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1 Introduction

Demand for higher quality steel products has become increasingly strong, and wire rods and bars are no exceptions. However, since wire rods and bars are generally products of very great length, full guarantee of their quality over their entire length requires that the production process itself be maintained in a highly stabilized condition, that a large amount of data be collected along the entire length of products, and that such data be handled through accurate piecewise tracking. Aiming at further strengthening such quality assurance, the Mizushima Works introduced a process instrumentation and control system centering around the process computer (P/C) system to its wire and rod mill, which was restarted in September 1984.[1)] The new system consists of P/C, sensors positioned along the production line, and process control DDC systems. It is linked with the on-line computer (O/C) system,[2)] which is a higher-stage operation control system, the central computer (C/C) of the works, and DDCs for electrical equipment, thereby greatly contributing to the stabilization and assurance of the quality of wire rods and bars, and playing an important role in the automation and stabilization of the operation.

This paper reviews the outline and features of the process instrumentation and control system of the wire rod and bar mill, with emphasis placed on P/C.

2 Aims of Introducting Process Instrumentation and Control System

For the introduction of the process instrumentation and control system into the wire rod and bar mill, the following objectives were set, with stress on the im-

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provement and stabilization of quality:

(1) Strengthening of Quality Assurance System
Production process data directly related to product quality are gathered automatically and in high density. These data are used for automatically judging the acceptability of the product on an on-line, real-time basis, thereby permitting early detection of anomalies in products or the production process and quick implementation of countermeasures.

(2) Strengthening of Quality Control and Operation Control
Data which will form the basis for determining quality design and production specifications and those which are necessary for controlling operation are gathered in high density to raise the data-base level of these control items.

(3) Stabilization of Operation, Labor-saving
Automation is to be realized in the processes of transferring production instructions from the production planning system to the actual site of production and of determining operating conditions. In addition to savings in labor, by eliminating human intervention, quality problems originating in human error and individual differences are reduced.

To realize these aims with the minimum expenditure, the process instrumentation and control system was planned and designed with the following considerations as conditions:

(1) The linkage between P/C, sensors, and control units such as DDC systems should be as close as possible, so that high-speed, bulk-data transmission and reception will be possible.
(2) Establishment of quality and quality stabilization in the upstream process should be given greatest importance in planning P/C functions.
(3) Measures should be taken in consideration of predicted future additions of functions.
(4) Use of existing resources (bar rolling facilities, etc.) should be maximized.

Condition (4) is included, because the new system was introduced simultaneously with the installation of additional wire rod rolling facilities at the existing bar rolling mill.

In view of the above, the following concrete measures were taken:

(1) In principle, no drastic modification of the existing bar production facilities was to be made. As a result, facilities such as the billet conditioning yard and straight-bar finishing yard were excluded from the process instrumentation and control system.
(2) A semiautomatic system was established as the basis of automation of existing facilities such as the reheating furnace, while the newly-installed facilities centering around the wire rod rolling facilities were made fully-automatic.

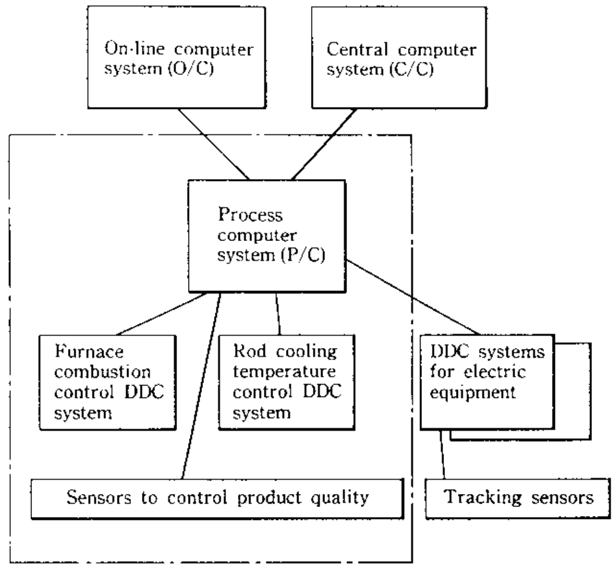


Fig. 1 Configuration of the process instrumentation and control system

(3) At the reheating furnace, high-accuracy temperature control was effected to ensure supply of materials of stabilized temperature to the rolling process.
(4) To make the development of the P/C system easier, a duplex system was adopted, in which parallel on-line runs are possible.

3 System Configuration

The configuration of the process instrumentation and control system is shown in **Fig. 1**. The new system consists of two instrumentation DDC systems, i.e., furnace combustion control and wire rod cooling temperature control systems, and sensors such as pyrometers and profile meters. It is linked to the higher-level O/C and C/C business computer systems and to lower-level DDC systems for electrical equipment.

3.1 P/C System

The configuration of the P/C system[3] and its main functions are shown in **Fig. 2** and **Table 1** respectively. Among the two CPUs which compose the duplex system, one CPU is used for system-development and as a back-up CPU. In terms of function, a single CPU covers all the functions ranging from the reheating furnace to the coil finishing line, thereby constituting a multifunction, concentrated-type configuration. The P/C system transmits and receives information to and from upper and lower systems and subsystems, using six modem system lines. Data are transmitted to and received from DDC system for electrical equipment, which require high response, via a 1-MB/s data way. Data transmission and reception to and from other devices and equipment

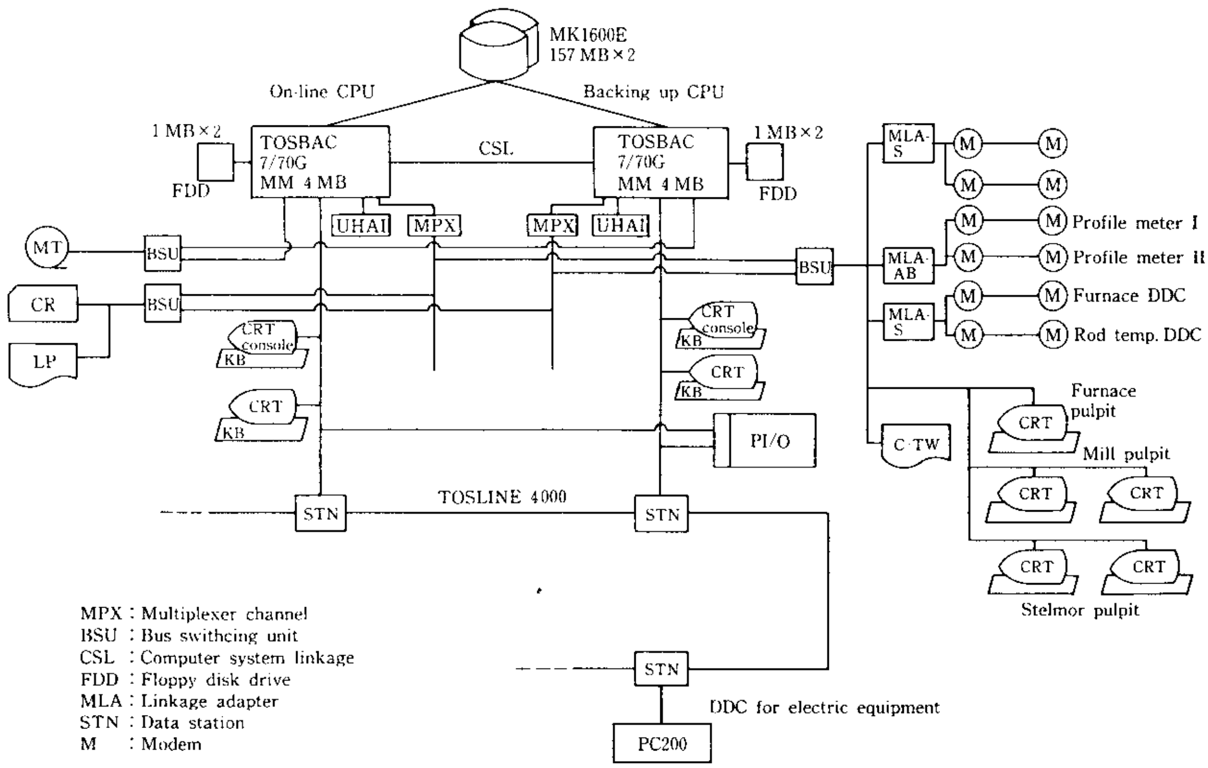


Fig. 2 Configuration of the process computer system

are performed by the process I/O controllers.

3.2 Instrumentation DDC System

For the furnace combustion controller and rod cooling temperature controller, split-type instrumentation DDC systems, which have advantages in the forming of data links with P/C and are easy to adopt advanced control technologies, are used. Configurations of these systems are shown in **Figs. 3** and **4**. Although there is no direct transfer of data between the two DDC systems, they use a common data way loop, permitting their use as mutual back-ups for major equipment, thereby improving system reliability.

3.3 Sensors

Major sensors of the new system are shown in **Fig. 5**. The rod and bar mill is provided with 21 radiation pyrometers for material. These are applied as appropriate to product type. Load cells are currently installed only on the roughing stands, though all stands are scheduled to be provided with load cells in the near future. Profile meters for both bars and wire rods are of the rotating type and give thickness outputs at every 6°. The eddy current flaw detector has been designed for some detection of seam-like linear flaws.

4 System Functions

4.1 Basic Functions

4.1.1 Data link

Among the data link functions of the process instrumentation and control system, the most important is the link between P/C and O/C. Information from O/C to P/C is mainly production instructions including rolling schedule information of a maximum 700 characters. Major information from P/C to O/C is of operation results, as shown in **Fig. 6**. Between P/C and C/C, only the actual result process data are transmitted from P/C to C/C. Between P/C and DDC systems for electrical equipment, transmission and reception of data are performed via the data way, which has transmission times of within 50 to 100 ms.

4.1.2 Tracking

Material tracking functions of the process instrumentation and control system are broadly divided into tracking for information, using sensors such as the photocell and HMD, and tracking for control in respective individual control functions. Main tracking functions for control include tracking of the positions of billets in the reheating furnace and tracking of the leading and tail ends of rods in the rod production line. The former

Table 1 Major functions of the process computer system

Process	Functions
Reheating furnace	1 Material tracking
	2 Automatic operation of the furnace entry roller tables
	3 Automatic transferring of billets in the furnace
	4 Control of extraction of billets
	5 Calculation of the temperature of billets
	6 Set up of the temperature for the furnace (future)
	7 Gathering and transmission of the actual data
	8 Automatic qualification of heated billets
Rolling line	1 Material tracking
	2 ·Set up of the revolution of the mill rolls
	·Set up of the speed and cutting length for the shears
	·Set up of the control parameter of the block mill
	·Set up of the speed of the stelmor conveyor
	·Set up of the revolution of the blowers, etc.
	3 Gathering and transmission of the product
	4 Automatic qualification of the product (based on the rolling temperature, coiling temperature, diameter, and defect)
Finishing line for coils	1 Material tracking
	2 ·Control of loading of coils to a hook
	·Control of transferring (from hook to hook) of coils
	·Control of unloading of coils from a hook
	·Control of the binding machines
	·Control of the coil scale, etc.

involves cumulative calculation of the motions of the walking beams, and the latter is precise tracking by counting pulses from the electric motors of the mill stands.

4.1.3 Simulation

In addition to the software-type simulation function of P/C, the process instrumentation and control system has a total simulator of the composition shown in **Fig.** 7, including the DDC systems for electrical equipment. This simulator is a system capable of high-speed simulation and is mainly aimed at the rolling line. For the P/C alone, nearly perfect on-line parallel-running simulation is possible using the CPU for system development.

4.2 Result Data Gathering and Quality Assurance

Result data items gathered by the new system for each product total more than 350 items. About 2/3 of these items consist of the "one data per item" type, such as in-furnace time of billets and product weight. The remainder consists of items for which plural data along the lengthwise direction of the product such as the product diameter and finishing temperature are required. The latter plural items concern temperature, roll separating force, and degree of surface flaws in the rolling line, and are obtained over the entire product length at a specified intervals of 0.2 to 1 sec, depending upon the item. These data are used in raw forms for quality assurance judgements, and after being processed, for quality control and operational control. One of the features of the quality

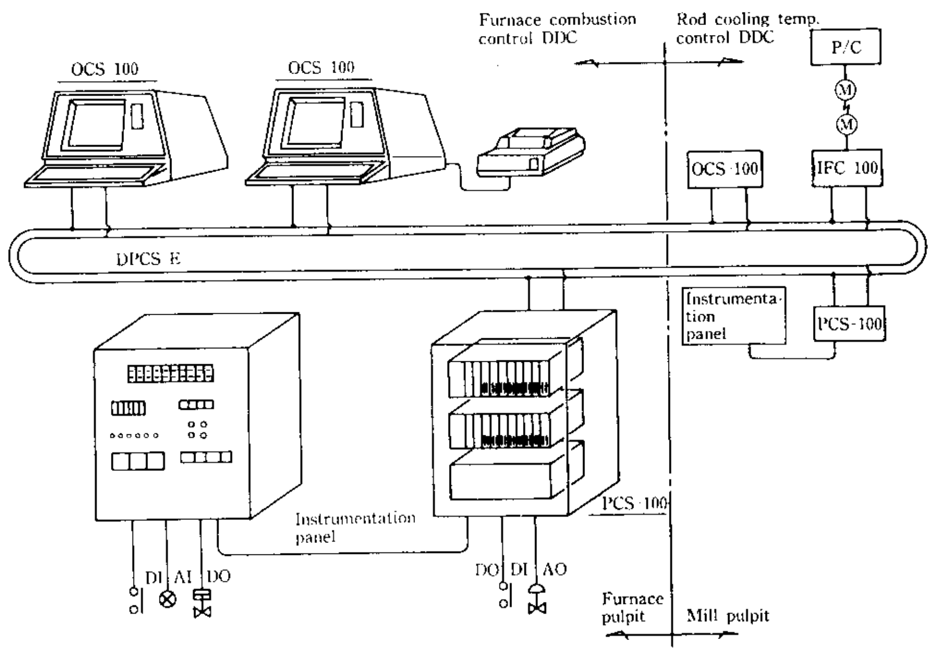


Fig. 3 Configuration of the furnace combustion control DDC system

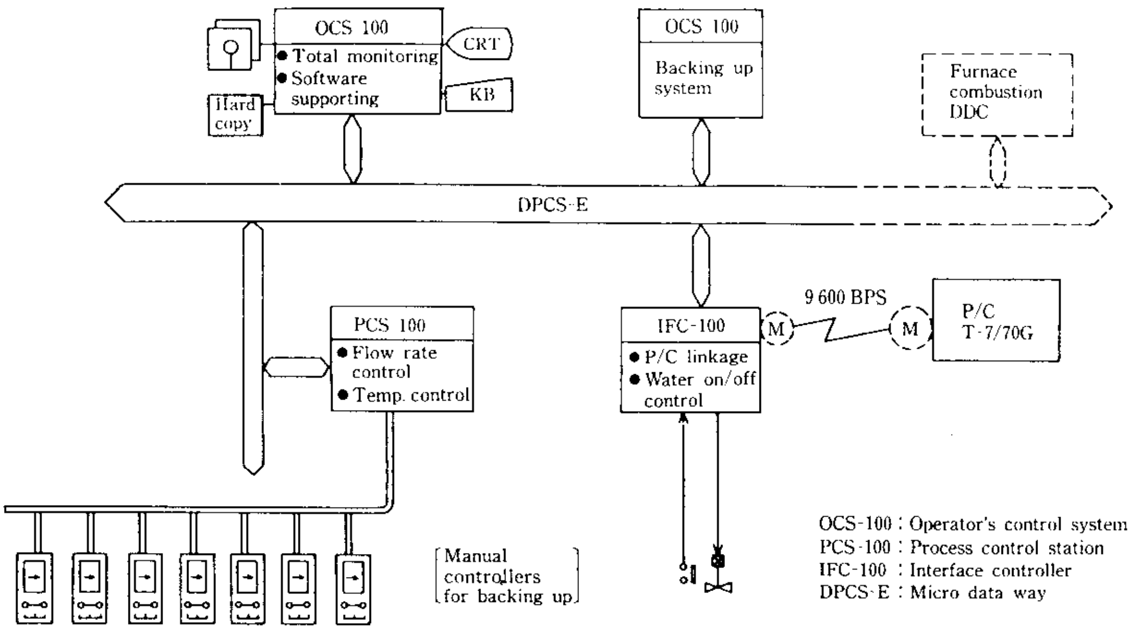
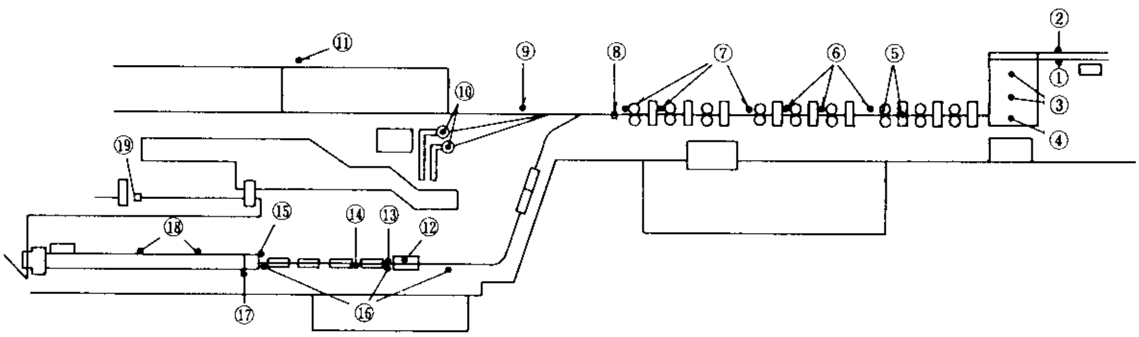


Fig. 4 Configuration of the rod cooling temperature control system



① Billet scale
② Charged billet thermometer
③ In-furnace billet pyrometers
④ Extracted billet pyrometer
⑤ Load cells
⑥ Bar line pyrometers (mono-color)
⑦ Bar line pyrometers (two-color)
⑧ Profile meter for bars
⑨ Straight bar pyrometer
⑩ BIC coiling pyrometers
⑪ Cold shear thermometer
⑫ Block mill metal thermometers
⑬ Eddy current flaw detector
⑭ Profile meter for rods
⑮ Machine vibration monitors
⑯ Rod line pyrometers
⑰ Rod coiling pyrometers
⑱ Stelmor pyrometers
⑲ Coil scale

Fig. 5 Location of the sensors

control functions of the new system is that P/C gives real-time judgement of product quality. An example of coiling temperature processing is shown in **Fig. 8**. In this example, the temperature is checked at 0.2 sec intervals.

4.3 Furnace-Vicinity Control

Furnace-vicinity control functions of the process instrumentation and control system include:

(1) Automatic transportation of billets from the furnace entry table to the furnace extraction hearth,
(2) Automatic control of furnace combustion,
(3) Calculation and control of in-furnace billet temperature,
(4) Billet extraction pace control (mill pacing).

Function (2) of the above is performed by the instrumentation DDC system, and other functions, by P/C. Functions (1), (3), and (4) are shown in detail in **Fig. 9** as FCC (Furnace computer control). Major functions of FCC are explained below.

4.3.1 Billet temperature estimation

Quality of wire rod and products is affected not only

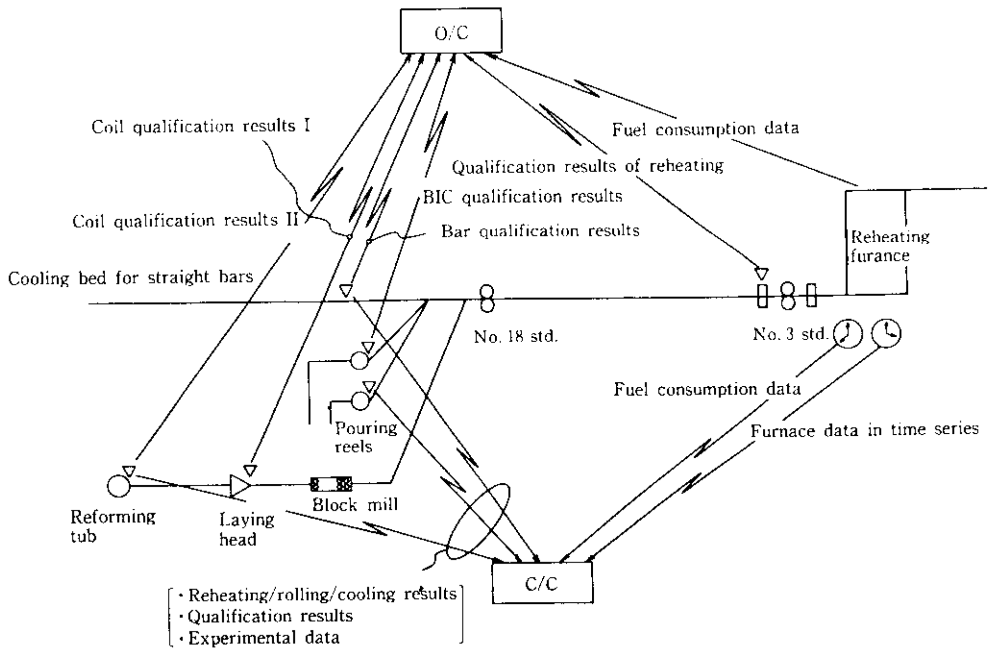


Fig. 6 Information flow of operation results

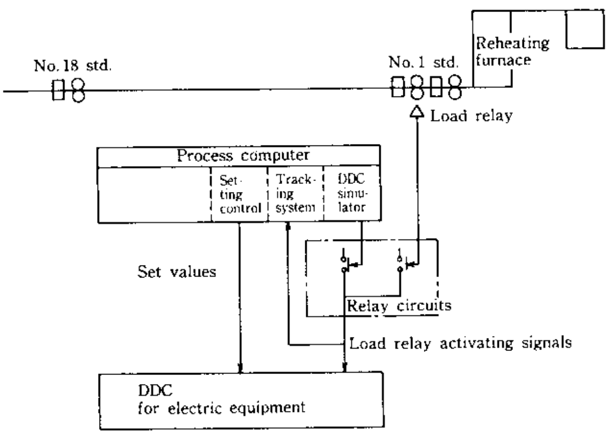


Fig. 7 Concept of the total simulation system for P/C and DDC

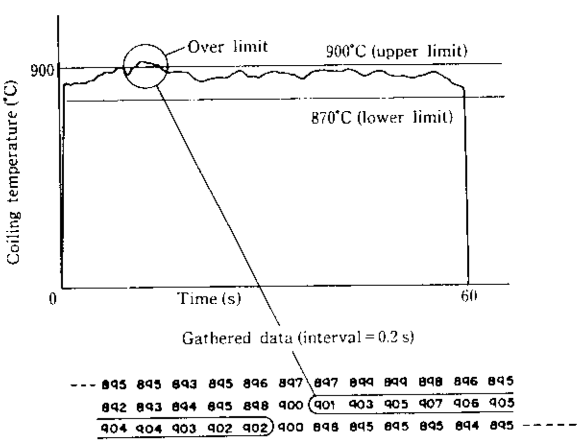


Fig. 8 Processing of the process data

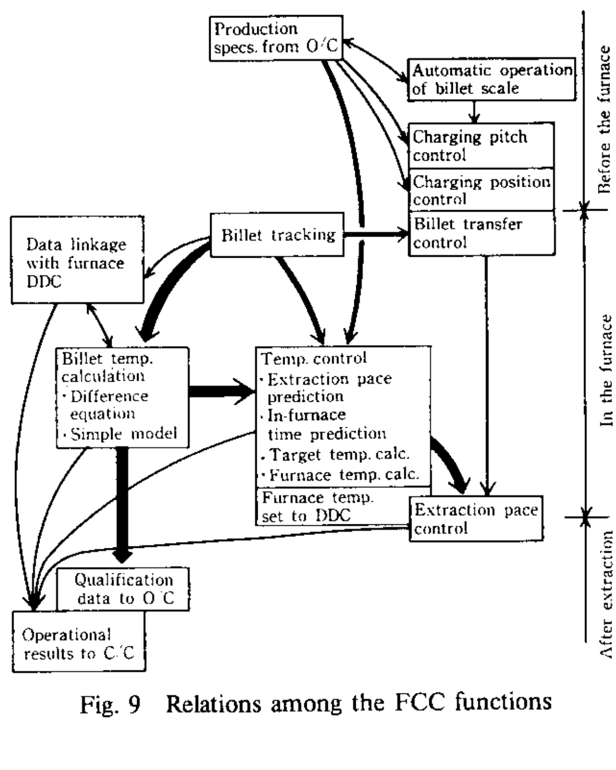


Fig. 9 Relations among the FCC functions

by temperature at extraction from the reheating furnace, but is also greatly affected by heating patterns of the billets in the furnace. Temperature control requires accurate information on the temperature of various parts of the billet. The new system divides a billet into meshes as shown in **Fig. 10**; temperature values are obtained by on-line solution of three-dimensional thermal transmission difference equations for all billets in process at each specified interval. The difference between the calculated value and the measured value is about ±40°C in the heating zone and about ±20°C at extraction temperature (**Fig. 11**). In the temperature control system shown in Fig. 9, the necessary furnace temperature is calculated on the basis of the temperature estimation; by setting the instrumentation DDC system to the calculated value, the appropriate billet heating temperature pattern is obtained. The calculated result temperatures are also compared with measurements by the billet surface pyrometers at the ceiling of the reheating furnace and checked.

4.3.2 Extraction pace control

From the wire rod and bar mill, three kinds of products, i.e., straight bars, bars-in-coil, and wire rods are shipped after being given different treatments. Even billets of the same product type vary in treatment time, depending upon specifications. Extraction pace control adjusts the balance between treatment conditions and the heating capacity of the reheating furnace. It determines the intervals of extraction from the furnace, so that maximum productive efficiency can be achieved. Depending upon the type of product, the extraction pace is classified as (1) the case in which time between two bars (bar-to-bar pitch) poses a problem, (2) the case in which time between the lead end of the preceding material and the lead end of the succeeding material (on pitch) poses a problem, and (3) the case in which time between the tail end of the material two materials previous and the lead end of the material in question (sep-up pitch) poses a problem. In each of these three cases, timing is controlled by P/C to achieve the optimum value for respective product types. There are cases in which processing capacity of processes after rolling causes bottlenecks, and those in which heating capacity of the reheating furnace itself is a bottleneck. In both cases, extraction pace control has learning and correcting functions for correcting predicted values on the basis of actual processing times of preceding material. As a result, the extraction pace control function is easily adapted to actual operation conditions. An example of improving rolling efficiency in the trial-use of this function is shown in **Fig. 12**. At the time of extraction, the process instrumentation and control system only gives signals to the operator, and the operation of the extraction ram itself is manually performed at the present stage.

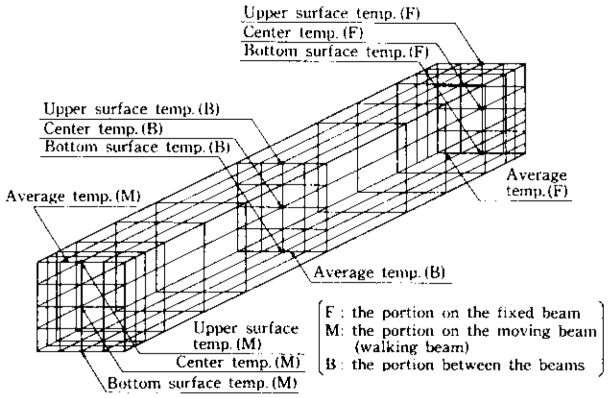


Fig. 10 Division of a billet and the points of temperature calculation

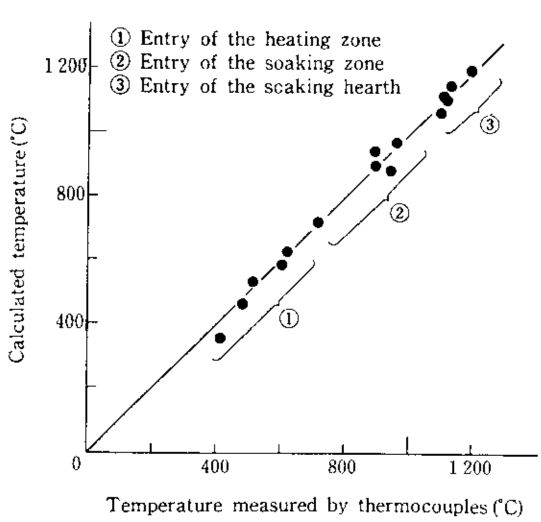


Fig. 11 Comparison between calculated and measured billet surface temperature

4.4 Automatic Operation of Rolling Facilities

The process instrumentation and control system performs automatic set-up of various facilities on the basis

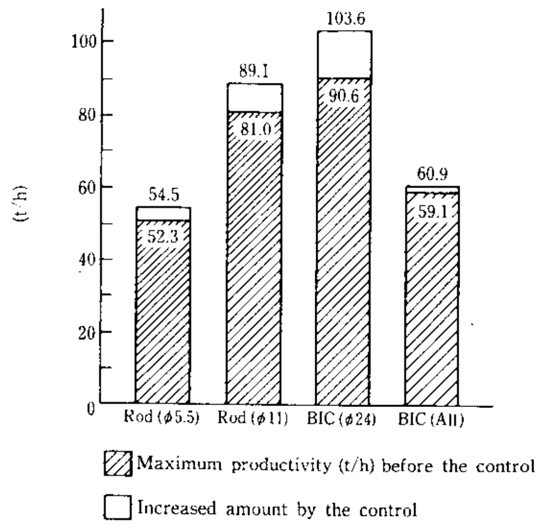


Fig. 12 Increase in tonnage per hour by extraction pace control

of the production specifications and operation conditions which are sent down from the higher-level O/C. Main set-up items are shown in Table 1. All these items are automatically set at the necessary timing for synchronization with the progress of the material, though the actual facilities are controlled mainly by the DDC systems for electrical equipment. The earlier-mentioned extraction pace control determines the extraction timing of succeeding material, taking into consideration the time required for reset-up of facilities. Set-up of the Stelmor process can be made separately for ten zones. Because of this, there is no need to widen interval between materials of different lots when set-up conditions are to be changed between lots. Tracking on the Stelmor for this function is performed by the material detectors and the integration of the speeds of various zones of the Stelmor.

4.5 Rod Cooling Control

Cooling temperature control of wire rods by water and air cooling is performed by P/C and the instrumentation DDC system shown in Fig. 4. The outline of the control system is shown in **Fig. 13**. At the two water-cooling zones on the inlet side of the rod block mill, combined use is made of feedback control by the mill inlet-side pyrometer and feed-forward control by the pyrometer following the bar mill stand No. 18. At the four water-cooling zones on the outlet side of the block mill, feedback control is effected using the coiling pyrometer under the laying head. On the Stelmor conveyor, temperature measurement at three points and wind pressure measurement at 20 points are performed. Wind pressure measurement is made at the center and edge of the 10 respective Stelmore zones. Wind pressure control is effected by the DDC functions of P/C at an accuracy of ±5 mm H_2O.

4.6 Automatic Operation of Coil Finishing Line

The outline of the coil finishing line of the rod and bar mill is shown in **Fig. 14**. While coil information is transmitted to and received from O/C, the process instrumentation and control system outputs operation instructions to the DDC system for hook conveyor driving and takes charge of automatic operations ranging from coil loading to unloading by the unloader. In addition to the transportation facilities, the finishing line has a coil scale, binding machines, and a metal tag puncher, most of which transmit and receive signals to and from P/C and share respective portions of the automatic operation functions of the finishing line. The functions of O/C, P/C, and DDC in performing the automatic operation are explained below.

(1) O/C

Coil tracking is performed by O/C on the basis of information from P/C, and information necessary for control by P/C is given by O/C at important locations. Although physical tracking of O/C are coarser than those of P/C, O/C is so composed as to ensure the most accurate information tracking.

(2) P/C

Receiving tracking signals from the DDC system, P/C carries out tracking of coils and hooks over the entire line. Every time a hook arives at a work station for loading or transferring coils, P/C receives from the DDC system a request for an operation command, and outputs an operation command in response. Upon completion of each operation, P/C transmits to O/C result information such as the number of the line used and the result of weighing the coil.

(3) DDC

While tracking all hooks in the line, and upon the arrival of a hook at a work station, the DDC system asks P/C for an operation command for the hook, and after receiving operation commands, runs the equipment. Hook number readers which are installed at important locations constitute input devices to the DDC system. The DDC system also

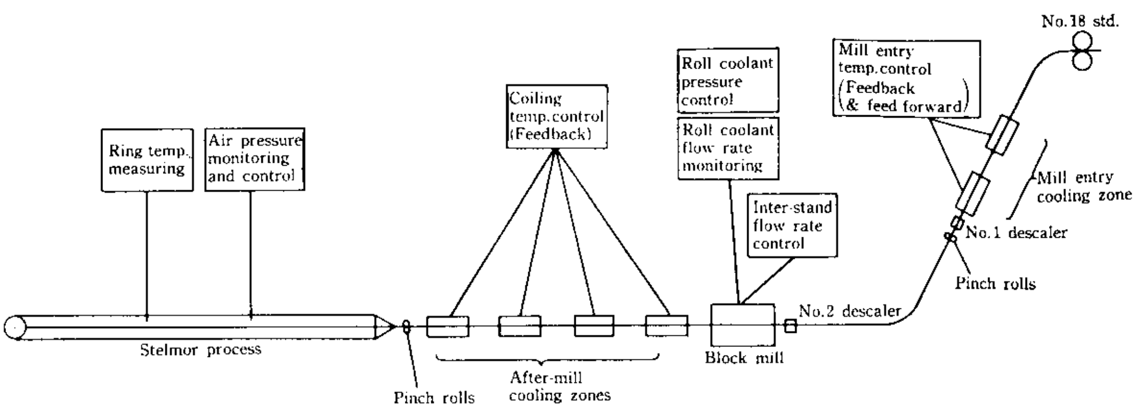


Fig. 13 Functions of the rod cooling temperature control system

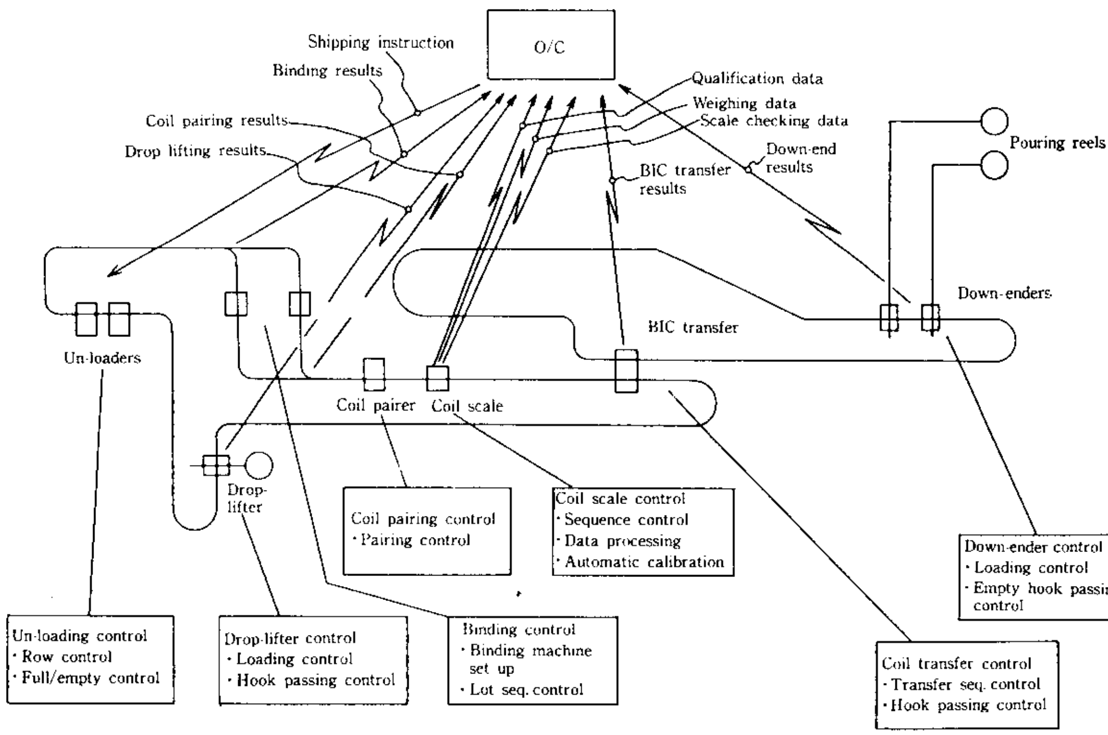


Fig. 14 Finishing line facilities for rods and bars in coil

detects whether a coil is riding on a hook or not.

5 Operation Results

The process instrumentation and control system is operating almost as planned. Major aspects of the actual operation of the system are described below.

(1) There is virtually no problem in basic functions, excepting errors occurring on very rare occasions in the P/C tracking between the reheating furnace and the reforming tub. Causes of the errors are chattering of the tracking sensors and, sometimes, extremely short material intervals. Countermeasures against the respective causes have been carried out to solve these problems.

(2) On-line judgment of quality by the result data has sometimes been markedly stricter than visual evaluation of a recording strip chart. This was because signal processing by P/C is much faster than the response of conventional chart recorders. As a result, qualification logic has been partially adjusted to yield more appropriate judgments. The data gathering function itself is working smoothly and plays a great role in operation control, gathering and processing of test data, development of process models, etc.

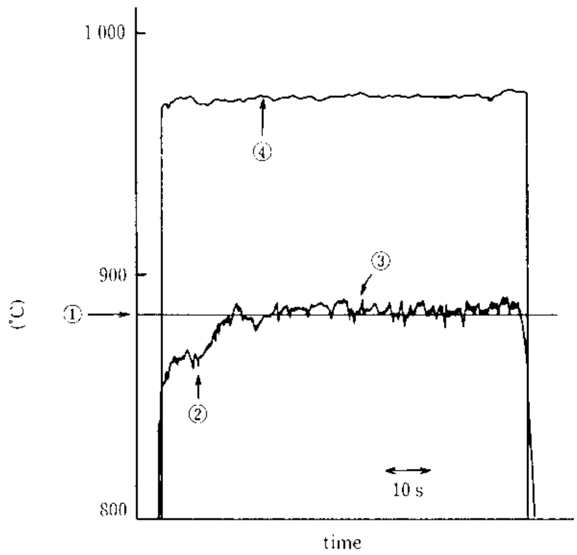
(3) Of the control functions of the reheating furnace, the calculation of actual billet temperature is functioning in a stabilized condition, and demonstrating its worth in quality analyses concerning heating. However, during a large-scale revamping of the reheating furnace, it has become necessary to re-identify the constants in the result calculation model; hence examination is now being made for standardization of this procedure. Extraction pace control for rods and bars-in-coil has produced favorable results, as shown in Fig. 12, although adjustments are being made for straight bars. Automation of furnace temperature set-up is now under development.

(4) Automatic set-up function for the rolling equipment and Stelmor is working smoothly and contributing to labor savings, reductions in the number of operation errors, and improvement in rolling efficiency.

(5) In rod cooling temperature control, satisfactory results have been obtained (**Fig. 15**). Aiming at further stabilization of this control function, P/C and DDC performance are being improved.

(6) To enhance the accuracy of tracking in the automatic operation of coil finishing, numerous improvements have been made, such as increasing the frequency of data transmission between the DDC system and P/C. As a result, stabilized operation is continuing.

(7) The entire system enjoys high reliability and satisfactory availability, but CPU load of P/C is 65–70%, which is rather high for this type of system. There-



① Aimed value of coiling temperature
② Starting point of automatic temperature control
③ Coiling temperature
④ Temperature at the entry of the cooling zones (after the mill)

Fig. 15 Example of the rod coiling temperature

fore, efforts are being made to maintain an equivalent level with all functions while at the same time adopting various CPU load reduction measures, including decreasing the frequency with which data is revised on CRT screens.

6 Conclusions

The process instrumentation and control system is an on-line system combining P/C and DDC systems. It was introduced for the first time at the wire rod and bar mill of Mizushima Works. Since the system has achieved highly-computerized operation control and information processing, it has become indispensable to mill operation. Computer control of the reheating furnace has resulted in stabilization of extraction temperatures and improvement in rolling efficiency, and the automatic operation function covering equipment from the rolling to the coil finishing facilities has permitted stabilized high-speed rod rolling.

At present some planned functions are being further developed in stages for the upgrading of the system. In this development program as well, one of the major functions of the system, the data gathering function, has become significantly useful, further demonstrating the value of the system.

To improve product quality, persistent efforts must be made. The authors are confident that this new system, together with future development of the functions, will become a powerful support for such efforts.

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