Calculation of the difference (Profile) between the measured values obtained by the fixed thickness gage and the scanning thickness gage.
The shift register is used to perform the time correction (Δt) of the measured value by the fixed gage for the purpose of matching the measuring position. Then the deflection (Δx) is obtained by eq. **(1)**.

$$\Delta x(t) = x_S(t) - x_F(t - \Delta t) \quad \cdots\cdots\cdots\cdots (1)$$

Δx: Difference between the measured values by the fixed gage and scanning gage (μm)
x_S: Measured value of the strip thick ness by the scanning gage (μm)
x_F: Measured value of the strip thickness by the fixed gage (μm)
t: Present time (s)
Δt: Difference in the measured time by the fixed and scanning gages (s)

(2) Change in Δx
The change in Δx in strip with the time is shown in **Fig. 4**. The symbols used in **Fig. 4** are as follows.
Δx_{d1}: Δx at the strip edge on the drive side in the way out
Δx_{c1}: Δx at the center in the way out
Δx_{o1}: Δx at the strip edge on operator side in the way out
Δx_{o2}: Δx at the strip edge section on operator side in the way back
Δx_{c2}: Δx at the center in the way in
Δx_{d2}: Δx at the strip edge on the drive side in the way back

(3) Crown calculation
Crown (C) is obtained by eq. **(2)** using Δx_{d1}, Δx_{c1} and Δx_{o2} indicated in **Fig. 4**.

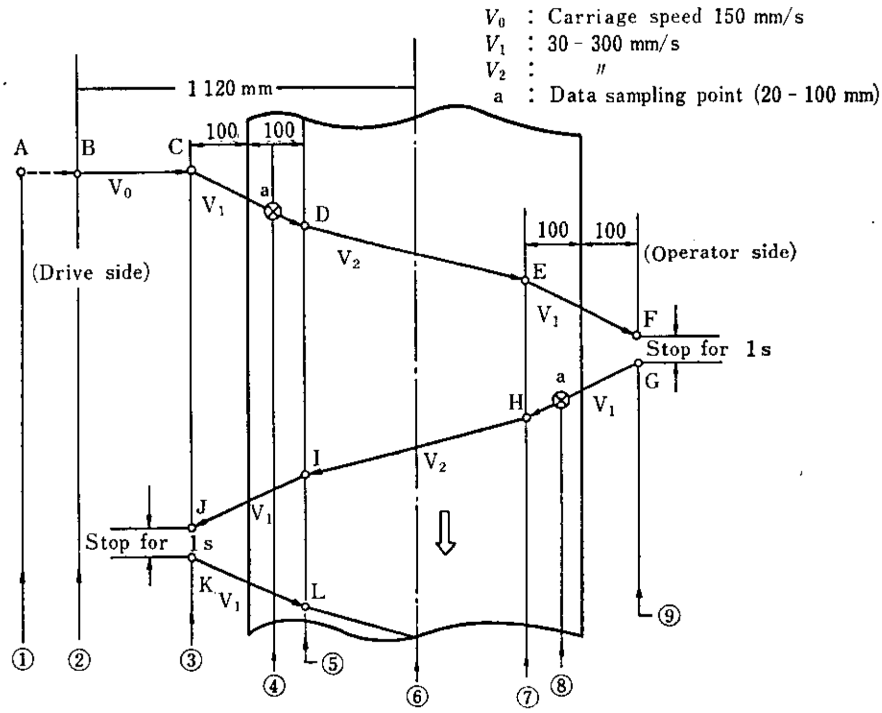
$$C = \Delta x_{c1} - \frac{\Delta x_{d1} + \Delta x_{o2}}{2} (\mu\text{m}) \quad \cdots\cdots (2)$$

If the profilemeter were equipped with a profilemeter control computer, the eq. **(2)** would be as follows:

$$C = \Delta x_{o1} - \frac{\Delta x_{d1} + \Delta x_{o1}}{2} \quad \cdots\cdots\cdots\cdots (3)$$

or

$$C = \Delta x_{c2} - \frac{\Delta x_{d2} + \Delta x_{o2}}{2} \quad \cdots\cdots\cdots\cdots (4)$$



①	Backward limit	⑥	Line center
②	Stand-by point	⑦	Speed alteration point
③	Stop point	⑧	Operator side data sampling point
④	Drive side data sampling point	⑨	Operator side stop point (Turn point)
⑤	Speed alteration point		

Fig. 3 Traversing method for scanning gage

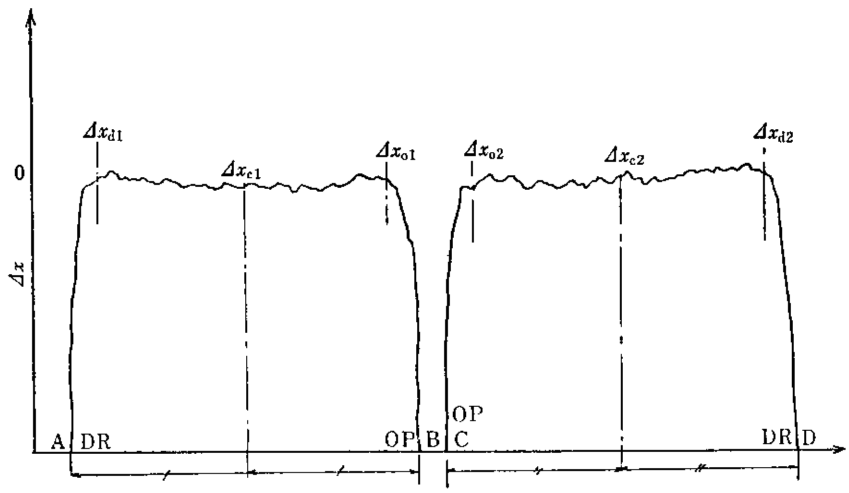


Fig. 4 Profile chart and calculation point

However, this system does not adopt the above method for the following reasons. In the case the system is equipped with a profilemeter control computer, the amount of traverse oscillation can be sampled at each time of thickness measurement while the gage is scanning over the entire strip width. In this way, upon completion of each measuring operation, each measuring position can be corrected, if necessary, by the amount of traverse oscillation of the strip, so as to assure the correspondence of the measuring position to the measured value. From the above results, the measured value at the point of x (20–40 mm from the strip edge toward the center) can be obtained. Consequently, the crown can be calculated by eq. **(3)** or **(4)**.

As this system is not equipped with such profilemeter control computer, the measurement is done in the following.

The strip edge on the side where the scanning starts (A point in **Fig. 4**) is detected first, then the measured value at the point x (20–40 mm from the strip edge) is obtained as Δx_{d1}. As for Δx_{o1} which is on the other side, it can not be determined which traverse point corresponds to the point of x from B in **Fig. 4**, as the definite strip width can not be obtained. For this reason, the strip edge (C) is detected again on the way back after the gage passes the point B and stops at a point approximately 100 mm away from B. Then the point traversed x mm toward the center from the point C is recognized as Δx_{o2}. This is because the crown is obtained by eq. **(2)** using Δx_{d1} which is close to Δx_{d1} in regard to measuring time.

(4) Calculation of wedge

Wedge is obtained by eq. **(5)** using Δx_{d1}, Δx_{o2} in **Fig. 4**.

$$w = \Delta x_{d1} - \Delta x_{o2} \cdots\cdots\cdots\cdots\cdots\cdots (5)$$

w: Wedge (μm)

2.5 Output of Thickness Deviation and Profile

(1) Record output

As shown in **Fig. 2**, two recorders are provided: a 3-pen recorder for recording ① the thickness deflection output from X-ray thickness gage, ② the width deflection output from the width gage and ③ the traverse oscillation, and a 2-pen recorder to record ① the specified position of both edges of strip and ② the strip profile. (An X-Y recorder is provided for No. 1 mill). The section of the coil on which the profile is recorded can be identified from these two recorders.

(2) Display and output to computer

The output of the measured values of crown and wedge is fed to the indicator and the mill control computer when the scanning thickness gage completes one cycle of scanning.

3 Off-line Accuracy

3.1 Accuracy of Thickness Gage

(1) Setting error

Fig. 5 shows the setting error and the data of its reproducibility. The reference value applied to obtain the setting error was determined by the primary standard gage of the company. The value

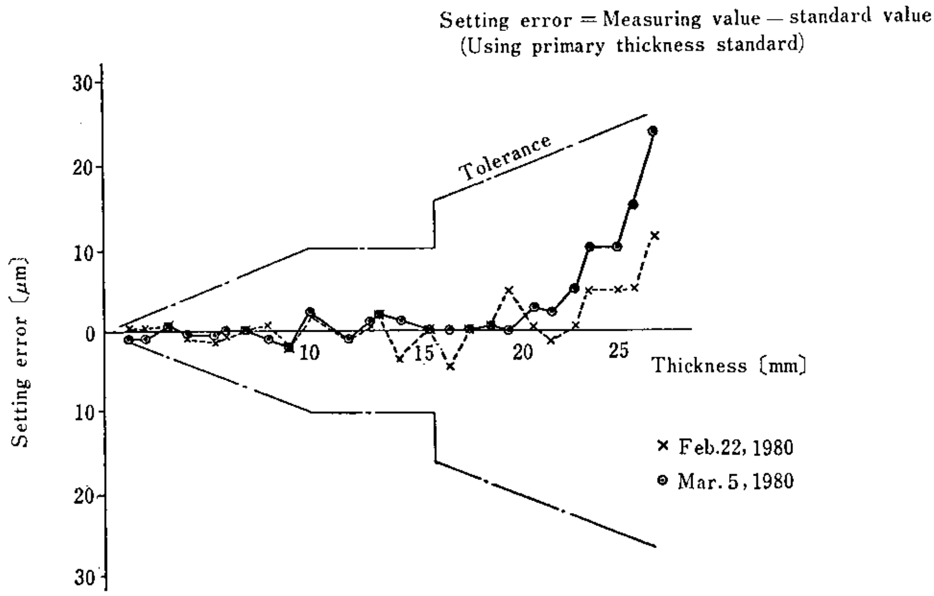


Fig. 5 Setting accuracy and reproducibility of scanning X-ray thickness gage at No. 1 hot strip mill

obtained is within the range of the manufacturer's guarantee and no problems are found as to its reproducibility. .

(2) Noise

Fig. 6 shows noise data. They are within the range manufacturer's guarantee and satisfy the specification accuracy.

$$\text{Noise level}(\%)=\frac{\text{Noise (mm)}}{\text{Setting thickness(mm)}}\times 100$$

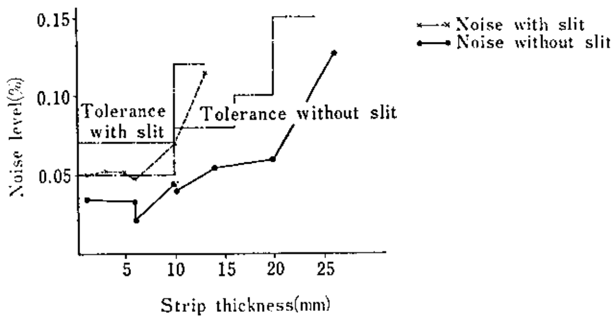


Fig. 6 Noise test data of scanning X-ray thickness gage at No. 1 hot strip mill

3.2 High Spot Detectability

Fig. 7 shows data obtained from a test performed by making an artificial high spot of 4.0–11.5 μm in height and 5–10 mm in width on a base strip (thickness: 3.14 mm). Scanning at the carriage speed was 100 mm/s. The detectability against the base strip of the same thickness differs depending on the carriage speed, the width of the sample spot and the traverse direction. This can be explained as follows:

(1) Relationship between the traversing speed of the carriage and the detectability
   (a) This is related to the influence of the noise and the response of the X-ray thickness gage. Accurate detection is performed at a lower carriage speed.
   (b) The vibration of the carriage motion becomes the noise. The noise is reduced at a lower traversing speed.

(2) Relationship between the width of the sample spot and detectability.
   X-ray reception is controlled by the slit width in the case of the scanning thickness gage so that the

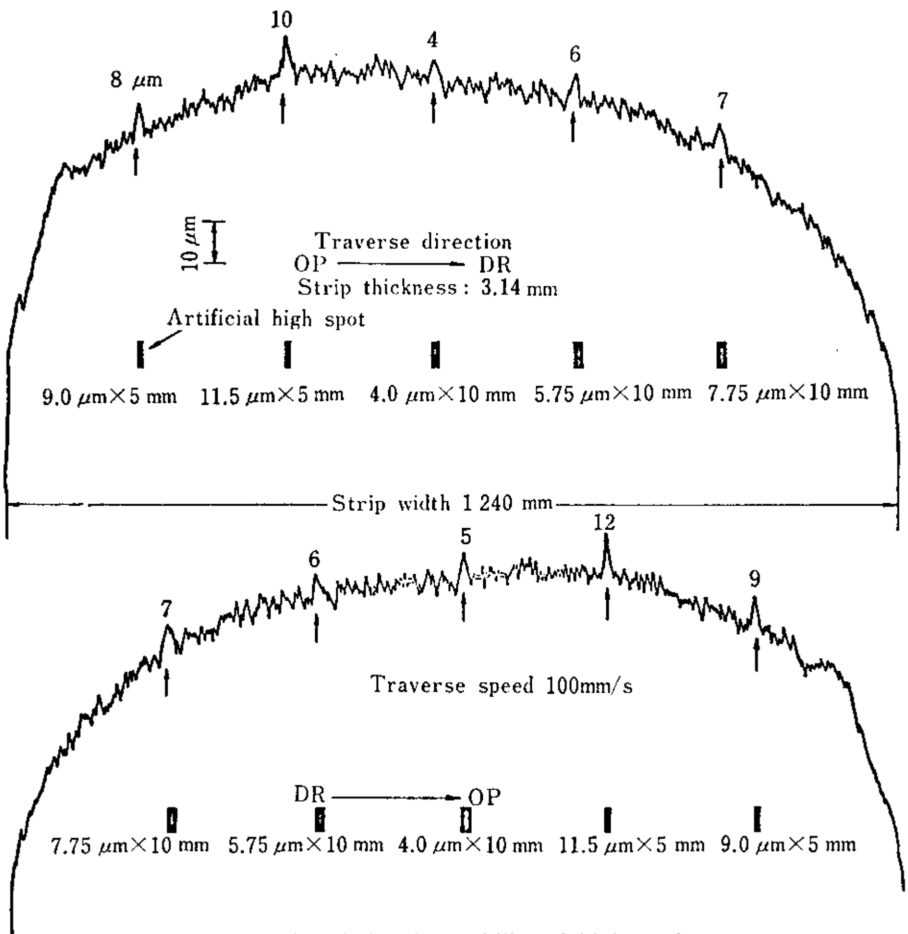


Fig. 7 Off-line detectability of 'high spot'

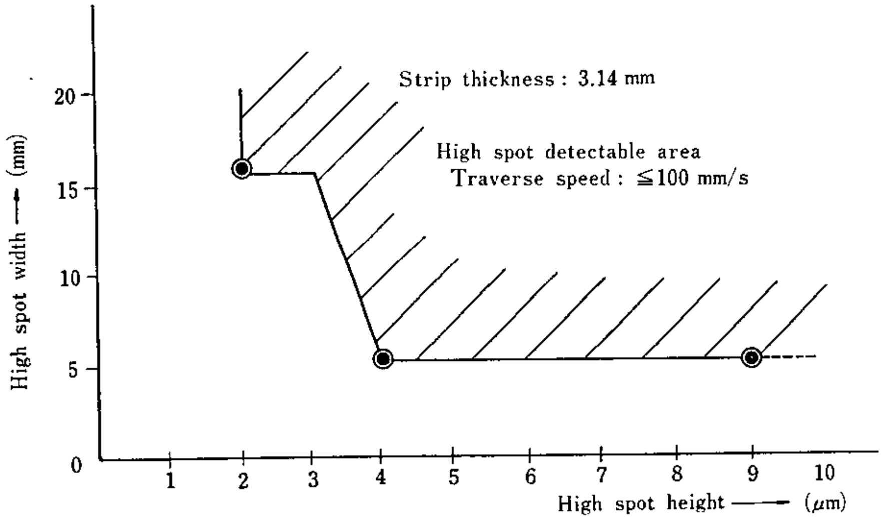


Fig. 8 Detectability of strip 'high spot' by the off-line test

amount of X-ray reception differs even on the high spot of the same height depending on the occupation ratio of the high spot width to the slit width. This results in the difference in the accuracy of the thickness detection, which in turn affects the accuracy of the high spot detection.

(3) Relationship between the traversing direction and detectability

This is based on the same principle as described in (2). The X-ray thickness gage detects the average strip thickness within the slit-width; therefore, even with the same 'high spot', the detection is influenced by the strip thickness near the 'high spot', in a particular traversing direction. Based on the data shown in **Fig. 7** and the results of other tests, the authors have concluded that 'high spots' with 2 μm height × 16 mm width, or 4 μm height × 5 mm width can be detected accurately at the carriage speed of less than 100 mm/s. The results of these measurements are summarized in **Fig. 8**.

4 On-line Accuracy

4.1 Measurement Error of Two Units of Thickness Gage

When the profile is measured on-line, noises caused by the difference in the position correcting accuracy of the two units of the thickness gage and the difference in the measuring environment of the two gages are added to the noise of the X-ray thickness gage itself. Among the above noises, the accuracy of the position correction and the measuring environment can be improved. **Fig. 9** shows the data obtained when both fixed and scanning gages are fixed at the line center. In this example, the thickness measured by the fixed thickness gage was corrected in its position. Then it was compared with the thickness of the same point measured by the scanning thickness gage and the difference obtained was outputted. Noise of ±2.5 μm is observed. This data was obtained with the 8-step register for correction of the measuring position. The results of the improved accuracy of position correction obtained by 16-step register are shown in **Fig. 10.** Data on the lower two coils are from the 8-step register (124 mm pitch), and that on the upper two coils is from the 16-step register (61.9 mm pitch). Despite the fact that there is almost no difference in the thickness of upper and lower steel strip, a significant difference is observed in the evenness of the profile as recorded between before and after the position accuracy correction. From the above data, it is made clear that the resolving power more than 50–60 mm is required at this mill.

4.2 Accuracy of High Spot Detection

Fig. 11 shows the accuracy of on-line high spot detection. This data was obtained by cutting the sample strip from the center section of coil and measuring it by hand micrometer, then comparing the results with the corresponding profile record chart. In the above example, the measured value of the hand micrometer is displaced in some distance on the Y axis for easier observation of the results. A 'high spot' with the height of 5 μm and the width of 10 mm can be identified.

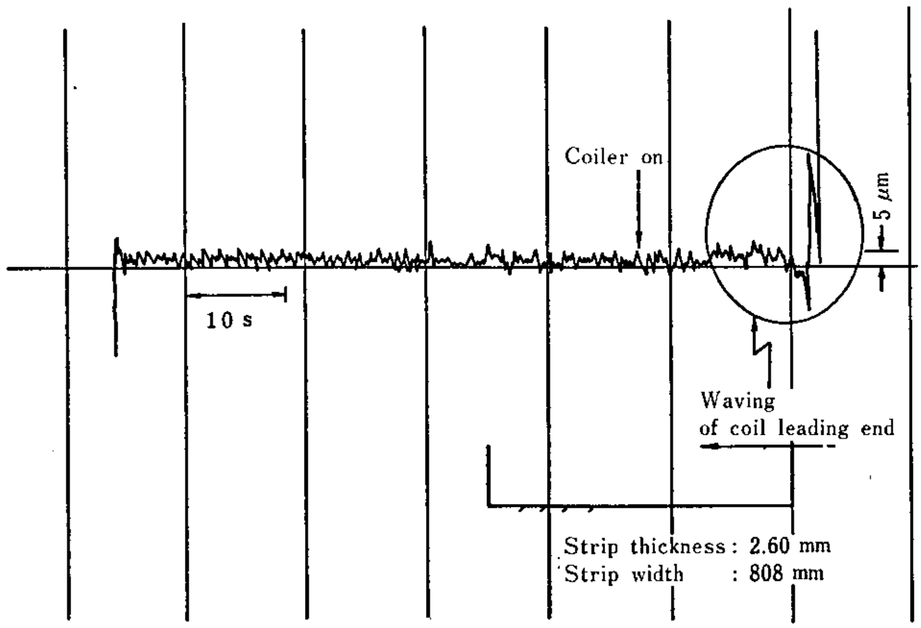


Fig. 9 Accuracy of position correction of two thickness gage

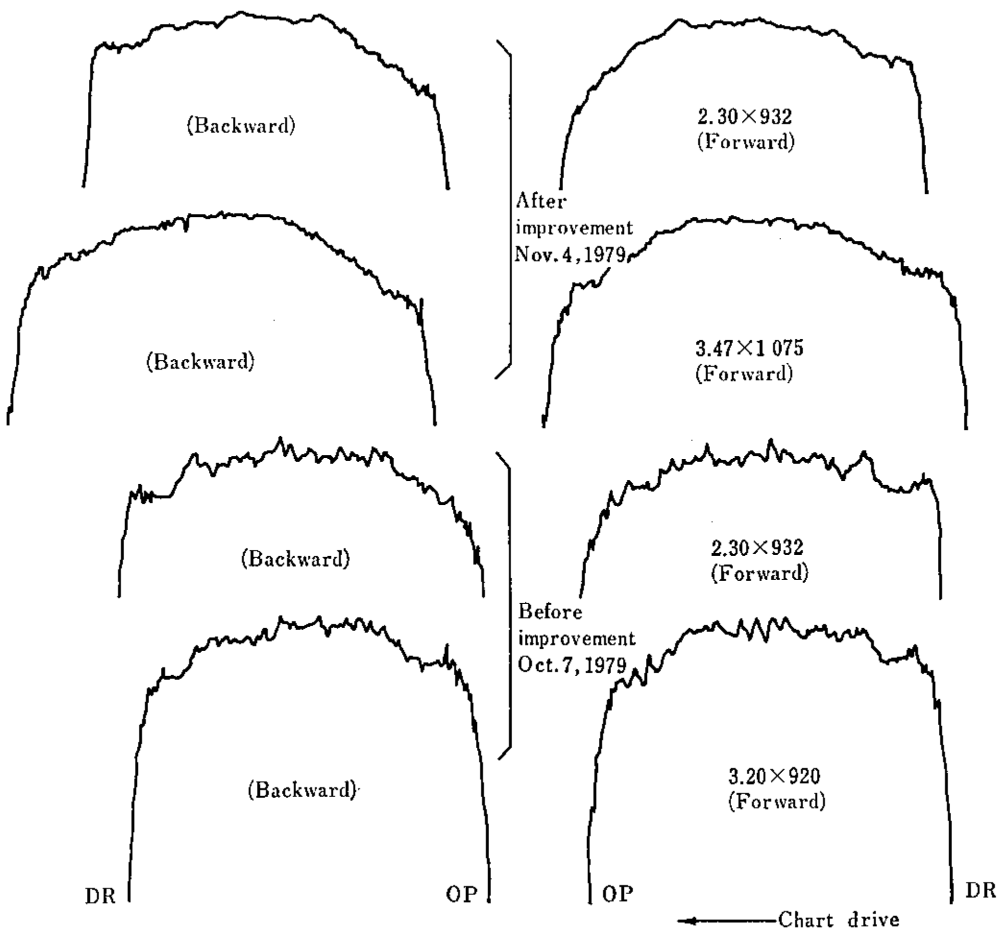


Fig. 10 Improvement of gage position correction (Data from No. 2 hot strip mill)

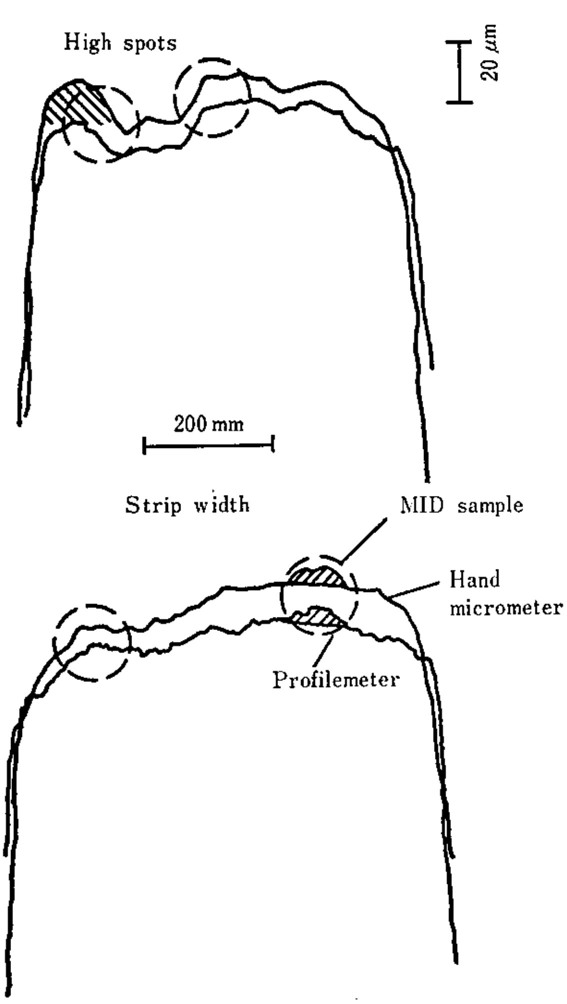


Fig. 11 Examples of detectability of strip 'high spots' during rolling

4.3 Accuracy of Crown Detection (Example at No. 1 mill)

The sample sheet was cut in a manner as described in 4.2, and the measured value of the hand micrometer and profile record chart were compared. The results are shown in **Fig. 12**. This example shows the data where crown was obtained by the hand micrometer and from the profile record chart with the reference points of 20, 30, and 40 mm from the strip edge. Accuracy of $\pm 10\ \mu m$ is observed regardless of the distance from the strip edge for the crown with less than 90 μm. It is confirmed that the reading accuracy from the chart is 10 μm at minimum. The reasons for the larger deviation in the data for the crowns over 100 μm obtained at the reference point of 20 mm are described in the following:

(1) Due to the large variation in the thickness at the strip edge, the accuracy of chart reading is low.
(2) The accuracy of hand micrometer measurement is insufficient. (A significant error occurs depending on where the hand micrometer is set at the edge, as the change in the thickness of the strip edge section is radical.)

4.4 Accuracy of Profile Measurement

Fig. 13 shows the examples of measurement by the profilemeter and hand micrometer. The solid line indicates the chart recorded by the profilemeter and the broken line shows the measured values by the hand micrometer. Each line corresponds to one full cycle of scanning. As the profilemeter scans in the rolling direction while traversing the strip diagonally, one

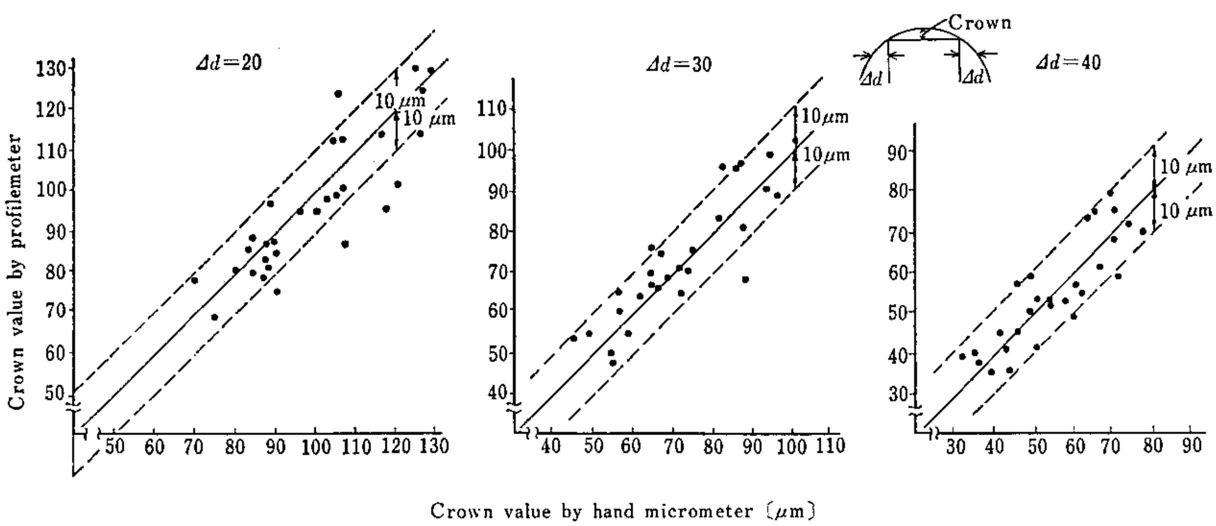


Fig. 12 On-line crown measuring accuracy of profilemeter by comparing crown value measured by hand micrometer at No. 1 hot strip mill

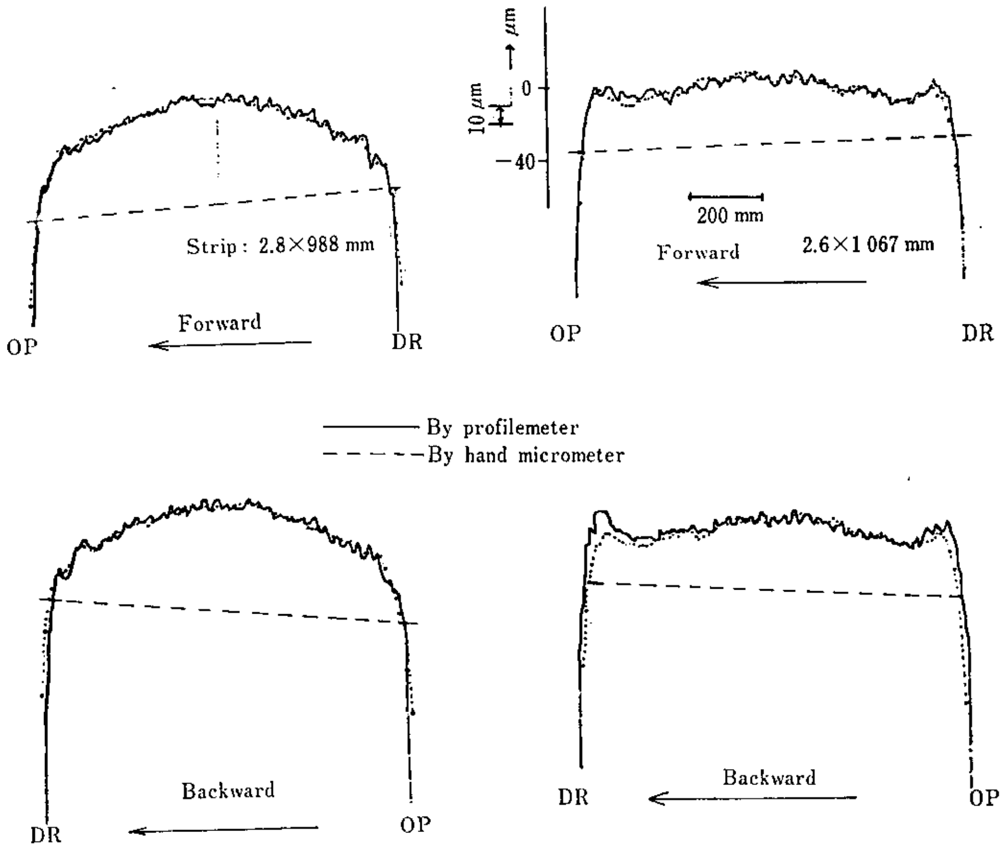


Fig. 13 Comparison between profiles measured by profilemeter and by hand micrometer

section from the part corresponding to the measuring point by the profilemeter was cut as a measurement sample by the hand micrometer. Most of the coils are well matched as represented by the sample of 2.80 mm × 988 mm (thickness × width). However, some coils (2.60 mm × 1 067 mm) cause the edge section to become unmatched. Causes for this are considered to be:

(1) The crown and wedge of the coil are changing while the profilemeter is scanning.
(2) The response of the profile recorder is not constant in its pen starting stage.

Of the above two, (2) should be observed in all the record charts so that the significant difference as observed in **Fig. 13** is unlikely to occur. Therefore, an investigation into (1) above has been made as follows. A scanning locus of the scanning thickness gage was assumed on the strip, and the profile was measured by γ-ray thickness gage in the downstream process. The results of the investigation are shown in **Fig. 14**. Profile was measured at the section (8), 810 m from the coil end, and measured again at the section (7), 830 mm, then measured up to the section (1), 945 m from the coil end. Furthermore, the scanning points

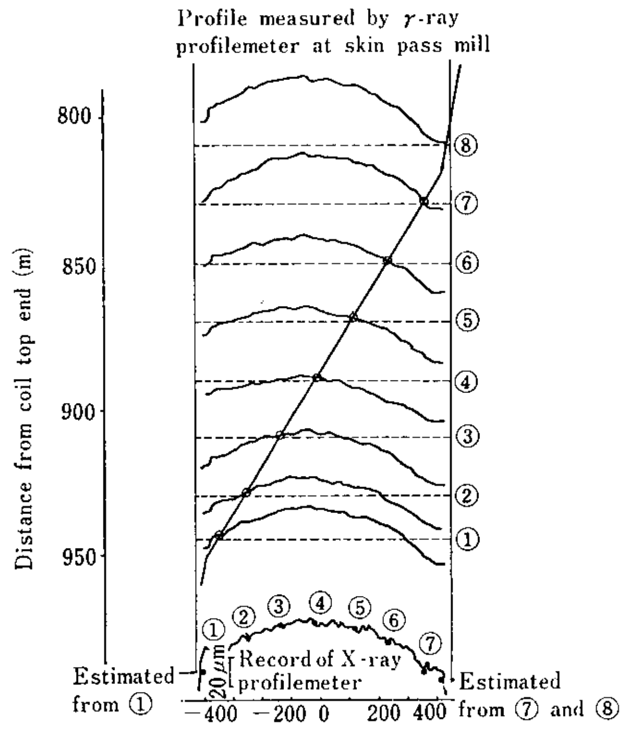


Fig. 14 Profile change during rolling and measured results by profilemeter

of the X-ray thickness gage among the values of profile measured by the γ-ray thickness gage (the cross point of profile record of the γ-ray thickness gage and the diagonal line that declines toward the left) are plotted in **Fig. 14**. The record of profilemeter and the measured values of γ-ray thickness gage agree well when the crown and wedge vary during the scanning of profilemeter. From this, the authors concluded that the discordance is due to the cause listed in item (1) and no problem exists in the measurement by the profilemeter.

5 Application of Profilemeter

5.1 Standards for Application of Profilemeter

The technical standards for hot rolling specify the standards for the application of profilemeter, setting forth the applicable objects, operating method and limit of control.

(1) Applicable object to be checked
The applicable objects are checked out according to the classification of general sales materials, cold rolling materials and checkered strip. Some are controlled separately depending on the purpose of application.

(2) Aimed values of control standard
Table 3 shows the aimed values of control standards on the typical examples of general sales materials.

Table 3 Aimed value for profile control of hot rolled strip

Item		Aimed value
Wedge		0 μm
Hot band as a finished product	High spot	Less than 15 μm
	Edge build-up	Less than 5 μm
Hot coil supplied to cold rolling	Crown	0 – 120 μm
	High spot	Less than 10 μm
	Edge build-up	Less than 20 μm

5.2 Crown and 'High Spot' Control

(1) Correction of abnormal profile
When an abnormal profile which is beyond the control standard described above occurs, the following measures are taken.

a. Abnormal wedge
  (a) Levelling of the roughing stand (to obtain horizontality)
  (b) Levelling of the finishing stand

b. Occurrence of 'high spot'
The change of rolls of the latter finishing stands (F3–F7) is carried out. The number of stands to be replaced is determined by the degree of abnormality and the number of steels yet to be rolled in the same rolling cycle.

c. Edge build-up
  (a) Alteration of the distribution of rolling reduction
  (b) Alteration of the rolling pitch
  (c) Replacement of the finish workrolls if the correction mentioned above is not possible.

d. Crown control
  (a) Alteration of the distribution of rolling reduction
  (b) Alteration of the rolling pitch

(2) Control of profile level
Correct understanding with regard to the actual situation of profile is not only necessary to ensure high quality for users, but also is important to maintain or improve stable product quality through the utilization of profilemeter. From this standpoint, a system is established at the plant to provide stable quality products and necessary information through the control of the following items:
  (a) Control of profile level
  Data is collected in accordance with the classification of the object being checked and analyzed.
  (b) Information on abnormality
  The information on abnormality is provided to the downstream process in an effort to accomplish early detection of defective coils.

6 Conclusion

The report presents the on-line hot strip profilemeter introduced into Chiba Works.

(1) The profilemeter is equipped with a microcomputer for profile calculation and a hardware logic for correction of the measuring position of thickness gages. Any process computer which exclusively serves for signal processing is not provided.
(2) The accuracy of abnormal projection ('high spot') detection is within 2 μm height × 5 mm width at the traverse speed of 100 mm/s.
(3) The accuracy of on-line detection is ±10 μm for crown and 5 μm height × 10 mm width of abnormal projection.
(4) The standards for the application of profilemeter are specified in the hot rolling technical standards, and the detailed control on the applicable objects, operating method and control limits are conducted

in accordance with the specified technical standards.

The initial aim of the profilemeter with regard to detection accuracy has been accomplished. The steel rolling technology of the company is expected to make a further advance utilizing the profilemeter.

Reference

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