KAWASAKI STEEL TECHNICAL REPORT
No.16 (June 1987)

Instrumentation and Control System for Sinter Plants

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The body can be viewed from the next page.

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1 Introduction

The computer control systems for sinter plants at Kawasaki Steel were installed in the 1970s, at the same time with the construction of the sinter plants, and have long contributed to the stable operation of the plants with minor modifications made from time to time. The recent severe environment of the steel industry intensify the requirements for energy saving, labor saving, etc. in sintering operation, magnifying the role of the computer control systems greatly. However, these systems fell short of meeting this new situation, calling for substantial revamping. Therefore, these systems at Mizushima and Chiba Works, including the central computer systems at both Works, were totally revamped in 1982 and 1985, respectively. In these new systems, the integrated control of information total process control, and an improvement of system maintainability in the ironmaking department are aimed at. Furthermore, the unification of the types of instruments used in the instrumentation systems, adoption of the centralized process computer system, and centralization of information on the central computers were carried out. This report presents an outline and features of these new computer control systems.

* Originally published in *Kawasaki Steel Giho*, **18**(1986)2, pp. 136-144

2 Configuration of Computer Control Systems

2.1 Characteristics of Sintering Process and Roles Required of Computer Systems

The sintering process involves adding coke to mixed powder materials, such as ore and fluxes, sintering them, and supplying the sinter products as the raw material to the blast furnace. The raw materials received from the raw material yard are charged into the raw material bin and are discharged at a given blending ratio. After water addition and mixing by the mixer, the mixed raw materials are charged into the surge hopper. The sinter mix is discharged from the surge hopper onto the sintering machine, the pallet is moved, the upper surface of the sinter mix is ignited in the ignition furnace and the sinter mix is sintered through suction with a blower. The produced sinter is transported to the blast furnace.

For the stable operation of the blast furnace, the sintering process must ensure adequate production of sinter having proper quality characteristics such as chemical composition, grain size and strength. For this purpose, appropriate sensors and control models are required and are constantly being developed. Since the characteristics of sintering raw materials, such as chemical composition and grain size, have an intrinsic element to cause fluctuations, it is necessary to use statistical methods in evaluating process data. Model development is not easy because of the complex process of sintering the raw materials. However, operation models that can be put into practical use online must be established. Furthermore, the operating method for sinter plants must accommodate flexibly to the requirements for cost minimization through energy saving, etc., while meeting changes in the raw material situation, and requirements from the blast-furnace operation standpoint.

For the above-mentioned reasons, a computer system for sinter plants is required to ensure effective control of subsystems, timely supply of process information, and total cost minimization, while securing the required production and quality. Furthermore, the computer system is required to construct a data base necessary for data analysis and to supply analytical tools for this purpose.

2.2 System Configuration

The existing computer systems at both Works were revamped to meet the above-mentioned requirements and a three-level hierarchical system, aimed at improving controllability and strengthening operation control functions, was introduced at each Works which comprises a distributed control system (DCS), a process computer (P/C) system, and a central computer (C/C) system.[1-4] The concept of allotment of computer functions is shown in **Fig. 1**.

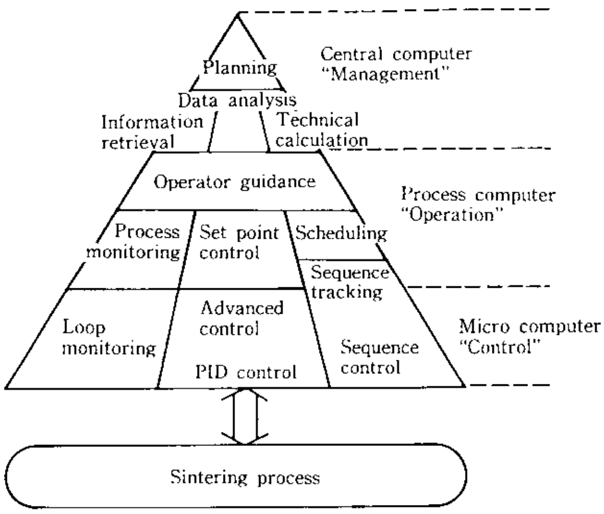

Fig. 1 Functional Hierarchy of the ironmaking computer system

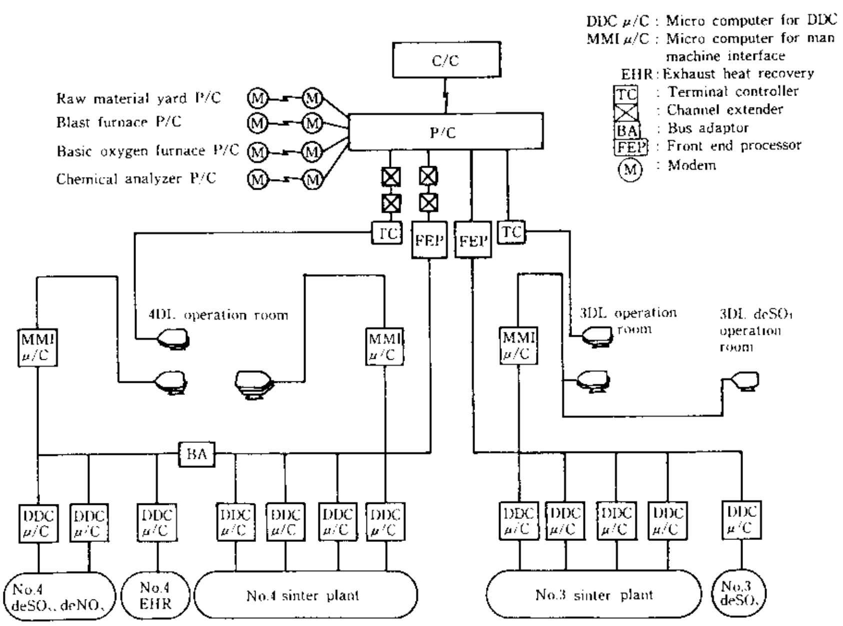

Fig. 2 New control system of sinter plant (Chiba Works)

2.2.1 DCS

The DCS is a total instrumentation control system aimed at functional enhancement and accuracy improvement and comprises duplex DDC (direct digital control) microcomputers, sensors, and actuators.[5,6] The DCS performs minor loop control and advanced control, such as raw material discharging control—a basic process operation function, based on set points from the P/C system. In addition, the DCS performs the instantaneous monitoring of the sintering process based on sensor information, such as the temperature and volume of exhaust gas.

2.2.2 P/C system

In general, process computers tend to be centralized to accomplish centralized data control and program standardization and to improve maintainability. The configurations of the computer systems for sinter plants at Chiba and Mizushima Works are shown in **Figs. 2** and 3, respectively. These two Works differ in the level of centralization. At Chiba, the information in the ironmaking district is centralized not only at the C/C level but also at the P/C level. At Mizushima, however, information at the P/C level alone is centralized, on a separate basis, for the ore bedding yard, sinter plants and blast furnaces.

The P/C system increases the efficiency of the whole sinter plant according to operation plans determined by the C/C. For example, SPC (set point control) for setting raw material blending ratios, calculation of operation indexes and comprehensive operation guide system are the functions of the P/C system.

2.2.3 C/C system

The C/C system is at a higher hierarchical level than the process instrumentation and control system composed of the DCS and P/C system and is connected to process computers via high-speed online data transmission lines. The C/C system prepares data bases, based on the data from the process computers, and determines optimum operation plans from wide viewpoint covering space and time. The functions of the C/C system include the formulation of blending plans based on production plans and raw material condition, output of reports to compare results and plans, and statistical analysis of large amounts of data.

3 Instrumentation Equipment for Sinter Plants

3.1 Basic Instrumentation for Sinter Plants

The basic functions of the instrumentation control system are illustrated in **Fig. 4** and listed in **Table 1**. The sintering equipment is broadly composed of four systems. An outline of each system and main control functions are described in the following.

3.1.1 Raw material system

The operation of the raw material system involves the raw material feed from the raw material bins and the level control in the surge hopper. The chemical compo-

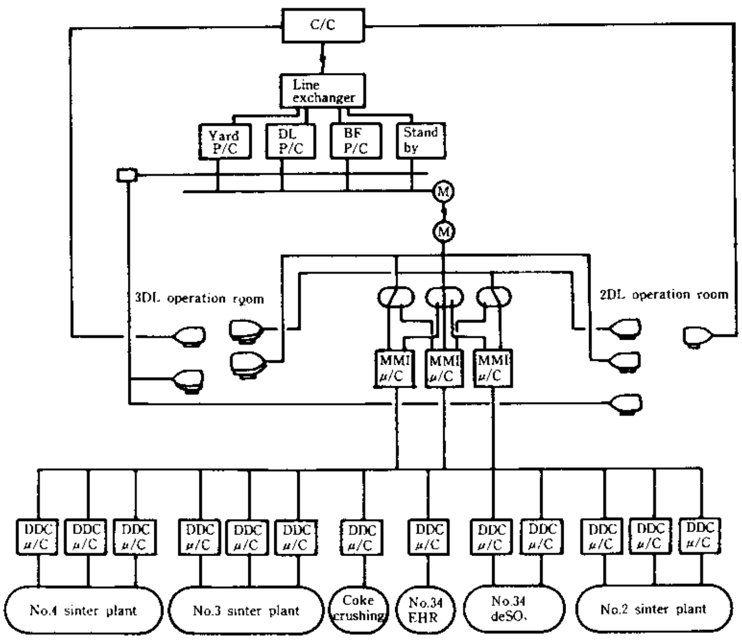

Fig. 3 New control system of sinter plant (Mizushima Works)

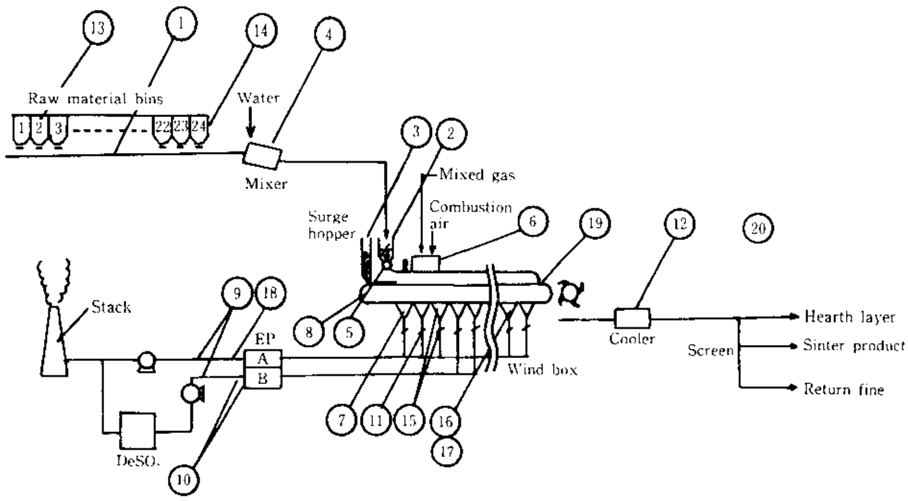

Fig. 4 Functions of the control system of No. 3 sintering plant at Chiba Works (①~⑳ of DDC functions are shown in Table 1)

Table 1 DDC fuctions (Chiba Works)

1	Raw material feed control
2	Level control of surge hopper
3	Level control of hearth layer hopper
4	Moisture control of raw material mix
5	Bed height control
6	Temperature control of ignition apparatus
7	Waste gas pressure control of wind box under ignition apparatus
8	Strand speed control
9	Waste gas pressure control of main duct
10	Waste gas temperature control of electrostatic precipitator
11	Opening control of wind box damper
12	Cooler bed height control
13	Automatic calibration of weighers
14	Level sounding of return fine bins
15	Measurement of permeability of sinter bed
16	Measurement of wind boxes waste gas temperature
17	Measurement of waste gas temperature under pallet in direction of the strand
18	Analysis of waste gas (CO, CO_2, O_2, N_2)
19	Monitoring system of the bed at the discharge side of the strand
20	Automatic sampler of the product

sition of sinter is almost determined by the control of this system.

The control of raw material feed, added water volume, surge hopper material level, etc., is carried out.[7]

(1) Raw Material Feed Control

Amounts of materials to be blended are determined, based on the total amount of materials transported and blending ratios set for each raw material bin, and constant feed control is performed. In changing blending ratio settings among bins, the starting time of change is staggered for each bin by tracking the raw materials on the collecting conveyor so as to minimize variations in the mixed raw materials. The total amount of raw materials used in this control is determined by the level control of the surge hopper described below. Results of raw material feed are used as input values for the level control of the surge hopper and both are closely related.

(2) Level Control of Surge Hopper

The structure of the surge hopper level control system is schematically shown in **Fig. 5**. Compared to other control systems, this system has longer time lags and more disturbance factors. When the raw material level in the surge hopper varies due to a change in production, etc., a change in the amount to be fed from the surge hopper found from the strand speed and bed height is fed forward to the raw material feed control system and, at the same time, a change in the level detected by load cell is also fed back to the raw material feed control system. The feed-forward control works constantly, while the feedback control works to control the delay time that occurs during the flow of the raw materials from the raw material bins to the surge hopper. **Figure 6** compares the hopper level control between the conventional and the improved methods in the new DDC system. It is apparent that the amplitude of deflection decreases in the new level control system.

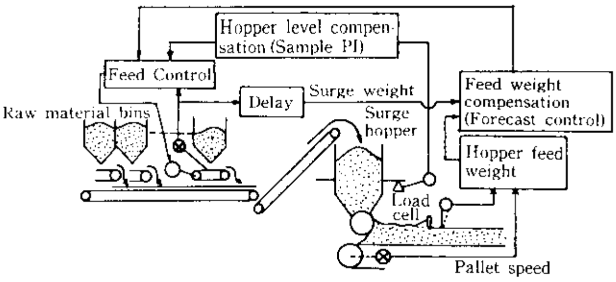

Fig. 5 Surge hopper level control (Mizushima Works)

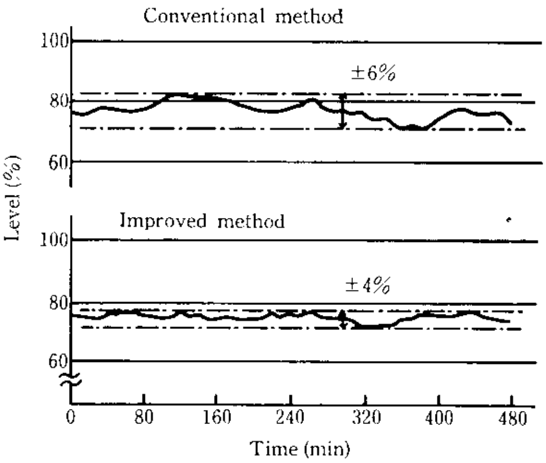

Fig. 6 Result of hopper level control (Mizushima Works)

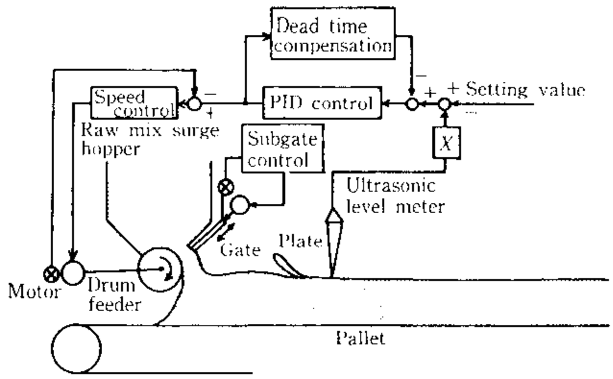

Fig. 7 Bed height control (Chiba Works)

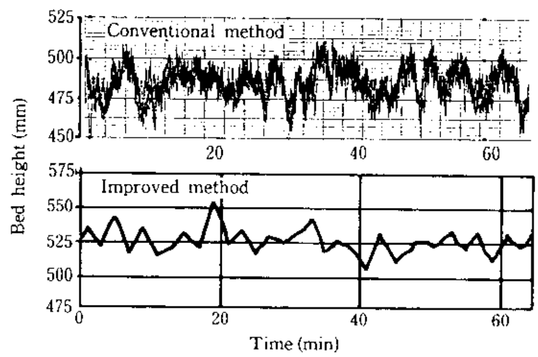

Fig. 8 Result of bed height control (Chiba Works)

3.1.2 Sintering machine proper

This system controls the process from the mixed raw material feed from the surge hopper to the entry side of the cooler. Production, the shatter index, etc., are determined by changing the sintering machine speed and bed height. The control includes those of the bed height, ignition furnace combustion, strand speed, etc.

(1) Bed Height Control

The structure of the bed height control system is schematically shown in **Fig. 7**. After the surface of the raw material mix fed from the surge hopper is leveled using a leveling plate, the bed height from the grate bar is continuously measured with an ultrasonic level gauge. Results of the measurement are fed back to the feed control system of surge hopper. In this instance, the delay time between the surge hopper and ultrasonic level gauge is compensated for (Smith compensation). The feed control of the surge hopper is conducted by two methods; one by a drum feeder and the other by a main gate. The overall level control, using average values obtained from measurements of ultrasonic level gauges installed in the width direction, is performed by the drum feeder, and the level control in the width direction of pallet, using each level gauge installed in the width direction, is performed by the subgates distributed in the width direction. It is apparent from **Fig. 8** that fluctuations in bed height measurements decreased from ±30 mm to ±20 mm, owing to the adoption of the ultrasonic level gauges and an improvement in the bed height control accuracy.

(2) Ignition Furnace Combustion Control

An ignition furnace which saves by far more energy than under the conventional combustion method is adopted. This combustion control involves measuring the surface temperature of the raw mix with radiation pyrometers and feeding results back to the mixed gas (blast furnace gas and coke oven gas) flow rate control system. In this case, cross limit check function is added to the control of air/gas ratio to increase stability by eliminating the lack of oxygen.

3.1.3 Sinter product line

The point in measurement of this system, extending from the cooler proper to the entry side of the raw material bins of blast furnace, is the analysis of the product. The results of this analysis are fed back to the above-mentioned control systems of the raw material system and sintering machine proper.

Only the number of revolutions of the cooler is controlled. Weighers for the bed ore, return fines, and the product are installed to measure the yield. Other functions are for quality control; automatic analyzers for the strength and size of the product and the FeO content of the product are installed.

3.1.4 Waste gas line

The waste gas system extends from the wind box of the sintering machine to the stack. The wind box damper, main waste gas pressure, etc., are controlled. This system has many measuring points important for operation. The pressure and wind volume are important data necessary for knowing the permeability of the sinter mix. Furthermore, the wind leg temperature distribution in the travel direction of the pallet provides important data for knowing the combustion condition of the sinter mix on the sintering machine. And especially, the temperature on the discharge side provides data indispensable for grasping the firing point of sinter. For this purpose, thermocouples for measuring the firing point more accurately are installed at short intervals immediately below the pallet on the discharge side.

3.2 Special Sensors

3.2.1 Infrared moisture meters

In sintering operation, the moisture of the raw materials is a very important measurement item. Especially, moisture values of the sinter mix must be controlled accurately because they influence the permeability of the sinter mix on the pallet. Infrared moisture meters are used to continuously measure the moisture of this sinter mix.

The infrared moisture meter utilizes the phenomenon that infrared rays of specific wavelength are absorbed by moisture. In general, the values measured by an infrared moisture meter are affected by the color and grain size of the object of measurement. However, in the infrared moisture meters used for the measurement of the moisture of the sinter mix, the wavelength of infrared rays used for measurement is optimally set; therefore there is no problem in measurement even if the properties of the raw materials to be blended change. **Figure 9** shows results of moisture control of the sinter mix, using the infrared moisture meters. Operation can be carried out by constantly keeping stable moisture values, even if changes in production rate take place. Moreover, the infrared moisture meters are used also for the measurement of the moisture of limestone and the amount of limestone fed is corrected using measured values.

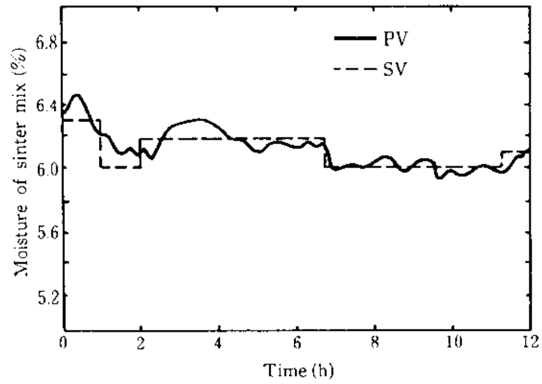

Fig. 9 Result of moisture control (Mizushima Works)

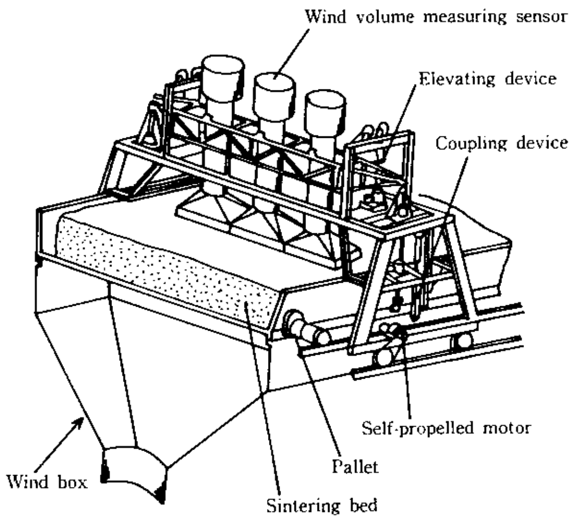

Fig. 10 Configuration of wind volume distribution measuring device (Mizushima Works)

3.2.2 Wind volume distribution measuring device

A device[8] for measuring the distribution of the wind volume through the sinter bed in the travel direction of the pallet is shown in **Fig. 10**. In this device, cylinders for measurement are placed on the surface of the sinter bed and the wind volume that passes through each cylinder is measured with a hot-wire anemometer. After the measuring cylinders are placed on the surface, the entire device is connected to the pallet and moves together with the pallet to the discharge end. The wind volume distribution is found by continuously measuring the wind volume during the travel.

Measurement data are processed by the C/C in real time and are outputted in the form of wind volume patterns shown in **Fig. 11**. At the same time, the shape of the red heat zone in the sinter bed is estimated from the pattern by using a mathematical model.

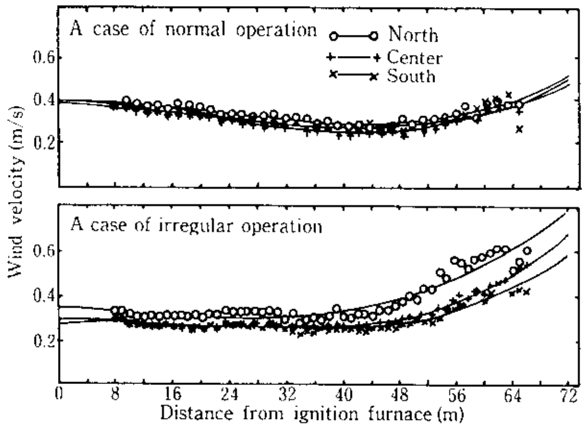

Fig. 11 Display of wind velocity distribution (Mizushima Works)

3.2.3 Heat pattern sensor

A device[9] for measuring changes in the temperature in the sinter bed is shown in **Fig. 12**. This device is equipped with a special grate bar for the temperature measurement on the pallet and measures the temperature in the bed, using a thermocouple installed to the grate bar. Since the grate bar moves together with the pallet, a radio apparatus is installed on the side of the pallet and temperature signals from the thermocouple are transmitted by FM to the ground. Because the thermocouple is embedded in the sinter bed during measurement, it is subjected to mechanical impact during sinter discharge. Therefore, a drive is provided to protect the thermocouple by retracting it into the grate bar before sinter discharge.

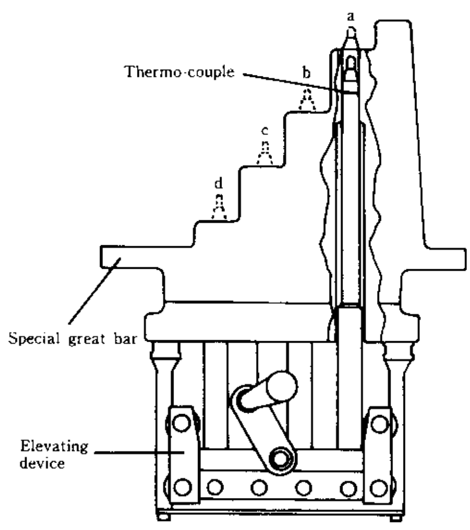

Fig. 12 Configuration of heat pattern sensor (Mizushima Works)

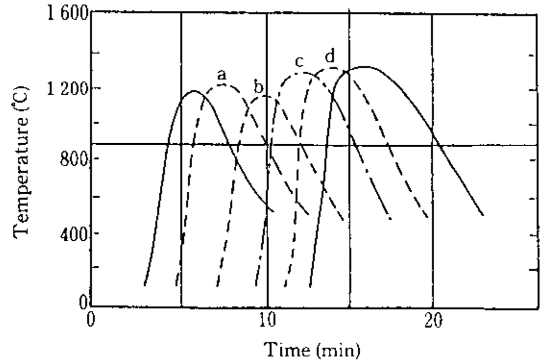

Fig. 13 Display of heat pattern (Mizushima Works)

Measurement data, along with the wind volume distribution, are processed by the C/C in real time and are outputted in the form of heat pattern shown in **Fig. 13**.

3.2.4 Discharge end monitoring device

This device catches sight of the section of sinter bed just before sinter falls down, with an ITV installed at the discharge end, and prepares an image divided into five parts in the width direction of the pallet. Based on this image, the heating zone ratio (HZR), which represents the area ratio of various red heat zones of sinter bed, is calculated every one second using a computing element in the device. The HZR is calculated by converting luminance data into 12-level binary values. Measurement data for each pallet are transmitted to the P/C at the same time with a pallet counter and are stored in a file. The data can be displayed by time series and for each pallet.

3.3 Equipment Condition Diagnosis

Almost all units of instrumentation equipment so far installed have been used for controlling and monitoring processes. However, requirements for instrumentation techniques in equipment condition diagnosis have increased due to the obsolescence of equipment, labor-saving, rationalization of spare parts, etc. Equipment condition diagnosis techniques being carried out are described in the following.

3.3.1 Check for equipment abnormalities by load currents

The relationship between the volume of transportation by the belt conveyor and the load current is shown in **Fig. 14**. The relationship between the two is expressed by a linear expression. However, when the belt shifts from the center, the load current increases even with the same weight, as shown in Fig. 14. An abnomality in the belt is found by detecting this. Furthermore, it is possible to detect an opening between pallets, deflection of the pallent in the width direction, etc., due to the load

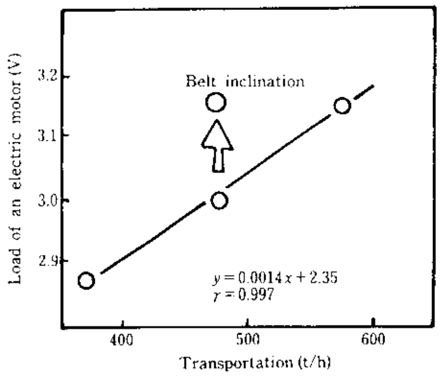

Fig. 14 Transportation and load of an electric motor (Chiba Works)

current of the driving motor for the pallets. At present, load currents are inputted to the P/C via the DCS and processing for judgment is carried out.

3.3.2 Measurement of wind leakage

The waste gas from the sintering machine is discharged by the blower of main exhauster through the pallet, wind box, and electrostatic precipitator. In some cases, the wind leakage during this process may exceed 30%. Wind leakage brings about many disadvantages, such as a decrease in yield, nonuniform product quality, and increase in power consumption. For this reason, the oxygen concentration is measured using O_2 analyzers of the same type, installed before and after each leak place, in order to measure the wind leakage. **Figure 15** shows results of wind leakage measured in the travel direction of the pallet. A 1.8% difference in the oxygen concentration is observed between in the wind box just under the pallet, which is little affected by wind leakage, and in the wind leg which is affected by it. This difference is due to the effect of wind leakage and is translated into 16.8% as wind leakage rate.

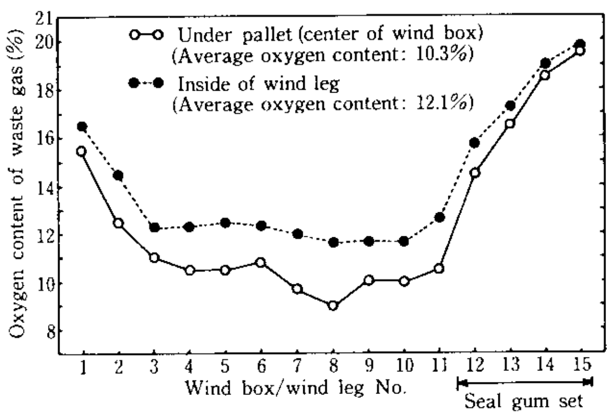

Fig. 15 Result of leak air measurement (Chiba Works)

4 Functions of Process Computer

4.1 Information Gathering and Supply of Operation Information

Process evaluation by indexes calculated, based on the process data gathered from the DCS, is important for process monitoring. Indexes calculated by the process computer include the burn-through point (BTP), that indicates the point on the sintering machine where sintering is completed in the height direction and that is important for controlling the pallet speed, the Japanese permeability unit (JPU) and resistance permeability (RP) important for monitoring the permeability of the sinter mix, the ununiformed sinter index (USI) for monitoring the nonuniform sintering condition on the sintering machines. Definitions of these indexes are shown in the following.

$$\mathrm{BTP} = f^{-1}[\max\{f(x)\}] \quad \cdots\cdots (1)$$

x: Position in the travel direction of pallet
f: Quadratic function to be determined by positions of 3 points in the travel direction of pallet and temperatures at these 3 points

$$\mathrm{JPU} = \frac{A}{B} \times \left(\frac{C}{D}\right)^{0.6} \quad \cdots\cdots (2)$$

A: Exhaust volume
B: Suction area
C: Bed height
D: Exhaust pressure

$$\mathrm{RP} = \frac{E}{F} \quad \cdots\cdots (3)$$

E: Wind box pressure
F: Wind box flow rate

$$\mathrm{USI} = \left(\sum_{i=1}^{n} (T_A - T_i)^2\right)^{1/2} \times \frac{1}{nT_A} \quad \cdots\cdots (4)$$

$$T_A = \sum_{i=1}^{n} T_i$$

$T_i (i = 1, 2, \cdots, n)$: Temperature in the width direction of pallet

Furthermore, the wind volume in each wind box is gathered as data for making sure of the sintering process. In addition, a special pallet with embedded thermometers is installed and data on heat patterns in the sinter bed experimentally measured are gathered. The heat retention index, cooling index, flame front speed (FFS), and flame behind speed (FBS) are calculated, filed and are transmitted to the central computer. The C/C stores the heat pattern data in an experimental data base and filed in a manner that permits analysis. The HZR (see 3.2.4.) is collected for each pallet from the DCS so that characteristics of pallets can be monitored. Furthermore, to prevent the grain size segregation of the sintering raw materials, it is necessary to keep the level in the raw material bins at a certain level or above. For this purpose, data on the level in the raw materials bin and tripper position are gathered through the linkage with the process computer for the yard and the level and charging condition are monitored. Moreover, through the linkage with the process computer of analysis center, the sinter plant P/C gathers analytical values of products and gives operators guidance.

The function of operation information supply at Chiba Works is described in the following. In order for the operator to evaluate process data easily, the P/C is provided with a general-purpose CRT screen to display trends, profiles, histograms and scatter diagrams. These data can be graphically displayed merely by entering data tag names. **Photo 1** shows the distribution of exhaust pressure as an example of histogram. Also, a special screen for general process monitoring is provided. With this special screen, it is possible to have a grasp of overall information on the raw material line, sintering line, etc. Thus, this information is very effective in operation. **Photo 2** shows an example of display of the blending hopper condition. This screen is also effective in causing the operator to grasp the overall condition of the blending hopper.

When automatic set point change by model is conducted in process computer, the manual intervention by the operator is indispensable. In this case, the operator uses two screens provided by the P/C as standard software. One displays information on single process data sufficient for process control, such as process data and set points. The other displays information on multiple process data. Moreover, for the ease of use, setting from a special screen is also possible. Other operator services include the printing of daily reports, which serve as quick reports and are used to ascertain whether operation has been conducted as planned. The daily reports are divided into summary operation results, 30-min operation records, quality log sheets, and records of setting changes. Furthermore, the transition of operation of the day can be outputted as a report and the operator can incorporate the result in operation.

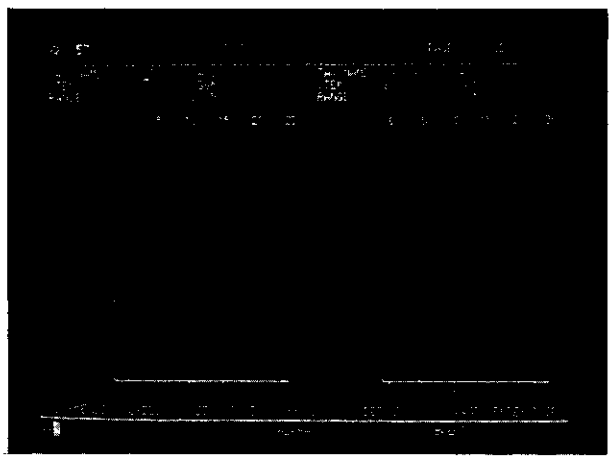

Photo 1 An example of histogram (Chiba Works)

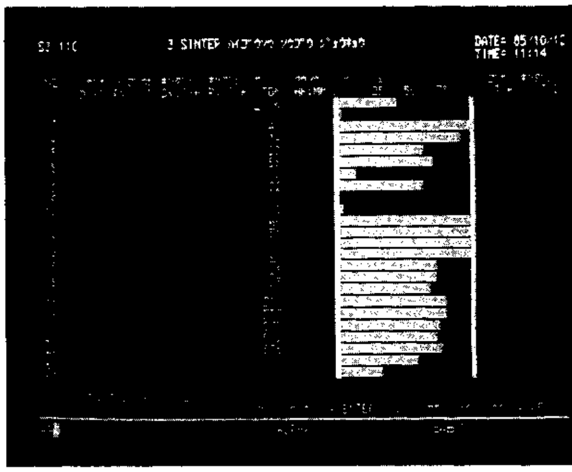

Photo 2 A screen of the blending hopper condition (Chiba Works)

4.2 Process Control

Another important function of the sintering P/C is process control. PID control and advanced control, such as feed control and Smith compensation, can be sufficiently performed by the DCS. Howeveer, it is difficult to control multi-variable process by using DCS. In this case, the P/C is used. At Kawasaki Steel, a process control system called the operation guide system (OGS)[10, 11, 12] is installed; it is performed by the P/C.

The OGS controls the burning process in the sintering process so as to reduce production costs, such as unit coke consumption, while keeping the productivity and quality of sinter at target values. The process data used for the OGS are shown in **Fig. 16**. In this figure, the controlled variables are productivity, product quality, unit coke consumption, etc, and the maniplulated variables are coke ratio, strand speed, charged density and moisture of sinter mix.

The basic flow of the OGS is shown in **Fig. 17**. The contents of each step are as follows:

(a) Judgment on Process
The process condition is judged by comparing data well representing the process condition, such as exhaust gas pressure and BTP, with their standard values.

(b) Judgement on Productivity and Quality
Whether productivity and quality meet the target values is judged by comparing productivity and quality data such as SI, with their target values. This

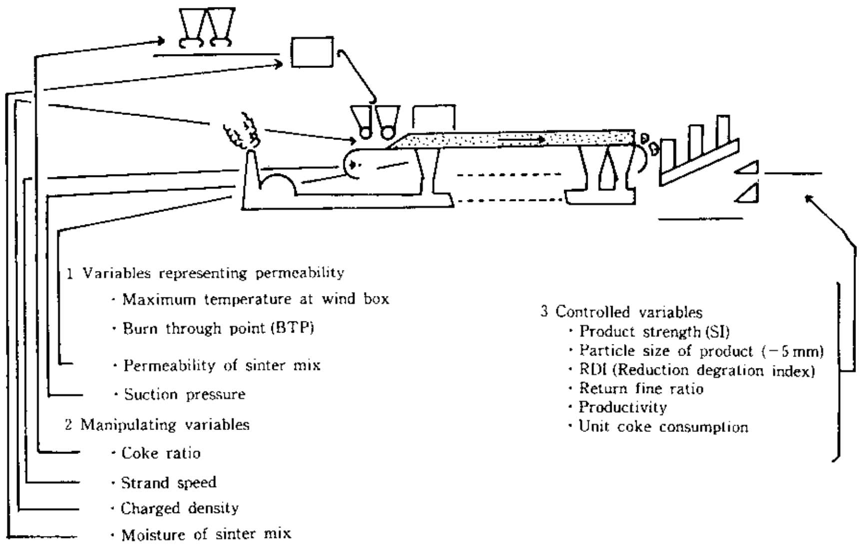

Fig. 16 Process data to be used for the OGS (Mizushima Works)

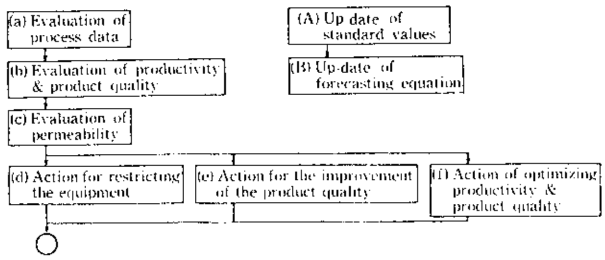

Fig. 17 Flow of the basic functions of the OGS (Mizushima Works)

judgment corresponds to the checking of deviation of the controlled variables from their settings.

(c) Judgment on Permeability

The permeability of the whole pallet is the most important index for sintering operation. This permeability is judged from the results of the judgment on the process data formed in (a) above. Only the present condition is not judged, but future possible changes in permeability are also taken into consideration. For this purpose, the following prediction equation is used:

$$y_i(s) = \sum_{k=1}^{l} a_{k_i} y_i(s-k) + \sum_{k=1}^{m} b_k x(s-k) \cdot \cdot (5)$$

$y_i(s)$: Predicted value of data i

y_1: Main exhaust pressure

y_2: Maximum temperature in wind box

y_3: BTP

$y_i(s-k)$: Time series data of data i

$x(s-k)$: Time series data of RP

a_{k_i}: Coefficients concerning data i $(k = 1, 2, \ldots, l)$

b_k: Coefficients concerning x $(k = 1, 2, \ldots, m)$

s: Time

i: Division of data

l: Order of regression equation

m: Order of regression equation

The prediction equation is determined by identifying the process with an autoregressive model.

(d)–(f) Actions

The actions (d) and (e) are emergency actions to be taken when the process is in such a condition as may cause damage to equipment and when product quality has worsened extremely. Whether these actions should be taken is judged based on the results of (a) and (b) above.

The action (f) is taken to cause productivity to meet the target, keep quality at an optimum level, and reduce the unit coke consumption. This logic is the key function of the OGS. In this logic, based on the results of judgment of heat level and permeability formed from the productivity and the return fine ratio obtained in (a), (b) and (c), manipulating variables and their action volumes are determined concerning the coke ratio, strand speed, charged density and moisture of sinter mix by the three-dimensional matrix shown in **Fig. 18**.

In addition to the functions (a) to (f), the OGS has the function of automatic updating standard values and prediction equations used for judgment to optimum values depending on the process condition.

The functions of the OGS are included in the P/C and set point control is performed in DCS using action volumes determined in P/C. The process is automatically controlled without the intervention by the operator. An example of change in productivity by the OGS is

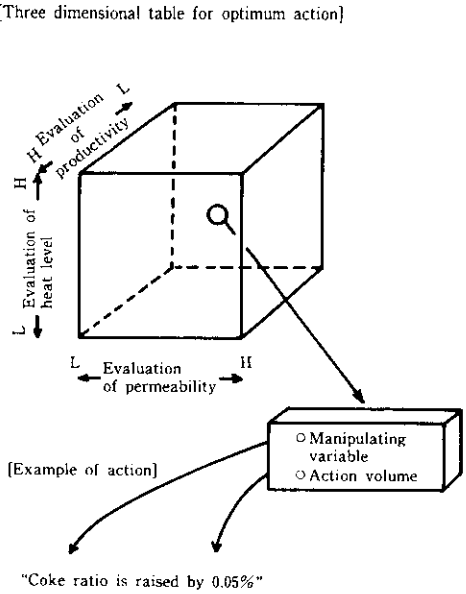

Fig. 18 Action for optimizing the productivity and product quality (Mizushima Works)

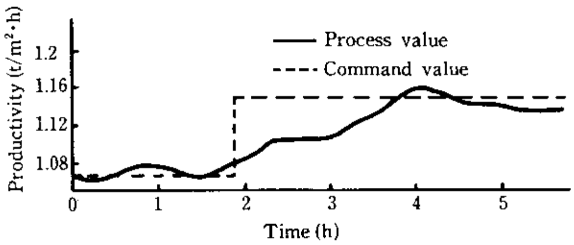

Fig. 19 Response to change in productivity (Mizushima Works)

shown in **Fig. 19**.

At present, more than 80% of all sintering operations is conducted by automatic operation using the OGS. All that is required of the operator to do is only to set the production target and the P/C performs all other operations, such as strand speed control and determination of the coke ratio.

5 Conclusions

The revamping of computer control systems for sinter plants, which has recently been carried out at Kawasaki Steel, was described, For the DCS, development of sensors was mainly described which is necessary for stable raw material supply and grasping the sintering process. Concerning the P/C, importance was attached to the operation prediction and guidance system based on the processing of various kinds of information for the operator for the purpose of opmizing operation. These computer control systems contributes greatly not only to saving in energy and labor in the sintering operation, but to the improvement of the level of operation control. The authors intend to further improve the level of computer control systems and to aim at pursuing the total merits of the ironmaking process, not restricted to the optimization of the sintering process alone, but in close cooperation with the blast furnace process.

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