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Establishment of a High Grade Steel Sheet Production System at Chiba Works No.3 Cold Rolling Mill

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No.3 tandem cold mill (TCM) in Chiba Works is a multi-purpose mill, whose production is ranging from the ordinary cold-rolled steel sheet to high carbon and stainless steel sheets. With the aim of improving the product quality, yield, cost, and productivity of this line, the fully continuous mill was put into operation in July 1988. To cope with high-grade quality requirements, additional improvement, mainly the installation of a final stand, was realized in July 1990. To achieve fully continuous operation, the laser welder was developed for use in the continuous rolling of a high carbon and stainless steel sheet. The shape control system using the mill with high shape control characteristics and the strip-surface quality improvement technique based on the coolant filtration system were also established to meet the quality requirements of high-grade products.

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1 Introduction

Against the background of increasing demand for high-grade steels, the requirements for uniform quality and freedom from defects have recently become strong also in cold-rolled steel products. Meeting these severe quality requirements has been a great problem also in the No. 3 tandem cold rolling mill (TCM) of No. 2 Cold Rolling Mill at Chiba Works.

The No. 3 TCM, which was brought into operation in 1972, is a multipurpose mill that produces a wide variety of steels ranging from general cold-rolled steel sheets used in automobiles and household appliances to high-carbon steel sheets and stainless steel sheets. Under the conventional rolling method that involves threading and tailing-off operations for each individual coil, defective parts at the leading and tailing ends of the strip are unavoidable; during these operations cracks are apt to be formed in the work rolls and the strip shape of these portions is apt to be unstable. To meet the above quality requirements, therefore, a continuous cold rolling mill has been sought for.[1,2] To ensure continuous operation in the No. 3 TCM that rolls a large number of steel grades, however, it was necessary to develop continuous rolling techniques and welding techniques for steels that are difficult to weld, such as high-carbon steels and stainless steels. Furthermore, these steel grades with high deformation resistance are difficult to roll and to ensure good shapes of these steel sheets it was necessary to develop a shape control system using a rolling mill excellent in shape control characteristics. To meet the requirement for defect-free products, it was necessary to develop a strip surface quality improvement technique by establishing a coolant filtration system.

These techniques were developed this time and the measures required for producing high-grade steels on

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the No. 3 TCM were taken. Concretely, fully continuous operation of the No. 3 TCM was achieved in July 1988[3)] and substantial automation and labor-saving were accomplished assisted by the introduction of process computers and direct digital controllers (DDCs). Furthermore, the final stand (No. 5 stand) of the rolling mill was brought into operation in July 1990 and the planned measures to meet requirements for high-grade products were completed.

An outline of this equipment and new techniques developed to meet such requirements are reported in the following.

2 Outline of Equipment

2.1 Specifications of Line

The main specifications of the line are shown in **Table 1**. This is a highly automated line, which requires only three operators in all: one in the entry section, one in the central mill operation room, and one for strip surface inspection. The general layout of the line is shown in **Fig. 1**.

Table 1 Main specifications of No. 3 tandem cold mill

Items		Type and specifications
Coil thickness		
Entry	(mm)	2.0~6.0
Delivery	(mm)	0.2~3.2
Width	(mm)	660~1 677
Weight		
Entry	(kg)	Max. 42 000
Delivery	(kg)	Max. 42 000
Speed		
Entry	(m/min)	700
Delivery	(m/min)	1 650
Welder		Fully automatic laser beam welder
Loop capacity of accumulator	(m)	550
Mill type		
1~4 std		4 Hi
5 std		CVC6*
Mill control		Digital ASR
Flying shear		
Type		Rotary shear
Max. cutting speed	(m/min)	250
Tension reels		Carrousel-type tension reels

* Continuous variable crown 6 Hi

2.2 Entry Equipment

To permit rolling of a wide variety of steel grades, such as high-carbon steels and stainless steels, and many sizes, the entry side of the line is equipped with a laser beam welder with a high output of 10 kW;[4,5)] the highest output ever given to a continuous rolling mill. The specifications of the welder are shown in **Table 2**. The functions required of this welder are high efficiency, high reliability and high automation level as a welder for the automated mass production line. Two oscillators were installed to improve maintainability. Furthermore, the number of pay-off reels was increased from 1 to 2 to shorten the preparation time on the entry side for stainless steel sheets, which are produced in small coils.

2.3 Rolling Mill

To meet user requirements for improved gauge accuracy for cold-rolled carbon, high-carbon and stainless

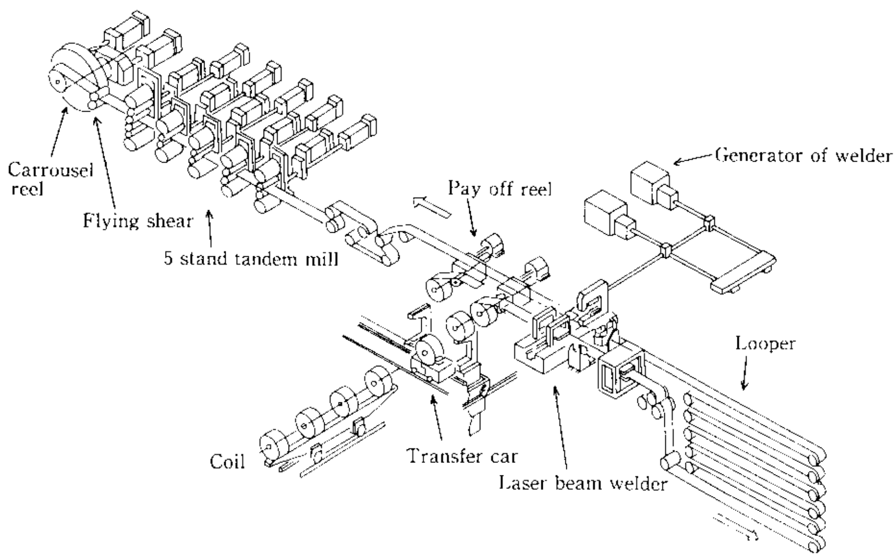

Fig. 1 Layout of the 5 stand tandem cold mill

Table 2 Specifications of laser beam welder

Items		Specifications
Laser beam oscillator	Type	CO_2 laser
	Output power	10 kW
	Head type	2-axes high gas pressure
	Laser gas	He, N_2, CO_2
Laser beam welder	Shear type	Dual cut shear
	Torch speed	Max. 10 m/min
	Wire feed rate	Max. 15 m/min
	Focusing system	Parabolic mirror
	Sielding gas	He, Ar, He+Ar

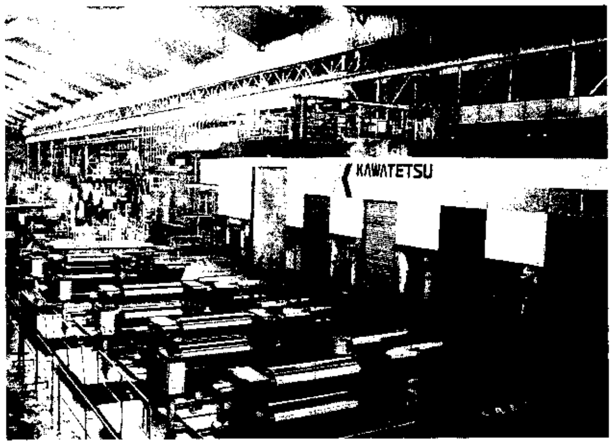

Photo 1 A view of No. 3 tandem cold mill

steel sheets, the following equipment-related measures were taken:

(1) Replacement of the conventional roll positioning device with a one-stand high-speed hydraulic roll positioning device for the purpose of improving the capacity to reduce gauge variations.
(2) Adoption of a digital ASR (automatic speed regulator) in the main motor control system of the rolling mill for the purpose of improving gauge accuracy during the acceleration and deceleration of the mill and during low-speed rolling.
(3) Renewal of automatic gauge control (AGC), involving mainly AGC digitization and addition of the roll eccentricity control function.

Furthermore, the No. 5 stand was added[6,7] to permit rolling of materials with high deformation resistance such as high-carbon steels and stainless steels. A CVC 6 mill (continuous variable crown 6-high mill) with excellent shape control characteristics was adopted as this final stand to ensure good strip shapes under a wide range of rolling conditions. In constructing this mill, the installation of the mill housing was completed beforehand to hold the mill shutdown period due to the construction work to a minimum; this enabled the work on weekdays and trial run to be executed during ordinary operation using temporary passes. Furthermore, to reduce off-gauge portions and increase productivity, all the stands were designed so that the work rolls can be changed with the strip kept in the line. The appearance of the rolling mill is shown in **Photo 1**.

2.4 Delivery Equipment

Pinch rolls, flying shears and a carrousel-type tension reel are installed on the delivery side of the rolling mill to permit on-line dividing and coiling. Coiled strip steels are transported by a delivery coil car and a delivery transfer bogie. A strip surface inspection device, marker and binder are installed here. In addition, a spool feeder for preventing the buckling of thin-gauge coils is installed. All these devices are fully automated.

2.5 Process Computer System

The process computer system[8] is shown in **Fig. 2**, and the layout of instrumentation devices is shown in **Fig. 3**.

In this line, rolled sheets of various steel grades and

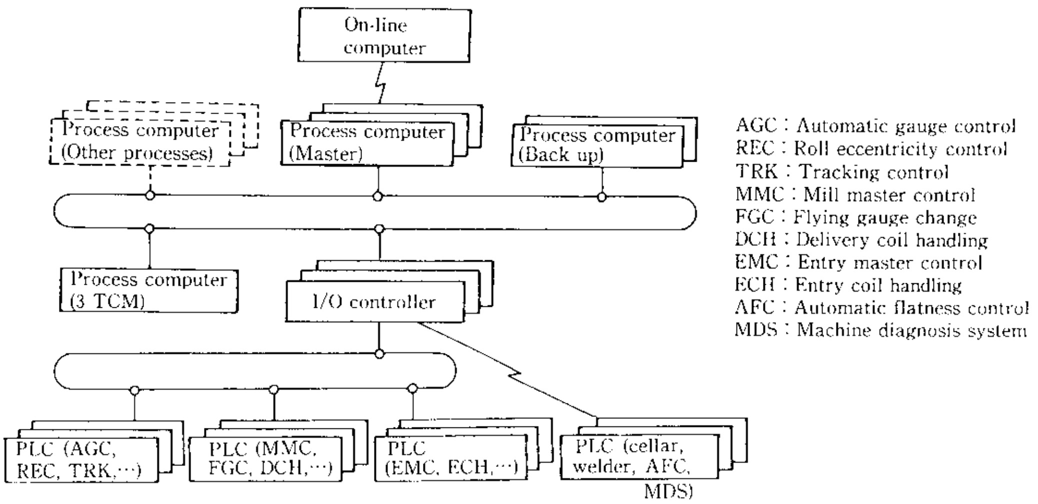

Fig. 2 Block diagram of process computer system

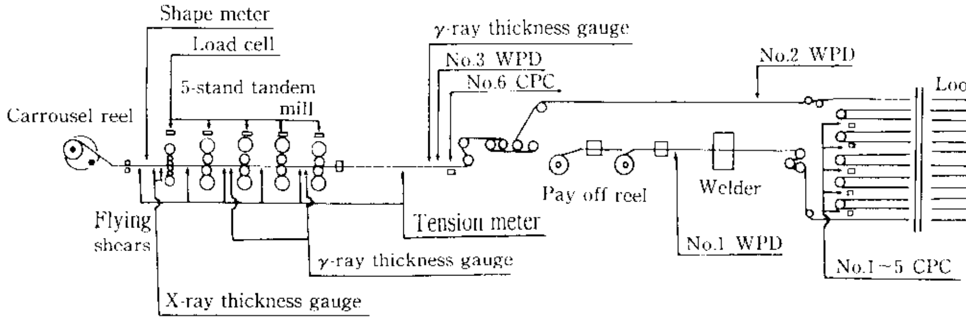

Fig. 3 Layout of instrumentation device

sizes are produced by one-man operation. The process computer system plays a pivotal role and has the following features:

(1) Improvement of the setup model and preset function suitable for rolled steels of various steel grades and many sizes.
(2) Realization of high-level automatic system and monitoring function by making the most of the process computers, DDCs and automated equipment.
(3) Configuring an automatic system for the oil cellar by CRT and keyboard operation.
(4) Adoption of an autonomous distributed process computer system to improve the efficiency of development and reliability.

3 New Techniques for Rolling High-Grade Steels

3.1 Development of Welding Techniques by Laser Welder

3.1.1 Necessity of laser welder

A flash butt welder has so far been used mainly as the welder for a continuous rolling mill. When this welding method is adopted, however, excessive heat input causes the hardening of welds and HAZ in high-carbon steels and martensitic stainless steels and grain coarsening in ferritic stainless steels, with the result that weld strength decreases drastically due to the embrittlement of welds. For this reason, the flash butt welder is unsuitable as a welder for a continuous rolling mill that rolls a wide range of steel grades including high-carbon steels and stainless steels and it was necessary to introduce a new welder. Against this background, a laser welder[9] characterized by a small heating zone, high in welding speed, with local heating and rapid cooling was developed and installed for use in continuous rolling operation.

3.1.2 Development of high-accuracy shearing technique

An extremely small diameter of the laser irradiation on the object to be welded requires high butting accuracy. To reproduce butting accuracy, it is necessary to

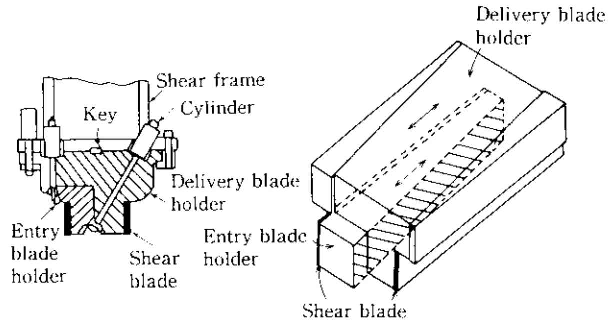

Fig. 4 Mechanism of automatic shear clearance

shear sheets with an appropriate clearance depending on steel grades and sheet thicknesses. Therefore, an automatic shear clearance adjustment mechanism was developed to maintain and reproduce cutting accuracy and butting accuracy. The automatic shear clearance adjustment mechanism is shown in **Fig. 4**. In this mechanism, it is possible to automatically adjust the shear clearances on the entry and delivery sides separately and rigidity is increased by locking the holder by means of a cylinder during shearing. As a result of the installation of this mechanism, it became possible to maintain butting accuracy within 0.03 mm for all steel grades and sizes, contributing greatly to an increase in weld strength.

3.1.3 Measures for welding of high-carbon steels

A filler wire feeder is attached to this welder to relieve the restriction for shape control and butting accuracy and to permit metallurgical control. Especially in high-carbon steels, the formation of blow holes was suppressed as shown in **Fig. 5** by increasing the amount of filler wire fed and diluting weld metal, and weld quality was thus improved. A post-annealing apparatus is provided to increase the weld strength of high-carbon steel sheets and martensitic stainless steels. The conventional post-annealing apparatus is installed outside the welder and it is necessary to transfer the weld in order to conduct post-annealing and, therefore, the transfer time is added to the cycle time. Furthermore, breakage occurred during transfer. These great operational problems had to be solved. In the present welder, the size of the post-annealing apparatus was decreased and the

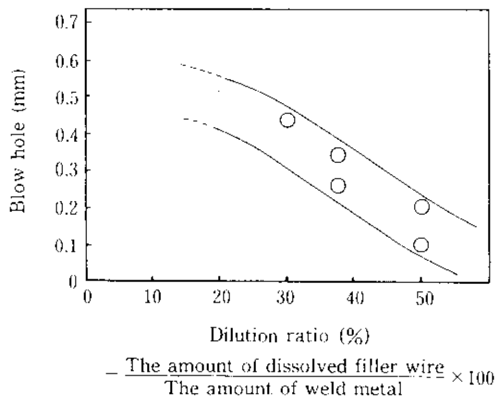

Fig. 5 Relation between dilution ratio and blow hole

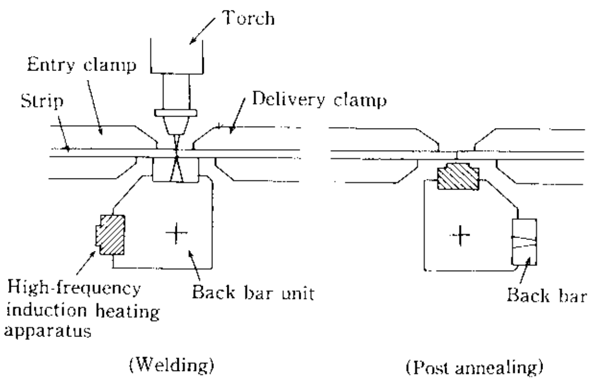

Fig. 6 Post annealing apparatus

heating apparatus was incorporated in a back bar unit used during welding as one unit; this permits post-annealing immediately after welding, thus solving the above problems. A schematic drawing of this post-annealing apparatus is shown in **Fig. 6**.

Owing to the above measures for the production of high-carbon steels, this line can perform a standard commercial production of high-carbon steels with a carbon content of up to 1.0% or less, displaying the continuous rolling effect to the full in terms of efficiency and yield.

3.2 Development of Automatic Shape Control Techniques

3.2.1 Development of CVC 6 mill shape control system

The CVC 6 mill is provided with work roll (WR) benders, intermediate roll (IMR) benders, IMR shift mechanism, spot coolant, and reduction levelers as shape control actuators, and has high flatness control capability. A flatness control system was developed to effectively utilize this capability.[10,11] The functions are shared by the host computers (process computers) that perform setup calculation, learning calculation, and results gathering and by subordinate computers (DDCs) that perform real-time feedback control using the shape detectors on the entry side of the mill.

The configuration of the flatness feedback control system is shown in **Fig. 7**. In designing this system, the functions of the actuators that perform flatness correction of symmetry elements based on the results of simulation conducted using a transverse division model:

(1) IMR Bender
Because the IMR bender has a tendency in flatness change similar to that observed in the WR bender of a 4-high mill, the IMR bender is used to control simple elongation.

(2) WR Bender
Unlike the IMR bender, the WR bender has a tendency to affect the edges of the strip. Therefore, the WR bender is used in combination with the IMR bender by utilizing the difference in the tendency in flatness change from the IMR bender.

(3) IMR Shifting Mechanism

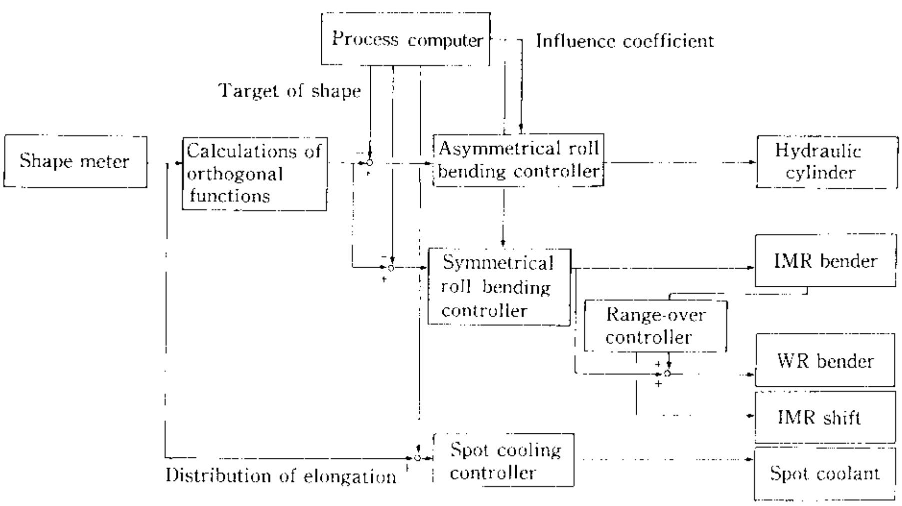

Fig. 7 Block diagram of shape control system

The IMRs are given a CVC curve that is a three-dimensional curve, and it is possible to continuously change the IMR crown according to the amount of IMR shift, and with its flatness changing tendency similar to that of IMR bender, IMR shifting mechanism is used in an over-ranging manner so as to maintain IMR bender as actuater of rapid response in effective function.

3.2.2 Results of application for production

The flatness control characteristic in actual mills is shown in **Fig. 8** by making a comparison between a 4-high mill and the CVC 6 mill. This system has made it possible to control the strip flatness within 0.5% steepness for about 80% of all rolled steels. In the conventional 4-high mill it was necessary to change the WR curve to compensate for the flatness control capability, while in the CVC mill it is possible to use the same WR curve for all steel grades and sizes, thus contributing greatly to an increase in productivity and a decrease in the number of work rolls to be possessed. For the IMRs also, it has become possible to use the kind of curve for all steel grades by giving an appropriate CVC curve to the IMRs. **Figure 9** shows actual amounts of shift of IMR within one rolling cycle for rolling about 3 000 t.

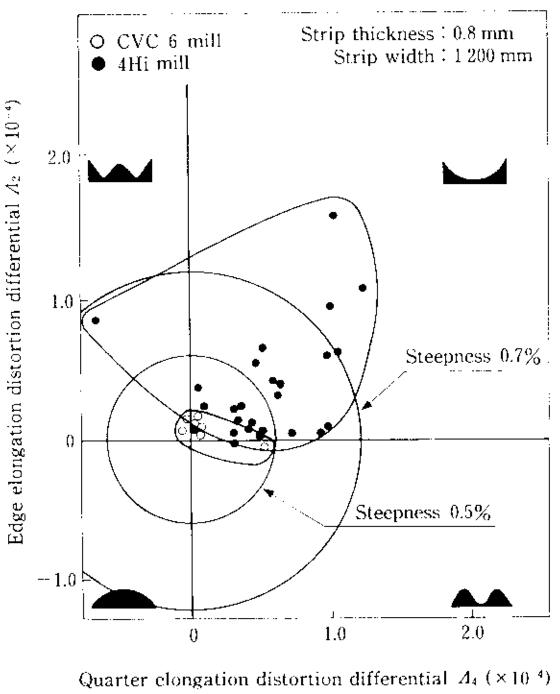

Fig. 8 Comparison of strip flatness by CVC 6 mill and 4 Hi mill

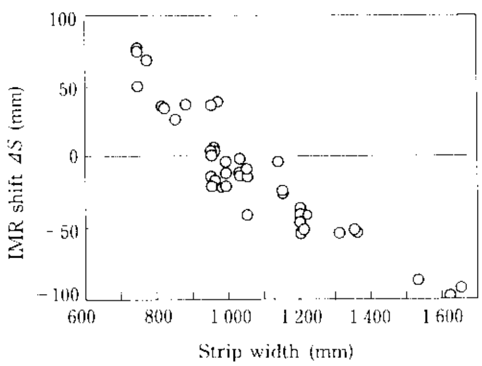

Fig. 9 Characteristics of IMR shift (actual mesurement)

3.3 Development of Technique for Improving Surface Quality

3.3.1. Development of technique for improving surface quality

With increasing demand for high image clarity steel sheets[12] and coated steel sheets, it has become increasingly necessary to stably roll coils free from surface defects, such as roll marks. To meet this requirement, rolls marks formed during threading and tailing-off were substantially reduced by adopting fully continuous operation. To prevent the occurrence of roll marks caused by the contamination with coolant, it was necessary to develop a filtration coolant system.[13] In designing this system various examinations were conducted and, as part of such examinations, the foreign substances in the coolant were analyzed. As a result, the foreign substances were divided into the following three types:

(1) Iron powder generated from the surface of rolled steels.

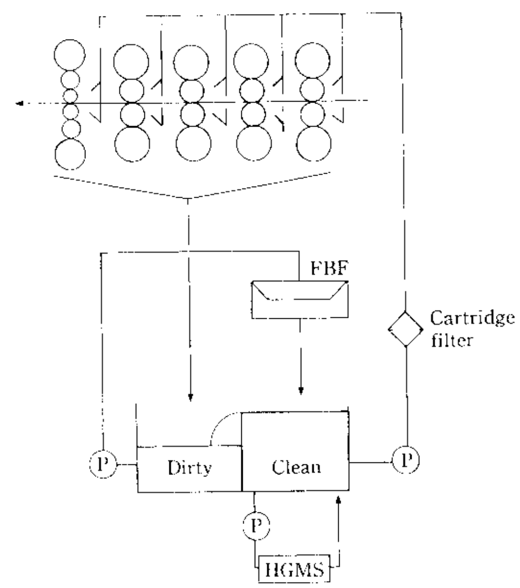

Fig. 10 Full flow filtration system with high gradient magnet separater (HGMS) and flat bed filter (FBF)

Table 3 Specifications of high gradient magnet separator (HGMS) and flat bed filter (FBF)

HGMS	Flow rate (m^3/min)	7
	Diameter of media (m)	ϕ1.2
	Magnetic flux density (T)	0.5
FBF	Flow rate (m^3/min)	30
	Opening size (μm)	150
	Filtration area (m^2)	15

(2) Organic iron formed by the reaction between the iron powder generated by wear and the rolling mill lubricant.

(3) Fibrous matter generated by the wear of auxiliary resin rolls on the entry side of the rolling mill.

A combination of a high-gradient magnet separator for removing iron powder that is a magnetic substance and a flat-bed filter for removing other nonmagnetic foreign substances was adopted as the filtration equipment. The filtration system is shown in **Fig. 10** and the specifications of the filters are shown in **Table 3**. The reason why the flat-bed filter was adopted is that the filter area is compact due to pressure filtration although its capacity must be larger than the coolant volume circulating to the mill after filtration because it filters the total quantity of coolant.

3.3.2 Performance of filtration equipment in actual mill

The strip surface cleanliness after rolling before and after the installation of the high-gradient magnet filter is shown in **Fig. 11**. Evaluation was conducted by measuring the tape to which foreign substances are adhering with an L-value color meter. After the installation of the high-gradient magnet separator, the iron content of the coolant decreased substantially and the strip surface cleanliness increased by about 5 point. **Figure 12** shows

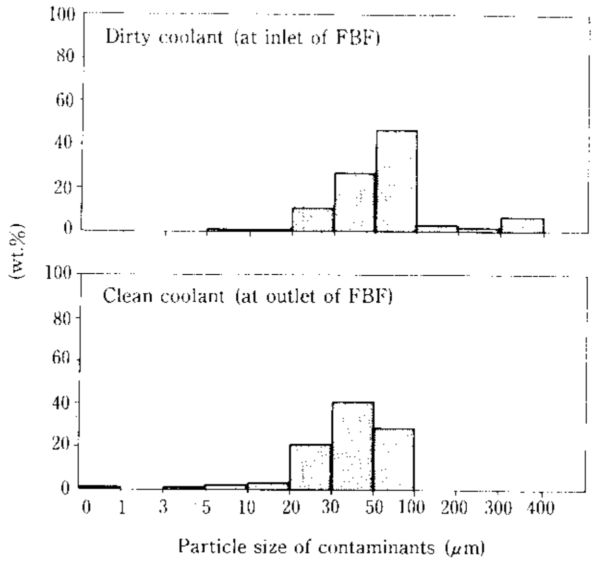

Fig. 12 Particle size distribution of contaminants in coolant

the particle size distribution of foreign substances in the coolant at the inlet and outlet of the filter, which represents the effect of the installation of the flat-bed filter. Owing to the effect of filtration, it was able to remove all foreign substances with particle size of more than 100 μm and part of foreign substances larger than 50 μm. **Figure 13** shows changes in the total iron content and organic iron content of the coolant before and after the operation of the above filtration equipment. The high-gradient magnet separator lowered the total iron content to about 500 ppm and the flat-head filter reduced the organic iron content to about 500 ppm. As a result, it was able to reduce the frequency of work-roll changes due to roll marks to 43% of the conventional level. Furthermore, because contaminants in the coolant were efficiently removed and disturbance factors in the emulsification of the rolling mill lubricant decreased, the emulsification condition became very stable and

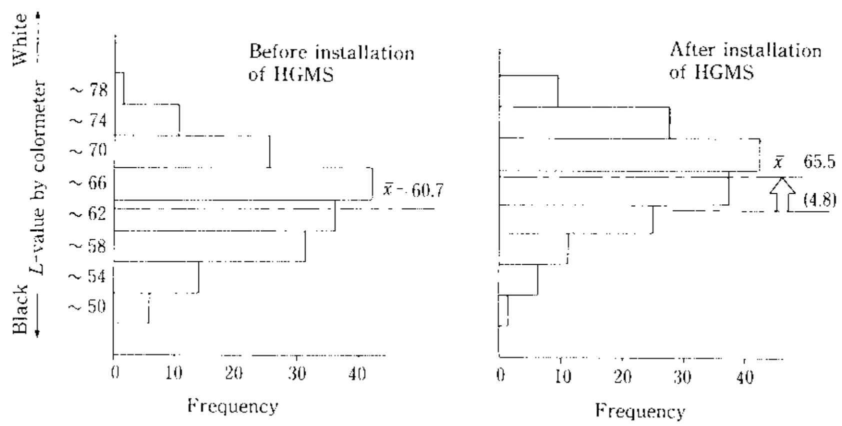

Fig. 11 Effect of HGMS on strip surface cleanliness after cold rolling

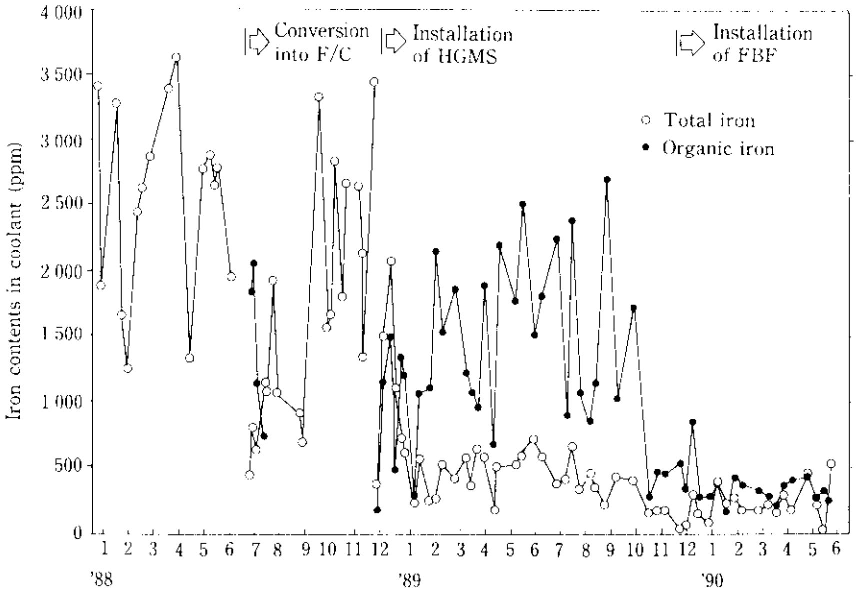

Fig. 13 Trend of total iron and organic iron contents in coolant

troubles related to lubrication, such as heat scratches and slip, decreased substantially.

4 Conclusions

The fully continuous operation of the multipurpose cold rolling mill at Chiba Works and the measures to produce high-grade steels were described. This line achieves high quality, high yield and high productivity to meet the requirements of the age. In the present equipment modification, not only carbon cold-rolled steel sheets, but also high-carbon and stainless steel products were taken into consideration and various techniques for rolling these steels, such as a welding technique using a laser welder, automatic flatness control technique and technique for improving the steel surface quality, were developed. This line is operating smoothly, displaying expected effects, and a system capable of coping with severer quality requirements in the future has been established.

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