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Construction and Operation of No. 4 Cold Mill for Stainless Steels at Hikari Works

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Abstract:

To improve the productivity and quality competitiveness of cold-rolled stainless steel products, a 12-high cluster mill with a maximum rolling speed of 1,200 m/min was installed and put into commercial operation at Hikari Works in November 1994. The new mill is characterized by 1) the realization of stable high-speed rolling; 2) the introduction of high-accuracy control functions to produce high-quality, cold-rolled products; and 3) the installation of automation devices to increase labor productivity. Since its full-fledged start-up, the mill has been smoothly producing cold-rolled stainless steel products with higher productivity and quality.

1. Introduction

Stainless steels have high corrosion resistance, heat resistance, and strength, among other properties. Taking advantage of their excellent properties, stainless steels have many new applications and can be substituted for carbon steels. As a result, demand for these stainless steels has been increasing yearly.

Surface quality is the main factor governing the commercial value of cold-rolled stainless steel products. Stainless steels generally have greater deformation resistance than carbon steels and, for example, are more difficult to tandem roll with high efficiency. For these reasons, stainless steels must be rolled on mills with small-diameter work rolls, and 20-high cluster mills (Sendzimir mills) have been traditionally used. Three Sendzimir mills are in operation at the Hikari Works of Nippon Steel.

Expanding markets for cold-rolled stainless steel products now have more severe requirements for thickness accuracy and flatness as well as surface quality. To meet these requirements, Hikari Works constructed a 12-high cluster mill (No. 4 cold mill) and put it into commercial operation in November 1994. The equipment and operation of the No. 4 cold mill are described here.

2. Basic Design of No. 4 Cold Mill

The following three purposes were established for the basic design of the No. 4 cold mill:

(1)Improvement in productivity by high-speed rolling
(2)Manufacture of high-quality, cold-rolled products
(3)Labor savings by automation

To accomplish these purposes, the equipment design of the No. 4 cold mill was carried out according to the policies described below.

2.1 Realization of rolling speed of 1,200 m/min

The maximum rolling speed of stainless steel cold-rolling mills constructed in recent years has tended to increase yearly as shown in **Fig. 1**. The Hikari No. 4 cold mill was designed for rolling at a higher maximum speed.

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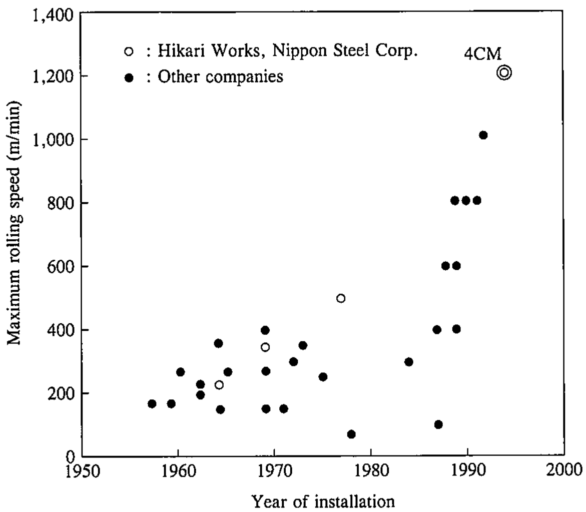


Fig. 1 Change in maximum speed of stainless steel cold-rolling mills in Japan

At its Sendzimir mills, Nippon Steel has traditionally used a soluble rolling oil that cools the strip and work rolls with excellent results. The technology of ensuring the desired surface quality of cold-rolled stainless steel by using soluble rolling oil was combined with automatic shape control (ASC) functions to cold roll stainless steel at 1,200 m/min, the highest speed in the industry.

2.2 Enhancement of gauge and shape control functions

The severity of thickness accuracy required of cold-rolled stainless steel products is increasing, as represented by manufacturing tolerances of increasing stringency for electronic parts and equipment. To meet stricter requirements, the prevention of declining thickness accuracy because of tension disturbance was introduced in addition to the conventional automatic gauge control (AGC) functions, or feedforward AGC, feedback AGC, and mass flow AGC. As a result, thickness accuracy far higher than the conventional levels was attained.

To ensure shape accuracy, shape meters and ASC functions were introduced. The initial setup conditions of the 12-high cluster mill were also improved to expand the mill's shape control capability. Consequently, the No. 4 cold mill could cold roll stainless steel products with better flatness.

2.3 Introduction of automation devices

To achieve improved productivity and save labor with the No. 4 cold mill, all tasks associated with coil handling and rolling and roll transfer were automated, from the identification of received coils to transportation of finish-rolled coils and to the next process. Automation equipment was installed mainly to shorten the idle time that was one factor limiting the productivity of conventional reversing mills.

3. Equipment Specifications and Configuration

3.1 Main equipment

The equipment layout of the No. 4 cold mill is shown in **Fig. 2**, and the mill's main equipment specifications are listed in **Table 1**.

The coil to be rolled is inserted onto the entry tension reel. The finish-rolled coil is removed from the delivery tension reel, carried by the coil car, bound with hoop, automatically marked with identification marks, and sent to the next process.

To improve strip thickness and shape accuracies, X-ray thickness gauges, laser velocimeters, and piezoelectric shape meters are installed in pairs across the mill.

The top and bottom intermediate rolls of the mill are driven by AC motors through speed reducers. The rolling force is a maximum of 1,000 tons and is servo controlled by a direct-acting hydraulic pushup system. The maximum rolling speed is 1,200 m/min, and a soluble rolling oil sufficiently cools the strip and rolls. A Hoffman filter filtrates the rolling oil. A magnetic separator removes iron fines from the rolling oil, thereby preventing rolling oil contaminants from adhering to the strip being rolled.

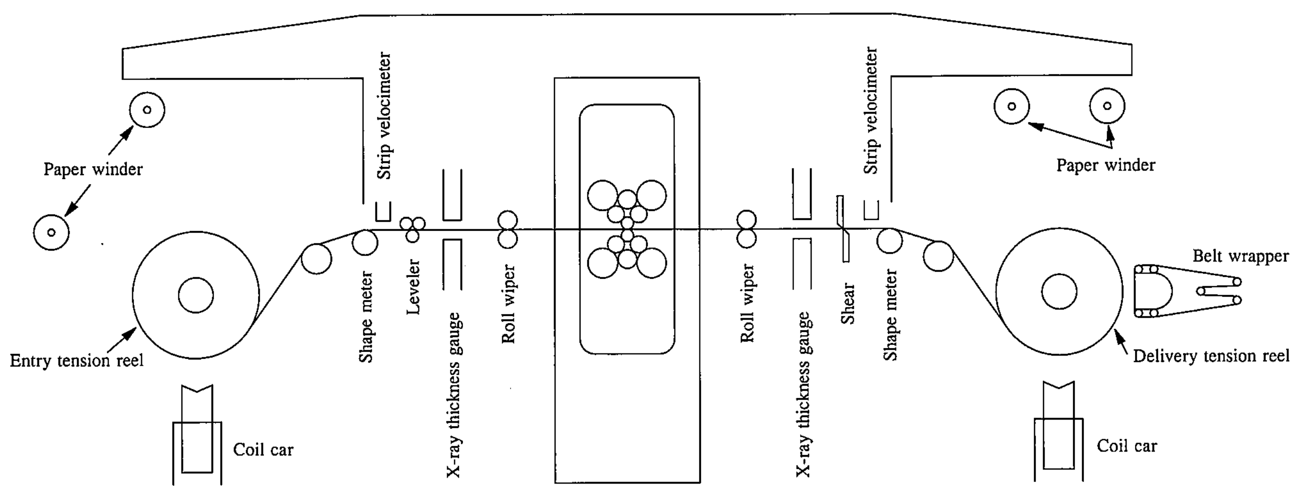


Fig. 2 Equipment layout of No. 4 cold mill

Table 1 Equipment specifications of No. 4 cold mill

Division	Item	Specifications
Line	Mill type	12-high cluster mill
	Production capacity	10,000 t/month
	Maximum rolling speed	1,200m/min
	Maximum rolling force	1,000t
	Maximum tension	50t
	Rolls	Work rolls: 80 mm ϕ -120 mm ϕ Intermediate rolls: 210 mm ϕ -255 mm ϕ Backup rolls Large-diameter rolls: 547 mm ϕ -550 mm ϕ Small-diameter rolls: 297 mm ϕ -300 mm ϕ
	Rolling oil	Soluble rolling oil
	Filter	Hoffman filter
Steel	Type	Stainless steel
	Thickness	Hot band thickness: 0.7 mm-4.0 mm Product thickness: 0.2 mm-1.0 mm
	Width	600-1,300mm
	Maximum coil weight	27.3t
	Coil inner diameter	660mm ϕ
	Maximum coil outer diameter	2,300mm ϕ

As for electric equipment, the mill and tension reels are driven by cycloconverter-fed motors to obtain high torque response. The reel motors have a 1:6 field cone and are field flux compensation controlled to achieve field weakening current control with the high accuracy and response required during high rates of acceleration and deceleration. The variations in cycloconverter-induced reactive power are reduced by the combination of cycloconverter circulating current control with a filter and a capacitor.

3.2 Auxiliary equipment

The cold rolling of stainless steel involves such a large rolling tension that interleaving paper is placed between coils wraps to prevent surface scratches from slippage. The No. 4 cold mill has paper winders above the entry and delivery tension reels to insert a roll of interleaving paper into each coil. At the rear of the mill, transfer equipment exchanges the interleaving paper between the entry and delivery paper winders.

A work roll changing car on rails in front of the mill removes used work rolls from the mill and inserts ground work rolls into the mill.

3.3 Control system

The configuration of the control system of the No. 4 cold mill is shown in **Fig. 3**. The control system consists of a process computer, 10 programmable logic controllers (PLCs), and a high-speed dataway. The process computer exchanges various items of information with the higher-level production control computer and the rolling mill PLCs. It also handles the information about rolls at a roll shop and tracks them. The PLC configuration is characteristic in that two AGC PLCs for high-speed calculation ensure high-accuracy AGC and two master PLCs ensure automatic rolling.

4. Operation and Product Quality of No. 4 Cold Mill

4.1 Thickness control methods and thickness accuracy

The configuration of the AGC system of the No. 4 cold mill is shown in **Fig. 4**, and the respective AGC functions are outlined in **Table 2**. Feedforward AGC (FFAGC), feedback AGC (FBAGC), and mass flow AGC (MFAGC) achieve thickness con-

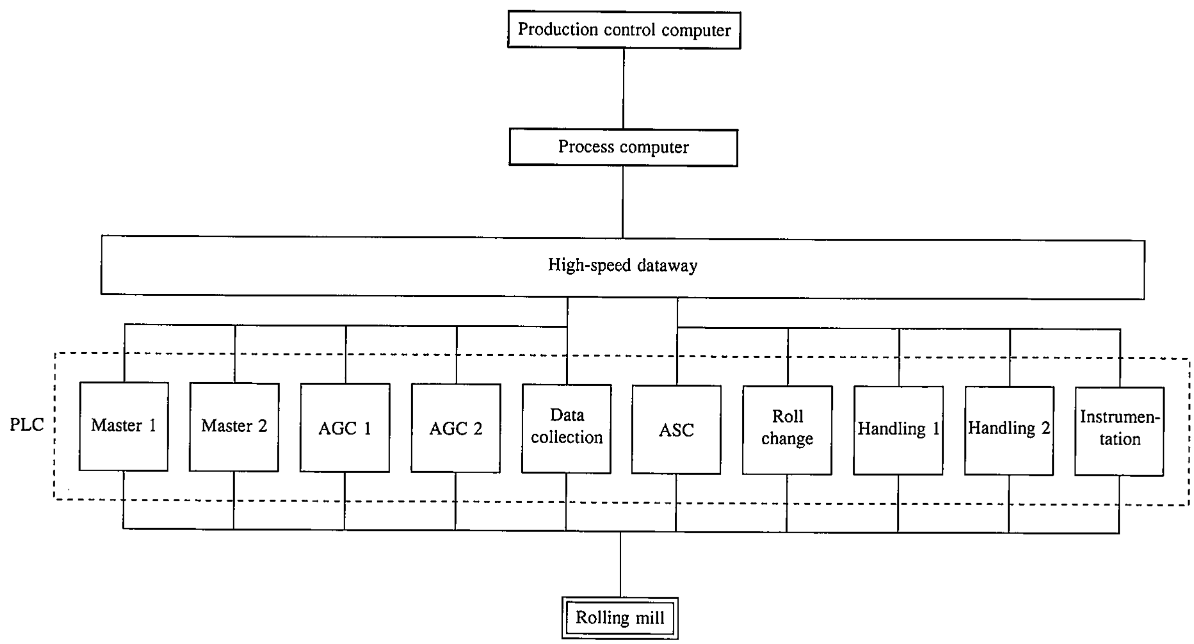


Fig. 3 Configuration of control system

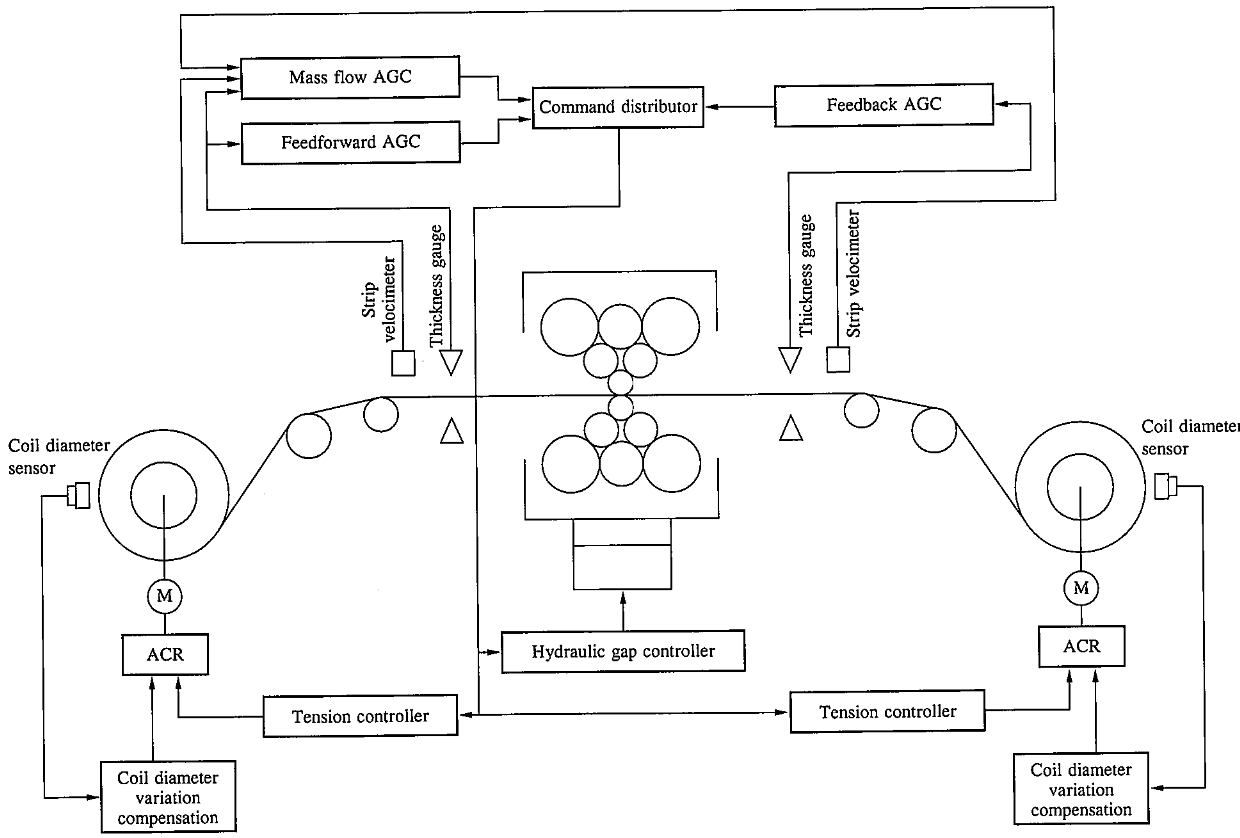


Fig. 4 Configuration of AGC system

Table 2 Automatic gauge control (AGC) functions

Control scheme	Function	Control method	
		Roll gap control	Tension control
Feedforward AGC	Deviation of entry thickness output from entry thickness set point is detected, and periodic variation of entry thickness is corrected.	○	○
Feedback AGC	Deviation of delivery thickness output from delivery thickness set point is detected, and delivery thickness offset error is corrected.	○	○
Mass flow AGC	Delivery thickness is estimated from entry thickness, entry speed and delivery speed, and thickness is controlled according to deviation from delivery thickness set point.	○	○
Coil diameter variation compensation	Change in coil peripheral speed with step at coil end is controlled, and tension variation is controlled accordingly.	×	○

trol with high accuracy. The strip thickness is controlled by regulating the roll gap and the strip tension.

Many of conventional reversing mills obtained the desired strip tension with tension reels. A small coil diameter variation resulted from the step at the end of the coil wrapped around the tension reel and caused the strip tension to vary, which in turn reduced the thickness accuracy. The No. 4 cold mill has coil diameter variation compensation to reduce this tension variation. The compensation function controls the peripheral speed of the coil at a constant level by detecting the change in the coil diameter with a gap sensor and tracking the coil in the circumferential direction as illustrated in **Fig.** 5. The coil diameter variation compensation function helped to restrict the tension variation with the change in the coil diameter as shown in **Fig.** 6 and substantially improved the thickness accuracy of the coil.

As a result of the coil diameter variation compensation function, the thickness variation at the center of the coil was reduced to a maximum of 1.3%, and the thickness accuracy was greatly improved compared with conventional mills. An overall thickness accuracy of 2.5%, including the thickness deviation in the transverse direction, was accomplished as shown in **Fig.** 7 by combining the technology of manufacturing hot coils of reduced crown in the hot-rolling process with the No. 4 cold mill.

4.2 Automatic shape control (ASC) functions and actual shape

The configuration of the ASC system of the No. 4 cold mill is shown in **Fig.** 8. Shape control is achieved by backup roll crown adjustment, intermediate roll bending, and hydraulic work roll leveling. The ASC functions are outlined in **Table** 3. The ACS system uses preset control to set the initial conditions in accordance with the changes in such rolling conditions as the steel type and strip width and reduction. The system also uses shape meter signal feedback control to accommodate variations of strip shape with the rolling force and strip tension. Learning control on

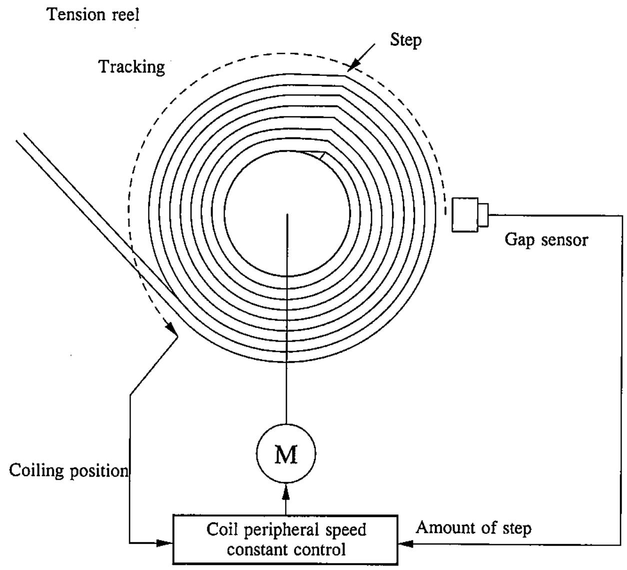


Fig. 5 Schematic illustration of coil diameter variation compensation

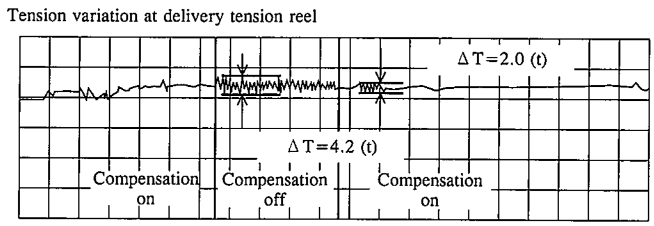
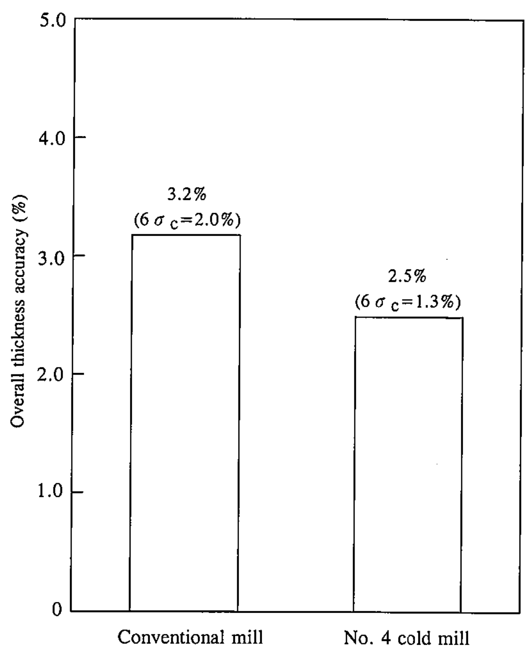


Fig. 6 Actual strip variation with coil diameter variation compensation



Overall thickness accuracy

$R = 3\sigma_C + \overline{X}_E + 3\sqrt{\sigma_C^2 + \sigma_E^2}$

σ_C = mill center thickness variation
$\overline{X}_E$ = mean of products strip crown
($\overline{X}_E$=0.94% : incoming strip crown ≦40μm)
σ_E = standard deviation of products strip crown
(σ_E=0.24% : incoming strip crown ≦40μm)

Fig. 7 Comparison of overall thickness accuracy

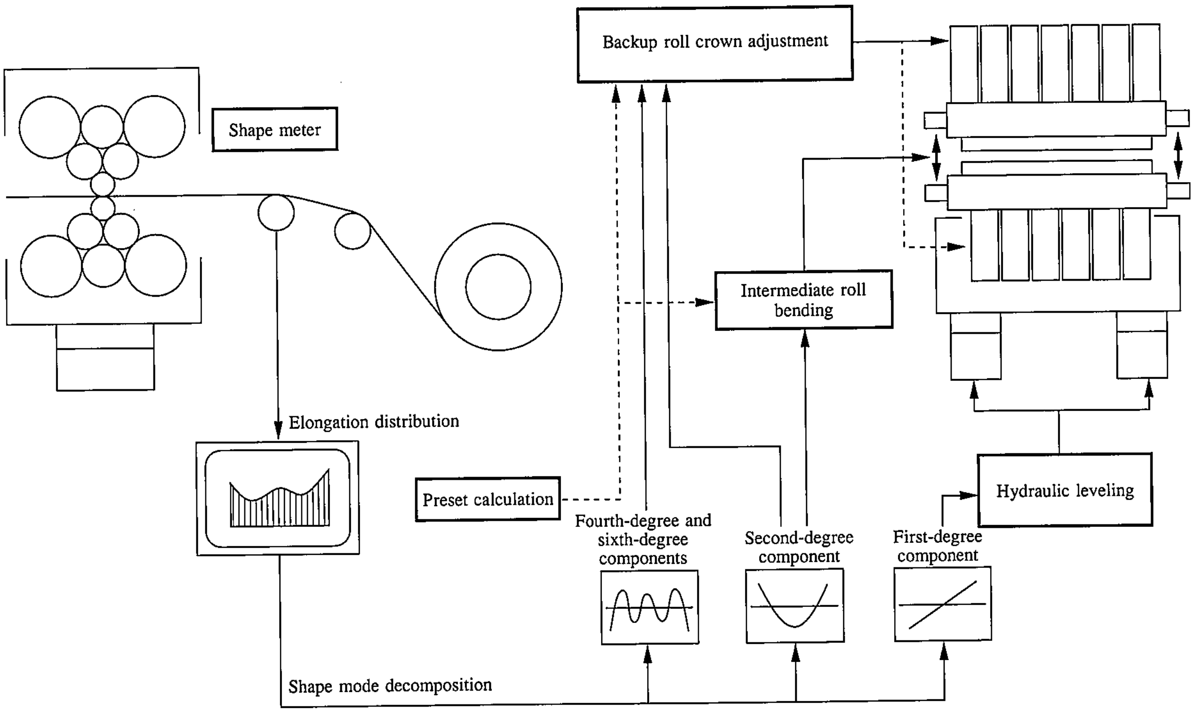


Fig. 8 Configuration of automatic shape control (ASC) system

Table 3 Automatic shape control (ASC) functions

Control scheme	Function	Control method		
		BUR* crown control	Intermediate roll bending	Hydraulic leveling
Preset control	Initial conditions before start of rolling are set.	○	○	×
Feedback control	On-line shape control is effected according to deviation of shape meter output from target shape.	○ (Top BUR alone)	○	○
Learning control	Deviation of actual rolling data from preset values is reflected in subsequent preset control to improve present control accuracy.	○ (Top BUR alone)	×	×

*BUR : backup roll

the basis of rolling results is also employed to improve the accuracy of preset control.

The ASC system of the No. 4 cold mill approximates and develops the shape of the strip being rolled by an orthogonal function of the sixth degree. Actuators are controlled optimally for the shape correction of the component of each degree. The first-degree, second-degree, and the fourth-degree and sixth-degree components are controlled mainly by hydraulic leveling, intermediate roll bending, and backup roll crown adjustment, respectively. The appropriate adjustment of backup roll crown is especially necessary for controlling compound shape defects such as quarter buckles. Conventional 12-high cluster mills have the crown of backup rolls controlled as follows. Each of the top backup rolls has a transversely symmetrical and independent eccentricity mechanism for feedback control during rolling. The crown of the bottom backup rolls is adjusted by preset control alone, and the rolls' eccentricity mechanism is based on spindle rotation alone. To expand the No. 4 cold mill's shape control capability, the mill is equipped with a transversely symmetrical and independent roll eccentricity mechanism for each bottom backup roll and is designed for selection of more preset conditions.

These ASC functions improve strip shape stability during rolling. **Fig. 9** shows examples of target shape and actual shape when strip was rolled to get edge waves. It was confirmed that very high shape control capability is ensured and that the drop of productivity owing to shape constraints can be prevented. As shown in **Fig. 10**, the No. 4 cold mill has dramatically improved the flatness of critical-shape strip compared with the conventional mill and the nonprice competitiveness of cold-rolled products as well.

4.3 Labor savings by automation

Many automation devices were introduced to reduce the number of operators and auxiliary equipment required for the rolling mill and to improve the availability of the mill motors.

The initial setup of rolling conditions — pass schedule calculation, rolling load and tension preset calculation, and shape preset calculation — is automatically performed by the process com-

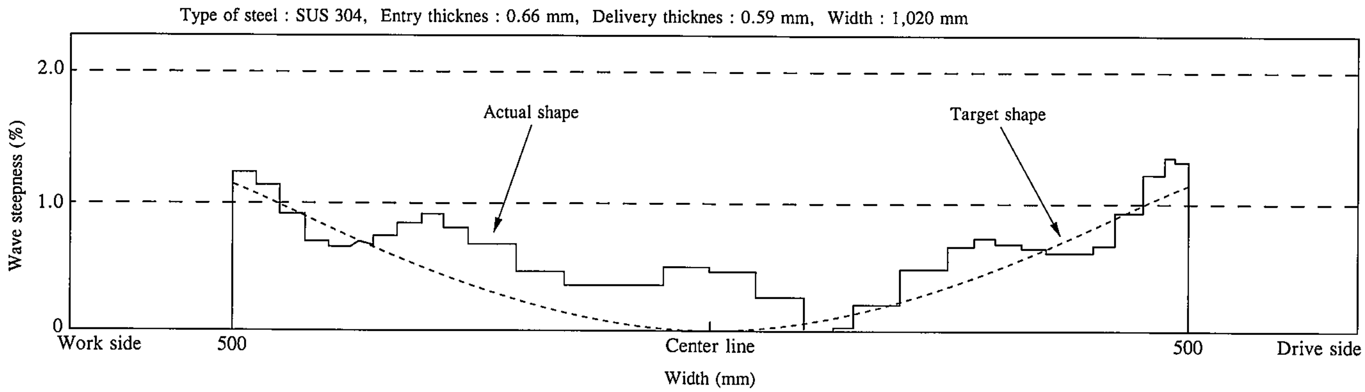


Fig. 9 Actual example of shape control

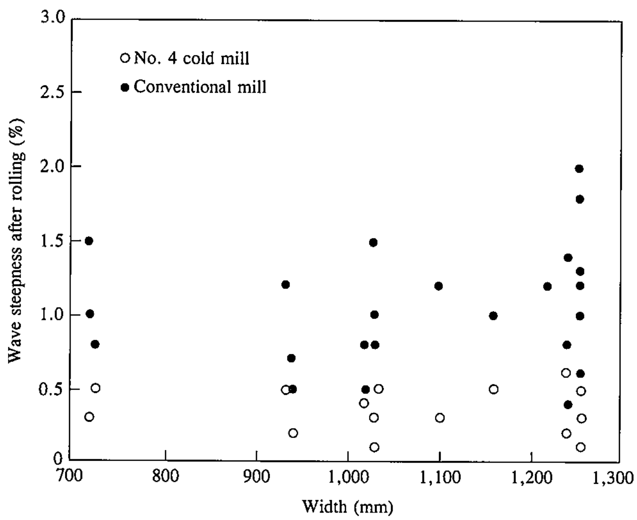


Fig. 10 Actual shape of critical-shape strip after rolling

puter. Besides routine rolling tasks on reversing mills, such as tail-end deceleration and stop-and-pass change, nonroutine tasks are automated as well, such as changing the strip thickness on the fly at an in-coil thickness change point and inserting an idle pass for adjusting the number of passes.

During a coil change, coil threading is automated by the introduction of a coil end guide of the swing arm type. A dedicated sleeve charger is installed to automate the sleeve charging operation and to shorten the sleeve charging time by avoiding interference with the coil delivery operation.

A special-purpose car is installed for automatically changing the work rolls, irrespective of whether or not strip is present in the mill, and each sequence is optimized to eliminate idle time.

The following automation devices are installed for auxiliary tasks. For the timely supply of interleaving paper to each coil as commanded by the higher-level production control computer, temporary paper storage stand is installed at the rear of the mill, and the transfer of paper from a stocker to a winder is automated. A movable paper deflector roll is installed above the delivery ten-

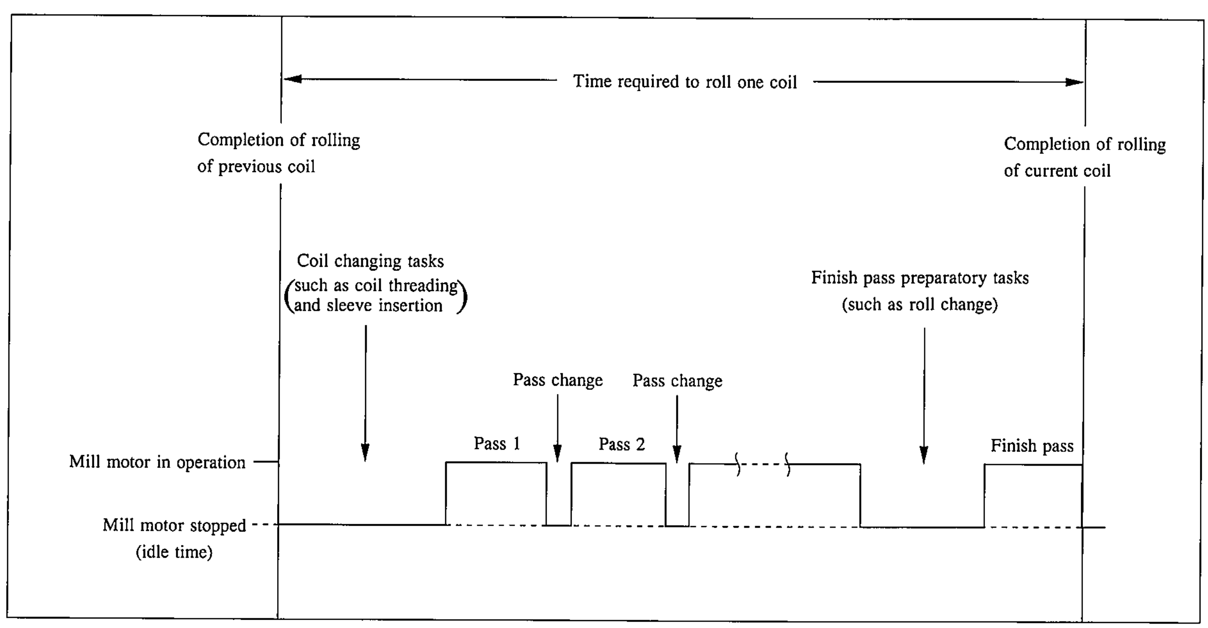


Fig. 11 Rolling pattern of reversing mill

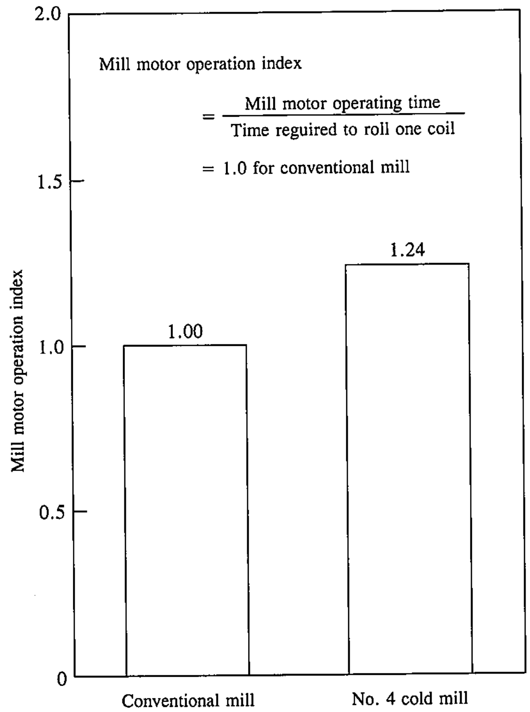


Fig. 12 Comparison of mill motor operation index

sion reel to automate the insertion of paper into the coil and to allow the stable insertion of paper during high-speed rolling.

Work rolls are identified and tracked by the mill's process computer and are automatically ground and carried. Operators schedule grinding and carrying of the work rolls.

Automation equipment helped to reduce the required mill operators per shift to two, to shorten the idle time experienced with reversing mills, and to improve the mill motor availability by about 24% compared with the conventional mill (see **Figs. 11** and **12**).

5. Conclusions

The No. 4 cold mill, constructed to improve the productivity and quality of stainless steel strip and sheet, started up smoothly and is performing fully as a principal mill at Hikari Works.

The authors are deeply indebted to suppliers for their cooperation in the construction of the No. 4 cold mill.