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High Quality Production Technology at the Chiba Works No. 3 Hot Strip Mill

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Kawasaki Steel started the operation of the No. 3 hot strip mill at its Chiba Works in May 1995. This is the first fully continuous hot strip mill in the world. To satisfy customer demands for the improvement of product qualities, the mill has the following features: (1) A high skid button was installed in reheating furnace to remove skid marks. (2) High speed processing, hydrauric edgers and long side guides were introduced in rougher mill. (3) A pair cross mill, a hydraulic screw down, an AC motor-drive and a low inertia looper were installed in finisher mill. (4) Subdivided control valves were installed in water cooling zone. These arrangements are controled precisely and thus, improved product accuracy in strip gauge, crown and width and the quality of the material.

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High Quality Production Technology at the Chiba Works No. 3 Hot Strip Mill*


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1 Introduction

Kawasaki Steel started operation of the No. 3 hot strip mill at its Chiba Works in May 1995[1]. This mill was constructed to meet customer demands for the improvement of product accuracy. The mill has the following features: (1) The world's first endless rolling technology was established to improve dimensional accuracy of products and expand the available sizes, especially in thinner hot finished strips. (2) Many sensors and actuators have been installed to improve the accuracy of products in terms of strip gauge, width, crown, and mechanical properties. (3) High-response, high-powered motors, and sturdy mill housings have been installed to achieve high speed processing with lower heating temperature. (4) A fully automated control system has been installed to handle the most dangerous work without human labor. This report describes the technology to produce high quality products.

2 Outline of the New Hot Strip Mill

The mill produces high grade steel sheets or coils for general uses such as beverage cans, automobiles, and stainless steel, and high carbon steel for special uses. Customers have been demanding that these products have much better surface quality, dimensional accuracy, and mechanical properties. To produce such high-quality products, various sensors and actuators have been installed to control gauge, width, profile, flatness, and temperature.

Figure 1 shows the layout of the No. 3 hot strip mill[2-5]. The mill comprises 3 reheating furnaces, a sizing press, 3 roughing mills, a sheet bar coiler, a sheet bar welder, 7 finishing mills, a cooling device, a strip shear, and 2 down coilers. The equipment has the following features: (1) A high skid button has been installed in the reheating furnace to equalize slab temperature. (2) A high speed sizing press, roughing mills, and finishing mills have been installed to prevent the thermal rundown. (3) Hydraulic edgers and long side guides have been installed in the roughing mills to improve the accuracy of width and prevent camber. (4) A pair cross mill, a hydraulic roll position controller, a high-response AC motor drive, and a low inertia looper have been installed in the finishing mill to improve the accuracy of gauge and inter-stand tension control. (5) Subdivided control valves have been installed in the water cooling zone to improve the accuracy of coiling temperature. The operation of this equipment is fully computerized and automated. In the central control room, only 3 operators

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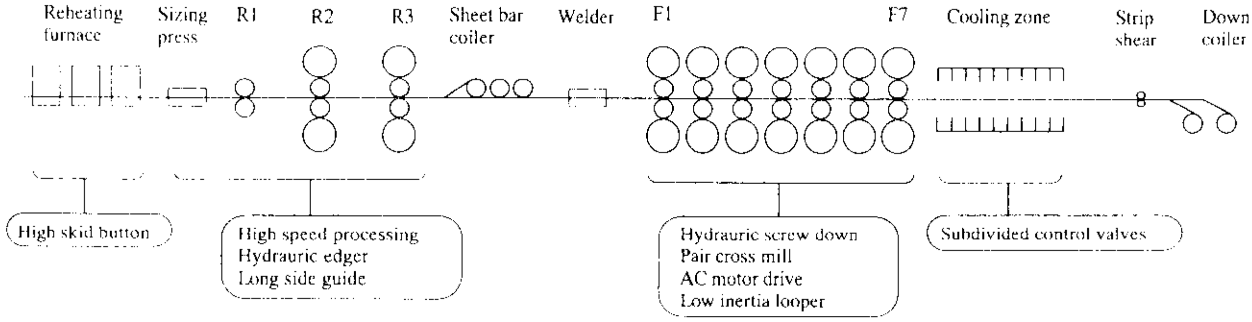

Fig. 1 Layout of No.3 hot strip mill

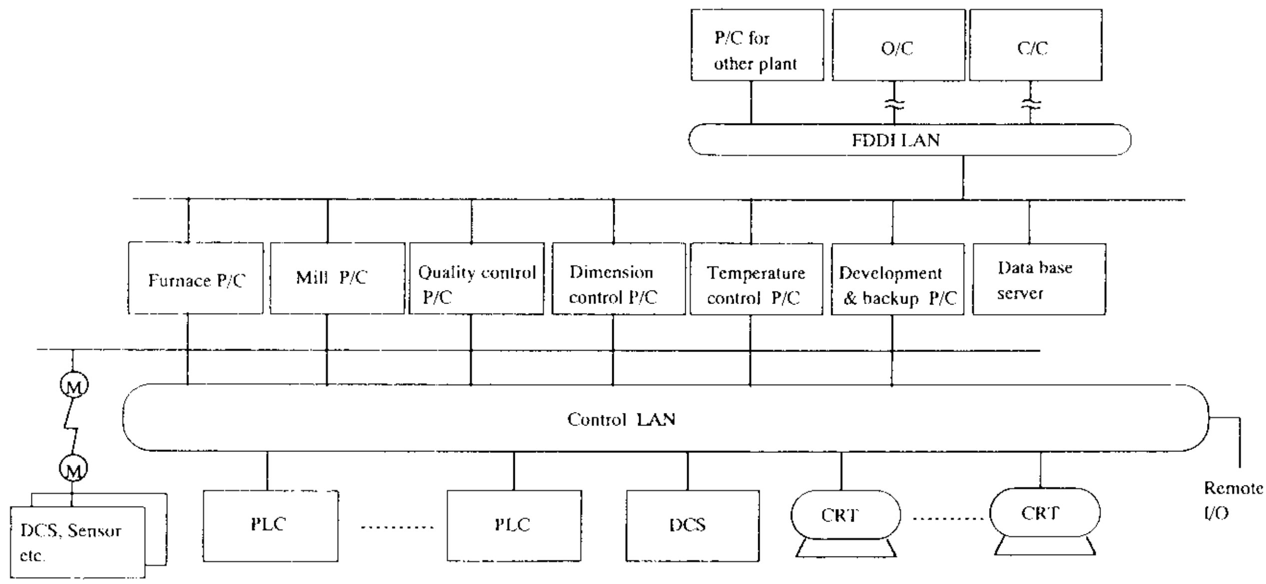

Fig. 2 Process computer system of No. 3 hot strip mill

monitor the entire mill, from slab preparation yard to down coiler.

Figure 2 shows the process computer system of the No. 3 hot strip mill[6]. A process computer, programmable logic controllers, digital control systems, and CRTs are linked by networks with huge transmission volume and speed. The mill process computer calculates various set-ups of mills. The programmable logic controllers control inter-stand tension and gauge in the finishing mill. A dimension control process computer controls width, profile, and flatness of strips, while a temperature control process computer controls FDT (finisher delivery temperature) and CT (coiling temperature).

Figure 3 shows the sensor arrangement on the No. 3 hot strip mill[7]. 12 pyrometers and 9 width-gauges have been installed between the sizing press and the down coiler. 4 thickness gauges and 3 profile gauges have been installed between and after finishing mill stands. A flatness-meter has been installed after finishing mill.

3 High Quality Production Technology

3.1 Inter-Stand Tension and Looper Control

A precise inter-stand tension and looper control system has been developed to improve the accuracy of gauge, width, and the stability of rolling[8]. The precise control of inter-stand tension is indispensable in flying gauge change and to roll the welding points smoothly in endless rolling. **Figure 4** shows the schematic diagram of the inter-stand tension and looper control system. The key equipment in this system is an AC motor-drive and low inertia looper. The controllers consist of simple main loops and disturbance compensators. The main loops consist of 2 PI controllers corresponding to inter-stand tension and looper angle control. The inter-stand tension control loop manipulates mill motor speed based on measured inter-stand tension. The looper angle control loop manipulates looper motor speed based on mea-

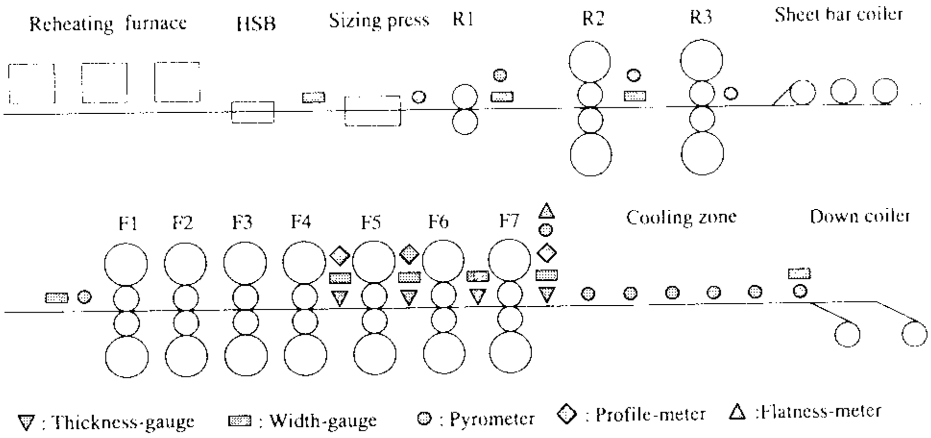

Fig. 3 Sensor arrangement in No. 3 hot strip mill

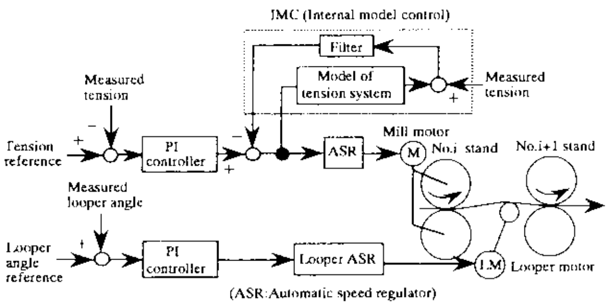

Fig. 4 Schematic diagram of tension and looper control system in No. 3 hot strip mill

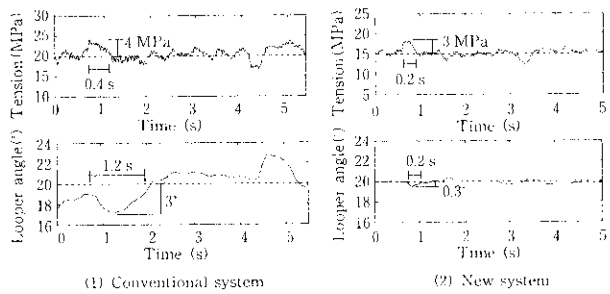

Fig. 5 Response to 1% thickness change in the actual system

sured looper angle. The inter-stand tension control loop responds faster than the looper control loop by tuning the PI controller and adding a disturbance compensator based on an internal model. The 2 control loops are independent of each other. There are no controllers nor compensators between them. This structure facilitates tuning and maintenance. **Figure 5** shows the responses of looper angle and inter-stand tension to 1% thickness change in the actual mill. The deviation of the inter-stand tension, which is 4 MPa in amplitude and 0.4 s in duration in the conventional control system, is reduced to 3 MPa and 0.2 s in the new system. At the same time, the deviation of the looper angle, which is 3° and 1.2 s in the conventional system, is reduced to 0.3° and 0.2 s in the new system. The new control system stabilizes both inter-stand tension and looper angle compared to the conventional system.

3.2 Gauge Control

Hydraulic roll position controller and high-response AC motor drives have been installed in all stands of the finishing mill. The strip gauge is controlled precisely using an X-ray thickness gauge installed after the F4, F5, F6, and F7 stands. **Figure 6** shows an outline of the automatic gauge control system. The gauge control system consists of following 4 subsystem: (1) a set-up control system, which predicts rolling force precisely and determines roll position before the rolling, (2) mill modulus control, which is equivalent to BISRA AGC (automatic gauge control), (3) absolute gauge AGC, (4) monitor AGC using an X-ray thickness gauge. **Figure 7** shows an example of strip gauge in the longitudinal direction. The gauge is controlled to $\pm 25\,\mu m$ of the aimed value along the entire coil length.

3.3 Width Control

Figure 8 shows an outline of automatic width control system. 9 width-gauges are installed between the sizing press and the down coiler. According to measured width, the dies position in the sizing press and the edging roll position in the roughing mill are adjusted to get appropriate width reduction. In the finishing mill, inter-stand tension is controlled to reduce the width margin. **Figure 9** shows an example of strip width in the longitudinal direction. The width is kept within -2 mm to $+4$ mm of the aimed value along the entire coil length.

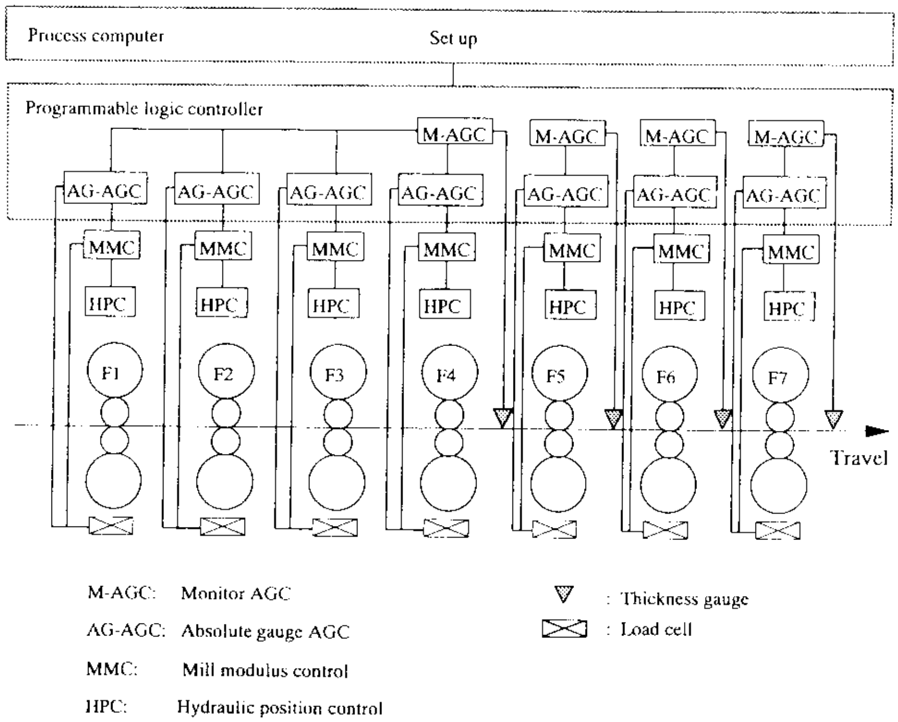

Fig. 6 Outline of automatic gauge control system in No. 3 hot finishing mill

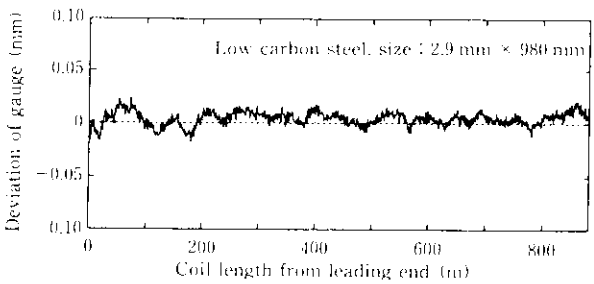

Fig. 7 Example of strip gauge in longitudinal direction

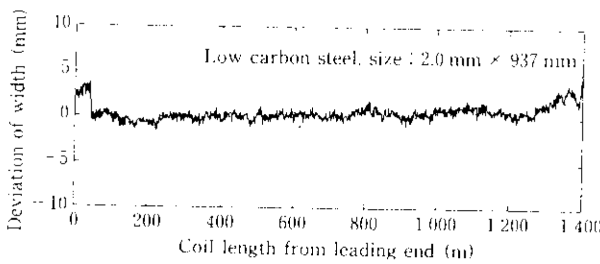

Fig. 9 Example of strip width in longitudinal direction

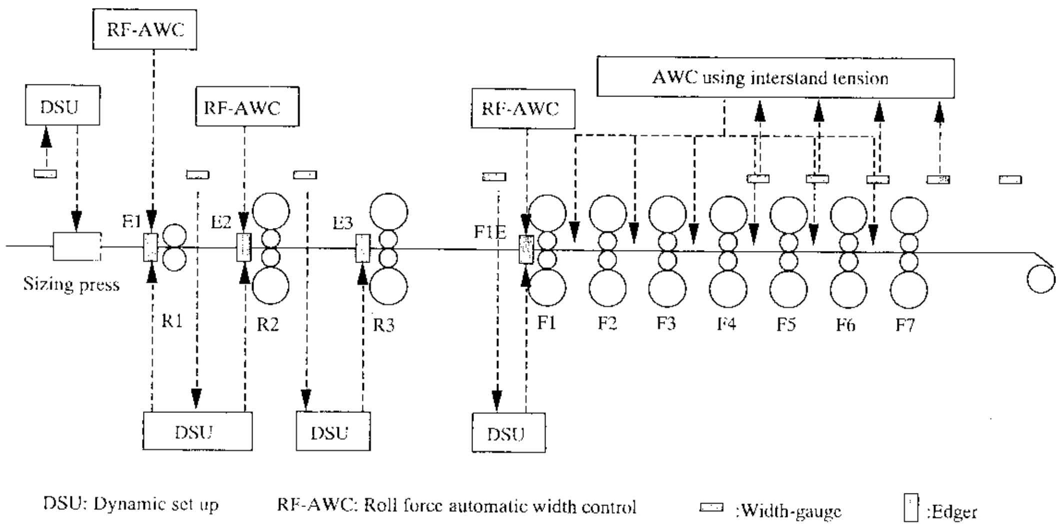

Fig. 8 Outline of automatic width control system in No. 3 hot strip mill

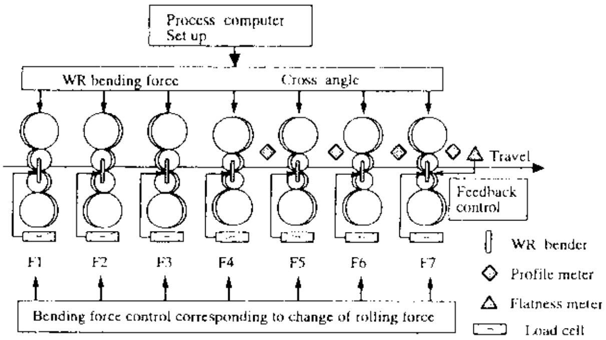

Fig. 10 Outline of crown and flatness control system in No. 3 hot strip mill

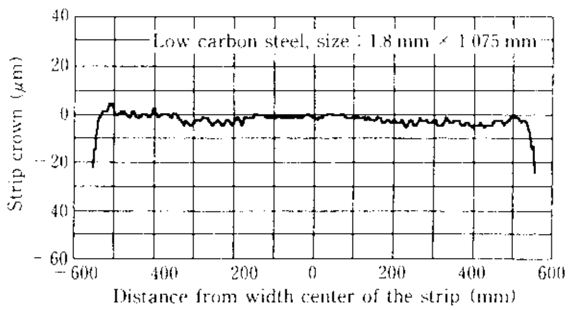

Fig. 11 Example of strip crown

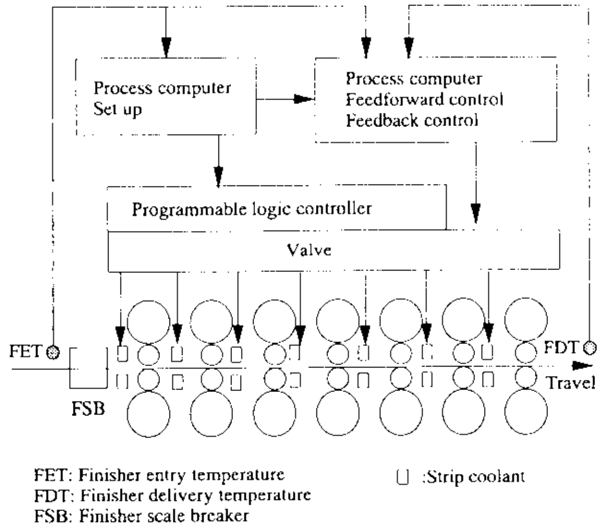

Fig. 12 Outline of finisher delivery temperature control system in No. 3 hot strip mill

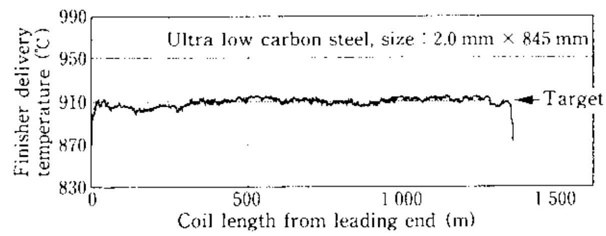

Fig. 13 Example of finisher delivery temperature

3.4 Crown and Flatness Control

A pair cross mill and strong work roll bender have been installed in all 7 stands in the finishing mill. They make it possible to control strip crown over a wide range. **Figure 10** shows an outline of the crown and flatness control system. In setting up, cross angle and work roll bending force are determined using predicted rolling force and roll profile. The actual profile of a strip measured by a profile-meter is used both in dynamic crown control and in automatic tuning of a set-up model. The measured flatness after the F7 stand is used in feedback control of the work roll bender in the F7 stand. In each stand, work roll bending force is controlled according to change of rolling force to keep the crown constant even if the rolling force changes largely. **Figure 11** shows an example of strip crown. A strip thickness is kept almost constant in width direction.

3.5 FDT Control

Precise control of FDT and CT is important to obtain required mechanical properties. Fully computerized and precise control system of FDT and CT has been established[9]. **Figure 12** shows an outline of FDT control system. The same tracking data are used in both the FDT and CT control systems. In the tracking data, the strip is assumed to be a procession of virtual cut sheets stretching from the entrance of the finishing mill to the down coiler. The FDT control system has following 3 functions: (1) Set-up function, which calculates how many coolant nozzles are to be open. The set-up calculation is executed when the leading end of the strip passes the entrance pyrometer of the finishing mill. (2) Feedforward control, which calculates how many coolant nozzles are to be open in downstream according to the actual FET (finisher entry temperature) and rolling speed. (3) Feedback control, which calculates how many coolant nozzles are to be open in upstream according to the actual FDT and rolling speed. **Figure 13** shows an example of FDT, which is controlled within ±15°C of the target along the entire coil length.

3.6 CT Control

A fully automated CT control system has been established[10]. **Figure 14** shows an outline of CT control system. Water cooling zone is subdivided into 21 sections. The CT control system has the following 4 functions: (1) Preset function, which determines how many nozzles are to be open. The calculation is executed when each

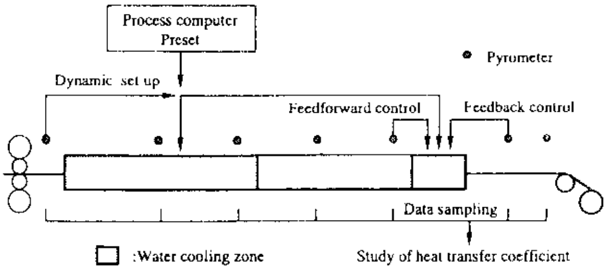

Fig. 14 Outline of coiling temperature control system in No. 3 hot strip mill

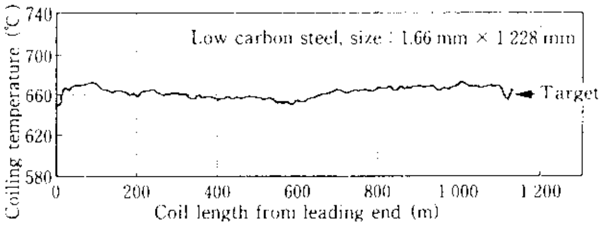

Fig. 15 Example of coiling temperature

virtual cut sheet enters the finishing mill. (2) Dynamic set up, which calculates how many nozzles are to be open according to an actual FDT. (3) Feedforward control, which recalculates how many nozzles are to be open according to the measured temperature of the intermediate pyrometer. (4) Feedback control, which recalculates how many nozzles are to be open according to the measured temperature of the pyrometer at the exit of the cooling zone. **Figure 15** shows an example of CT, which is controlled within ±10°C of the target along the entire coil length. Cooling control is conducted for every virtual cut sheet, thus CT is kept almost constant even if strip speed changes largely or is extremely high.

4 Conclusion

Kawasaki Steel Chiba Works No. 3 hot strip mill was constructed to meet customer demand for better product accuracy. To manufacture high quality products, new precise control technology was established for the following functions: (1) inter-stand tension and looper control, (2) gauge control, (3) width control, (4) crown and flatness control, (5) FDT control, and (6) CT control. In each of these functions, the precision of the control has been improved remarkably.

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