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The body can be viewed from the next page.

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On-line Size and Shape Measurement Techniques for Hot Steel Rolling Process*


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1 Introduction

After World War II, the steel industry in Japan has rapidly expanded with construction of coastal steel mills including the Chiba Works of Kawasaki Steel, achieving the world's highest level of production in terms of quality and quantity. Despite the growing competition with Asian mills in recent years, the steel industry in Japan still holds the world's highest competitiveness by developing high-quality products and slashing costs.

In this modern age of global competition, the development of high quality products and the enhancement of productivity are required for further strengthening of the company's competitiveness, putting the process measurement and control techniques all the more important position.

Because of the versatility of steel production process, measurement requirements by those processes are also various. Furthermore, the operating conditions are very severe due to heat, vibration, dust and water, making it impossible to directly use commercially available sensors in most cases. For this reason, Kawasaki Steel has been developing sensors suitable for these severe conditions by itself for many years, leading measurement techniques in the steel industry by developing especially on-line size and shape measurement techniques in cooperation with sensor suppliers. In this paper, the sensing techniques developed in Kawasaki Steel will be reviewed and the technical features of those sensors will be described in detail.

2 Developed Techniques

2.1 Calibration Techniques for Laser Distance Meters

2.1.1 Off-line calibration technique

The laser distance meter is currently the most frequently used instrument for size and shape measurement. The company has developed a highly-accurate calibration technique for laser distance meters[1,2] and has been using this technique for each measurement apparatus. The measurement principle of the laser distance meter is shown in **Fig. 1**. The basic principle is the triangulation method. Laser light reflected at the surface of the measured object is converged by the focusing lens and produces an image on the light receiving elements. The position of measured object is determined from this imaging position by making use of the preliminary-obtained relationship between the imaging and measuring positions.

Linearity between imaging positions and measuring positions for laser distance meters greatly depends on the shape of the receiving-light energy distribution on the light receiving elements when first obtaining the relationship between these positions, i.e. when calibrat-

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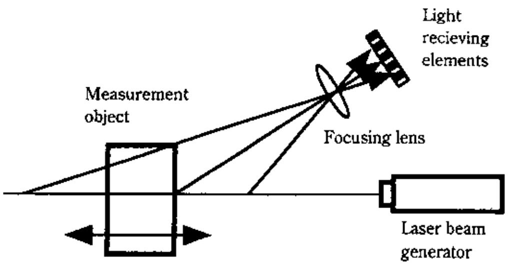

Fig. 1 Measurement principle of laser distance meter

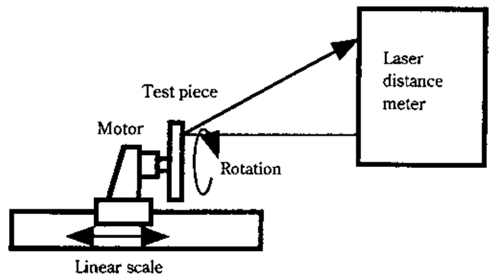

Fig. 2 Newly developed calibration method

ing. The shape of distribution is influenced by such factors as the roughness of the measured object surface and the change of reflectance, and the measurement range had been limited to a measurement accuracy of ±0.05% with existing methods of calibration. In order to stabilize the shape of distribution, the influence of roughness and changes in reflectance were reduced by rotating the measured object surface when calibrating and a received light distribution stabilized to almost equal to the normal distribution has successfully been achieved. This new method is illustrated in **Fig. 2**. As a result of adopting this method, it has become possible to improve the linearity of laser distance meters to better than ±0.015% of the measurement range, thus dramatically improving the on-line measurement accuracy.

2.1.2 On-line calibration techniques

Together with off-line calibration techniques, on-line calibration techniques are needed to maintain the performance of measurement apparatus. It is the company's practice to prevent time-dependent deterioration of measurement accuracy by periodically performing on-line calibration or by performing on-line calibration using the calibrated standard samples at each time before starting measurement.

2.2 Environmental Endurance Techniques

The most important subject for measurement techniques in steel production processes is countermeasures for the tough environment. The environment of hot rolling processes with heat, vibration, dust, water, etc. is very severe on measurement apparatus, in particular. Therefore, stable on-line measurements cannot be expected unless proper countermeasures are taken for these matters. Some typical environmental countermeasures developed by Kawasaki Steel are explained in the following.

2.2.1 Countermeasures for heat

A precisely prepared countermeasure for heat is necessary for highly accurate size measurement of hot-rolled steel materials. For size measurement apparatus using laser distance meters, therefore, materials having an extremely low thermal expansion coefficient are used for the frames to mount distance meters and for the apparatus themselves and at the same time, such apparatus is designed in such a way that cooling water regulated to a constant temperature is circulated inside.[2] By taking this measure, the space configuration of the distance meters is kept accurate. Furthermore, the containers housing various measurement devices such as distance meters are located in a thermally insulated, temperature controlled containers to always maintain a constant temperature.

2.2.2 Countermeasures for vibration

A proper countermeasure must be taken for vibration prevention when installing measurement devices just in the vicinity of rolling mills or when putting measurement devices in contact with measured objects. In such cases, the measurement devices are designed in such a structure that makes the devices unaffected by vibration by using a shock absorber built by combining laminated rubber, springs and dampers.[3] Furthermore, frames independent of the mill housing should be provided for these measurement devices, when possible.[3,4]

2.2.3 Countermeasure for dust penetration prevention

Regardless whether hot rolling or cold rolling, a huge amount of oxidized scale dust exists in steel production process and this obstructs stable measurement. When measuring size using optical instruments such as a laser distance meter, in particular, scale dust often causes serious disturbances. In order to cope with such problems, the design prevents dust accumulation by adopting a powerful air-purge on the surface. In addition, the control panel housing measurement devices are located, in some cases, inside multi-layer structures, which can endure the penetration of dust as well as of cooling water. **Figure 3** shows the design of a panel housing a laser distance meter located immediately in the vicinity of a hot rolling mill.[5] By adopting this design, it becomes possible to keep the optical surface of the laser distance meter clean for over six months.

2.2.4 Countermeasure for thermal fluctuation

When measuring the size of hot-rolled steel materials using laser distance meters, it becomes important to

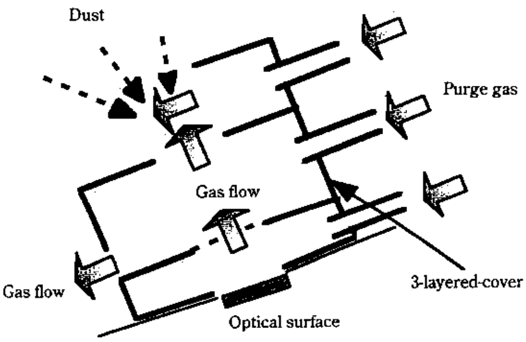

Fig. 3 Dust-proof structure

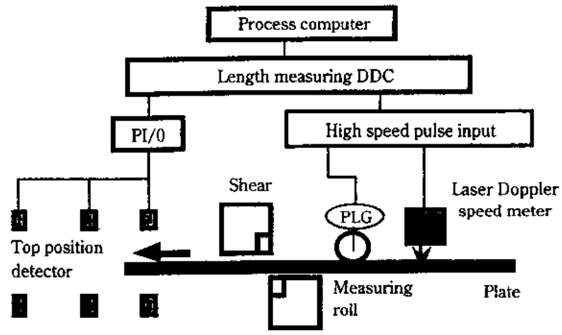

Fig. 4 System configuration of plate length meter

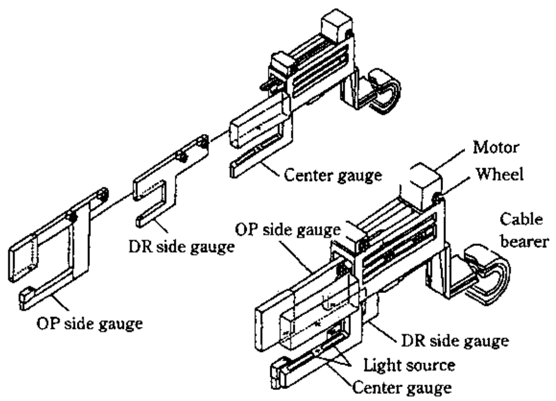

Fig. 5 Layout of inter-stand sensor

take proper countermeasures for thermal fluctuation caused air expansion in the optical path by radiation heat. The chosen countermeasure for thermal fluctuation is to properly air-purge the inside of the optical path.[2)]

2.3 Maintenance Techniques

In order to improve the workability and safety of maintenance, every measurement apparatus is located in an off-line retractable structure in principle. In addition, the system is designed in such a way that by linking to a host computer, the data at calibration and various data such as temperature, vibration and voltage are stored for a long period and can be analyzed at any moment. By adopting such method, quick response is possible in the case of emergency troubles.

3 Size Measurement Techniques

3.1 Length Measurement Techniques

As a technique to highly accurately measure the length of materials on-line, the following explains the length meter used in the thick plate mill, Mizushima Works.[6)] The configuration of this length meter is illustrated in **Fig. 4**. The special features are as follows:

(1) By using a laser Doppler type speed meter and a measuring roll type meter together, highly accurate length measurement has been actualized over the entire speed range of steel strips including temporary stopping.

(2) In order to actualize a measurement environment which maximizes the performance of laser-Doppler speed meters on the market, a holding mechanism was developed. The mechanism enables the uniform control of measurement distance, vibration-free operation and vertical holding of length meter possible.

(3) By performing plate tip detection using light activator switches, a measurement standard was established and self-diagnosis was performed, thus accuracy and reliability of the length meters were ensured.

As a result, highly accurate length measurement with $1\sigma = 1.97$ mm per 10 m of product length has been made possible.

3.2 Thickness and Width Measurement Techniques

As an apparatus for measuring plate width, thickness, etc. of hot-rolled steel plates, inter-stand sensors were introduced in the finishing mill of the No. 3 hot rolling mill, Chiba Works.[4)]

3.2.1 Design

The system was designed in a nesting-type structure consisting of a center-locked type X-ray thickness gauge and two cross-web direction scanning type X-ray thickness gauges. Furthermore, the center thickness gauge was designed to incorporate a width and meandering meter in its frame so that the gauge can be installed in a narrow space. (**Fig. 5**)

With respect to the width meter, the distance between the camera and the measured objects (steel plates) is small and there is no space to put the width adjustment mechanism in-between, therefore, the design was made to use four cameras for small widths and four cameras for large widths, eight in total, as shown in **Fig. 6**.

3.2.2 Environmental countermeasures

The inter-stand space of a finishing mill is in a tough and severe environment with heat, water, scale, vibration, etc., therefore, environmental countermea-

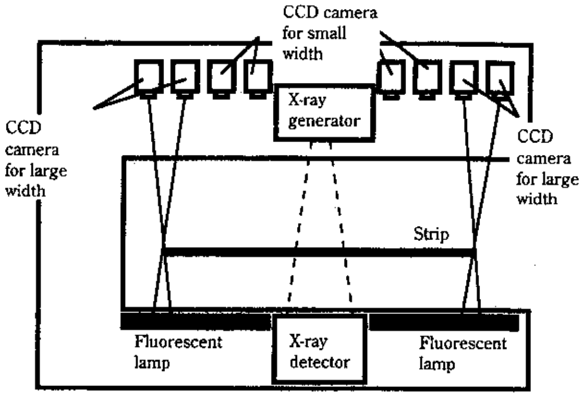

Fig. 6 Center gauge

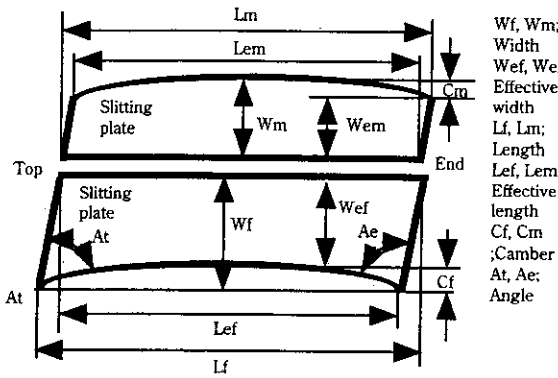

Fig. 7 Measurement items of plate shape meter

sures become important. As for the vibration countermeasures, the frame was made in a stand-alone type independent of the mill housing. As for the countermeasure for water on strips, a two-stage purge system with air and water was adopted. Furthermore, as for the countermeasure for steam in the measurement space, an air purge is used for the entire range in width direction.

3.2.3 Maintenance environment

In order to properly maintain delicate instruments, whole inter-stand sensors were made capable of being moved to the motor room so that maintenance work could be done in a comfortable atmosphere. As a result, the accuracy of the size measurement of hot strips in the rolling process were improved to $\pm 0.2\%$ of the full range in thickness and to ± 1 mm with respect to width. This means a large contribution to an improved environment leading to improved size accuracy.

4 Shape Measurement Techniques

4.1 Plate Shape Measurement Technique

As an example of plate shape measurement, a plate shape meter used on shearing lines in the plate mill of Mizushima Works is described in this section.[7] This is an inexpensive and high performance measurement device made by combining a 2-dimensional laser distance meter and a laser-Doppler speed meter of common use together with an image processing device and has the following special features.

(1) The inspection of all size and shape assurance items except thickness have been made automatic. The measurement items of the plate shape meter are shown in **Fig. 7**.

(2) By using a scanning-type 2-dimensional laser distance meter, width shapes of parallel movement plates have been made measurable simultaneously.

(3) By adequately taking environmental countermeasures, highly accurate length measurement has been realized at a low cost using commercially available laser Doppler speed meters.

(4) By utilizing a conventional image-processing device, on-line measurement of rectangular accuracy and detection of irregular edges have been actualized. By virtue of developing this technique, on-line measurement of the entire size quality assurance items for thick plates including those of parallel movement has been made possible. With respect to length measurement, it has been made possible to measure length to an accuracy better than $\pm 0.2\%$ of the full scale.

4.2 Cross-shape Measurement Techniques

As shown in **Fig. 8**, many instruments are installed to measure cross-sectional size and shape in the H-shape Mill, Mizushima Works. As typical examples of these instruments, the profile gauges for hot rolling and cold

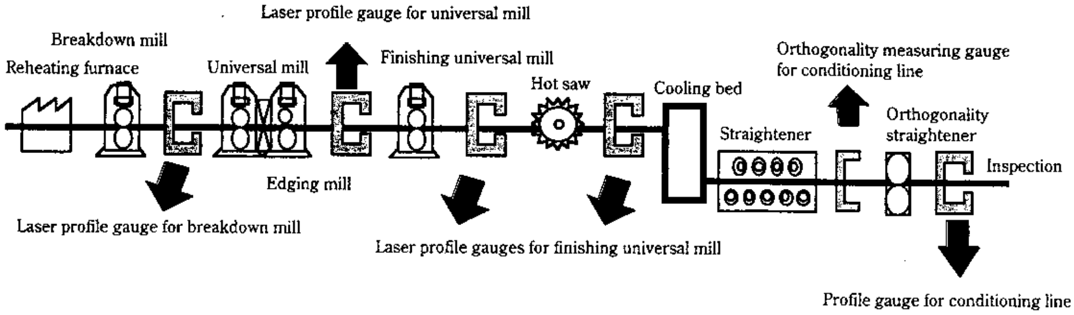

Fig. 8 Layout of continuous on-line H-shapes measurement gauges

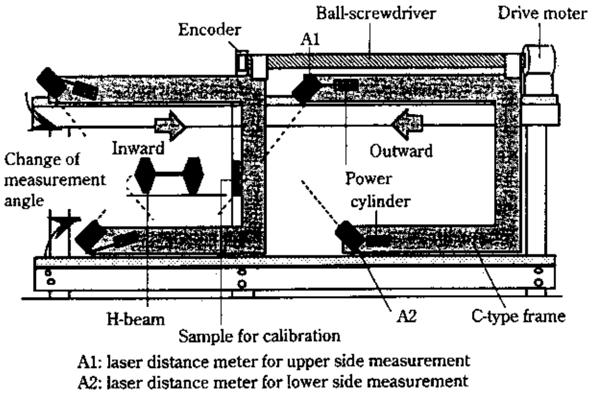

Fig. 9 Laser profile gauge for breakdown mill

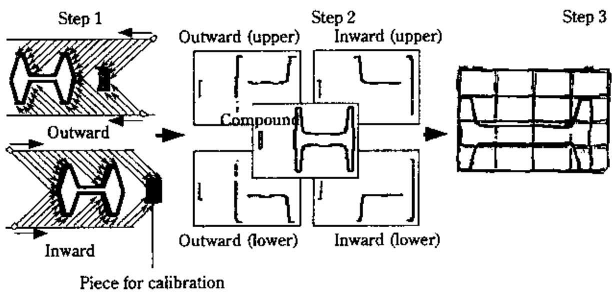

Fig. 10 Measurement block diagram

rolling are described hereunder.

4.2.1 Hot rolling profile gauge for break down mills[8)]

The profile gauge for hot rolling used at the exit side of the break down mill measures the cross-sectional shape of products making use of the stationary state while sawing off the tongue after break down rolling. The structure of this gauge is shown in **Fig. 9** and the special features are as follows:

(1) The method to measure the cross profile of H-beams with a minimum number of meters, i.e. two sets of distance meters was established for the first time by reciprocating C-type frame mounting distance meters on its driving mechanism.

(2) As shown in **Fig. 10**, the method measures the calibration piece on-line at each measurement and composes the results of four measurements taken for the upper and lower sides of the calibration piece in outward and inward movements. By using the calibration piece, various errors such as those due to changes of movement level, rotation angle and the drift of distance meters can be cancelled and a highly accurate measuring method is realized.

The time required for measurement is 18 s and the total measurement accuracy including the composing process with hot rolled strips is better than 0.5 mm in 2 σ.

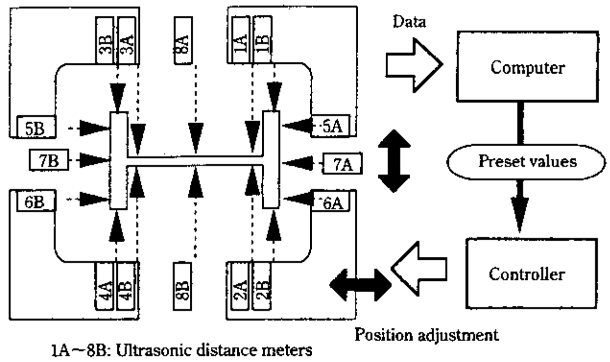

Fig. 11 Configuration of profile gauge

4.2.2 Cold rolling profile gauge[9)]

The profile gauge for cold rolling is installed at the finishing line of the H-shape mill and continuously measures the cross-sectional size and shape of H-beams while moving. The important feature of this gauge is that measurement of the flange width of H-beams, which was once thought difficult before, was made possible at a low cost with these gauges by utilizing ultrasonic spatial distribution analysis through the use of ultrasonic distance meters. This profile gauge is composed of 16 sets of ultrasonic distance meters, a computer and a controller as shown in **Fig. 11**. The computer calculates various items such as flange width, center deviation and rectangularity on the basis of the values measured by the 16 distance meters, and the controller adjusts the position of the distance meters according to product size. The gauge starts on-line measurement after completing calibration using a test piece at each size change.

On-line measurement accuracy better than 0.25 mm in σ in flange width has been achieved with this gauge. This is nearly equivalent to the accuracy using conventional 2-dimensional laser distance meters.

5 Conclusion

This paper outlines the size and shape measurement techniques that Kawasaki Steel has created and developed. The essential points described in this paper are as shown below and the development of these techniques has been making great contributions to the improvement of product size accuracy, and thus quality and enhancement of productivity.

(1) By combining on-line and off-line calibration techniques and environmental endurance techniques, the company developed its original measurement system which makes it possible to take stable measurements over a long period of time even in tough environments for measurement in steel production processes.

(2) As typical examples of size measurement techniques, a thick plate shear line length meter and an inter-stand sensor for hot rolling finishing mills were

described in this paper.

(3) As for shape measurement techniques, plate profile gauges and H-beam cross-sectional profile measurement apparatuses for hot rolling and cold rolling were described.

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