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The body can be viewed from the next page.

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1 Features of New Hot Strip Mill

In May 1995, No. 3 Hot Strip Mill was put into operation in the West Area of Chiba Works. This mill was constructed to achieve a substantial reduction of manufacturing cost while meeting customer requirements for the improvement of product accuracy and the expansion of the dimensional range, in particular, a decrease in the gauge of products. This mill, aimed at the realization of an ideal hot strip mill, has the following features:

(1) This mill has all the mill functions necessary for realizing the world's first continuous rolling by sheet bar joining (hereinafter referred to as "endless rolling").

(2) This mill has all the rolling equipment, groups of accessory machinery, and control functions necessary for realizing the production of sheets of top-level quality and performance.

By lightening the conventional hot rolling restrictions using the above features, it becomes possible to realize the rolling of new products including hot-rolled sheets whose formability is substantially improved compared with conventional products.

The general arrangement of No. 3 Hot Strip Mill at Chiba Works is shown in **Fig. 1**. This hot strip mill will replace No. 1 and No. 2 Hot Strip Mills in the East Area and will have monthly production capacity of 450 000 t. The West Area provides a base for the production of crude steel, and the layout is such that No. 3 Hot Strip Mill is directly connected to the continuous casting plant. Therefore, it is also possible to achieve advantages such as energy-saving by the effective utilization of the sensible heat of slabs, rationalization of the material distribution, and shortening of lead times.

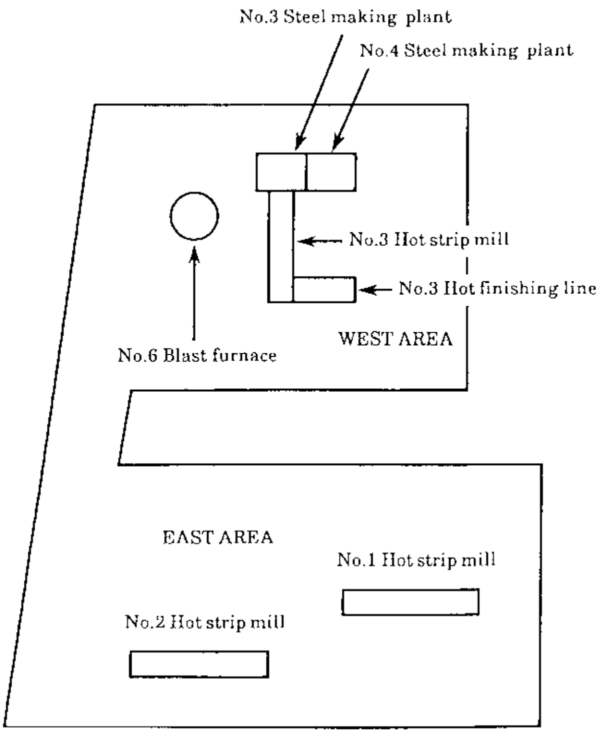

Fig. 1 General arrangement of No. 3 hot strip mill

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2 Outline and Effects of Endless Rolling

In conventional hot rolling, slabs are individually rolled by a roughing mill to sheet bars 30 to 60 mm in thickness, which are then rolled by a finishing mill to the specified finished size.

The rolling mill setup for threading sheet bar into the finishing mill is conducted by predictive control on the basis of information such as finisher entry temperature. For this reason, the accuracy of product size, temperature, etc., is governed by prediction accuracy. Although the prediction of rolling behavior in hot rolling has a long history, it is conducted under severe abrupt transition conditions of temperature, etc., and has not yet reached the stage of completion. However, quality and accuracy can be rapidly improved, because the feedback control of various kinds of sensors can be utilized once the top end of the sheet bar is threaded. For this reason, low product accuracy of gauge, etc., occurs at the top end.

In conventional hot rolling, the critical gauge of rolling has been limited by the stability of the strip during the transfer to the coiler after the completion of finish rolling. Hot rolling is generally conducted in the austenite single-phase region.[1] The temperature drop due to contact with the rolls increases with decreasing gauge[2]; in order to achieve the specified temperature at which finish rolling is completed, high-speed rolling is required for thin strips. However, when a thin strip runs on the delivery table of finishing mill (run-out table) at high speeds, its run is unstable. For example, the top end tends to jump. In general, approximately 800 mpm is the critical speed limit for 2.0-mm-thick strips.[1] Therefore, the threading speed is limited. To compensate for this, it is necessary to raise the finisher entry temperature by raising the slab reheating temperature when rolling thin strips. However, when the finisher entry temperature is raised to above a certain level, the oxide film (scale) generated between the stands of the finishing mill is rolled into the product surface, causing surface defects in products.[2] As a result, it is impossible to obtain the specified mechanical properties or surface property in materials at gauges below a certain level. This is the mechanism of the rolling limit in hot strip mills using the conventional rolling method.

Furthermore, the problem of pinchers tends to occur when the gauge of the strip is thin and the rigidity of the strip decreases. Incidentally, pincher marks occur in connection with side walk during the tailing out at the finishing mill.

Continuous rolling is a rolling method in which before finish rolling, sheet bars are joined and continuously supplied to the finishing mill.

The following effects can be obtained from this method:

(1) The threading of the leading top of the material through the finishing mill is conducted only for the top end of a series of joined sheet bars. As a result, quality and accuracy can be substantially improved.

(2) The effects obtained by lightening the restrictions on the threading speed of the top end, such as
- Expansion of the gauge range of rolled sheets toward the light gauge side,
- Decrease in the slab reheating temperature, and
- Increase in rolling efficiency.

(3) Rolling at a uniform speed along the full length improved controllability of the finisher delivery temperature and coiling temperature.

(4) Pincher trouble at the tail end decreases.

(5) Rolling under a uniform inter-stand tension along the full length expands the effect of lubrication rolling; hot-rolled products with new functions can be rolled by utilizing this advantage.

3 Equipment Composition Permitting Endless Rolling

The equipment layout of No. 3 Hot Strip Mill is shown in **Fig. 2**. The equipment basically comprises three reheating furnaces, a sizing press, three roughing mills, a coil box, a joining device, a 7-stand finishing mill, a strip shear, and two down coilers. The main equipment specifications are shown in **Table 1**. The main product specifications are shown in **Table 2**.

To conduct endless rolling, it is necessary that the hot strip mill be equipped with a joining device and, in addition, the whole rolling equipment must have the functions suited to this kind of rolling. **Table 3** shows the features of each equipment function suited to endless rolling.

First, it is necessary that the succeeding sheet bar be

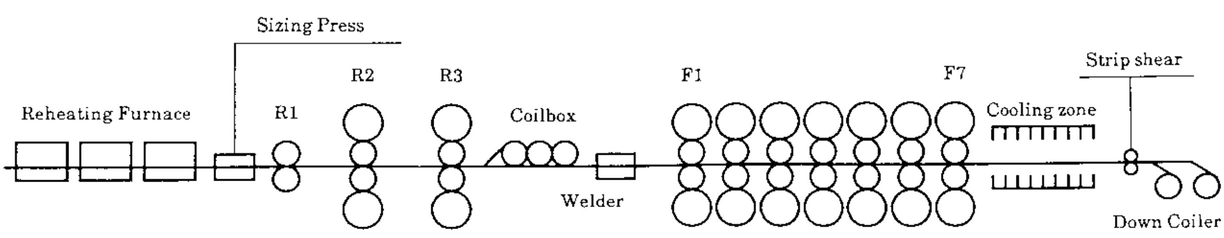

Fig. 2 Layout of No. 3 hot strip mill

Table 1 Main equipment specifications

Reheating furnace Capacity	Walking beam type Total 700 t/h
Sizing press Max. width reduction	300 mm
Roughing mill	
R1	4 000 t 2-high reversible
R2	4 200 t 4-high reversible
R3	3 800 t 4-high reversible
Finishing mill	4-high pair-cross mill
F1-3	5 000 t
F4-7	3 800 t
Max. rolling speed	1 680 mpm
Down coiler	Hydrauric 4-wrapper roll type×2

Table 2 Product specifications

	Carbon steel	Stainless steel
Gauge (mm)	(0.8)[a]—1.2-24	1.5—10
Width (mm)	600—1 900	600—1 600
Coil diameter (mm)	1 300—2 200(max. 1 400 PIW)	
Max. weight (t)	32	

[a]At continuous (endless) rolling

Table 3 Characteristics of main equipment supporting endless rolling

Reheating furnace	High-speed slab transportation by walking beam (max. 2 000 mm/min)
Sizing press	High-speed press (20 mpm)
Roughing mill	High-speed rolling (R3 max. 340 mpm) Layout minimizing intervention between bars
Coilbox	3-position and 2-peeler
Finishing mill	Flying gauge change Hydraulic screw down Work-roll bender Flying cross-angle change High-responsiblity A.C. motor-drive
Down coiler	High-speed dividing shear High-speed wrapping and tailing High-speed coil transportation

supplied simultaneously with the arrival of the tail end of the preceding sheet bar at the joining device. The transfer of slabs in the reheating furnace is conducted by walking beams. Speedy transfer of slabs in the furnace in the period from the extraction of the preceding slab to that of the succeeding slab is a condition for supplying the succeeding sheet bar without delay. This is especially important for the continuous rolling of wide strips. For this reason, the reheating furnaces have the function of transfer of slabs at much higher speeds than in conventional furnaces.

Moreover, less rolling time is required with shorter slabs. This applies to both the roughing mill and the finishing mill. When the preceding slab is short, rolling is finished in a short time. When the succeeding slab is long, it is important to shorten the rolling time of this succeeding slab as far as possible. For this reason, the sizing press and roughing mill operate at higher speeds than in conventional equipment.

If an error occurs in the arrival of the succeeding sheet bar, the temperature of the succeeding sheet bar drops or it becomes impossible to join the succeeding sheet bar. As a buffer, a coil box for winding sheet bar in coil form was installed. The coil box has the three positions of coiling, waiting, and uncoiling in order to compensate for differences in the rolling time between materials and expand the joining region.

It is necessary that the finishing mill not only be a high-load, large-output rolling mill for the rolling of thin and wide materials, but also that it have a profile control capacity and flying gauge changing capacity for appropriately making different product sizes according to differences in the size and steel grade of the series of materials in endless rolling. For this reason, all stands are equipped with hydraulic screwdown devices, and AC motor drives capable of substantially improving response are adopted. Pair-cross mills are adopted in all stands, and a mechanism capable of adjusting the cross angle during rolling is provided in F4 and the following stands.

After joining, the strip is divided by a high-speed strip dividing shear installed before the coiler. After the dividing of the strip, it is important to stably stop the tail end of the preceding strip entering the coiler, to stably guide the top end of the succeeding strip to the coiler, and to coil the top end of the succeeding strip running at a high speed. Improvements were made to solve these problems.

In endless rolling, coils are completed at much shorter intervals than in the conventional rolling method. Therefore, it was also necessary to install a group of coil transporting devices capable of transporting these coils without delay.

4 Control Functions Permitting Endless Rolling

To carry out endless rolling, it is necessary to raise the automation levels of the whole strip mill greatly compared with the conventional rolling method. The features of the control functions of No. 3 Hot Strip Mill are shown in **Fig. 3**.

Mill pacing control plays an important role in mill automation. Mill pacing control is used to determine the

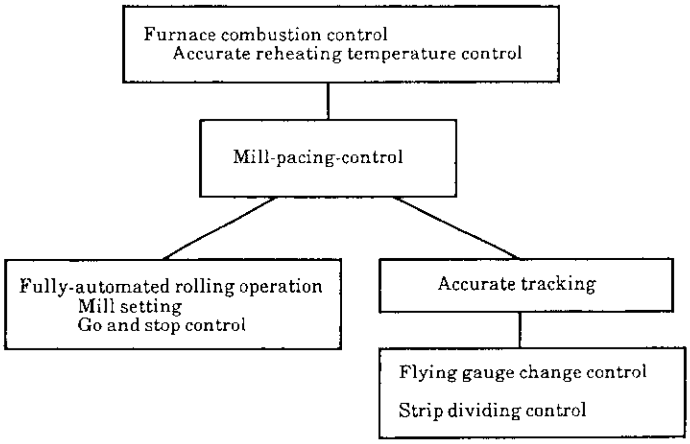

Fig. 3 Schematic diagram of control functions supporting endless rolling

timing of slab extraction and adjust the rolling timing of the succeeding material according to the progress status of the preceding material. As mentioned above, it is necessary to accurately feed the succeeding sheet bar to the finishing mill simultaneously with the completion of rolling of the preceding sheet bar. Therefore, it is necessary to realize high-accuracy mill pacing control.

Furthermore, it is also necessary that a slab temperature rise be completed at the timing of extraction instructions of mill pacing. For this reason, close linkage between mill pacing and furnace combustion control, and the realization of high-accuracy combustion control are also necessary.

In addition, various factors that cause disturbances in mill pacing, for example, fluctuations in the timing of rough reverse rolling and operator intervention in rolling schedules must be completely eliminated in endless rolling, because they cause errors in the prediction of the rolling time. Therefore, the establishment of fully automatic setup and fully automatic rolling in the whole line are prerequisites for endless rolling.

In the finishing mill, it is necessary to control the flying gauge changes according to differences in the size and steel grade between the preceding and succeeding sheet bars during endless rolling. Furthermore, to accurately conduct flying gauge changes and accurately perform strip dividing, it is necessary to accurately track the joining point.

Table 4 Characteristics of main equipment for accurate and uniform production

Furnace	High skid button adoption (200 mm height) All ceramic fiber construction : Low thermal inertia (12℃/min) Reheating temperature accuracy, ±15℃
Sizing press and roughing mill	High-speed processing : temperature drop from extraction to finisher entry, ≦100℃ Camberless production : rolling under restraint using long side guides
Finishing mill	Accurate mill set-up using inter-stand sensor : Profile meters/thickness gauge Width gauge Quick response AGC and tension control : Hydraulic screw down A.C. moter-drive Low inertia looper Gauge accuracy at head end, $\sigma=10\ \mu m$ Crown≦30 μm
Cooling system	Stable flow rate : Head water tank method Clean water (prevent nozzle clogging) Subdivided control valves : Coiling temperature accuracy, ±15℃

5 Measures to Accomplish High-Accuracy, High-Quality Rolling

Endless rolling is a rolling method capable of greatly improving quality and accuracy by the effect of a uniform finish rolling speed (temperature) and uniform tension. However, the temperature and dimensional accuracy of sheet bars have a great effect on product quality. Changes in conditions such as rolling speed occur depending on product sizes, etc., even in endless rolling, and it is necessary to appropriately cope with these changes and to provide hardware and software for imparting high-accuracy quality to products. The features of the main equipment of No. 3 Hot Strip Mill necessary for meeting these requirements are shown in **Table 4**.

5.1 Reheating Furnace

The uniform reheating of slabs is the key to product quality. Skid marks are prevented by using a special alloy material for the skid buttons and increasing the skid button height to 200 mm. Furthermore, ceramic fiber was adopted as the furnace refractories in all places except the furnace hearth in order to improve the response to reheating temperature control. These measures enable uniform reheating with a deviation of only ±15°C.

5.2 Roughing Mill

Lowering the reheating temperature is very important for reducing various surface defects (for example, hardening cracks on the slab surface) that occur due to excessive slab surface temperatures. The finisher entry temperature is determined by the finisher delivery temperature, which is in turn determined by the mechanical properties of the material, and the temperature drop during finish rolling, which is determined by gauge and finish rolling conditions. To lower the reheating temperature, therefore, it is necessary to reduce the temperature drop during rolling at the roughing mill.

In No. 3 Hot Strip Mill, the temperature drop in the time from slab extraction to arrival at the entry side of the finishing mill can be reduced to 100°C with the high-speed roughing mill.

Bar cambers that occur during rolling not only impair threading stability, but also have a serious effect on the quality of finished products. To reduce cambers, therefore, the side guides at the entry and delivery sides of the mill were improved so as to increase their restraint capacity, thus improving their capacity to reduce cambers.

5.3 Finishing Mill

Raising the level of finishing mill setup has so far been prevented by the fact that the load at each rolling mill is the only means of judging changes in the strip condition from the entry side to the delivery side of the mill. In No. 3 Hot Strip Mill, strip thickness gauges, width gauges, and profile meters were installed between the stands of the finishing mill, greatly improving the capacity to gather the data necessary for this analysis. In addition, the dimensional accuracy of products is improved by dynamic control of hydraulic screwdown, work-roll bending, and the cross angle using the output of these sensors.

Furthermore, strip width accuracy can also be improved by ensuring high tension control accuracy using the high-response motor drives.

5.4 Coiling Temperature Control

The coiling temperature greatly influences the mechanical properties of products. To improve coiling temperature control accuracy, the following improvements were made:

(1) The water injection pressure was stabilized by adopting a head tank for the cooling system.

(2) The water injection sections were subdivided. (They were subdivided so that changes in the coiling temperature by the on-off operation in one control section are held to within 5°C.)

(3) To prevent the clogging of the cooling headers, the cooling water system was made independent and water quality was improved.

6 Measures for Rationalization

6.1 Design of Control Room

When the automation function in a hot strip mill is incomplete, it is necessary to conduct operation while observing the condition of the actual equipment or materials being rolled. In conventional hot strip mills, therefore, operators were assigned to several distributed pulpits installed near the main equipment, such as at the slab yard, reheating furnace exit, finishing mill, coiler, and inspection equipment.

In the No. 3 Hot Strip Mill, all rolling operations can be continued without operator intervention as mentioned above. In a mill of this type, a distributed arrangement of pulpits would only increase the required number of operators. For this reason, all the monitoring functions are concentrated in a single, general control room.

In the general control room, it is possible to monitor all the rolling equipment from the slab yard to the coiler and transportation equipment and to take action in case of abnormality. The general control room was designed so that all equipment in this region can be controlled by three persons.

The general control room is installed almost at the center of the line, before the finishing mill, where the possible need for emergency measures is highest.

6.2 Design of Roll Shop

A roll shop is attached to a rolling mill to grind the rolls used for rolling. The material flow is diverse, as is apparent from various operations in the roll shop, such as the conveyance of used rolls, setting of rolls to the grinder, removal of the ground roll from the grinder, and arrangement of rolls before the mill. Because rolls are generally moved by crane, much labor has been required in the roll shop.

A schematic diagram of the roll shop of No. 3 Hot Strip Mill is shown in **Fig. 4**. Used rolls extracted from the finishing mill are transported by roll transporters directly to the boundary of the roll shop. In the roll shop, roll-change cars travel to deliver rolls to the roll transporters, stock yards, and roll grinders and receive rolls from them. These roll-change cars rearrange the rolls based on instructions from the computer. The grinders are of the fully continuous type and have the function of separating the top and bottom work rolls transported in two tiers and setting each roll in the grinding position. These measures permit fully automatic computer control

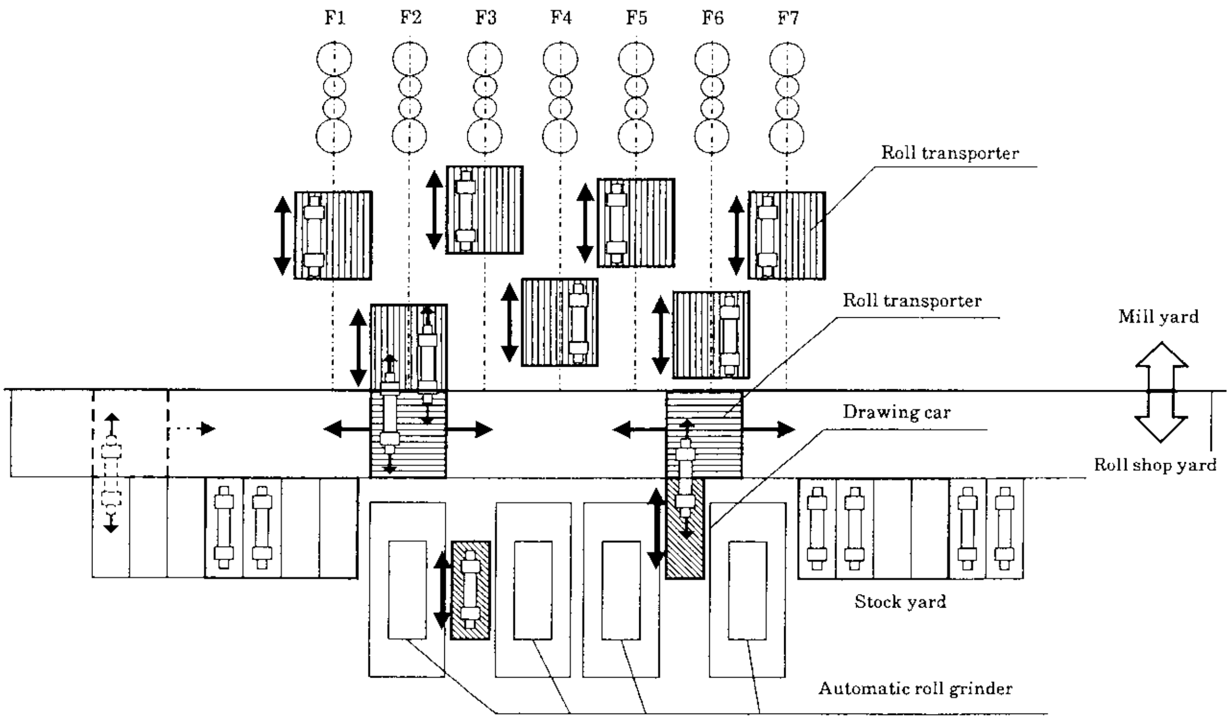

Fig. 4 Full-automatized work-roll transportation system at No. 3 hot strip mill

of the roll change, transportation, and grinding of finisher work rolls.

7 Conclusion

No. 3 Hot Strip Mill at Chiba Works was put into operation in May 1995 on schedule. The features of this mill are as follows:

(1) This mill has all the functions necessary for realizing the world's first continuous rolling.

(2) This mill has all the functions of sensors and controllers for realizing high-quality, high-accuracy rolling.

(3) New products, such as extra-thin sheets and hot-rolled sheets with good formability, can be produced using the above functions.

(4) Energy is saved by adopting a layout directly connected to the continuous casting plant.

(5) Substantial rationalization is achieved by integrating pulpits into a general control room and fully automating the roll shop.

References

1) The Iron and Steel Institute of Japan: "Advanced Technology of Hot Strip Mill in Japan (the Second Edition)," (1987), 152, 36, 154

2) The Iron and Steel Institute of Japan: "Theory and Practice of Flat Rolling," (1984), 158