Upgrading of Hot Finishing Mill to 4-Stands, and Replacement of Computer Control System

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ABSTRACT Since 1994, in response to increasing demand for can body stock and other aluminum strip products and to users' requirements for higher quality, work has been going forward on a program to upgrade the hot finishing mill at the Fukui Works. Phase I of the program involved expansion to 4 stands and introduction of a new computer control system, and went into service in March 1997. The result has been the capability of high-speed rolling of thinner strips providing increased capacity, together with significant improvements in thickness accuracy due to the introduction of the new control technology as well as in the properties of the material and other aspects of quality. Phase II of the upgrade--introduction of a computer control system for the rougher--went forward to completion in March 1998.

1. INTRODUCTION

A program to upgrade the hot finishing mill at the Fukui Works involving expansion to 4 stands and introduction of a new computer control system went into service in March 1997.

The result has been increased hot rolling capacity and improved yield, together with significant improvements in thickness accuracy as well as in the properties of the material and other aspects of quality. This paper provides an overview of the hot finisher mill after the upgrade, and describes the new control technology and hot rolling process control system that were introduced.

2. GENERAL DESCRIPTION

The hot rolling mill of the Fukui Works went into service in May, 1983 as a world-class facility, equipped with large rolling stands capable of producing wide, large-diameter coils and featuring the latest in computer control. Since then, continuing improvements have been made in response to increasing demand for aluminum strip products --particularly can stock--and users' requirements for higher quality in terms of dimensional accuracy, performance and strip surface quality, but given the inadequate capacity of the computer control system and the addition of further stands by other players in the industry, we were faced with difficulty in coping with the situation regarding aluminum strip products. Accordingly a plan was developed to upgrade the Fukui hot finisher by expansion to 4 stands and by replacement of the computer control system. The plan had the following objectives:

1) To address users requirements by increasing the number of finishing stands and the total reduction, thereby improving the quality of aluminum strip products--specifically can body stock--and increasing product coil diameter.
2) To increase productivity by reducing the thickness of hot-rolled coils, thereby effecting pass cutting in the cold-rolling process.
3) To realize a high-productivity hot-rolling mill by replacing the computer control system with one of the latest design that achieved a significant degree of automation.

The expansion of the hot finisher to 4 stands, which was Phase I of the upgrade program, has been achieved. Figure 1 shows line layout.

2.1 Equipment Specifications

The hot finishing line was expanded by adding a fourth stand (F0) upstream of the three existing stands (F1-F3). Photo 1 shows the appearance of the finishing mill and Table 1 shows main specifications.

The newly installed F0 stand is of 4-high construction with hydraulic screw-down, and to provide for the rolling of

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Photo 1 Hot finishing mill

Table 1 Specifications of Hot Finishing Mill

Stand no.	F0	F1-F3
Manufacturer	IHI/Toshiba	IHI/Fuji Denki/Toshiba
Type	Non-reversing 4-stands	
Main motor rating	5000 kW AC	3750 kW DC
Max. rolling force	40.0 MN	31.2 MN
Max. rolling speed	112 m/min	175/270/360 m/min
Roll dimensions	WR 800 x 2850 mm BUR 1620 x 2850 mm	WR 720 x 2850 mm BUR 1520 x 2850 mm TP 1620 x 2850 mm
Profile actuator	WRB TP roll (top / bottom)	WRB TP roll (top) Cold coolant sprayer

high-quality aluminum products with high productivity it has the following features:

(1) Use of rollers with high power (5,000 kW) and high screw down force (40 MN).
(2) Ample profile correction capability (large-capacity work roll bender (WRB) and taper piston (TP) roll).
(3) Adoption of high-response hydraulic screw-down system and high-response mill drive system to prevent tension fluctuation between stands and improve thickness correction capability.
(4) Provision of side guides to prevent snaking of the strip --hydraulic at the entry side of hot finisher, F0 and F1 and screw + pneumatic at the entry of F2 and F3.
(5) Provision of a cold coolant sprayer mechanism to improve profile correction capability as thickness is decreased.

The F0 stand is powered by a high-response, low-maintenance AC motor (5,000 kW), with a large-capacity gate turn-off (GTO) thyristor drive unit (10,000 kVA).

2.2 Computer Control System

The plan to upgrade the hot finishing line also provided for introducing a new computer control system, involving renovation of control for the expanded hot finishing stand and the addition of process computers. This was accompanied by significantly augmented functions.

Figure 2 shows the configuration of the computer control system for the hot strip rolling mill. It was transitional, having been completed with the renovation of the control system for the rougher in March, 1998.

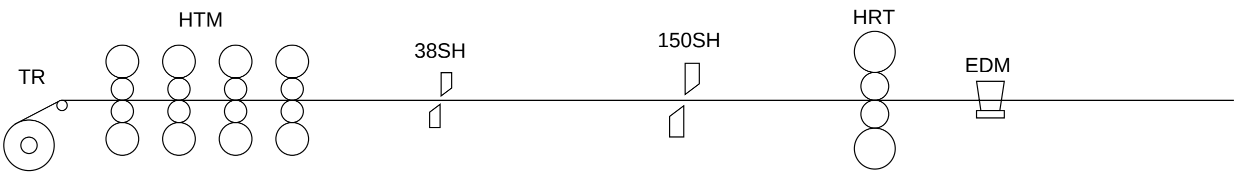
2.2.1 Control System

The control system comprises a digital controller capable of high-speed, high-volume calculations, an operator guidance device operated by touch panels, and an FDDI-I compatible control system dataway with a data transmission capacity of 100 Mbps, and having a wide scan transmission data region. Taking advantage of the features of this high-speed, high-capacity control system makes it possible to:

(1) achieve high-precision rolling control, including tension control and thickness control;
(2) improve operating convenience by means of fully implemented operator guidance and use of touch panel operation for items of infrequent use; and
(3) improve flexibility of control system structure and reduce the space occupied by electrical equipment through use of remote I/Os.

2.2.2 Computer System

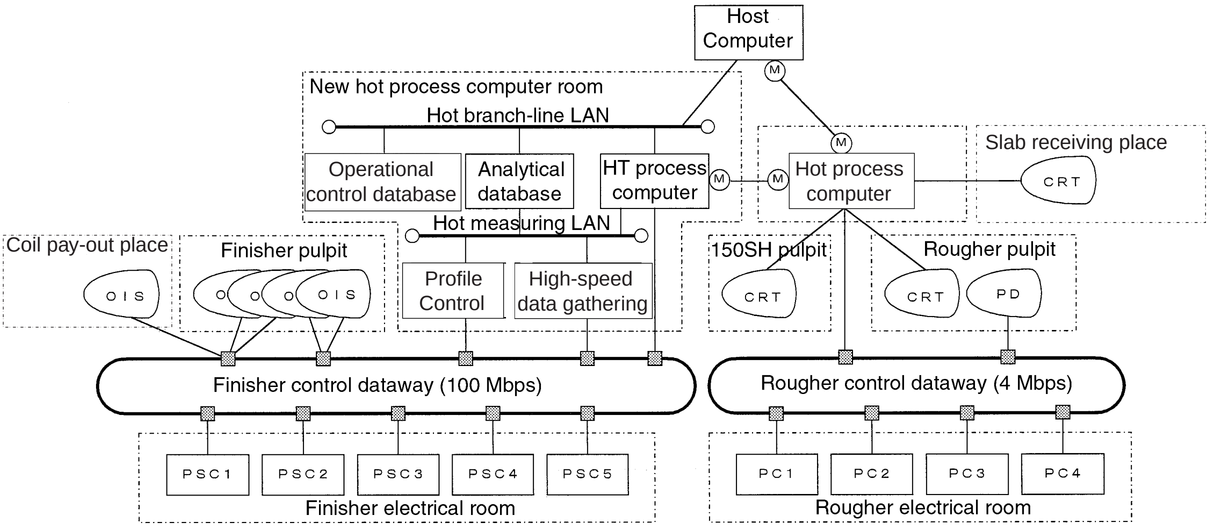
In the computer control system, a process computer dedicated to finisher set-up calculation/learning and finisher process data gathering is introduced. In addition engineering workstations for dynamic profile control and high-speed data gathering are connected to the control system dataway, and EWSs for engineering data and the production database and an EWS for the process analysis database are connected to the information system LAN. All of this data can be referenced and acquired at any time by personal computers connected to the on-site LAN.



EDM : Edger mill
HRM : Hot reversing mill
HTM : Hot tandem mill

150SH : 150-mm cut shear
38SH : 38-mm cut shear
TR : Tension reel

Figure 1 Layout of hot rolling line



HOT process computer
- Mill line tracking,
- Rougher set-up calculation/learning,
- Rougher pre-setting,
- Rougher process data gathering,
- Hot production control

HT process computer
- Finisher set-up calculation/learning,
- Finisher pre-setting,
- Finisher process data gathering,
- Hot production control,
- Coil transfer line tracking

PSC1:
- Finisher mill control master,
- Temperature control

PSC2:
- Finisher thickness control

PSC3:
- Coiler master

PSC4:
- Spray control,
- Crown control actuator settings

PSC5:
- Roll eccentricity elimination control

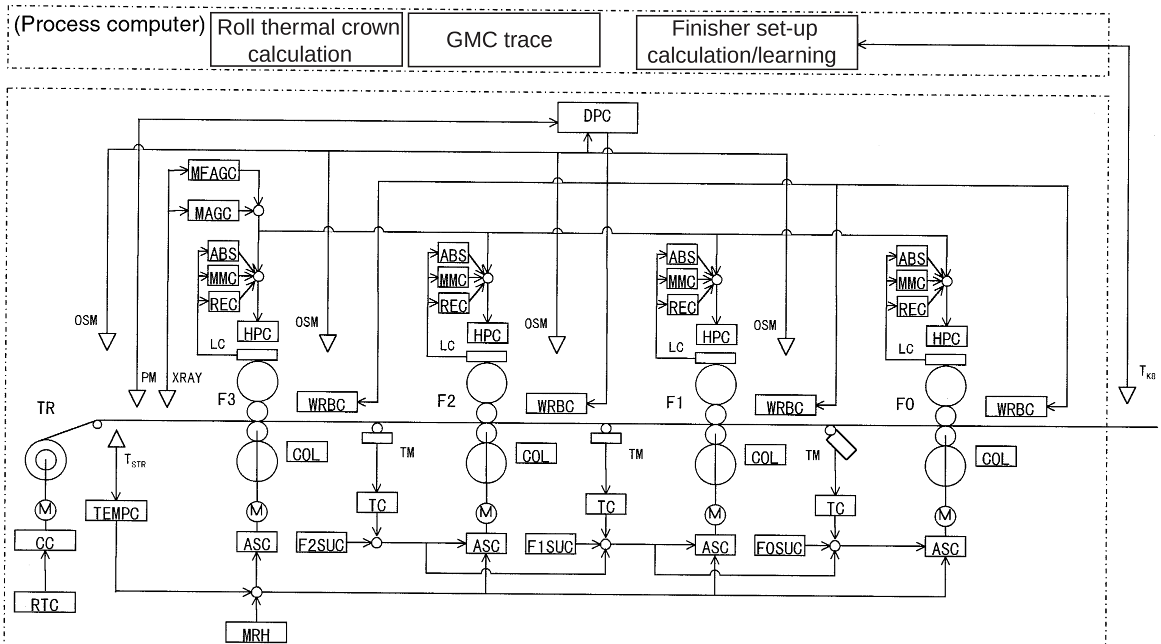
PC1:
- Rougher master, table master

PC2:
- Rougher sub-machine control master

PC3:
- Machines around rougher mill control master,
- Automatic gauge control

PC4:
- Slab cooling temperature control

Figure 2 Configuration of computer control system for hot strip rolling mill



(Control system)

ABS:	Absolute AGC	LC:	Load cell	RTC:	Reel tension control
ASC:	Speed control	MAGC:	Monitor AGC	T:	Thermometer
CC:	Current control	MCAGC:	Mass flow AGC	TC:	Tension control
COL:	Coolant spray control	MMC:	Mill modulus control	TEMPC:	Temperature control
DPC:	Dynamic profile control	MRH:	Master speed reference	TM:	Tension meter
FiSUC:	Fi stand ACG (successive)	OSM:	Optical shape meter	WRBC:	WRB control
HPC:	Hydraulic position control	PM:	Profile meter	XRAY:	X-ray gauge meter
		REC:	Roll eccentricity elimination control		

Figure 3 Block diagram of control system for hot finisher

3. CONTROL TECHNOLOGIES

Figure 3 is a diagram showing the control system. The renovation described here introduced new techniques for gauge control, profile control and temperature control. These techniques, and the results obtained, are discussed below.

3.1 Automatic Gauge Control

In addition to conventional methods such as monitor AGC, thickness control for the hot finisher effects mass flow thickness control using a high-speed hydraulic screw-down system combined with positive methods such as absolute AGC, thereby suppressing thickness amplitude of the steady-state portion and reducing top-end off gauge length. Further, with a view to automating the avoidance of rolling problems in high-load rolling, a new excessive rolling force/torque avoidance control function has been incorporated.

3.1.1 Thickness Control of Steady-State Portion

In controlling the thickness of the steady-state portion, a combination of mill modulus control (MMC) to compensate for high-frequency thickness deviation, monitor AGC to compensate for low-frequency deviation in steady-state thickness, and roll eccentricity elimination control to compensate for periodic deviation in thickness due to the eccentricity of the rolls is used to improve thickness accuracy. Mass-flow AGC is also implemented to maintain the drafting schedule at each of the intermediate stands, and thereby stabilize the properties of the rolled material.

3.1.2 Top-End Absolute AGC

With the objective of raising yield by reducing the off-gauge length of the hot-rolled coils, top-end absolute AGC has been newly implemented.

To assure thickness accuracy using absolute AGC, it is essential than accuracy be increased by gauge meter equation.[1] To this end a function is newly incorporated whereby the elastic curve of the mill is measured automatically and computer and controller data are constantly updated. To obtain consistently accurate values for gauge meter compensation (GMC), which is made up primarily of thermal expansion of the rolls, the thermal expansion is calculated by means of a mathematical thermal crown model, allowing the GMC value to be corrected at set intervals. This results in a significant reduction in the off-gauge length of the top end compared to previously. Figure 4 shows the results of adopting absolute AGC.

3.1.3 Excessive Rolling Force/Torque Avoidance Control

In the case of material that is particularly hard or wide, rolling requires greater rolling force and torque. Towards the end of the strip this tendency gradually strengthens due to the effects of cooling, and if rolling continues unchanged the excessive force/torque may result in mill stoppage. In the new AGC system, therefore, a new function has been added whereby the drafting schedule is automatically changed when maximum rolling force or rolling torque is approached, thus avoiding mill stoppage. The basic concept is to reduce the load on a given stand by closing the roll gap of the upstream stand when there is a margin at the upstream stand and opening the roll gap of the given stand when there is no margin at the upstream stand.

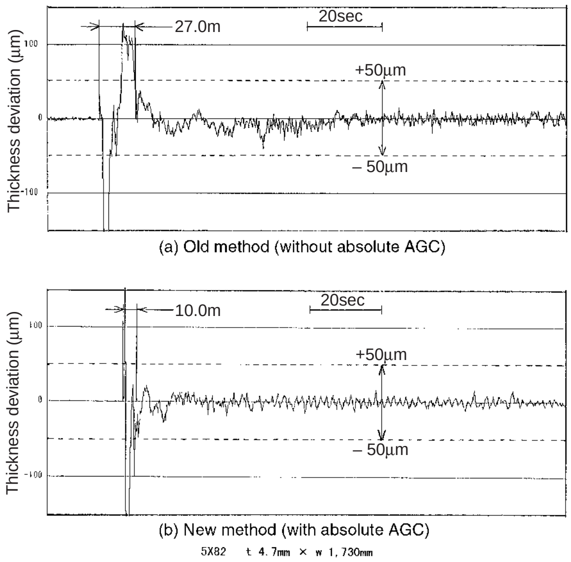


Figure 4 Thickness deviation at delivery side of F3 stand

3.2 Profile Control

In recent years there has been an increase in the accuracy demanded with respect to the thickness distribution (profile) and shape. Since the profile of the product is determined by the hot finisher, profile control is important for quality but because it also involves the elastic deformation of the rolls and the plastic deformation of the rolled material, automatic control is extremely difficult.[1]

For the present system upgrade, new models were developed for both pre-setting and dynamic control. This system assures minimum profile error distribution at the delivery side of the final stand mainly by pre-setting and controlling the WRB force, and in addition to a mathematical model, operator knowhow is factored in, thereby approaching the touch of a human operator. It features may be enumerated as follows:

(1) Actuators are the WRB, TP roll and roll spray pattern.
(2) Sensors are the profile gauge at the delivery side of the final stand and optical shape meters mounted between stands.
(3) The F3 delivery-side profile control sector is given a weighting and divided into 20 so that the edge portion is finely divided in the direction transverse to the strip, and, based on the delivery-side target profile distribution and the delivery-side actual profile, a delivery profile deviation $\Delta\varepsilon(i)$ is obtained by

$$\Delta\varepsilon(i) = P_{ACT}(i) - P_{REF}(i) \quad .....(1)$$

where:
$\Delta\varepsilon(i)$: Delivery-side profile deviation (zone i),
$P_{ACT}(i)$: Actual delivery-side profile,

$P_{REF}(i)$: Target delivery-side profile,

(4) The WRB control input for each stand is set so that the evaluation function Φ in Equation (2) is minimized.

$$\Phi = \Sigma \{ \Delta\varepsilon(i) - \Sigma\, \alpha_j(i)\, F_j \}^2 + \Sigma\, W_j\, n\, \Delta\Phi_j^{\,2} \quad .....(2)$$

where:
Φ: evaluation function,
$\Delta\varepsilon(i)$: Delivery-side profile deviation (zone i),
$\alpha_j(i)$: WRB effect function for stand j (zone i),
ΔF_j: WRB control input for stand j
W_j: WRB control weighting coefficient for stand j
n: number of divisions in transverse direction (20).

(5) The shape limits are set from the optical shape meter and information on WRB manual intervention by the operator, and the initial settings of WRB force and automatic control during rolling are carried out in such a way that these are not exceeded.

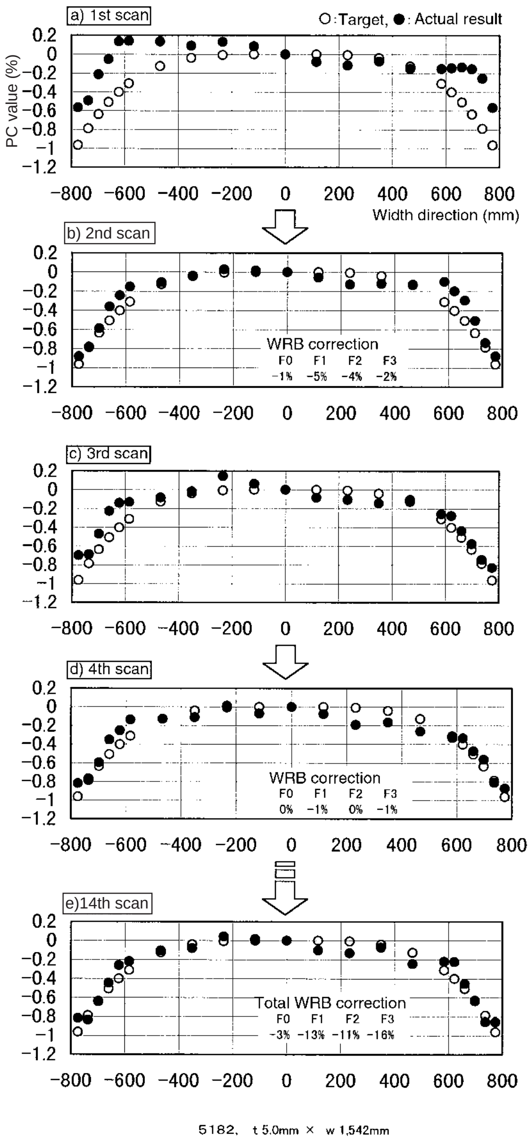


Figure 5 Effects of dynamic profile control

Figure 5 shows a typical application of this control.

3.3 Temperature Control

In aluminum hot rolling, and particularly in hot finishing, accurate control of the temperature of the material is crucial to the quality of the finished product. In the present project, a new material temperature model was developed to optimize temperature control gain for each material to be rolled, and a new type of radiance thermometer was adopted, thereby increasing the accuracy of temperature measurements.

3.3.1 High-Accuracy Exact-Solution Analytical Temperature Model

Generally speaking, the material temperature model made use of an approximation equation derived from the following one-dimensional thermal conduction equation at non-steady-state

$$T = (T_0 - \theta_L) \exp(-4a / h^2 \cdot K \cdot t) + \theta_L \quad .....(3)$$

where:
T: material temperature (°C),
T_0: initial material temperature (°C),
θ_L: coolant temperature (°C),
a: temperature conduction rate (mm²/sec),
h: strip thickness (mm),
K: recovery coefficient,
t: thermal conduction time (sec).

Previously, the approximation equation used in Equation (3) had a large error with respect to coefficient K, but in the present work, by subjecting the one-dimensional thermal conduction equation at non-steady-state to logical analysis and by determining the various coefficients from experiments on the cooling capacity of coolants, it was possible to raise the accuracy of the temperature prediction model. Figure 6 shows how it was possible, using the new temperature model to obtain a predictive accuracy for rolling speed of approximately 90%, with an error range of ±10%.

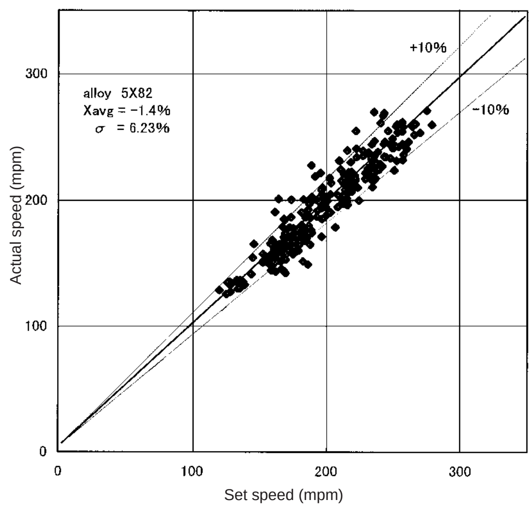


Figure 6 Anticipated accuracy of temperature model (Stand F3)

3.3.2 New Type Of Two-Wavelength Radiance Thermometer

Until now, the radiance thermometer used was of the one-wavelength type, but problems of temperature control accuracy were posed by the difficulty of setting the appropriate emissivity, and by susceptibility to the influence of the strip surface conditions. Accordingly it was decided to adopt a new type of two-wavelength thermometer, the ASTS® from the LAND Corporation.

This thermometer is characterized by introducing, with respect to the Wien's approximation equations (4) and (5) of Plank's law relating to heat radiation on two wavelengths λ_1 and λ_2, a new relational equation (6) for two-wavelength emissivity in aluminum. That is to say,

$$V_1 = \varepsilon_1 \lambda_1^{-5} \exp(-C / \lambda_1 T) \quad .....(4)$$
$$V_2 = \varepsilon_2 \lambda_2^{-5} \exp(-C / \lambda_2 T) \quad .....(5)$$
$$\ln \varepsilon_2 = A \cdot \ln \varepsilon_1 + B \quad .....(6)$$

where:
V_1, V_2: thermometer output,
λ_1,λ_2: measuring wavelength,
ε_1: emissivity at wavelength λ_1,
ε_2: emissivity at wavelength λ_2,
T: material temperature (K),
C: constant (= 14,388 µmK).

From Equations (4) through (6), we obtain

$$1/T - 1/T_1 = A' (1/T_2 - 1/T_1) + B' \quad .....(7)$$

where:
T_1: radiance temperature at λ_1 (K)
T_2: radiance temperature at λ_2 (K)

If coefficients A' and B' are first determined experimentally using Equation (7), measurement of true temperature T can be made using the measurements of radiance temperatures T_1 and T_2. Figure 7 shows the experimental results, and good correlation was obtained for all main alloys.

Through the adoption of this thermometer, it was possible to measure material temperature with good accuracy, without having to revise emissivity settings each time the alloy was changed (Figure 8). Learning accuracy for the setting calculations was also improved, in effect raising the predictive accuracy of the rolling model.

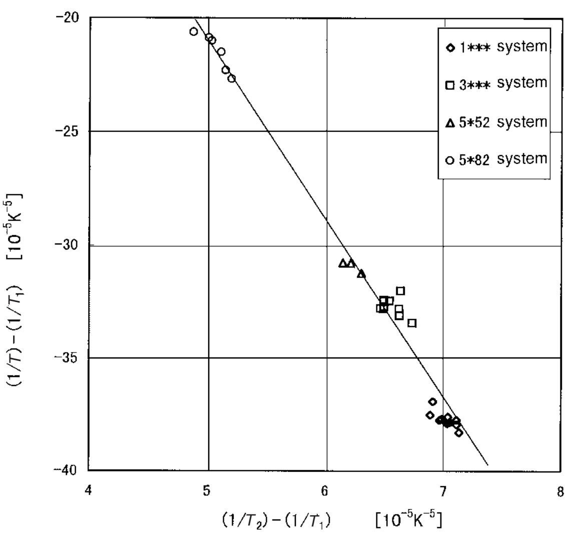


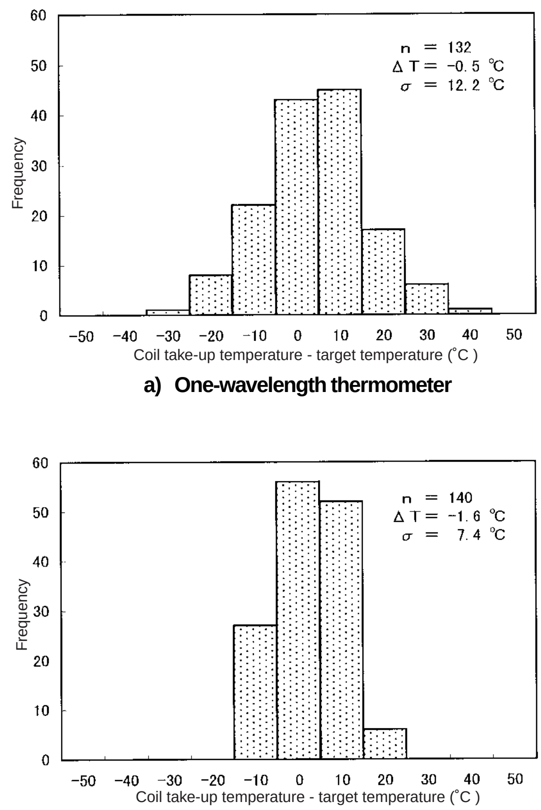
Figure 7 Relationship between radiance temperatures T_1 (at λ_1) and T_2 (at λ_2) and true temperature T for aluminum strip

3.4 Hot Rolling Process Control System

The present renovation was accompanied by development of a variety of control and support systems, contributing to maintaining and improving the quality of the rolled products, and to speeding up problem analysis thereby shortening equipment down-time. The main functions are described in the following.

3.4.1 Quality SPC System

The statistical process control (SPC) system gathers data for strip thickness, strip profile and material temperature at intervals of only 10 ms, and these data are then subjected to FFT analysis, profile waveform analysis and statistical analysis to allow the automation of quality decisions. As a result, in the event of a quality abnormality, the operator is notified immediately as to thickness off-gauge length, thickness amplitude, strip profile estimation values, off-temperature length, etc., to prevent continuance of the abnormality.[3)]



b) Two-wavelength thermometer

Figure 8 Histogram of temperature errors on one- and two-wavelength radiation thermometers

3.4.2 High-Speed Data Gathering/Analysis System

Using the high-speed, large-capacity control system dataway, rolling process data and control output data of all types is gathered at 50-ms intervals and stored in the database, creating a system that supports graphic displays on personal computer screens. This makes it possible to analyze rolling phenomena as well as rolling problems due to control faults, so that causes can be identified. This contributes greatly to the rapid solution of the problem, and to the prevention of its recurrence.

3.4.3 Quality Database System

At the Fukui Works a database is maintained containing quality data generated at all stages of the production process. In the case of the hot rolling process, engineering data gathered automatically by the process computers is stored automatically in the quality database. It is thus possible to analyze data across processes, contributing to higher quality.

3.4.4 Automatic Hydraulic Screw-Down Step-Response Measurement

Deterioration of the servo valve of the hydraulic screw-down system has an adverse effect on its response and interferes with thickness control. To prevent this, routine measurements of the system's step response must be taken to evaluate the degree of deterioration. In the present program, automatically performing step response measurement and data analysis at the time of roll gap zeroing has made it possible to confirm deterioration quickly and easily.

4. CONCLUSION

The Fukui Works is pressing ahead with Phase II of the renovation of the hot rolling line--upgrading the control system of the hot rougher. The upgrade program was implemented in January 1998, and after on-line adjustment was completed on schedule in March of the same year. This has brought to completion Furukawa Electric's program of renovating the hot rolling line of the Fukui Works, creating a line that is fully responsive to the quality and productivity requirements of our customers.

We are committed to further advances in automation and further integration with the outstanding capabilities of our staff, so as to achieve even higher levels of quality and productivity.

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Manuscript received on July 17, 1998.