Abridged version

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Remodelling of Chiba No.2 Hot Strip Mill to Meet Higher Quality Requirements

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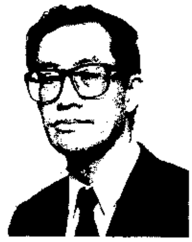
Remodelling of Chiba No. 2 Hot Strip Mill to Meet Higher Quality Requirements*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1 Introduction

Recently, along with increasing needs of customers for process streamlining, automatization, yield improvement, cost reduction, and higher tensile strength materials, steelmakers are strongly requested to supply flat-rolled products satisfying these requirements. Under these circumstances, quality requirements for hot rolled products of Chiba Works are also getting far more stringent than before, covering automotive use, mother coils for coating, stainless steel, and high-carbon steel. Not to mention uniformity of mechanical properties, the requirements include higher accuracy of product size and shape in thickness, width, flatness, and profile; as well as the upgrading of products to prime level in full-length covering coil ends, and the just-in-time delivery control. Manufacturing capability to meet all this is the requirement for Chiba Works today.

In the No. 2 Hot Strip Mill at Chiba Works, the latter stands of the finishing mill were equipped in 1986 with work-roll shifting (WRS) setup (on F5, F6 and F7), hydraulic automatic gauge control (AGC) system (in F6 and F7) and automatic width control (AWC) unit in order to meet quality requirements concerning thickness, width, flatness and profile.[1-3] The recent more stringent requirements for higher accuracy, thinner products with higher tensile strength, however, have required the all stands of the finishing mill to be equipped with long-stroke WRS, and more strong hydraulic AGC system to be added to the F5 stand. This is the first time in Japan that long-stroke WRS has been installed on the front stands of a finishing mill, enabling the profile control capability and thickness accuracy of the hot strip mill to be substantially improved. In addi-

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tion, this modification permited schedule-free rolling (SFR) and direct hot-charge rolling (DHCR) on the No. 2 Hot Strip Mill to produce many steel grades such as tinplate, stainless steel, high-carbon alloy steel and silicon steel. This has made it possible to supply customers on time with high-quality products of the required profile and stable shape in a wide variety of steel grades with different rolling characteristics and target crowns.

To obtain uniform mechanical properties and a good coiling shape, the coiler was modified in 1982 and a coil box introduced in 1986. To further improve quality, more uniform mechanical properties were obtained by edge heating, and coiling control was improved by installing a hydraulic side guide in the coiler.

This report gives an outline of all these appratuses installed for these modifications and describes the operating results obtained.

2 Outline of the Equipment

An outline of the recent modifications to the No. 2 Hot Strip Mill is given in **Fig. 1**, and the purpose of the hitherto carried-out modifications is shown in **Table 1**. The equipment modifications of the finishing stands are shown in **Fig. 2**. To further improve the strip crown and flatness and perform scheduling-free rolling, WRS and benders were added to the front four stands (F1 to F4), in addition to the long-stroke WRS installed on the latter three stands (F5 to F7). For the front stands, the amount of shifting of the WRS and the bending force of the benders are both comparable to those of the latter stands; this enables the strip-crown reduction effect to be increased in the rolling of high-strength steels, stainless steels, alloy steels, etc. on the front stands, and at the same time, this provides the capacity to change the crown so that it can meet the required profile during the alternate scheduling-free rolling of narrow and wide strip.[4-6)]

To improve the thickness accuracy, hydraulic AGC was installed on stand F5. As a result, the number of stands equipped with hydraulic AGC was increased to three, supplementing that on stands F6 and F7 where hydraulic AGC was installed in 1986. The new hydraulic AGC setup is more powerful than that on F6 and F7, and is also provided with sensor-type steering control.

At the same time as these modifications were carried

Table 1 Items of modified equipments

	Item	Main purpose	Start-up
Former modification	(1) Automatic jumping control in coilers	Coiling shape	July '81
	(2) Automatic width control in R4	Width	Nov. '84
	(3) To change walking beam type in No. 4 furnace	Surface of hot coil	July '84
	(4) Workroll shift in F5~7 and hydraulic AGC in F6, 7	Thickness and profile	Apr. '86
	(5) Coil box	Mechanical property	'86
Recent modification	(1) To change walking beam type in No. 2 and 3 furnaces	Surface of hot coil	Ang. '88
	(2) Direct hot charge rolling	Lead time	Apr. '89
	(3) Edge heater	Mechanical property	July '89
	(4) Hydraulic side guide in coiler	Coiling shape	Apr. '90
	(5) Workroll shift in F1~4, hydraulic AGC in F5, and absolute gauge AGC	Thickness and profile	Apr. '90

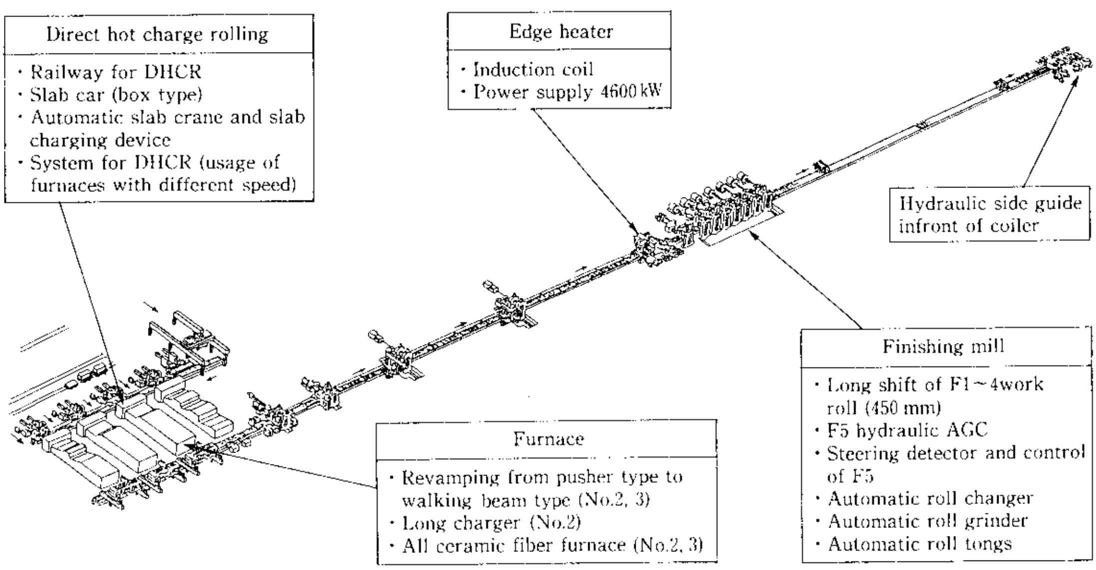

Fig. 1 Outline of recently modified equipments in No. 2 Hot Strip Mill

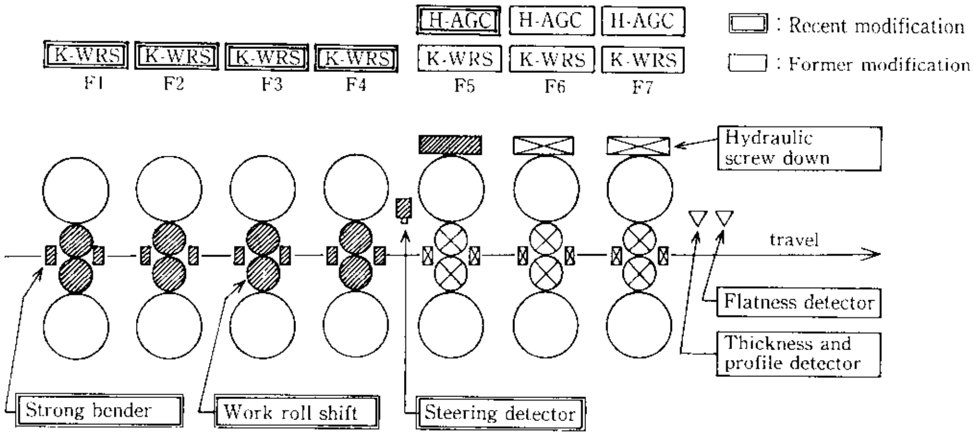

Fig. 2 Configuration of reconstruction of finishing mill

out, a fully automatic roll changer, automatic work-roll grinder, and automatic roll tongs for a simultaneous lifting of pair rolls were installed to increase efficiency.

To obtain uniform mechanical properties, a high-power edge heater was installed. The heating effect can be increased with a large gap even in a case where conventionally, the gap during energizing cannot be narrowed with low power because of a bad strip shape. Strip leveling equipment is installed immediately before the edge heater, and the working rate is increased by leveling the strip. The longitudinal mechanical properties of the strip have been made more uniform by the coil box installed in a previous modification, and the transverse mechanical properties are made more uniform by the edge heater installed this time. As a result, it has now become possible to supply coils with uniform mechanical properties along the full length of the strip.

The No. 2 and No. 3 reheating furnaces were modified to adopt walking beams. As a result, all the three reheating furnaces, together with the No. 4 furnace modified in 1984, are now of the walking-beam type. In the No. 2 furnace, a long charger was installed in the charging inlet to conduct direct hot-charge rolling of hot slabs from the No. 3 Continuous Caster, and a matching zone was provided. At the same time, the cycle time of the walking beams was shortened. In addition, the side walls and roof were completely lined with ceramic fiber to lower the thermal inertia and allow the changeover between hot and cold slabs to be more closely controlled. This also reduced the losses due to heat release.

In the slab yard, a freight car line for DHCR was constructed, and heat-insulated slab boxes, an automatic charging crane and a charging loader were installed. DHCR operating systems such as one for separately controlling the furnaces for charging hot and cold slabs at different speeds were developed. As a result, it has become possible to automatically supply high-temperature slabs from the No. 3 Continuous Caster to the reheating furnaces.

The coiler and its control system were modified in 1982 to improve the coil shape and prevent end marks by incorporating automatic jumping control (AJC). Furthermore, the side guide ahead of the coiler was replaced by long-guide comprising both plate and roller guides, and hydraulic servo control was adopted for its short-stroke operation. The hot strip coiling shape, including the innermost and outermost layers, was thus improved by accurately guiding the full-length of the strip from its top to tail. These facilities were installed from July 1988 to April 1990 and have proved most effective.

3 Improvement of Dimensional Accuracy

3.1 Equipment Specifications

The specifications of the WRS are shown in **Table 2**. The shifting stroke is 0–450 mm, which is the same as that in the latter stands. The use of tapered-crown work rolls permits adaptation to width changes in the rolling unit of up to 900 mm, and the shift range of ±225 mm allows operation for a width difference of 450 mm from a narrow strip to wide strip during sheduling-free rolling. The high shifting speed fully matches the requirements of SFR.

The specifications for the hydraulic AGC setup are

Table 2 Specifications of work roll shift

Stands	F 1∼4	F 5∼7
Shift stroke	0∼450 mm (±225 mm)	
Shift speed	40 mm/s	
WR bending force	50∼250 t/chock (only increase)	
Start up	Apr. 1990	1986

Table 3 Specifications of hydraulic AGC

		F 5	F 6·7
Cylinder stroke		16 mm	20 mm
Cylinder diameter		ϕ 1 060 mm	ϕ 1 000 mm
Speed		5 mm/s	
Responce		25 Hz at phase lag 90 deg.	
Control	AGC	Gage-meter X-ray monitor Absolute gage	
	Steering control	Sensor type	Load difference type
	Others	Roll eccentricity control	
Start-up		Jul. 1989	Apr. 1986

shown in **Table 3**. This setup was installed in the rear three stands, and at the same time, a steering control image sensor (CCD type) was installed on the entry side of stand F5 to improve steering control.

3.2 Profile

In this hot strip mill, the tapered-crown work-roll shifting (the taper adjustment method or taper oscillation method shown in **Fig. 3**) is axially performed to obtain the desired profile of the strip. By adding the tapered-crown WRS (K-WRS) to the front stands of the finishing mill, the following have become possible:

(1) The amount of crown change per stand can be distributed by employing K-WRS in multiple stands;

(2) A substantial crown change can be made in a region with small shape sensitivity (the front stands of the finishing mill).

As a result, the strip crown has been greatly reduced. **Figure 4** shows the impovement in the strip crown that has been achieved to meet the more stringent thickness tolerances. The K-WRS installed in the front stands of the hot strip mill enabled the strip crown Cr_{25} value to be reduced from 60 to 25 μm in carbon steels and from 85 to 40 μm in high-strength steels. At the same time, by adopting cyclic shifting in the latter three stands in combination with the tapered-crown work-roll shifting to prevent box wear of the work roll, a width range from narrow to wide strip has become possible for strip that must meet severe crown requirements. An example of improvement in strip profile is shown in **Fig. 5**.

The improvement in strip crown for a stainless steel (SUS 304) is shown in **Fig. 6**. By installing K-WRS in multiple stands, it was possible to reduce the strip crown from 60 to 40 μm, the inter-stand strip shape becoming more stable by distributing the amount of crown adjustment among the stands.

At the same time as the foregoing modifications were made to the rolling stands, the bending force control system was revised. A crown correction plan for all the

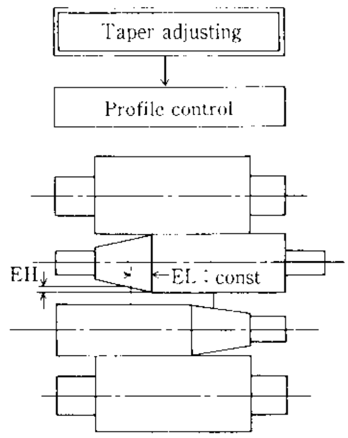

Fig. 3 Taper adjustment method

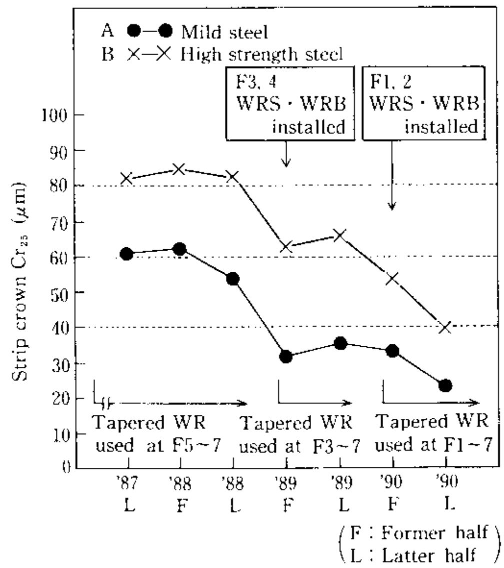

Fig. 4 Improvement in strip crown

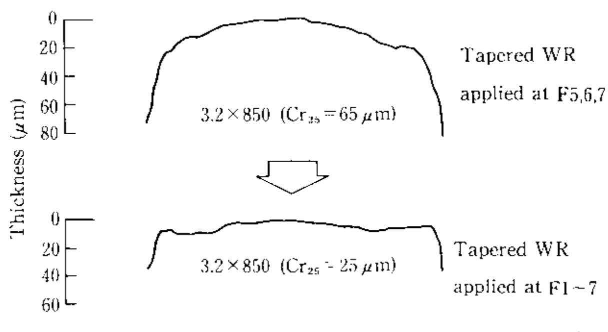

Fig. 5 Strip profile of high strength steel (540 N/m^2)

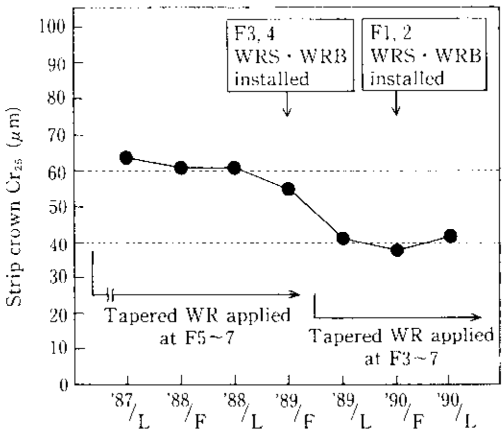

Fig. 6 History of improvement of strip crown of stainless steel

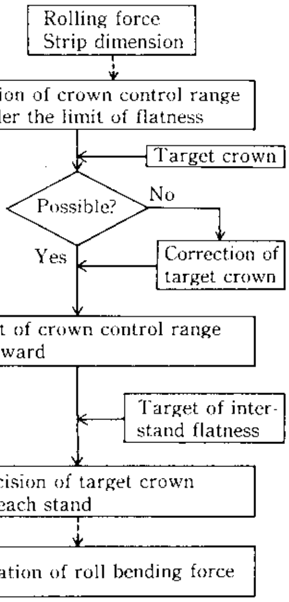

Fig. 7 Schematic diagram of crown correction plan

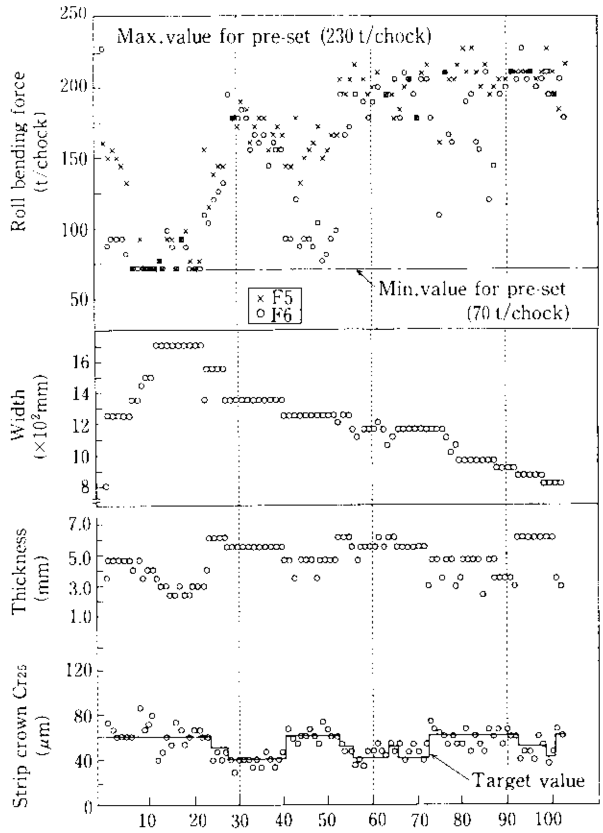

Fig. 8 Change in strip crown in hot rolling with crown and bender set up control

stands was prepared so that the target crown could be achieved on the delivery side of the finishing mill. A schematic diagram of this concept is shown in **Fig. 7**. The features of this crown correction plan are:

(1) A range of strip crown available from the delivery end of the final stand is obtained based on the capacity of finishing mill as hardware and a range of available strip product shape from each stand of the finishing mill.
(2) From the final aimed value, an aimed crown at the mid-stand is obtained, keeping in mind minimized change in strip shape at the latter stands.
(3) Bending force at front stands is calculated so as to attain aimed crown at the mid-stand. Similarly, bending force at the latter stands is calculated.
(4) In case crown change capacity and shape change limits can not be achieved at each stand, final crown aimed shall be modified so that they can be met.

An example of bending force setup calculation is shown in **Fig. 8**. This figure shows an average deviation of actual crown Cr_{25} vs target crown values $\bar{x} = -2.6\,\mu$m and a standard deviation $\sigma = 9.2\,\mu$m, which are good control results. A strong capability provided to front stands in changing crown enables crown at mid-stand deviery end to be obtained in such a way as not to interfere with shape limitation and crown change capability at latter stands in virtually all types of steel, thus contributing to reducing crown and improving accuracy.

3.3 Thickness Accuracy

The addition of hydraulic AGC to stand F5 has made it possible to correct the strip thickness in this upstream stand. The AGC gain has been increased greatly compared to that in the hot strip mill before the recent modifications, which was provided with hydraulic AGC

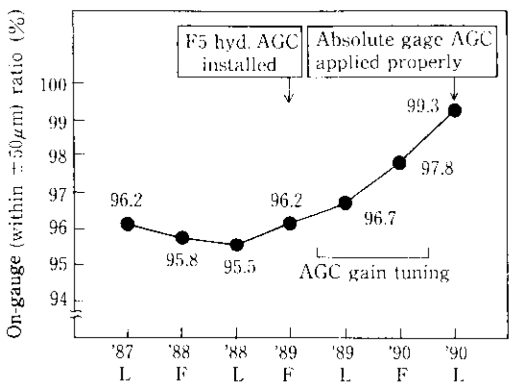

Fig. 9 History of improvement of thickness gauge

only in the two F6 and F7 stands, and higher thickness accuracy has been obtained. This seems to be the result of AGC control being distributed between F5 and F6, compared to mainly in the F6 stand, and because greater thickness correction is possible due to the more stable interstand shape obtainable from the setting of crown and shape on the delivery side of each stand. Furthermore, a $\pm 50\,\mu m$ on-gage ratio of 99.3% has been achieved for low-carbon steels (2.0 to 3.2 mm thickness) by applying absolute AGC at the entry of the leading end of the strip into the rolls. Tuning was conducted to enhance absolute AGC results, and the improvement in the on-gage ratio obtained is shown in **Fig. 9**.

4 Direct Hot-Charge Rolling (DHCR)

The application of WRS, crown and shape setting and hydraulic AGC has made it possible to substantially relax the rolling requirements in the finishing mill to the benefit of local wear of the work rolls, wear of the roll surfaces, thickness and width relationships, and the initial curvature of the rolls, while maintaining a high-level of integrated process quality assurance. In addition Kawasaki Steel has established schedule-free rolling techniques that can be used for DHCR.[7,8]

At Chiba Works, the distance between the No. 3 Continuous Caster that mainly produces ordinary steel slabs for the hot strip mills and the No. 2 Hot Strip Mill is about 6.5 km, and it therefore takes time to transport the hot slabs. In addition, the original layout of the slab yards for the hot strip mills was only suitable for storing cold slabs.

As shown in **Fig. 10**, a hot slab charging line has been added to the existing cold slab charging equipment. This new charging line comprises a railway for transporting the hot slabs, an automatic charging crane and a slab loader, and provides automatic transportation from the slab yard of the No. 3 Continuous Caster to the reheating furnaces of the No. 2 Hot Strip Mill.

As shown in **Fig. 11**, a fully enclosed, fiber-insulated slab box car with good heat retention capability was developed, and slab-charging temperatures close to 800°C are obtained after a tracking time of 4 to 5 h that results from the long transportation distance. Opening and closing the box is conducted fully automatically in the CC plant and hot strip mill to reduce heat losses.

With the expansion of the SFR range in the finishing mill, hot slabs are charged to the No. 2 reheating furnace in a quantity corresponding to the output capacity of the No. 3 Continuous Caster, and cold slabs are charged to the Nos. 3 and 4 reheating furnace in a quantity corresponding to the capacity difference between the hot strip mill and the No. 3 Continuous Caster, as is apparent from the example shown **Fig. 12**, so that completely mixed rolling can be carried out. In the Nos. 2 and 3 reheating furnaces, the conventional pusher mechanism was replaced by the walking beam

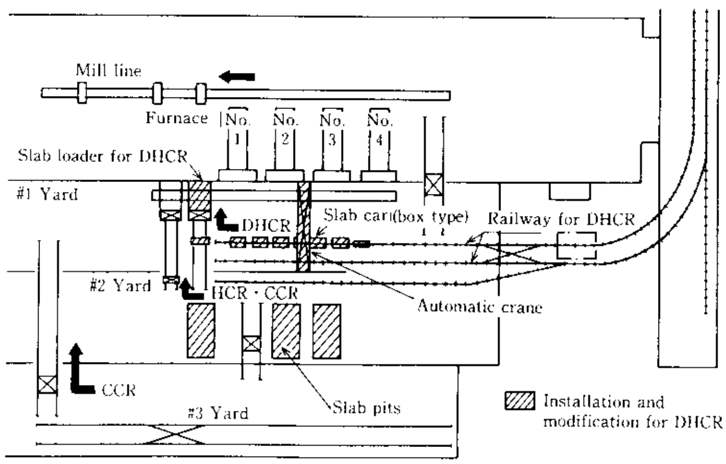

Fig. 10 Layout of slab yard

between a coil in process and the next coil.

As a result, the manufacturing period from the No. 3 Continuous Caster to the No. 2 Hot Strip Mill is now only 4 to 5 h instead of 1 to 1.5 days with the previous warm slab charging procedure. The lead time has thus been substantially reduced.

Stainless and alloy steels are scheduled to fit in with the casting schedule of the CC plant so that they can be rolled at regular intervals when slabs for the No.1 Hot Strip Mill or non-DHCR slabs for the No. 2 Hot Strip Mill are being cast, which takes places at an even frequency of twice or three times a week. As a result, the lead time has also been reduced for stainless and alloy steels. The throughput by DHCR has been greatly increased by this schedule-free rolling system and now exceeds 110 000 t/month.

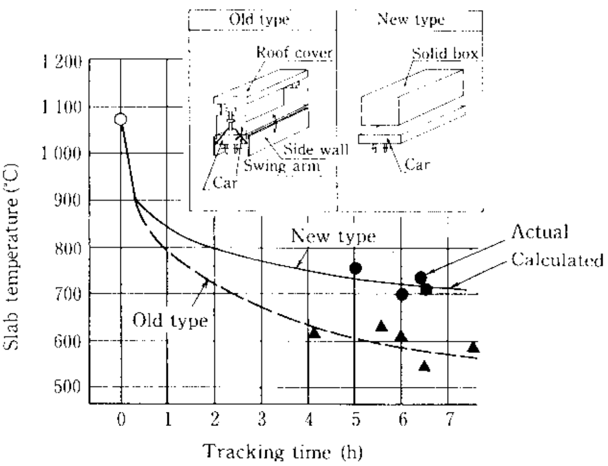

Fig. 11 Relation between slab temperature and tracking time

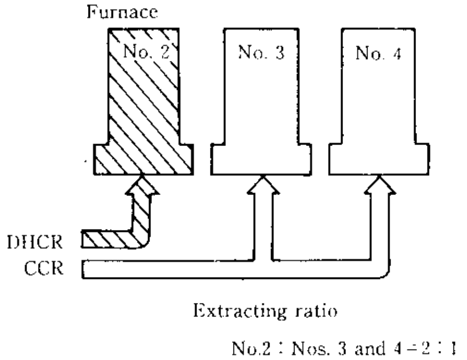

Fig. 12 Example of DHCR operation

(WB) type, heat insulation by ceramic fiber was adopted to reduce thermal inertia, and the follow-up speed for hot slab/cold slab changeover and the slab speed in the furnace were increased. A long charger of about 8 m was installed on the entry side of the No. 2 reheating furnace, and the capacity of this furnace can be matched to the 480 t/h of the No. 3 Continuous Caster so that any delay in the arrival of CC slabs can be handled. The DHCR capacity is influenced by various factors of the CC plant, hot strip mill, etc. Therefore, a system for independent control of each reheating furnace was developed to provide flexible DHCR capacity according to need, and optimum furnace operation is achieved by taking into account the predicted operation of the CC plant and hot strip mill, which both increase the quantity and improve the efficiency.

With the present SFR system, rolling can be continued with no time lost for roll change and the required quality level maintained, as long as the ratio on thickness difference remains in the ranges from 1/3 to 3 and width extension by 450 mm at max, respectively,

5 Uniformity of Transverse Mechanical Properties

Hot-rolled products must possess uniform properties in both the longitudinal and transverse directions of the material. Good uniformity of longitudinal properties has already been obtained by laminar cooling in the hot strip mill, by developing a strip cooling control system that follows the laminar cooling, and by introducing the coil box. The more recent provision of sheet bar edge heater equipment was introduced to uniform transverse mechanical properties. This apparatus has the following features:

(1) It can raise the finisher delivery temperature (FDT) to the same level as the center temperature. Even if corrections are mode to the sheet bar shape and position, the edge temperature can be sufficiently raised (**Table 4**).

(2) Leveler is provided immediately before the edge heater so that it does not need to be retracted due to bad top and bottom shapes of the strip, nor have its efficiency reduced by widening of the gap. As a result, even a sheet bar from the coil box can be thoroughly leveled, so that the working rate of the edge heater is almost 99% when in operation.

Table 4 Specifications of edge heater

Item	Content
Heating method	Induction heating
Power supply	2 300 kW × 2
Heating capacity	Temperature rises 35°C at edge 30 mm (bar thickness 35 mm)
Number of coils	2 × 4
Car position control	AC motor: stroke 1 525 mm
Leveling device	Knock down roll, leveler roll (five rolls of 470 mmϕ)

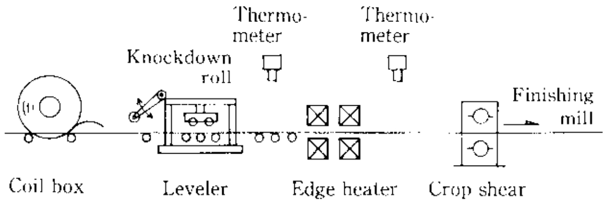

Fig. 13 Layout of edge heater

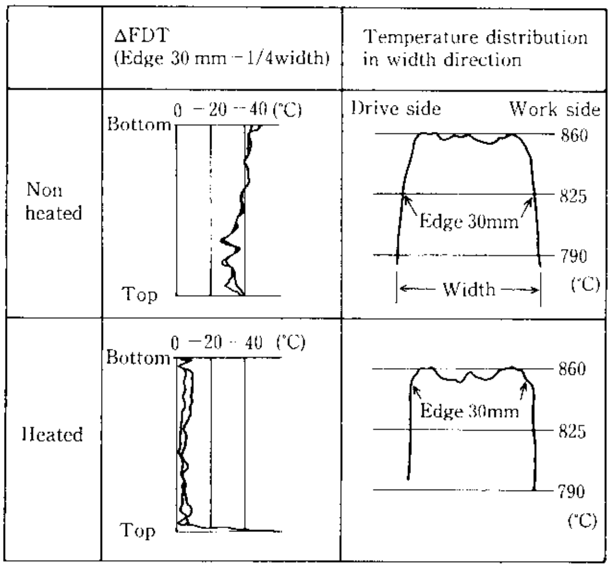

Fig. 14 Comparison of temperature distribution in width direction on the delivery side of finishing mill

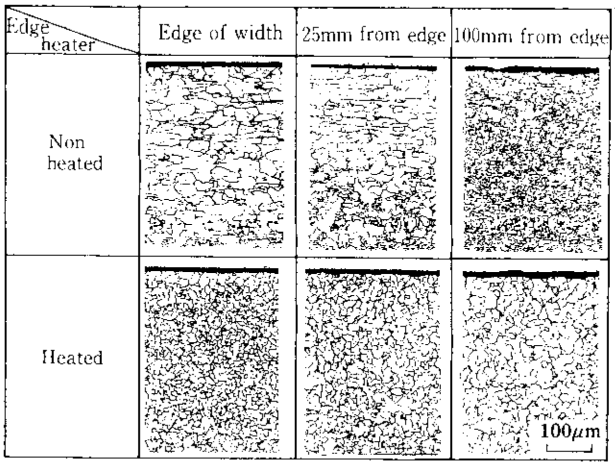

Photo 1 Effect of heating by edge heater on strip microstructures in width direction

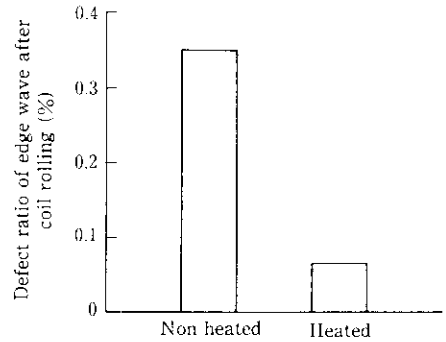

Fig. 15 Inprovement in edge wave defect ratio after cold rolling by applying edge heater

The layout of the edge heater is shown in **Fig. 13**, and its effect on the edge temperature is shown in **Fig. 14**. The temperature at a point 30 mm inward from the edge can be heated nearly to the center temperature. Longitudinal temperature drops and temperature differences between the work side and the drive side can be almost completely corrected.

By controlling the edge temperature in this manner, it is possible to obtain a homogeneous, fine-grain structure from near the edges of the hot-rolled strip as shown in **Photo 1**. As a result, a great improvement has been made to the rough edge surface of stainless steel strip, serrated edges of ultra-low-carbon steel strip, and defective edge waves of re-rolled strip.

Figure 15 shows an example of the improvement in edge-wave defect ratio for extra-thin strip after re-rolling. The edge-wave defect ratio has been reduced to less than 1/5 due to improvements in the microstructure of edges by using the edge heater.

6 Improvement of Coiling Shape

The coiling shape of hot-rolled products is important for avoiding quality problems such as broken edges and edge cracks during coiling, and for preventing scratches during handling in the subsequent process or in customers' premises. It is also important from the standpoint of appearance. The coiling device had previously been improved by adopting hydraulic wrapper roll drives and automatic jumping control (AJC), and by modifying coiling control system for tension, gap, etc. to achieve better quality. However, because the extreme top and bottom of the strip includes flares (a width increase at the ends), bends, etc., complete control had not been possible only by improving the coiling device. To solve these problems, Kawasaki Steel developed a method[9] by which hydraulic servo control is used for the side guide immediately before the coiler, the strip width and bends are measured, and the strip is coiled while using the guide all the way from the top to bottom of the strip.

The general arrangement of this device is shown in

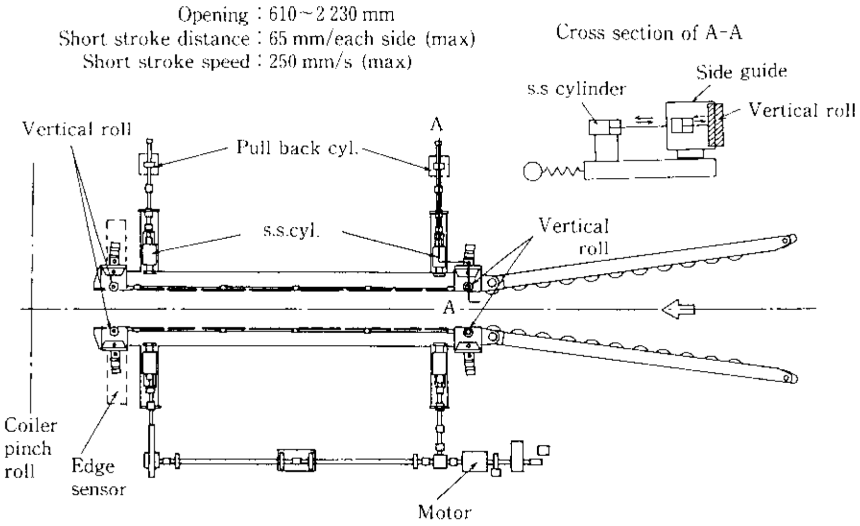

Fig. 16 General arrangement of side guide in front of the coiler

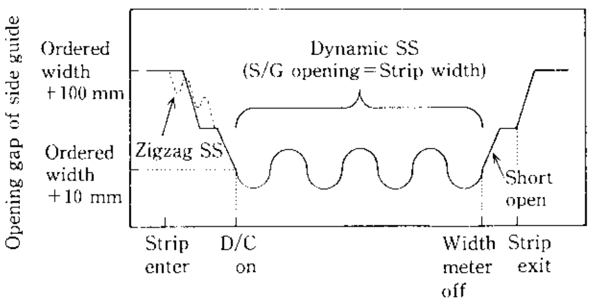

Fig. 17 Control of side guide

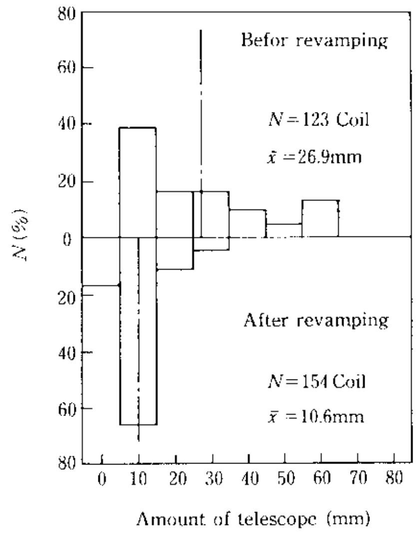

Fig. 18 Amount of telescope in hot coil

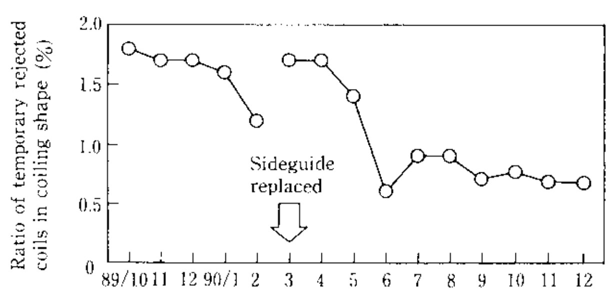

Fig. 19 Improvement in edge defect ratio by appling side guide

Fig. 16. The device proper is a high-rigidity long guide, comprising divided guide plates, and a set of vertical rollers each on the entry and delivery side. This motor-driven device has a function for rough setting of strip width to (strip width + alpha), a short-stroke function driven by hydr-servo-sylinder to detect strip width and set up strip pass to an optimumum-detectable guide width, and a vertical roller opening and closing function. The vertical roller guide is used mainly for stainless steel and thick gages, and the plate guide is for thin strip and low-carbon steels, thus optimumizing the use of device for the type of steel.

An example of guide control is shown in **Fig. 17**. When the leading end of the strip enters the guide, it is wound at the center by zigzag closing or short-stroke multistage closing. The guides are controlled in such a manner that the strip is constrained and centered by optimum gap control according to the actual strip width measured. At the tail end of the strip, gap control works depends on the flare so that the tail end is guided without damage to the end. In this manner, the coiling position can be fully controlled along the full length of the strip. Based on the above control, coiling pattern control is conducted according to the longitudinal position of the strip and edge damage is minimized.

As shown in **Figs. 18** and **19**, the amount of telescoping of the coil between the top of the strip (the innermost turn) and the bottom (the outermost turn) is decreased, and the incidence of defective coils ascribable to bad coiling shape has been reduced to less than 1/3 of the level before this modification.

7 Conclusions

The thickness, profile, uniformity of mechanical properties, coiling shape, and delivery time of hot-rolled strip from the No. 2 Hot Strip Mill at Chiba Works are meeting stringent quality standards by using long-stroke K-WRS system installed in the front stands of the finishing mill to supplement those installed in the latter stands, hydraulic AGC in the F5 stand, and steering control. As a result, the strip crown is held to within 25 μm for commercial grade steels and to 40 μm for stainless steels, and an on-gage ratio of 99.3% is achieved with a thickness accuracy of ± 50 μm.

These equipment modifications have enabled the application range for hot rolling without roll changing to be widened, and achieved direct hot-charge rolling with an output of 110 000 t/month assisted by the installation of direct charging devices for hot slabs from the No. 3 Continuous Caster. To improve the mechanical properties of the strip edges, high-capacity edge-heating apparatus was been installed, while hydraulic servo driven coiler guide has been installed immediately before the coiler. These modifications have improved the quality of hot-rolled strip. As a consequence of this, Kawasaki Steel has established techniques for stably manufacturing hot strip products with thickness accuracy capable of thoroughly meeting severe quality requirements, with excellent profile and flatness, uniform mechanical properties and excellent coiling shape.

The authors intend to continue developing these techniques to achieve even higher levels of quality in the production of each grade of steel strip. They also intend to expland these techniques into the development of innovative equipment.

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