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Manufacturing Method and Equipment for Hot Rolled H-Shapes with Fixed Outer Dimension

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1 Introduction

H-shaped products, which are usually manufactured by hot rolling in a conventional universal mill, are sized according to an inner web height that is governed by the width of the horizontal roll. However, for many years, users have asked for H-shapes with outer fixed dimensions for easier use in construction. Kawasaki Steel has studied methods for manufacturing H-shapes with fixed outer dimensions by hot rolling, and developed flange width control techniques for use with a universal mill. The company has also established manufacturing techniques for hot-rolling H-shapes to fixed outer dimensions in a new type of universal mill by controlling the inner web width. This paper describes the manufacturing techniques and equipment for producing the Super HISLEND-H series of H-shape with fixed outer dimensions.

2 Goals and Tasks of Development

2.1 Goals of Development

H-shapes manufactured by the conventional hot rolling method have fixed inner dimensions as shown in **Fig. 1**(a), while fixed outer dimension H-shapes are usually manufactured as welded assemblies. Both methods have advantages and shortcomings. H-shapes with fixed outer dimensions produced by hot rolling as shown in Fig. 1 (b) offer the combined advantages of both methods. The features of these newly developed H-shapes are as follows:

(1) Stable supply and economy by mass production
(2) Uniform and reliable quality
(3) Fixed outer dimensions
(4) High dimensional accuracy

The specifications of the new product have been covered in the paper entitled "Development of Fixed Outer Dimension H-Shapes, Super HISLEND-H."[1] **Table 1** shows examples of typical sizes, and when

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flange thickness and web thickness are changed, the outer dimensions are held constant within the nominal size group.

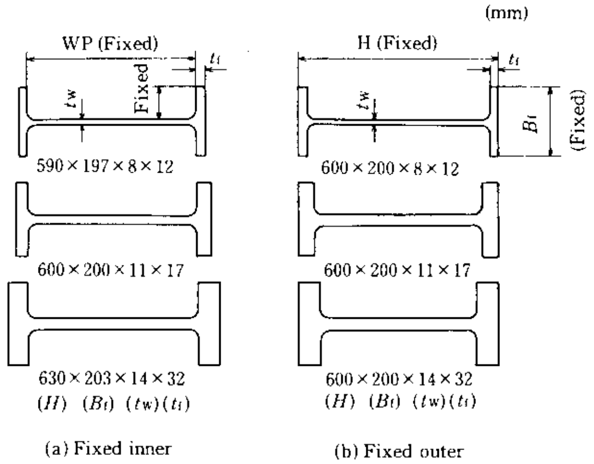
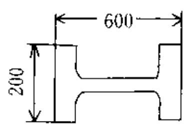


Fig. 1 Comparison between H-shapes with fixed inner and outer dimensions

Table 1 Example of a fixed outer dimension H-shape

Dimension(mm)	Thickness(mm)	
	Flange	Web
	12~28	9~12

2.2 Technical Aspects of Development

Figure 2 shows technical aspects involved in the rolling of H-shapes with fixed outer dimentions by the web inner width reduction method, which has been developed and put into practical use by Kawasaki Steel, and **Fig. 3** shows the development program. In order to develop hot rolling techniques for manufacturing H-shapes with cross-sectional efficiency and dimensional accuracy equivalent to welded H-shapes, the company pursued its R&D as follows: (1) widening of web inner width[2)] by web partial rolling in 1980, (2) research on web inner width reduction rolling[3-5)] in 1986, and (3) inner width control techniques by the web inner width reduction method in December 1988. Later, rolling characteristics were investigated by applying the method to commercial equipment, and in November 1989, the actual application of the new rolling method was put into practical operation.

Since the manufacture and sales of Super HISLEND-H by the new process started in November 1989, smooth manufacturing has been continued. The Super HISLEND-H rolling technique fundamentally improved the problems of the conventional hot-rolled H-shapes. The main problems overcome can be summarized as follows:

(1) Achieving web height uniformity
(2) Achieving flange width uniformity
(3) Achieving reduced web thickness
(4) Achieving high accuracy for dimension and shape

All these problems have previously been considered theoretically difficult, but the Kawasaki Steel development program has made it possible to manufacture fixed outer dimension H-shapes by hot rolling for the first time. The new techniques that were developed will be described in detail in this report, except for the tech-

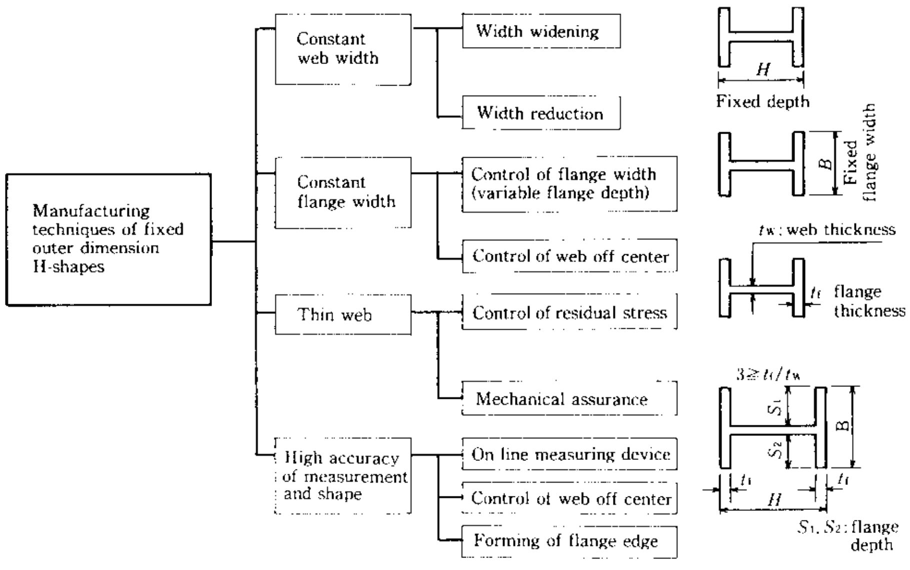


Fig. 2 Technical subject of rolling process for fixed outer dimension H-shapes

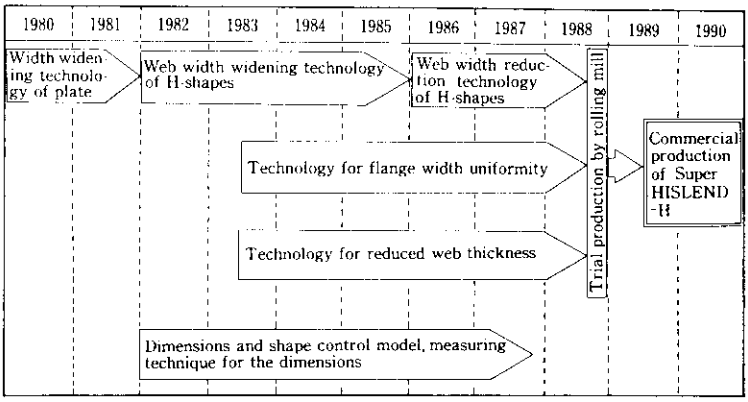


Fig. 3 Progress of technical development at Kawasaki Steel

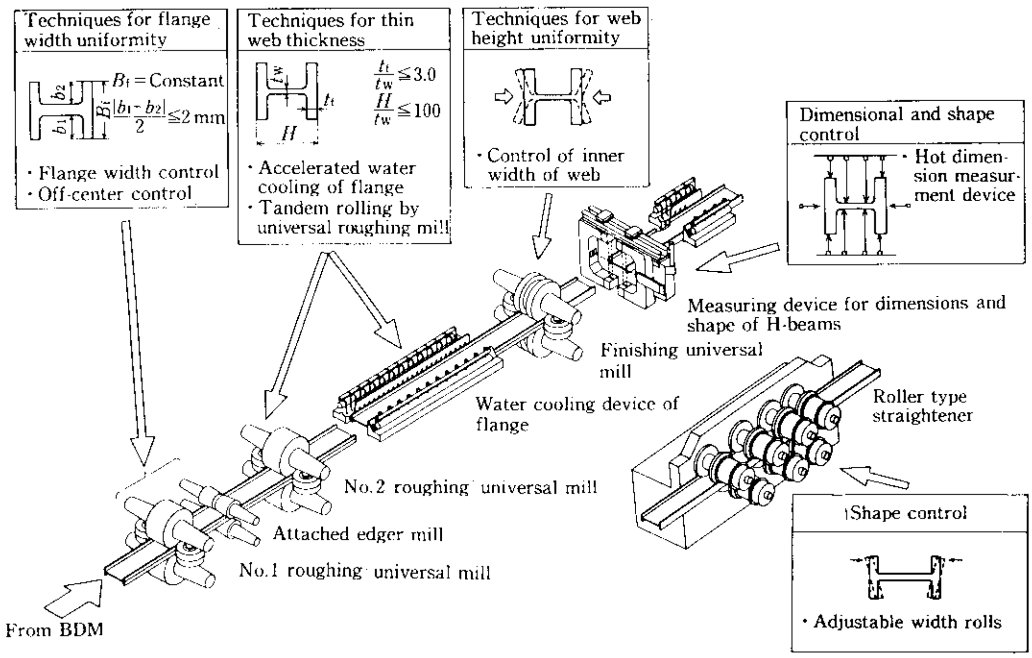


Fig. 4 Production process for fixed outer dimension H-shape and technical subject

niques to reduce web thickness, which are described in the paper entitled "Development of a Process for Manufacturing Rolled H-Shapes with Light-Web".[6]

The new rolling method utilizes existing manufacturing facilities, and new equipment has been connected to the existing rolling line. The production process for fixed outer dimension H-shapes is shown in **Fig. 4**.

3 Web Height Uniformity

Regardless of whether the fixed inner dimension or fixed outer dimension system is adopted, the manufacture of H-shapes by hot rolling involves plastic deformation by inducing both tensile and compressive stresses. The concept of the manufacturing method is shown in **Fig. 5**.

3.1 Examination of the Hot Rolling Method

The manufacturing method shown in Fig. 5 includes both inner width widening of the web by partial rolling and inner width reducing of the web by universal rolling mill that incorporates an adjustable-width horizontal roll.[7]

3.1.1 Inner width widening by web partial rolling

The principle of web partial rolling is shown in **Fig. 6**. At the stage of roughing by universal rolling, a zone of increased web thickness is formed at each end of the web, these zones then being finished by universal rolling, which increases the height of the web. However, this method proved not to be practical, because there were problems with the wear resistance and durability

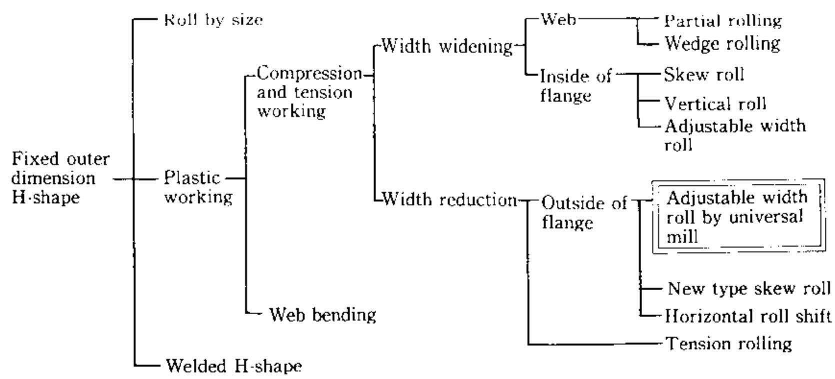


Fig. 5 Concept of the manufacturing method for fixed outer dimension H-shapes

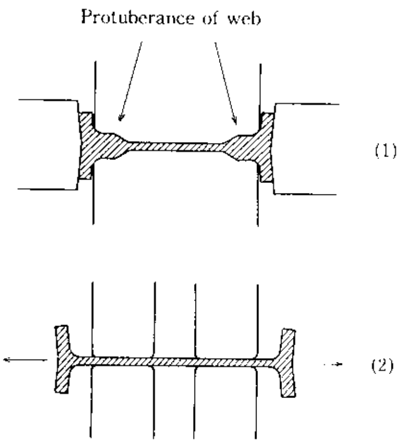


Fig. 6 Web partial rolling method

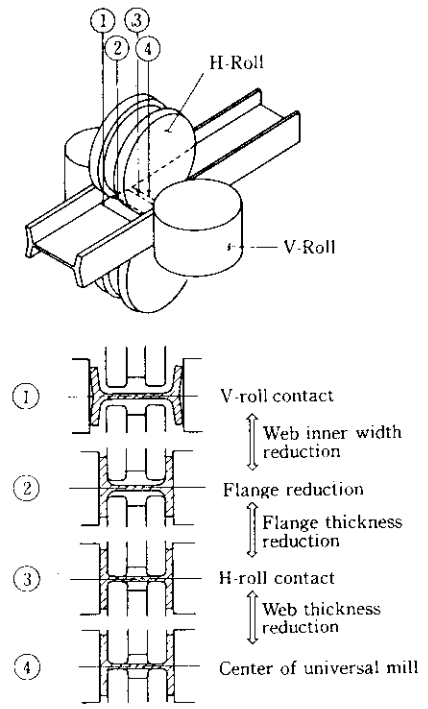


Fig. 7 Procedure for web inner width reduction in a universal mill

of the rolls and with the degree of web widening.

3.1.2 Web inner width reduction

The procedure for this method is shown in **Fig. 7**. Compared with the web width widening method, web inner width reduction compresses the material at a higher temperature, and was found to be more effective for easy shape changing. When reducing the web width, such problems as web buckling, web thickness changes and web off-centering can occur. These problems can be overcome by utilizing the feature of the universal rolling mill that both the horizontal and vertical rolls are in the same plane. If, using the universal rolling mill, compressive forming of the web is done and the flange is rolled by vertical roll, and the web is constrained and rolled by horizontal rolls, these problems can be overcome. This new method has proved to be eminently practical.

3.2 Development of the Rolling Equipment

3.2.1 Adjustable-width horizontal rolls[8)]

In order to reduce the web inner width by rolling, which makes the web height of an H-shapes controllable, it is necessary to adjust the width on-line according to the thickness of the flange, to have an adequate flange rolling pressure, and to adjust the roll width accurately. However, existing equipment cannot achieve all these functiones, so Kawasaki Steel has developed the necessary rolling equipment. The construction of the adjustable-width horizontal roll which the company developed and has put into practical use is shown in **Fig. 8**, and the specifications are shown in **Table 2**.

A highly rigid arbor is positioned between two roll chocks, and the roll width-adjusting mechanism is situated outside the roll chocks. This design configuration has proved highly-reliable in providing accurate roll-

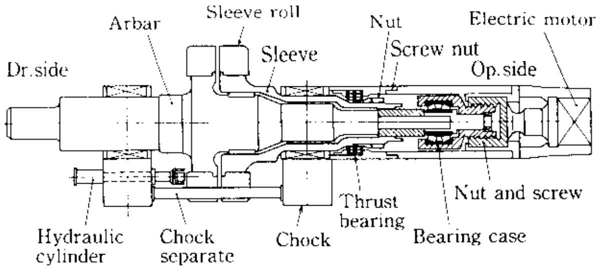


Fig. 8 Schematic diagram of an adjustable width rolls

Table 2 Specifications of the adjustable-width rolls

Type	
W. S.	Rigid
D. S.	Shift
Drive	Electric motor and hydraulic cylinder
Axial mill modulus	85 t/mm
Accuracy of adjustable width	±0.1 mm
Width adjustment speed	1.0 mm/s
Axial load	200 t
Range of adjustable width	0～110 mm

width adjustment. The separate roll sleeves that are necessary for adjustable width are shrink-fitted to the arbor and sleeve, respectively. The arbor on the drive side, which carries the drive side roll sleeve, is axially located by the thrust bearing, which is assembled with the roll chock on the operation side. The operation side of the arbor passes through the sleeve, and its end comes into contact with the adjustable-width mechanism. Consequently, although this mechanism is on the operation side, it is the roll on the drive side that moves. The adjustable-width mechanism consists of an electric motor, reducer, screw and nut, all these components being accommodated in a cartridge that can be easily replaced.

The method for web inner width reduction by the universal mill is shown in **Fig. 9**. With conventional rolling, the clearance between the right- and left-hand vertical rolls is determined by the barrel width of the horizontal roll, and the clearance between the flanks of the horizontal roll and the vertical rolls is used to obtain the prescribed flange thickness. This clearance in the new rolling method is determined by the required web height, and is set adjusting the width of the horizontal roll.

3.2.2 Through-type guide for the vertical rolls

When the reduction of the inner width of the web is excessive, movement of the flange may occur in the flange width direction, resulting in web off-centering. To

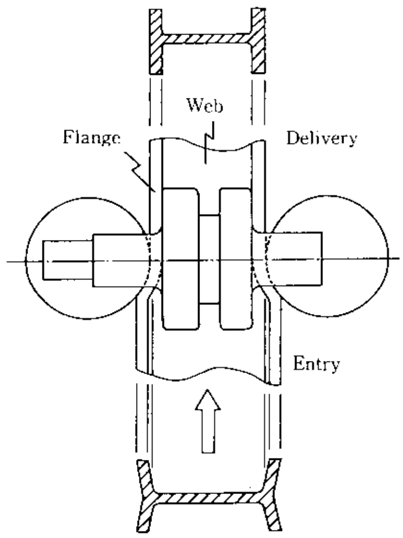


Fig. 9 Web inner width reduction method

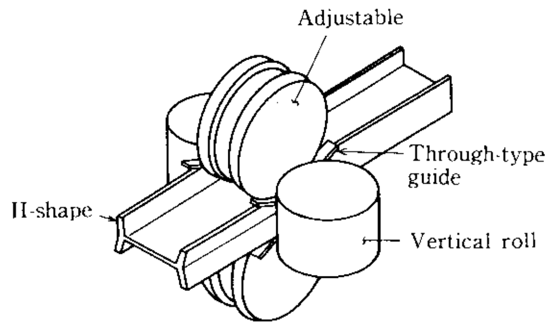


Fig. 10 Guide for H-shape in universal mill

prevent this and maintain the required flange width guides are provided between the horizontal and vertical rolls to constrain the flange tips as the H-shapes passes from the inlet side of the vertical roll to the roll center. This feature is shown in **Fig. 10**.

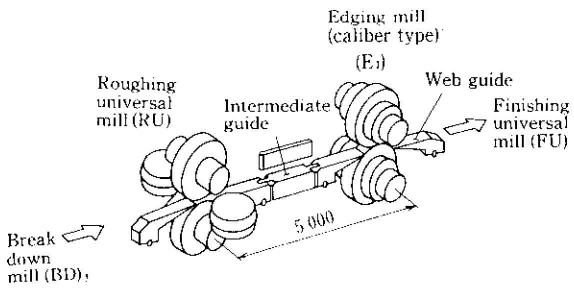
4 Flange Width Uniformity

Uniform flange width is controlled by edger rolls, and the two operations of web centering and flange width control have been separated with the new system.

4.1 Techniques Required for Uniform Flange Width

A conventional universal mill train consists of the mill itself, edger, and guide as shown in **Fig. 11**. The flange width is controlled by the edging roll. Since the flange depth is determined by the caliber depth of the edging roll, the flange width changes with different web thickness.

Because the flange width is kept constant for the Super HISLEND-H shapes, however, it is necessary to



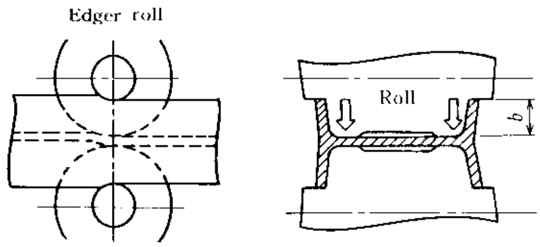


Fig. 12 Principle of reformation of web off-center by edging mill

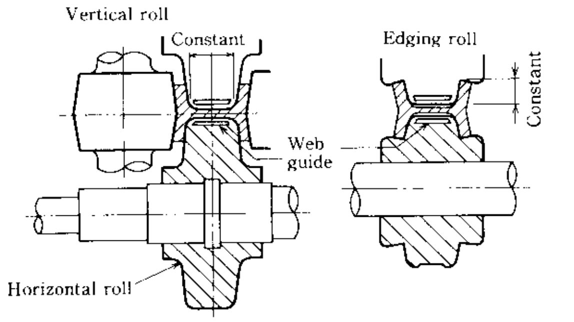


Fig. 11 Conventional rolling method for H-shapes by universal and edging mill

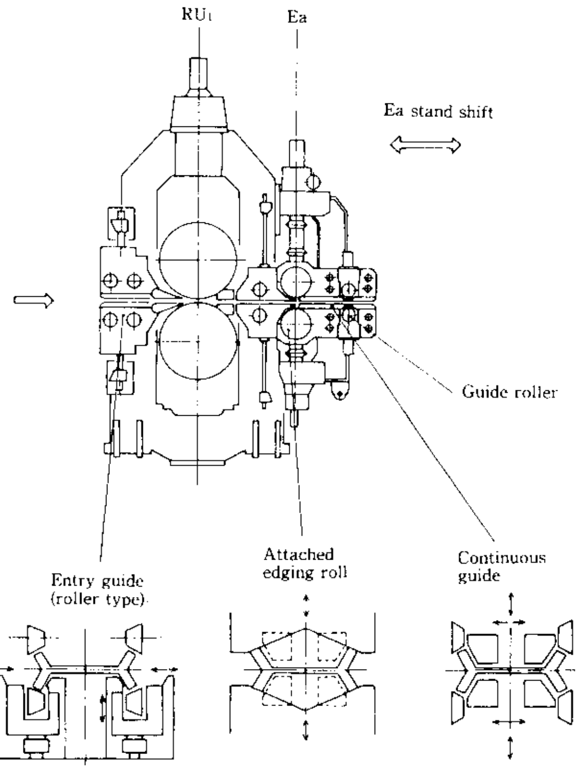


Fig. 13 Conception of the new type universal and edging mill (compact universal mill)

adjust the flange depth according to required web thickness. Consequently, a rolling technique with flange-depth adjustment was developed together with flange-width control.

4.1.1 Functions of the conventional edger

Ordinarily, the edger has the function of flange-width rolling and correction of off-centering caused by cross-sectional variations in the material and non-uniform rolling at the roughing universal mill. These operations are carried out together by constraining the flange depth with the caliber of the edging roll and by reforming the web, as shown in **Fig. 12**.

4.1.2 Concept of the new edger

The newly developed edger separates these two functions. The flange of the H-shapes, which has high rigidity, is constrained by a roller-type guide and the web position and shape are controlled by edging rolls, after which the shape is guided out of the universal mill by a combination of roller and continuous guides.

4.2 Development of the New Rolling Equipment

An outline of new-type universal mill[4,9,10] is shown in **Fig. 13**, and the main components are explained in the following section.

4.2.1 New-type edging mill (attached edger)

By limiting the functions of the edger to the flange width rolling alone, the roll is of the drum type and of relatively small diameter. This enables the edger to be installed immediately next to the roughing universal mill, roll changing being unnecessary. The specifications of this attached edger are shown in **Table 3**.

Table 3 Specifications of the attached edger mill

Item	Specification
Roll	O. D. 698, I. D. 600, L 1 270 (mm)
Roll taper	5 deg.
Radial load	Max. 300 t

4.2.2 New-type mill guide method

An investigation of the relationship between web off-centering and the rolling conditions revealed that there is correlation between the bite height, bite angle, and horizontal roll level. Namely:

(1) Changing the bite height and bite angle causes reforming of the web and the web off center is changed.

(2) Any difference in the reduction in thickness of the upper and lower flanges affect the web off center.

Consequently, it was found that to prevent the web off-centering from occurring, it is necessary to make the pass line of the horizontal roll coincident with the vertical roll center and to cause the flange center of the piece to bite horizontally into the mill center. To achieve this, the flange tips are constrained at the entry and exit of the universal mill, as shown in **Fig. 13**, by a guide system, which acts on both the inner surface of the flange and the web surface.

4.3 Roller Straightener for Adjustable-Width Rolls

The construction of the adjustable-width rolls for the roller leveller is shown in **Fig. 14**. This makes it possible to manufacture the Super HISLEND-H shapes with the horizontal roll of the finishing universal mill by profile changes to the web inner width of the H-shapes and by allowing on-line roller width adjustment. The adjustable-width roller straightener has the fixed-side roller installed on the fixed sleeve of the main spindle, and the movable-side roller installed on a movable sleeve that can slide on the fixed sleeve. The width-adjustment mechanism consists of an electric motor, screw, nut, etc., which are installed at the end of the spindle.

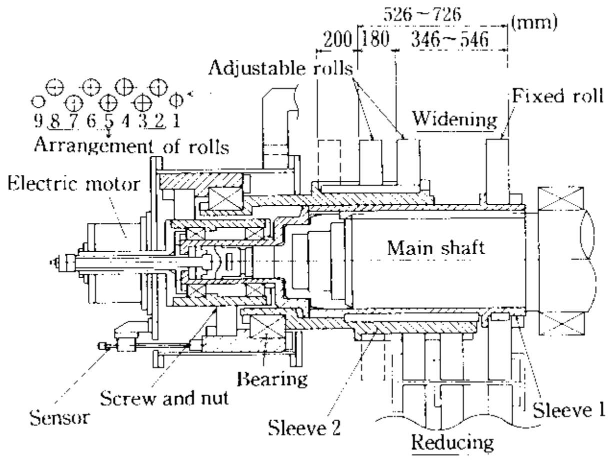


Fig. 14 Roller straightener for the adjustable-width rolls

5 Dimension and Shape Control System

5.1 Outline of the Process Control System

In order to manufacture Super HISLEND-H, the large-size H-shape mill uses process computers (P/C), direct digital controllers (DDC), a hot dimensional measurement device, many sensors such as thermometers, and other controllers. Automatic operation of the rolling machines and water cooling is handled by the process control system to maintain the correct dimensions and temperatures. An outline of the system is shown in **Fig. 15**.

5.2 Development Techniques

In order to manufacture H-shapes of high dimensional accuracy, it is necessary to control to high accuracy the dimensions and shape at the universal mill, and

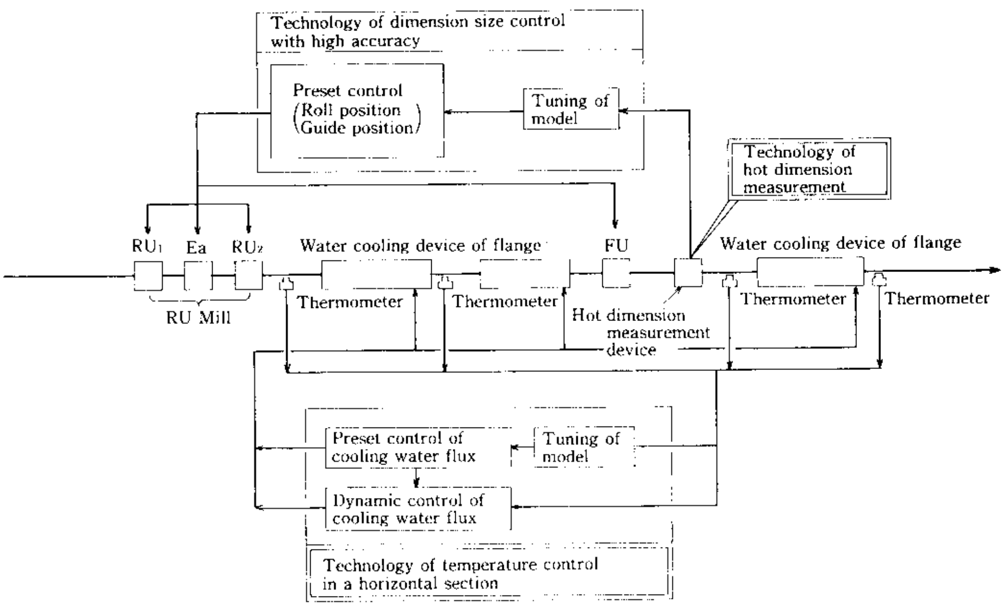


Fig. 15 Schematic diagram of the process control system

the temperature of flange water-cooling.

However, it was impossible to achieve the high dimensional accuracy required by Super HISLEND-H with conventional sensors and control techniques, and the following methods were developed:

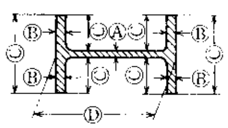
(1) Hot measurement of the H-shapes dimensions
(2) Dimension control
(3) Cross-sectional temperature control

5.3 Development of Dimensional Measurement Techniques for Hot-Rolling H-Shapes

The measurement requirements for dimensional control of the Super HISLEND-H rolling are shown in **Table 4**. Since there were no adequate conventional techniques for continuous on-line measurement of hot-rolled H-shapes, the authors have developed the necessary high-accuracy dimensional measurement methods.[11,12]

Table 4 Measurement parameters and accuracy (μm)

	Item	accuracy (1σ)
A	Web thickness	45
B	Flange thickness	77
C	Symmetry Flange width	210 130
D	Web height	180



5.3.1 Method for calibrating a laser distance meter

The linearity of conventional distance meters is limited to ±0.05%, whereas we required a target accuracy of ±0.03% or better. It was found that higher accuracy of the distance meter could be achieved if the profile of the light-receiving energy distribution was stabilized at the time of calibration. This could be done by rotating and translating the measurement surface, and a significant improvement was obtained. This calibration method is shown in **Fig. 16**, and it has been possible to improve the linearity of the laser distance meter to ±0.015% or better throughout its measurement range.

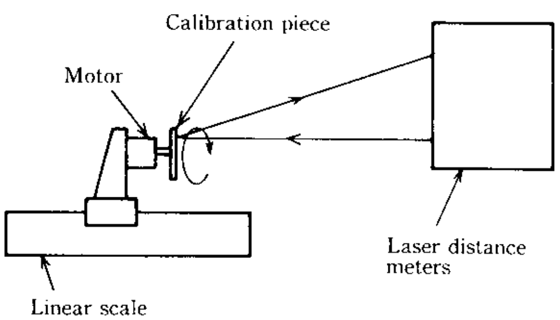


Fig. 16 Method for calibrating the laser distance meter

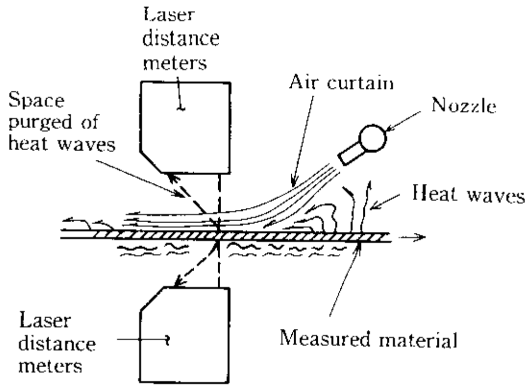


Fig. 17 Method of heat wave purging

5.3.2 Purging of thermally radiated waves

When the object of measurement is a hot rolled H-shapes, the air in the vicinity of the object is heated and heat waves are generated, which cause a measuring error. After completing various tests on the method for heat wave purging, the method shown in **Fig. 17** proved effective, hardly any heat waves being radiated from the lower surface of the measured object.

5.4 Dimensional and Rolling Control of H-Shapes

The manufacture of Super HISLEND-H to high dimensional accuracy involves precise positional control of the mill rolls and guides. Computer modeling and hot measurement sensors are used to achieve this.

5.4.1 Dimensional control

(1) Web Thickness and Flange Thickness
Temperature and load prediction from data for various mills, and by using gauge-meter formulas, enabled the settings for roll positions to be calculated. Measured values from thermometers, load meters and dimensional measurement meters enabled the settings to be progressively refined until the required results were obtained.

(2) Flange Width
The formulae for flange width widening by a roughing universal mill and for flange width widening by a finishing universal mill were applied for reducing the web inner width by rolling, and after the prescribed calculation procedure, the target flange width from various passes were obtained so that the roll position of the edger could be set.

(3) Web Height
Web height is the total of the thickness of both flanges and the web inner width. The web inner width can be controlled by the adjustable-width horizontal roll in the finishing universal mill. To optimize the web height accuracy, the dimensions measured by the hot-rolling meter installed at the end of the mill were analyzed by the process computer.

(4) Web Off-Centering
In order to prevent web off-centering, the guide rollers for constraining the upper and lower flange tips were set in the roughing mill. This setting took into consideration flange width spread, so that the mill center would coincide with the flange width center of the work piece. The positions of the flange constraining and penetrating guide and the adjustable width web guide were set in the finishing universal mil, taking into consideration the width increase resulting from web reducing.

5.4.2 Rolling control

Dimensional control is achieved by controlling rolling with the process computers.

(1) Calculating the Initial Roll Positions
According to the control information for the material to be rolled, temperature and load calculations are made for each job, and the roll positions in the mill are ascertained.

(2) Refinement
After taking the measured values from the various hot-rolling dimensional meters, the model coefficients are corrected by exponential smoothing.

(3) Automatic Setting of the Rolling Mill
The settings for the adjustable-width horizontal roll in the finishing universal mill and the flange-constraining roller guide are calculated and output to the direct digital controllers.

The principal formulas which were developed for controlling the process include those for the temperature, load, flange-width increase, and gauging. Among these, the load formulas were as follows:

Vertical Rolling Load

$$PV = B_f L_{dv} K_{ff} Q_f Q_{pf} \cos\theta$$

Horizontal Rolling Load

$$PH = B_W L_{dH} K_{fw} Q_W Q_{pW} + PV \cdot (\tan\theta + C)$$

$$QW = Q_{W0} + Q_{C0}(r_W - r_f)$$

where PV, PH: Vertical and horizontal rolling loads
K_f: Average deformation resistance
Q: Universal rolling force function
Q_p: Rolling force function for plate rolling
θ: Horizontal flange roll inclination angle
C: Flange inner-surface friction coefficient
r_W, r_f: Web and flange reduction in thickness
L_d: Roll contact length
R: Roll radius
B_f: Flange width
t_W, t_f: Web and flange thickness

Suffixes V, H and f indicate the vertical roll, horizontal roll and flange, respectively.

6 Conclusions

Kawasaki Steel has developed new techniques to control the web height and flange width of hot-rolled H-shapes that allow these H-shapes to be produced to high dimensional accuracy with fixed outer dimensions. These fixed outer dimention H-shapes "Super HISLEND-H" were the long-cherished dream of persons concerned with H-shape manufacture, and also opened the road for establishing the "roll chance free" rolling techniques. These developed techniques are summarized as follows:

(1) Web height uniformity is achieved by the web inner width reducing method in a finishing universal mill provided with adjustable-width horizontal rolls and through-type guides for the vertical rolls.
(2) The new guide system, in which the high-rigidity flanges are constrained at the entry and exist of the roughing universal mill by roller-type guides, controls web centering, and flange width uniformity is ensured by a drum-type edging roll.
(3) Roll changing is unnecessary after converting the roller straightener into an on-line adjustable-width roller, which maintains the required web inner width.
(4) On-line hot-rolling dimension measurement with a laser distance meter was developed, and high-accuracy control of the system has been established.

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