UDC621.771.23.016.3 : 681.5

New Technologies Implemented at New Cold Strip Mill of Yawata Works

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Abstract:

To meet the growing stringency in product quality requirements in terms of gage accuracy and so forth, and to drastically raise productivity, Nippon Steel built a new cold strip mill as a replacement for three existing mills at Yawata Works. Starting commercial operation in August 1990, the new cold strip mill fully continuously rolls stainless steel and electrical steel as well as carbon steel in a wide size range with high quality and at high efficiency. Among the new technologies adopted to make the mill a most up-to-date facility even in the 21st century are high-performance AC drives, a new AGC system utilizing high-performance control terminals, product crown and flatness control using the six-high work roll shifting mill function, and an approach to skill-free operation with advanced man-machine interface. A fully automatic roll shop is attached to the new cold strip mill.

1. Introduction

Nippon Steel at its Yawata Works built a new cold strip mill that incorporates the world's latest technologies. It meets the ever increasing sophistication and diversification of gage accuracy and other product quality requirements of late. With this new facility, the Works has raised its productivity and improved its production structure by replacing the old No. 1, 2, and 3 cold strip mills that had been commissioned during the period from the 1920s to the late 1950s. The new mill started commercial operation in August 1990 and now continuously rolls a great variety of steel grades, including carbon, electrical, and stainless steels, with high quality and functionality. The main specifications of the mill are as listed in **Table 1**.

This report introduces the new technologies developed and implemented to accomplish the functions required of the new cold strip mill: 1) continuous, high-efficiency rolling of diverse steel grades, including mild carbon steel, high-strength steel, electrical steel and stainless steel ranging from 0.25 to 3.2 mm in thickness and from 600 to 1,880 mm in width; 2) high-precision rolling control to meet closer profile, gage, and shape tolerances; 3) skill-free rolling to realize the largest possible labor savings and to stabilize the equipment performance and operation, and automatic mill operation with a minimum of labor; and 4) automation of the roll shop.

Table 1 Main specifications of new cold strip mill at Yawata Works

Mill type	5-stands 6-high fully continuous tandem cold mill with work roll shift and IMR bender
Capacity	147,000 ton/month
Products	Mild steel, electrical steel, stainless steel
Strip thickness	Ent. 1.6-6.0mm, del. 0.25-3.2mm
Strip width	600-1,880mm
Coil weight	Ent. 40 ton max, del. 27.3 ton max.
Coil outer dia.	2,300mm
Roll size	WR/IMR/BUR 530/620/1,420mmΦ×2,180 mmL
Max. line speed	Ent. 750mpm, mill 1,800mpm
Mill motor power	30,000kW (AC motor)
Welder	Flash butt welder and laser beam welder
Tension reel	Carrousel type two tension reel

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2. High-Efficiency Continuous Rolling Functions

2.1 High-performance AC drive system

As a replacement for three old cold strip mills, the new mill must roll many steel grades, including such hard materials as stainless steel and electrical steel. This requirement imposes an extremely wide torque range on the mill drive system. Increasing the field range from the conventional value of 2.5 to 3 to a new value of 4.5 or more was found to improve the effective utilization rate of the mill power, namely, to drastically reduce the motor capacity while securing the desired production capacity (see **Fig. 1**).

Noting the effectiveness of AC motors in expanding the field range, the authors carried out the development of a high-precision and rapid-response variable-speed AC drive system applicable to tandem mill drives. The outcome of the development work was a fully-digital 72-arm circulating-current cycloconverter drive system with controllers using latest 32-bit high-speed microprocessors. The cycloconverter drive system made it possible to reduce the total mill power requirement to a large degree (about 15,000 kW) and to reduce the required amount of investment by increasing the capacity of individual motors. AC motors eliminated the restriction of commutation, and high-speed and high-precision digital control provided much better control characteristics (such as response and speed control accuracy) than obtainable with conventional DC motors (see **Table 2**).

While four to six motors were required for each stand in the past, the increase of individual motor capacity allowed a single-stand single-motor configuration. Coupled with the simplification of speed reducers, the single-stand single-motor configuration made it possible to improve the torsional stiffness of the drive system, to eliminate harmful resonance frequency, and to best utilize the rapid-response characteristic of AC drives without any constriction.

Increasing the response of the speed control system enhances the effectiveness of speed feedforward (FF) AGC and mass flow (MF) AGC, and improves the gage accuracy of product to a high degree in combination with the new AGC system described later. Speed control in a speed range of less than 1% was impossible with conventional DC motors. With excellent speed matching from zero speed, AC motors permit extremely smooth mill restart operation after a roll change, prevent strip breakage, and stabilize the rolling operation. An AC drive system was developed using cycloconverters for main drive motors and transistorized inverters for auxiliary drive motors. The entire mill line thus came to be driven by AC motors to enhance equipment reliability and reduce maintenance cost.

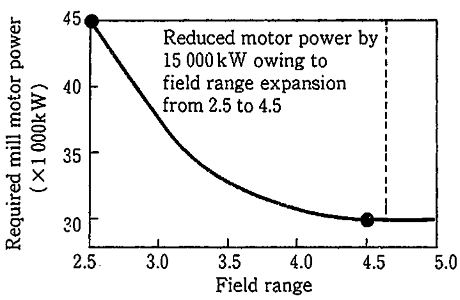
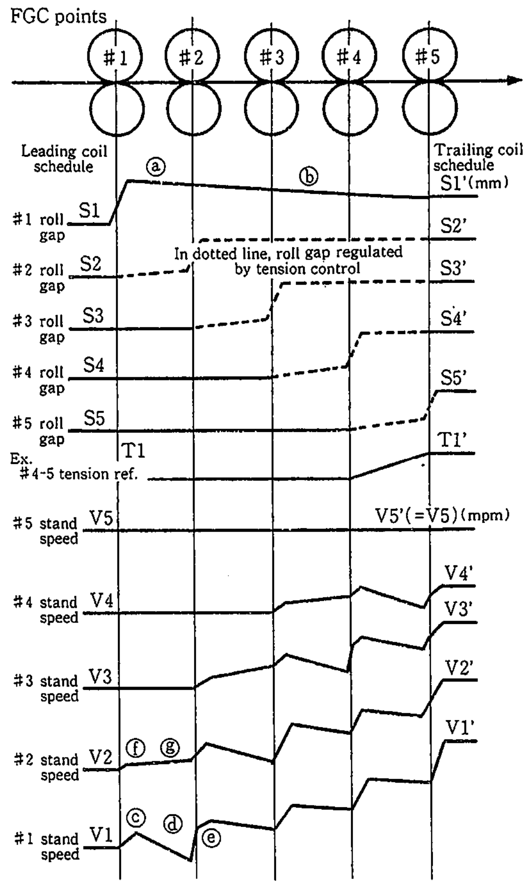


Fig. 1 Field range and motor capacity

2.2 New flying gage change

A new flying gage change (FGC) technique was developed that utilizes the functions of high-accuracy preset calculation with a newly developed fuzzy model and of high-accuracy controllers (AC drives and hydraulic screwdowns). The new technique 1)



ⓐ: At the top of trailing coil, #1 stand roll gap is varied larger than S1' owing to lower rolling speed.
ⓑ: Roll gap is continuously regulated according to speed variation.
ⓒ, ⓓ, ⓔ, ⓕ, ⓖ: At FGC point, each stand speed is regulated to compensate disturbance owing to variation of forward slope and tension during FGC.

Fig. 2 FGC change patterns

Table 2 Comparison of AC drive and conventional DC drive in Performance

	AC drive	DC drive	Expected Effects
Speed control range	0-100%	1-100%	Prevent strip breakage
Speed control accuracy	±0.01%	±0.05%	Strip gage accuracy
	(0-100%) speed range	(1-100%) speed range	Prevent strip breakage
Speed response	ω_c = 47 rad/s	ω_c = 5-20 rad/s	Improvement in AGC effect
Current Control response	ω_c = 900 rad/s	ω_c = 100 rad/s	Suppress torsional vibration
Stall operation	100% load, continuous	50% load, within 30s	Wound coil shape
Field range	max. 6	max.3	Reduce investment cost

minimizes the tension variation and off-gage length during an FGC; and 2) widenes the allowable gage and width differences and the dissimilar steel jointing limits between coils. (For example, the off-gage length can be held at 10 m or less when the gage control pattern is changed from one "from incoming gage of 2.7 mm to product gage of 0.35 mm" to one "from incoming gage of 3.5 mm to product gage of 0.8 mm".) **Fig. 2** shows the stand roll gap and speed change patterns with the FGC system. The FGC technique is characteristic in that strip breakage is prevented and gage variations are minimized by continuously changing the tension reference value with the FGC point and by applying compensation to offset the forward slip ratio to each stand speed change.

3. High-Precision Rolling

3.1 New gage control (new AGC)

A new AGC system was built through the effective utilization of rapid-response and high-precision controllers and sensors. The system stably provides far better gage accuracy over the entire coil length, including acceleration and deceleration portions, than achievable on conventional mills. **Fig. 3** shows the system configuration. The features of the system are described below.

(1) Achievement of rapid-response high-precision control: A frequency response of 23 Hz is achieved over the full stroke by rapid-response and high-precision controllers and hydraulic screwdown cylinders. A frequency response of 47 rad/s and speed control accuracy of ±0.01% are achieved by the AC drive system. These characteristics are put to the best use in processing about 30 control loops at control intervals of 15 ms to realize precise AGC on all stands.

(2) Improvement in gage accuracy of acceleration and deceleration portions by high-precision mass flow control: The gage accuracy of acceleration and deceleration portions is enhanced to the level of steady-state rolled portions by using high-accuracy strip thickness and speed meters installed on the entry and exit sides of all stands and by eliminating forward slip variations. This was difficult to achieve with conventional AGC systems.

(3) Minimizing gage disturbance by stands themselves: A good inter-stand speed balance is maintained by the high-accuracy speed control capability (±0.01%) of the AC drive system. Roller bearings are used as backup roll bearings to minimize the oil film thickness variation and roll eccentricity. A constant-rolling force loop is incorporated in the hydraulic screwdown system to eliminate the gage variation arising from the roll eccentricity. (A gage control reference is converted into a rolling force deviation reference by a screwdown position reference.)

(4) Noninteracting control with other controls: Noninteracting control loops are provided for tension control and gage control, in order to distinguish main final control elements and achieve stable rolling.

As shown in **Figs. 4** and **5**, extremely high gage accuracies are obtained. These results agree well with the results of simulation performed before the construction of the AGC system.

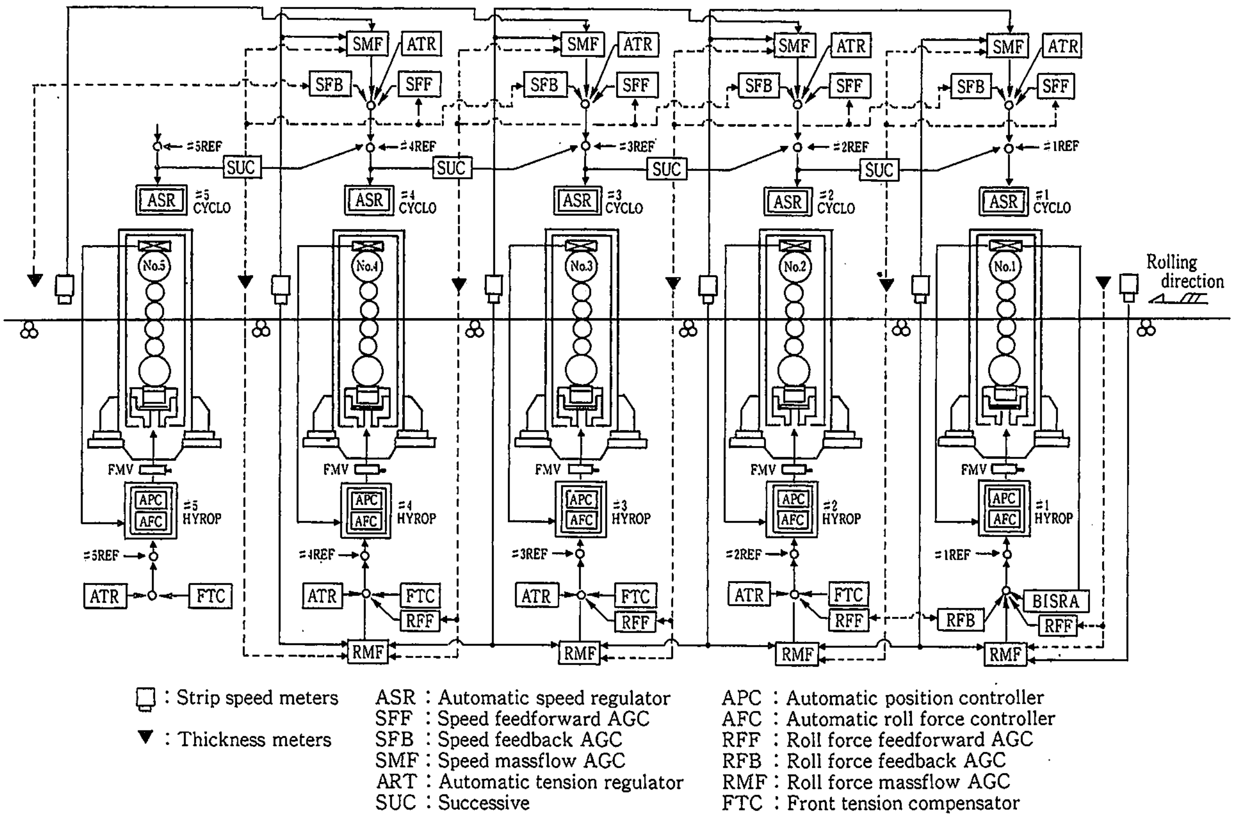


Fig. 3 AGC system configuration of new cold strip mill at Yawata Works

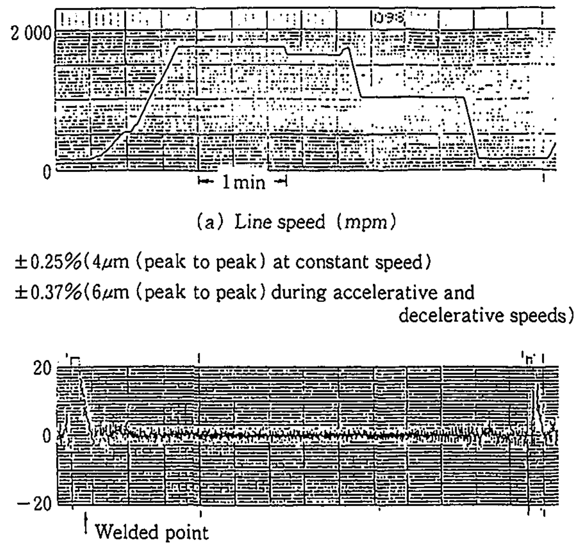


Fig. 4 Examples of gage control results

3.2 Crown control

Higher strip gage accuracy is being demanded both in the longitudinal and transverse directions. In cold rolling, the edge drop and hence the product crown can be improved by shifting tapered work rolls. The following measures were taken to enhance the control accuracy of the tapered work roll shifting technique and to stabilize the mill operation:

(1) Improvement in edge drop and shape control by equipping all stands with long-stroke work roll shifting devices and intermediate roll benders: To meet the broad product width range of 600 to 1,880 mm, all the stands are equipped with a long-stroke (650 mm for both the top and bottom work rolls) work roll shifting device along with the intermediate rolls. Both the work and intermediate rolls are fitted with benders to improve the edge drop and shape control over the entire gage rar°e. It was traditionally difficult to provide both the work a.. intermediate rolls with long-stroke shifting and bending functions. This difficulty was solved by installing shift blocks, for both WR and IMR, which contain bending cylinders and follow the roll shift.

(2) Construction of new edge drop control system: The new edge drop control system adds feedforward control with an entry crown meter to feedback control with an exit crown meter and incorporates fuzzy control as well. It can reduce the edge drop to a considerable extent.

4. Skill-Free Rolling

4.1 Integrated EIC (electrical equipment, instrumentation and computers) system and man-machine interface

To realize a high-quality and high-functionality continuous rolling and skill-free production system, the functions of electrical equipment, instrumentation, and computers were integrated for the first time for a cold strip mill. The large-scale integrated EIC system has the functions of man-machine interfaces adapted to one-man operation, and features excellent functionality, expandability, reliability and maintainability. The integration reduced the hardware cost of the system, ensured the desired system quality through field assembly tests, and contributed to smooth startup of mill operations. **Fig. 6** shows the configuration of the integrated EIC control system. The features of the system are as described below.

(1) One-man operation: Eleven high-functionality intelligent CRT display terminals and two 58-inch projectors are used for integrated EIC information presentation and touch operation. The control panel size and operator workload were thus reduced to allow one-man operation and monitoring.

(2) Large-scale system with functionality and expandability: Three process computers and eleven electrical equipment and instrumentation controllers were combined at high density by a high-speed local area network (LAN) to optimize the functional distribution among the E, I and C areas, to effect high-accuracy control like AGC, and to gather data at high speed.

(3) Improvement in reliability and maintainability: The reliability and maintainability of the large-scale system were drastically improved by many support functions like a cold run simulator and an on-line monitor for each controller, storage of large amounts of data by the process computers, EIC software, and integrated CRT screen management.

4.2 Skill-free system

An equipment and process diagnostic system (skill-free system) was built by incorporating artificial intelligence (AI) functions to lessen the monitoring and judging tasks of operators and support the operators in taking appropriate emergency measures with increasing speed, automation and functionality of equipment. One of the process computers in the integrated EIC control system shown in **Fig. 6** is used exclusively for the skill-free system. Most of the data for the skill-free system are gathered, processed, and diagnosed at high speed by the LAN in common use with the integrated EIC control system.

Fig. 7 *shows the functional configuration of the skill-free system.* The system consists of three complementary functions as described below.

(1) Equipment diagnosis function: The diagnosis of control system was added to the conventional drive system diagnosis (trend control of vibration and other conditions). This made it possible to evaluate the performance of the control system during rolling without injuring the product quality.

(2) Process diagnosis function: An AI system is built to evaluate the rolling conditions comprehensively. The AI system monitors gage and other variables, judges the causes of abnormal conditions, and provides guidance for actions to be taken

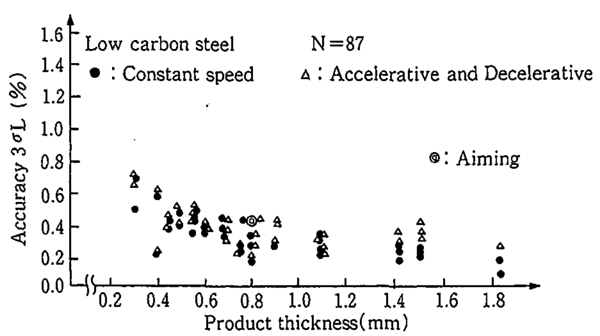


Fig. 5 Gage accuracy by product thickness

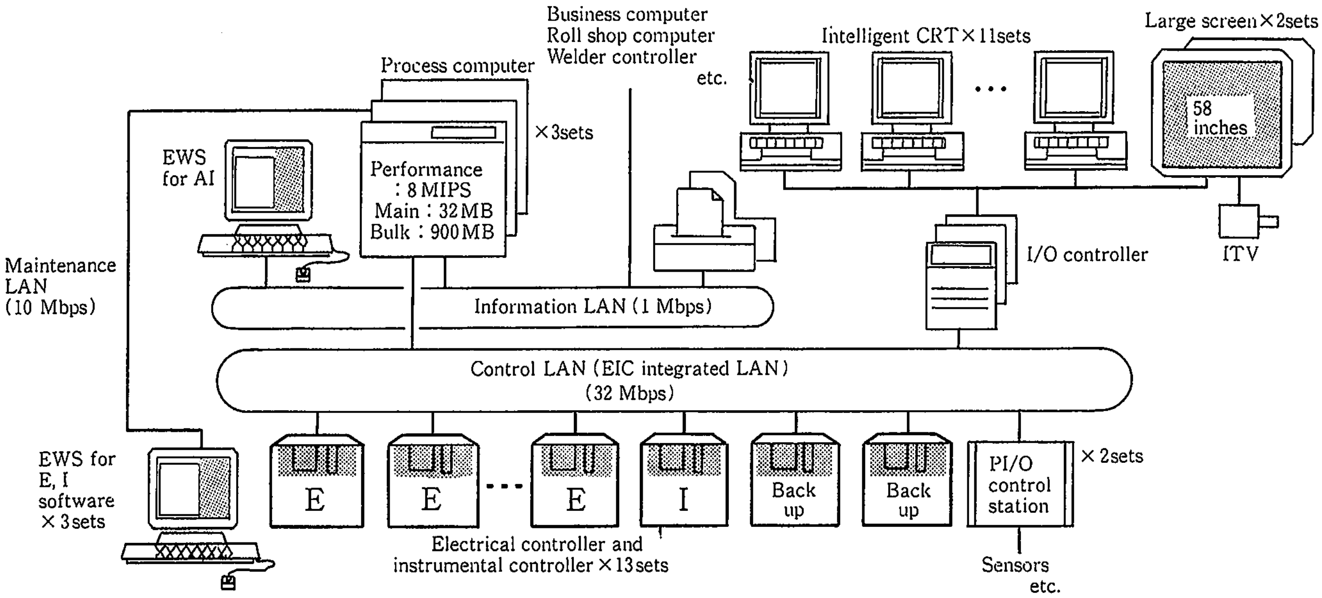


Fig. 6 Integrated EIC control system

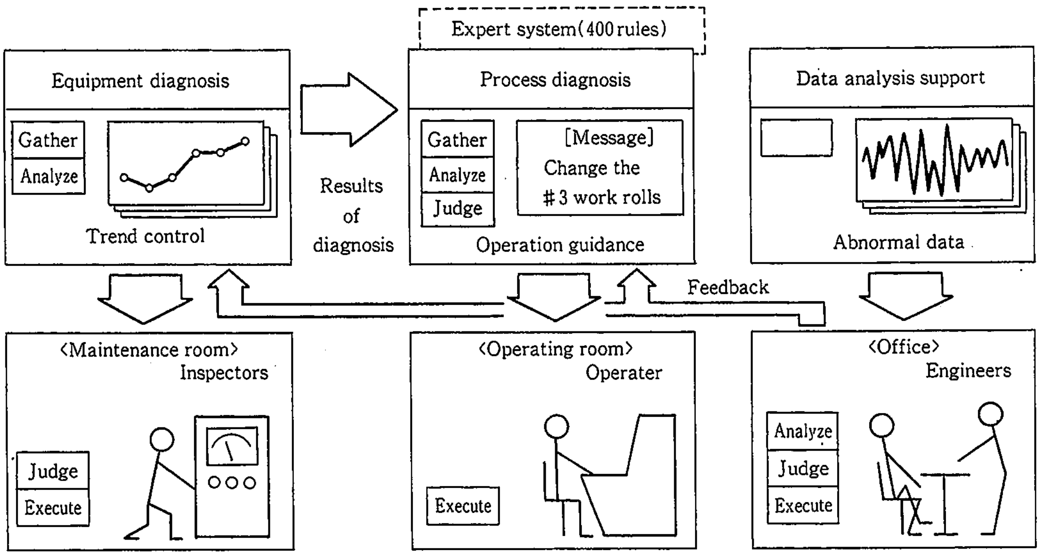


Fig. 7 Functional configuration of skill-free system

against the abnormality. The results of equipment diagnosis are utilized for the AI systems to identify the causes of abnormality.

(3) Data analysis support function: About 600 types of data are stored for 2 min before and after each preset trigger, such as an abnormal line stop, in order to support data collection and analysis in abnormal conditions. Interfaces are provided to facilitate data selection and analysis in respective time and frequency regions. The troubleshooting time is sharply reduced accordingly.

5. Fully Automated Roll Shop

Work rolls and intermediate rolls can be automatically changed while the strip is threaded through the stands. Roll maintenance (such as roll transportation, chock installation and removal, and roll grinding) and roll preparation scheduling are automated. The roll shop is fully automated for the work rolls and intermediate rolls that must be frequently changed. **Fig. 8** shows the task flow and equipment configuration of the roll shop. Its features are as described below.

(1) Automatic operation system: Using AI, the roll shop process computer receives preset and actual rolling data from the business computer and the mill process computer, prepares schedules for changing, grinding and transporting the rolls, and performs real-time control according to the schedules on automatic roll changing, grinding and transporting devices.

(2) Automatic transportation devices

1) Roll changing buggy and roll assembling buggy: Used rolls on the roll changing buggy of each stand are automatically changed with new rolls.

2) Automatic roll chock changer and chock buggy: Chocks are automatically removed from the old rolls and attached

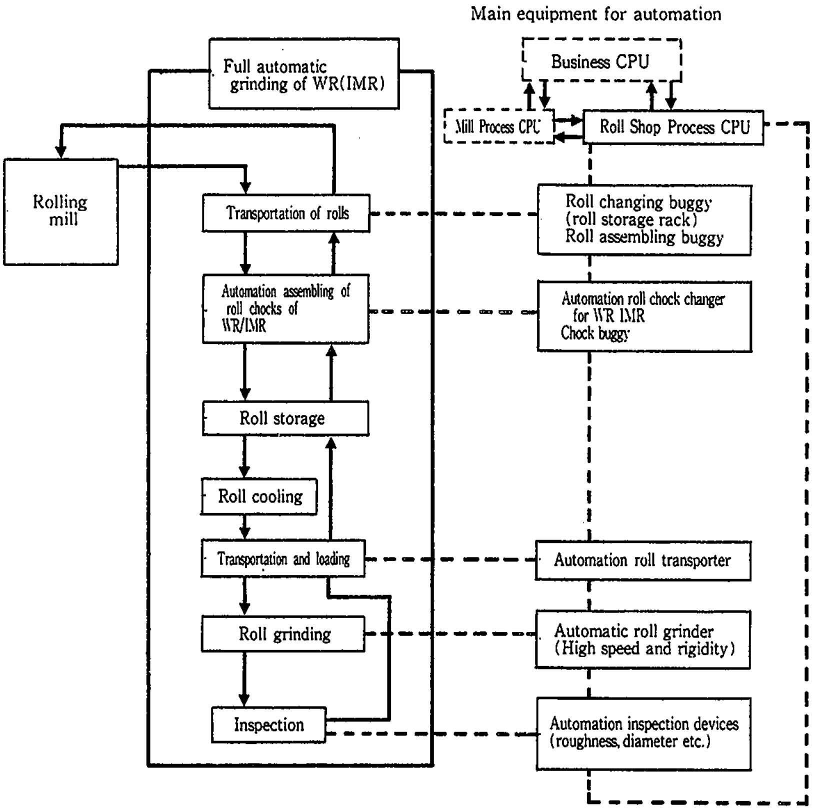


Fig. 8 Task flow and equipment configuration of automatic roll shop

to the new rolls. Auxiliary tasks such as roll neck lubrication are also automated.

3) Automatic roll transporter: All rolls without chocks are automatically transported with high accuracy within the roll shop. Roll transportation to and from the roll grinding machine and chock changer where especially high positioning tolerances are specified is achieved with high speed and accuracy.

(3) Automatic roll grinding machine: Besides the conventional functions of a CNC grinding machine, the following functions were developed for the automation of grinding operations except for sensory inspection:

1) Exchange of grinding conditions, results, and other data with the roll shop process computer
2) Smooth transfer of rolls to and from the aforementioned automatic roll transporter
3) Automation of grinding wheel dressing and roll oiling, and measurement of roll surface profile and roughness

A method was also developed for automatically grinding tapered work rolls all over. It ensures a good grinding finish.

6. Conclusions

New technologies implemented at the new cold strip mill of Yawata Works have been described above. The mill is now smoothly operating as a high-performance facility for cold rolling a variety of steel grades, including electrical and stainless steels. These new technologies including the AC drive system are expected to be applicable also to hot rolling and other processes, and are believed to contribute to the progress of strip rolling processes. The authors gratefully acknowledge the cooperation of Hitachi, Ltd. and other component manufacturers in the construction of the new cold strip mill.

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