JFE TECHNICAL REPORT
No. 27 (Mar. 2022)

Introduction of Automatic Measuring Instrument at Shapes Plant in West Japan Works (Fukuyama)

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Abstract:

JFE Steel has introduced and operated an online cold dimension and surface defect measuring instrument (OSIRIS, NEXTSENSE/Austria) for the purpose of guaranteeing the overall length of shape steel and preventing the outflow of surface defects at Shapes Plant in West Japan Works (Fukuyama). This device is a measuring instrument using Light-Section Method to measure all types and sizes of shapes products manufactured at the Shapes Plant in Fukuyama. In Light-Section Method, the calculation speed is faster than that of the conventional dimension measuring meter, and it is possible to measure and guarantee the total length of the conveying shape steels with high accuracy. In addition, surface defects can be measured at the same time as dimensional measurement, contributing to the improvement of quality assurance level. This report introduces the principle and configuration of the equipment, and the measurement accuracy and inspection judgment method for guaranteeing the quality of the product.

1. Introduction

In the Shapes Plant at West Japan Works (Fukuyama) of JFE Steel, an on-line cold dimension and surface defect measuring instrument (OSIRIS, NEXTSENSE GmbH, Austria) was introduced and is now in operation. This device uses the Light-Section method to measure all 10 types of products produced at the Shapes Plant, and enables highly accurate measurement of the overall length dimension of products during transportation by improving measurement accuracy and operation speed. Surface defects can also be judged simultaneously with dimension measurements, contributing to improvement of the quality assurance level. This report presents an outline of the equipment and the results of an examination of accuracy assurance carried out when the equipment was introduced.

2. Dimension and Surface Defect Meter Using Light-Section Method

2.1 Measurement Principle

The main specifications required in measuring instruments for shape steel products are shown below[1).

(1) Object: (**Fig. 1**)
- (a) Product types: Unequal leg and thickness angles, H-section steels, U-shaped sheet piles, bulb plates, parallel flange channel beams, rails, equal leg angles, forklift mast shapes
- (b) Measurement area: Height 0 to 300 mm
  Width 0 to 525 mm
- (c) Length: 6 to 100 m
- (d) Conveyance speed: 0 to 4 m/s

(2) Measurement location
- (a) Thickness/width: Arbitrary position of section
- (b) Length direction: 25 mm interval
  (Scanning frequency: up to 5 kHz)

(3) Measurement accuracy (online):
- (a) Dimensions: +/− 0.1 mm
- (b) Surface defects: Defect depth of 0.5 mm or more
  Defect height 0.5 mm or more

(4) Unmeasurable areas:
- (a) End of length : <25 mm
- (b) Non-laser irradiatable sites (inside of sheet pile claw)

The automatic measuring methods using conventional dimension gauges are the method of automatically measuring the product by scanning the sensor while the product is stopped, and the method of measuring the product during transportation using an arrangement of multiple sensors. Measuring the product while stopped enables highly accurate measurement but the time required for measurement and the fact that measurement of the overall length is impossible are drawbacks. On the other hand, conventional meth-

† Originally published in *JFE GIHO* No. 48 (Aug. 2021), p. 84−89

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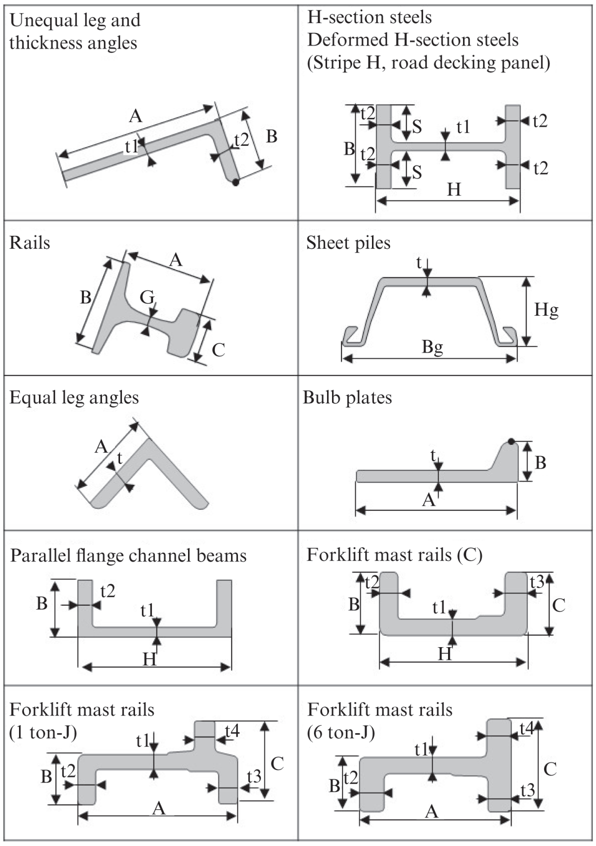

Fig. 1 Products to be measured and main dimensions

ods for measuring the product during transportation, it is necessary to install a plurality of pairs of sensors in accordance with the plate thickness, width and other dimensions or adjust the movement of the sensors, which result in a complicated measuring system.

In this system, a two-dimensional laser beam is irradiated on the product, the reflected light is detected by a high-speed camera, and the distance between the product and the camera is acquired as a two-dimensional profile by triangulation (**Fig. 2**). In this device, eight sets of sensors each consisting of a two-dimensional laser and a high-speed camera are arranged on the same cross section so that measurements can be made in the transport area of products of all sizes (**Fig. 3**). The eight two-dimensional profiles are synthesized to obtain one cross-sectional profile. The three-dimensional profile can be acquired by measuring the product during transportation, continuously acquiring the cross-sectional profile, and combining the profiles in the longitudinal direction. The cross-sectional profile is used for the product dimensions, and the three-dimensional profile is used for surface defects. Measurement of the overall length is carried out with high accuracy and high speed.

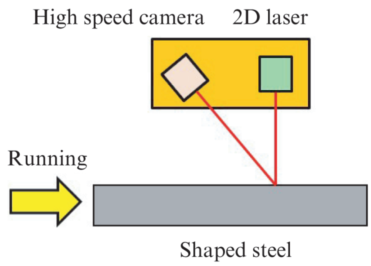

Fig. 2 Light-section method

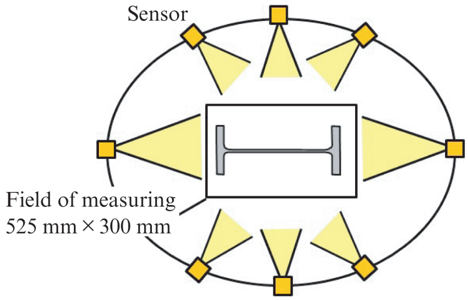

Fig. 3 Placement of sensors

2.2 Dimension Measurement Method

This system employs a dimension measurement program for each dimension of each product type, and the dimensions are calculated using the obtained cross section profile. **Figure 4** shows a profile and an example of a reference line for measuring the flange width of H-section steel.

In the measurement, the coordinate position on the cross section profile is decided first, and then the reference line which decides the direction of the dimension is decided. Dimensions are measured by determining the measurement points based on the reference line. Because the cross-sectional shape of shape steel products varies slightly with respect to the normal catalog shape due to wear of rolling rolls and other factors, this reference line should be determined from a more stable profile line according to the characteristics of each steel shape.

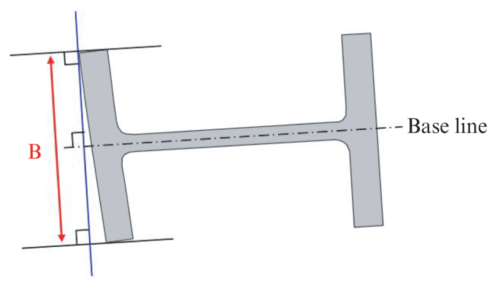

Fig. 4 Example of cross sectional profile and base line

Fig. 5 Example of learned defect (rolled marking on rail)

In conventional dimension measuring instruments, the reference plane used as the measurement direction of each dimension is set during the calibration of the measuring instrument, but as a result, shifting from the reference plane may occur due to abrasion of the conveyance table, fluttering of the material to be measured during conveyance, etc. In the equipment described here, the appropriate reference line is always decided from the cross-sectional profile produced by the operation, enabling measurement with high accuracy.

2.3 Surface Defect Measuring Method

The whole surface of the three-dimensional profile is converted into image data, and defects are detected by observing differences in the contrast of the surface image. Among detected defects, only those which have already been learned are judged to be defects.

Since shape steels such as rails have raised markings produced by rolling (**Fig. 5**) and stamped markings on the web surface, these features are learned so that they are not judged to be surface defects.

3. Instrument Configuration of Measuring Device

3.1 Layout and Equipment Configuration

This measuring instrument is installed on the table line at the outlet side of the straightening machine (**Fig. 6**). There is an inspection bed in the post-process of this equipment, and the final inspection is carried out based on the measurement results of the measuring instrument. This system can be operated on-line or off-line by using a retractor. Measurement is performed at the on-line position, and maintenance is performed off-line (**Fig. 7**). The instrument is equipped with 8 sets of sensors, and measurements are carried out by passing the product through the center of the sensors. A sample measuring device is installed off-line to confirm operation and accuracy. Calibration test pieces are installed in this equipment, enabling automatic calibration. The peripheral equipment of the dimension meter is described below.

(1) Laser doppler velocimeter

Information on the longitudinal position of the dimension meter measurement result is calculated from

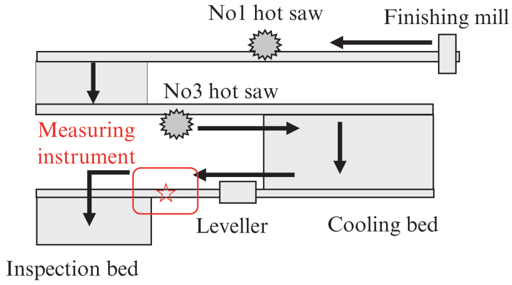

Fig. 6 Equipment layout

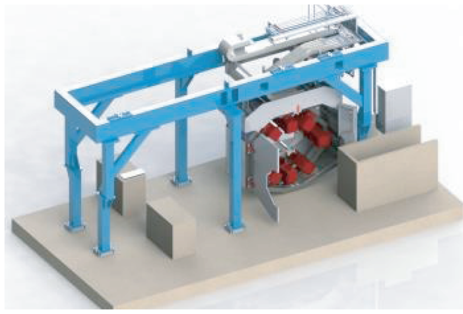

Fig. 7 Equipment overview

the speed data.

(2) Air purge

Air purge is performed to remove water droplets on the product surface and prevent over-detection of flaws due to water droplets and defects of the profile caused by wetting.

(3) Variable guide

This device is used to prevent contact between the measuring instrument and product and to suppress meandering and inclination of the product by constraining it to the measuring region.

(4) Sample measuring device

The sample measuring device is installed in off-line and is used to confirm the operation and accuracy of measurements.

(5) Calibration equipment

Calibration test pieces are installed in the measuring instrument, and automatic calibration is possible in the off-line position.

3.2 Tilt Compensation Function

Tilt correction is performed to improve dimensional measurement accuracy. Although the product is restrained by the guide to prevent meandering, from the viewpoint of product conveyance, the clearance between the product and the guide cannot be eliminated. However, as a result, the width dimension is measured larger than the actual dimension and accuracy is reduced by product tilting in the guide. In order to correct this skew, a sensor is installed in the front stage of the dimension measurement to measure the

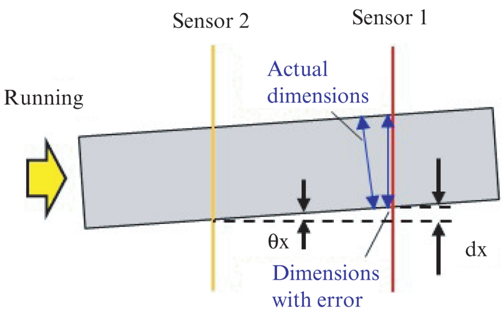

Fig. 8 Tilt correction

amount of product tilt in the longitudinal direction, and the tilt angle is calculated in order to correct the dimension (**Fig. 8**). To improve the accuracy of tilt correction, the measurement point of the product cross section is set to a point with small dimensional variation in the overall length when tilt is measured.

4. Measurement Accuracy

4.1 Dimensional Accuracy

A sample is prepared for the accuracy test, in which dimensions are measured in advance by a contact-type three-dimensional measuring instrument, and verification of dimensional accuracy is carried out by on-line measurement during transportation. **Figure 9** shows an example of the measurement results of the dimension meter. The dispersion of the measurement is $3\sigma < 0.1$ mm, showing that measurement is possible with high accuracy.

4.2 Accuracy of Defect Measurement

The accuracy of surface defect detection is verified by conveying a sample with an artificial defect on the line. The result of verification of the depth of the defect is shown in **Fig. 10**. Flaws with a size of 0.2 mm or more can be detected with accuracy of ±0.1 mm.

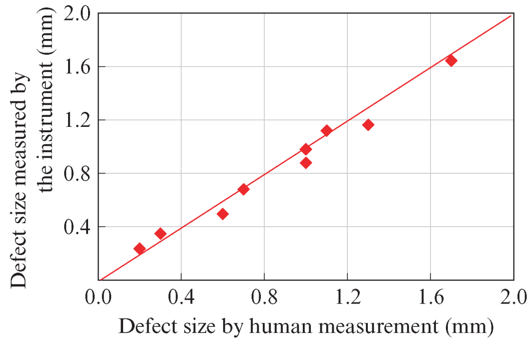

Fig. 10 Example of defect accuracy verification

For the measurement specification "defects over 0.5 mm," although it is possible to detect defects over 0.2 mm, it is difficult to detect flaws with a size of less than 0.5 mm because minute defects which do not affect the judgment of acceptance are also detected due to scale peeling, water wetting, etc. Therefore, the cold measuring instrument judges defects with depths over 0.5 mm.

5. Dimensional Quality Assurance

5.1 Dimension Judgment Method

This instrument received JIS certification for dimensional measurement in November 2018 and is now in operation as a quality assurance device. **Figure 11** shows the judgment method used in the measuring instrument. In case of a control tolerance $\pm T$, a decision of acceptance by the measuring instrument is made in the control range $\pm(T\text{-}A)$ considering the guaranteed accuracy A of the instrument. For products which are judged as failing by the measuring instrument, the operator makes the final judgment at the inspection bed.

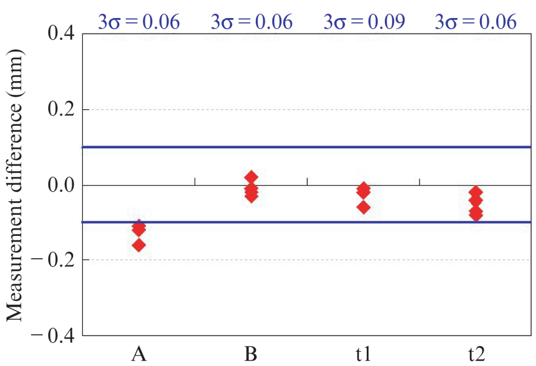

Fig. 9 Example of dimensional accuracy verification

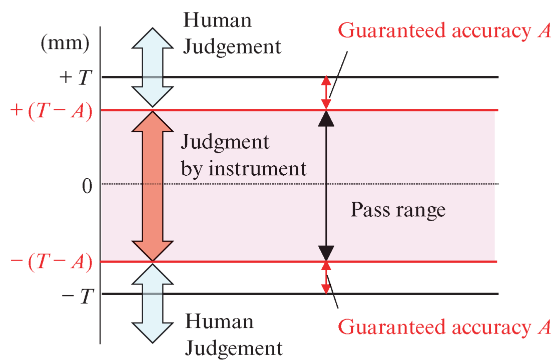

Fig. 11 Dimension judgment method

5.2 Concept of Dimensional Accuracy Assurance and Measurement Uncertainty

Uncertainty is evaluated and incorporated in the judgment criteria based on GUM (Guide to the Expression of Uncertainty in Measurement).

(1) Concept of assurance accuracy, *A*

(a) The sum of the deviation from the true value and the uncertainty is the guaranteed accuracy, *A* (**Fig. 12**).

(b) Deviation from true value means the difference between the results of the dimensional measurement and the results of the precision sample measurement.

(2) Uncertainty calculation method

The main factors of uncertainty considered here were the four factors of dispersion of repeated measurement, measuring instrument, product temperature, and product inclination. The standard uncertainty, $sn(x)$, of each of these items was calculated by the following method.

(a) Uncertainty when the same product is measured repeatedly n times. $s(x)$: standard deviation

$$s1(\bar{x}) = \frac{s(x)}{\sqrt{n}}$$

(b) Uncertainty of the measuring instrument used to measure the sample for accuracy verification. (For U_1, the uncertainty described in the calibration certificate of the measuring instrument alone is used.)

$$s2(\bar{x}) = \frac{U_1}{2}$$

(c) Uncertainty of thermal expansion at measurement site due to product temperature. (Rectangular distribution)

a: Dimensional variation due to temperature variation

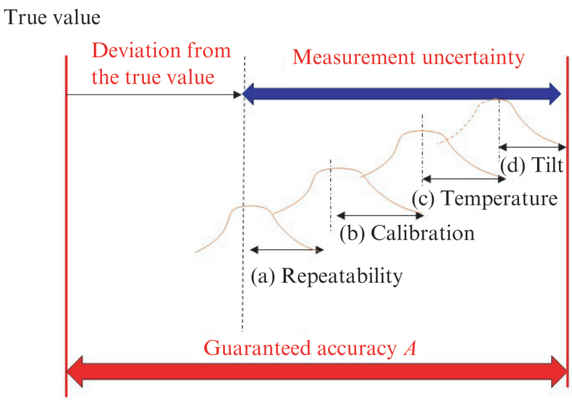

Fig. 12 Guaranteed accuracy *A*

$$s3(\bar{x}) = \frac{a}{\sqrt{3}}$$

(d) Uncertainty of dimensional variation due to product inclination (Triangular distribution)

b: inclination correction accuracy

$$s4(\bar{x}) = \frac{b}{\sqrt{6}}$$

The extended uncertainty *U* is calculated from each the standard uncertainties of (a) to (d). The inclusion factor k=2.

$$U = \sqrt{\sum s^2(\bar{x})} \times k$$

The extended uncertainty, *U*, is defined as the guaranteed Accuracy, *A*.

6. Effect

Figure 13 shows the overall length profile of the height dimension of H-shaped steel measured by the dimension meter. Introduction of the dimension meter has made it possible to manage the dimension trend of the total length. Surface defects are displayed and confirmed as a 3D profile, enabling more accurate decision of defects. The cross-sectional profile of the product is displayed to the operator and is also utilized for inspec-

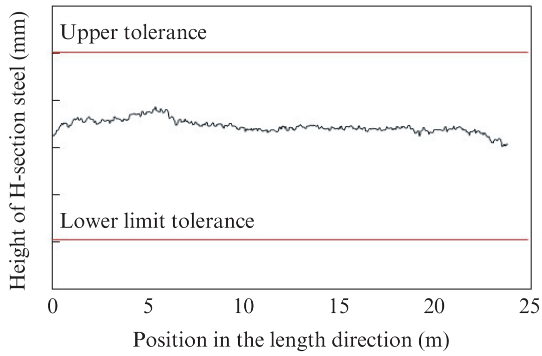

Fig. 13 Overall length profile of dimensions

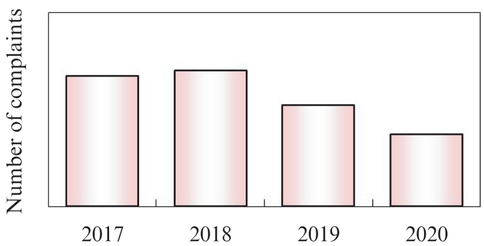

Fig. 14 Transition of number of complaints

tion of the cross-sectional shape in response to the requirements for shape steel in the IMO Performance Standards for Protective Coatings (PSPC) for shipbuilding in recent years. **Figure 14** shows the transition of the number of complaints related to surface defects over time. The number of complaints has decreased since the introduction of the dimension measuring instrument in 2018, and in 2020 the number decreased by about 40%.

7. Conclusion

A cold dimension and surface defect measuring instrument was introduced at the Shapes Plant of JFE Steel's West Japan Works (Fukuyama). The features of this equipment and the results of its introduction are summarized as follows.

(1) By using the light-section method, it is possible to measure the 10 types of shape steel products manufactured at the Fukuyama Shapes Plant with high accuracy and operation speed over the entire length of the product.

(2) JIS certification was received in November 2018. Introduction of the dimension and surface defect measuring instrument has reduced the number of complaints, contributing to improvement of the quality assurance level.

(3) Dimensional data for the total product length, which could not be detected until now, can now be acquired and is utilized for further improvement in the fabrication technology. Reduction of the manual inspection process by automation of inspections and improvement of the working rate can also be expected.

References

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