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Computer Control System for Coal Yard Operation at Mizushima Works

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The body can be viewed from the next page.

Computer Control System for Coal Yard Operation at Mizushima Works*

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(1) Simplification of planning the blending composition using models of coal quality prediction, coke strength prediction and coal crushing grain programming,
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1 Introduction

The Mizushima Works of Kawasaki Steel, as part of its systems designing efforts of coke-making, has promoted the introduction of a computer system as a measure to improve techniques for quality and operation control and to reduce labor costs in the coal preparation process and coke transportation processes. In 1980, process computers were introduced in the coal preparation process, and in 1983, the control rooms of the two processes were integrated and the system was upgraded. In this systems design project, importance was attached to the organic linkage of quality information and operation information and to the improvement of the quality of control work in the control room through utilization of this information. This report presents the functions of the software of the system, referring to typical examples.

2 Outline of the System

An outline of the computer system of the entire coke-making department is shown in **Fig. 1.** Functionally, this system is composed of an operation control system for the coal preparation process and the coke transportation process, a coke-oven combustion control system, and a personal computer network system. In the systems designing of the coal preparation process and coke transportation process described in this paper, consideration was given to the following points in terms of the one-man operation of the central control room:

(1) The approximately 200 monitoring instruments previously used were substantially reduced in number and replaced by a process condition monitoring system using CRTs.
(2) The selection switch system was replaced by a route number setting system using sequencers with respect to operations such as the start and stop of conveyors and crushers.
(3) Some of daily scheduling jobs and operation condition setting jobs require careful judgment and complex handling. These jobs were standardized and incorporated in the computer system.
(4) The greater part of document preparation work was automated.

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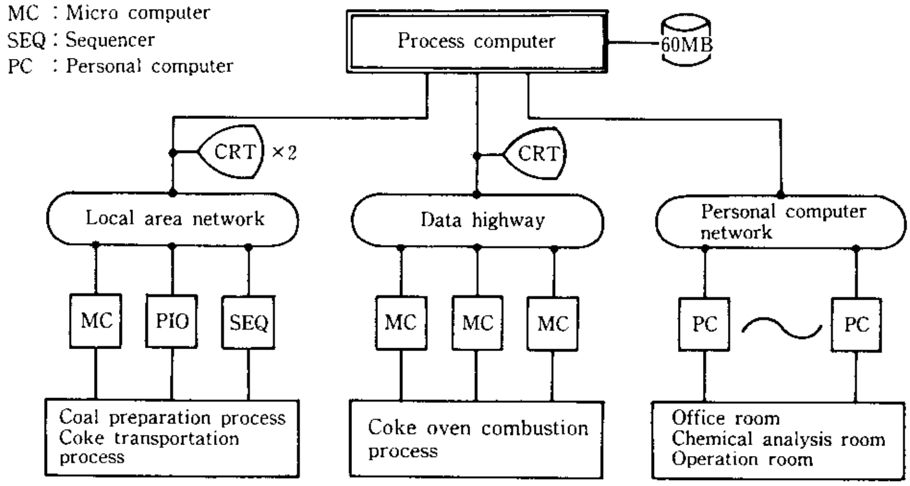


Fig. 1 Outline of the computer system in the coke-making department at Mizushima Works

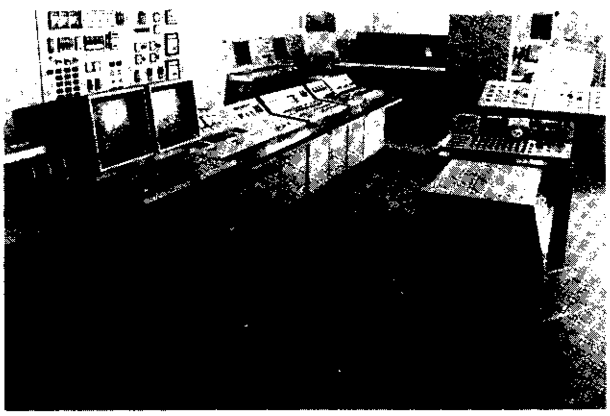


Photo 1 Central control room

(5) Two dedicated CRTs were installed and planned in such a way that all tasks can now be initiated at either of the two CRTs. Furthermore, the system was planned so that all tasks can, as a rule, be started by single finger motions on CRT keys and the access time from the request for a start to display is kept within several seconds. In addition, screens requiring constant monitoring were planned in such a way that data displayed on them is automatically updated every 5 or 10 seconds.

Photo 1 shows a general view of the central control room.

3 Quality Control Function

3.1 Evaluation of Coking Coal Quality

Table 1 gives main information items concerning coal quality which are important for quality control. This data is obtained by calculation from manually entered analytical values of coal received. The ϕ-value is an especially important factor for estimating coke strength and is theoretically expressed as a function of values of physical properties of coal (linear shrinkage coefficient, Young's modulus, and Poisson's ratio) that affect the thermal stress of semi-coke. In the actual system, the mean maximum reflectance $\bar{R}_0$ of vitrinite in oil and the content TR of total reactives are estimated from Eqs. (1) and (2), and the ϕ-value is calculated from Eq. (3).[1)]

Table 1 Received coal analysis

Analysis item		Use
Proximate analysis	TW: Total moisture VM: Volatile matter Ash	Prediction of coal ash, TS, and P_2O_5
Ultimate analysis	TS : Total sulfer P_2O_5: Phosphorus pentaoxide	
Sieve analysis	P_0: Plus 3 mm percentage n_0: Rosin-Rammler's distribution constant	Size monitoring system in coal crushing
Grindability	HGI: Hardgrove grindability index	
Plasticity	MF: Common logarithm of Gieseler plastometer maximum fluidity	Coke strength prediction
Coal rank	ϕ: Calculated parameter using Eq. (3)	

$$\bar{R}_0 = f(\mathrm{VM_{daf}}, \mathrm{MF}) \quad \cdots\cdots (1)$$

$$\mathrm{TR} = g(\mathrm{VM_{daf}}, \mathrm{MF}) \quad \cdots\cdots (2)$$

$\mathrm{VM_{daf}}$: Volatile matter (dry ash free base)

$$\phi = [a_1(\mathrm{TR})^2 + a_2 \cdot \mathrm{TR} + a_3]\bar{R}_0 + a_4(\mathrm{TR})^2 + a_5 \cdot \mathrm{TR} + a_6 \quad \cdots\cdots (3)$$

a_i: constant ($i = 1, 2, \ldots, 6$)

The total moisture TW, volatile matter VM, and ash content of coal are analyzed and entered each time coal is reclaimed for blending. On that time, predicted quality values of coal to be reclaimed next are determined by statistical processing using the smoothing prediction method. These quality values of coking coal are filed for each lot, with lots classified according to coal brands and dates of ship arrival.

3.2 Coal Blending Plan

At the Mizushima Works, each brand of coal is reclaimed from the coal yard, crushed to a pre-determined size, and blended by the yard blending method. Therefore, blending plans are prepared for each bed. Consideration was given mainly to the following points in the systematization to facilitate the work of the control room operator.

(1) Coke quality prediction model

The total sulfur content (TS) and ash content of coke are predicted from calculated values of total sulfur content, ash content, and volatile matter of blended coal. Coke strength is predicted from factors including the ϕ-value, maximum fluidity MF, −3 mm% of blended coal, and the coke-oven flue temperature, using a coke strength prediction model. For further details the reader should refer to the published work of Suginobe, *et al.*[1)]

(2) Model for programming crushed coal sizes

When the target crushed grain size of blended coal is given, the crushed sizes, −3 mm%, of each lot of coal are automatically determined in consideration of the effect of crushing on the improvement of coke strength and the power consumption of the crusher.

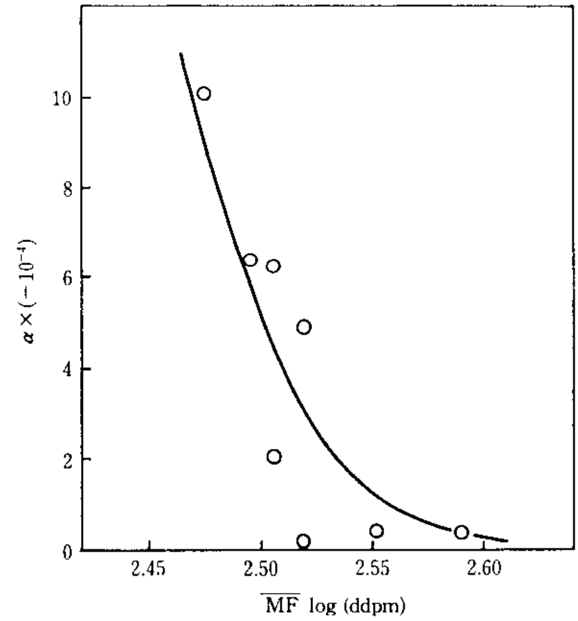
A theoretical model represents the effect of the crushing of coking coal on the improvement in coke strength. Results of calculation using this model show that the higher the value of $F_i(\overline{MF} - MF_i)^2$, the more finely coal grains should be ground.[2)]

$$F_i(\overline{MF} - MF_i)^2 \quad \cdots\cdots\cdots\cdots\cdots\cdots (4)$$

where

F_i: Blending ratio of each lot of coal
MF_i: Maximum fluidity of each lot of coal
$\overline{MF}$: Maximum fluidity of blended coal

The results of a confirmation of this theory in actual operation are shown in **Fig. 2**. The higher the absolute value of α, the greater the effect of crushing on the improvement in coke strength. It is evident, however, that the higher the value of $\overline{MF}$, the smaller the effect will be. Therefore, when $\overline{MF}$ is excessive, −3 mm% of crushed coal for each coal lot is planned, considering electric power savings of the crusher. This parameter is given by Eq. (5), which is derived from a crusher power model shown in Eq. (6), described later.



S=coke strength, DI^{30}_{15}
$D = \sum_{i=1}^{m} F_i(\overline{MF} - MF_i)^2 f(P_i)$
m=number of coals blended
P_i=minus 3 mm crushed coal percent

Fig. 2 Coefficient $\alpha(=\partial S/\partial D)$ as a function of coal blend maximum fluidity ($\overline{MF}$)

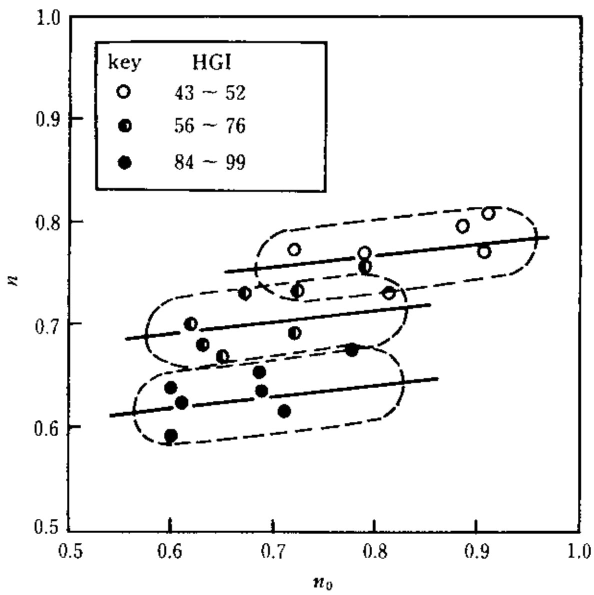


Fig. 3 Relation between n and n_0 for various coals[4)]

$$\frac{b_1^{1/2n} - (b_2 \ln P_0)^{1/2n_0}}{\sqrt{HGI}} \quad \cdots\cdots\cdots\cdots\cdots (5)$$

Table 2 Actual results of coal size preparation

	Case I	Case II
Coal charge MF	2.46	2.58
Coal charge ϕ	0.96	0.98
Coke strength DI^{30}_{15}	93.7	93.6
Crusher power consumption (kWh/t-coal)	1.25	1.10
Size preparation parameter	Expression (4)	Expression (5)

where

b_1, b_2: constants

The parameters of P_0, n_0 and HGI are shown in Table 1 and n is calculated from n_0 and HGI, as shown in **Fig. 3**.

Table 2 gives results of an actual operation in which −3 mm% was planned using this model. In this table, case II represents a case where the $\overline{MF}$ of charging coal is excessive and hence the coal size is planned in consideration of Eq. (5). A comparison of case II with case I reveals no great difference in coke strength and crusher power consumption about 10% smaller than in case I.

(3) Checking the stock of coal

Stock of coal used for blending is checked, and a judgment is rendered on the suitability of blending ratios. This checking is conducted by gathering information on the present stock, the planned tonnage of reclaimed coal, and the scheduled tonnage of received coal.

An actual blending plan is made in the following manner. Results of blending at the preceding bed are displayed on a CRT screen, and the blending ratio of each coal brand, place code of the discharge yard, average target crushed coal size (−3 mm%) of the blended coal, and coke-oven flue temperature are inputted. Based on the latest information, the computer prepares the prediction model and the model for programming crushed coal size, and checks coal stock, as discussed in (1) through (3) above. Results are displayed on the CRT screen. Quality specifications and stocks are confirmed and a blending plan is prepared with corrective input as required. In planning a lot to be received, past information on the average quality of the same coal brand is retrieved. Subsequently, predicted quality in the blending plan is automatically corrected when analytical values of the received coal are inputted. Planning jobs which previously required a great deal of time can now be quickly on site, due to the introduction of this computer system.

4 Operation Control Function

4.1 Simplification of Operation in Control Room

4.1.1 Starting of conveyors and other equipment

To start equipment such as conveyors, from the control room, it has to date been necessary for operators well-acquainted with the machines to manipulate numerous selection switches without error. In this system, all transport system combinations are numbered, and start numbers can easily be judged from CRT information, lightening the burden of operators. Functions which characterize each process are outlined below.

(1) Receiving process

There are 70 receiving route combinations. Frequent route changeovers are required when many coal brands are unloaded simultaneously. In such cases, complicated operations have so far been required for starting conveyors and setting samplers. A sampler is installed for each of three receiving conveyor lines; each sampler is equipped with four sample bins. It has so far been necessary to set the sample bin and the sampling intervals each time routes are changed.

In this system, the following measures for simplification were taken to solve such problems. A yard plan, made beforehand, is first displayed on the CRT screen and the number of a lot for which unloading or a route changeover is to be carried out is inputted. The conveyor route diagram and its route number are automatically displayed on the CRT screen when the input is normal (refer to **Photo 2**). At the same time, allocation of coal brands to the sample bins, the above-mentioned sampler setup, procedures and the monitoring of sampling are automatically carried out. Incidentally, the conveyors are started by inputting the route number to the sequencers. Therefore, the operator can start

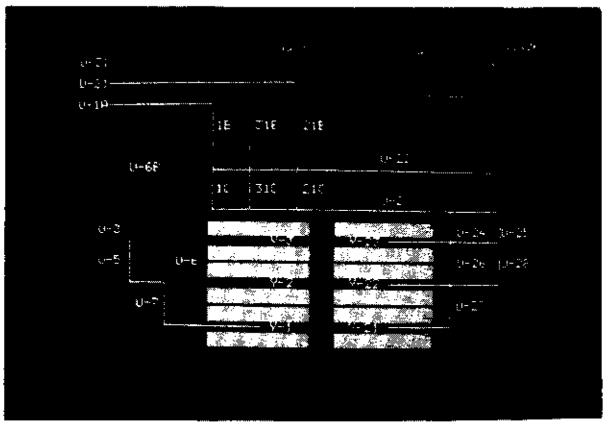


Photo 2 Conveyor route guidance display

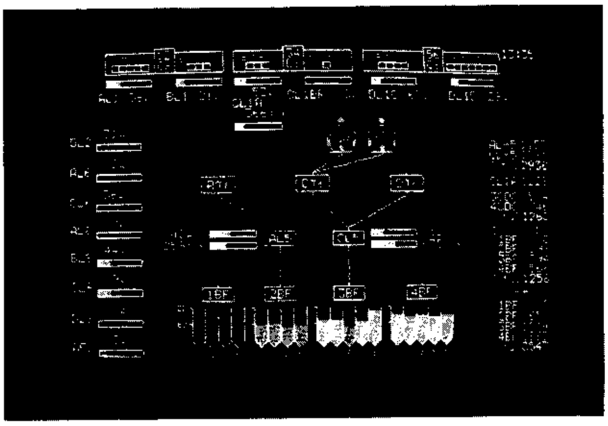


Photo 3 Coke transportation process display

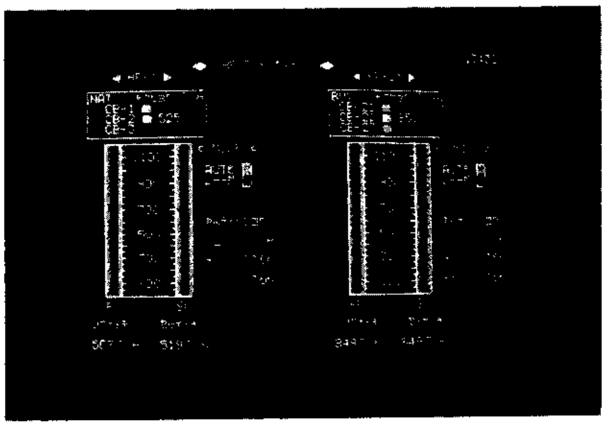


Photo 4 Crushed feed rate guidance display

the conveyors without a complicated operation, provided he identifies unloaded lots correctly.

(2) Discharging process

The discharging process is composed of two lines. Each line is equipped with a surge hopper and three impact-type crushers. In this process, the determination of the surge hopper discharge rate setting and the control of crushed coal sizes required skill and experience. These jobs were standardized, permitting systematization. Details will be described in 4.1.2.

(3) Charging process

A total of six coal bunkers is installed for the coke ovens. Changes in stocks are predicted for each coal bunker from present stock and the production plans of each coke battery and displayed on the CRT screen. The operator monitors these stock levels and determines route numbers.

(4) Coke transport process

The operator, by means of the CRT, monitors information on the coke bunker stocks of each blast furnace and coke wharf stocks (refer to **Photo 3**) and determines route numbers. To optimize suction volumes necessary for dust collection, changeover dampers for bag-filter type and wet type conveyor dust collectors are set, depending on whether the transported coke is CDQ coke or WET coke.

4.1.2 Crusher operation guide

The gap between the crusher impact plates and baffle plates is usually adjusted when the coal size after crushing has been ascertained. Coal size measurement is very time-consuming. Furthermore, the gap adjustment varies by type of coal and feed rate to the crusher. Therefore, attaining competence in making such judgments required to many years' experience.

A theoretical model of the crusher had previously been created to solve this problem.[3] The model was modified at the time of this systems design. Equation (6) represents the basic equation for the crusher.

$$W = \frac{c_1 Q}{\sqrt{\mathrm{HGI}}} \cdot [(c_2 \ln P)^{1/2n} - (c_2 \ln P_0)^{1/2n_0}] + W_0 \quad \cdots\cdots (6)$$

where

- W: Power consumption by the crusher (kW)
- W_0: No-load power of the crusher, which is constant (kW)
- Q: Coal feed rate to the crusher (t/h)
- HGI: Hardgrove grindability index of coal
- P_0, P: Weight percentage of +3 mm coal before and after crushing
- n_0, n: Parameters showing the size distribution range before and after grinding, which are Rosin-Rammler's distribution constant
- c_1, c_2: Constants

HGI, P_0 and n_0 are retrieved from the analysis information on received coal shown in Table 1. W is calculated from load current signals of the crusher and Q is given by conveyor weigher signals. The parameter n was investigated in actual operation; it was found that, as shown in Fig. 3, n can be calculated with high accuracy as a function of n_0 and HGI. Therefore, P can be calculated by substituting these numerical values in Eq.(6).

The actual system using Eq.(6) is as follows. The operator displays a blending plan for a bed on the CRT screen and enters the number of a lot to be blended on the screen. When the input is normal, the target surge hopper discharge setting is displayed (refer to **Photo 4**) and the constant feeder is automatically set. This target value (t/h) is determined from the target crushed coal size and the maximum load current value of the crusher using Eq. (6). Furthermore the value is corrected in consideration of the moisture of coal and the transportation capacity of equipment. The introduction of this system has resulted in an increase in Q and a decrease of

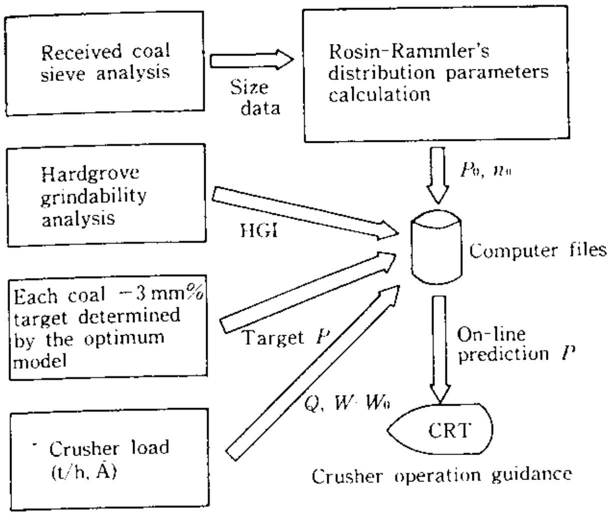


Fig. 4 Crushed coal size monitoring system

about 0.03 kW · h/t in power consumption.

As shown in **Fig. 4**, coal size after crushing is predicted online. Changes with time and guidance for crusher gap adjustment are displayed on the CRT screen. As a result, it has become possible to save labor in on-site coal size measurement for crusher gap adjustment purposes and to improve the accuracy of −3 mm grains.

4.1.3 Monitoring of process condition

The monitoring of the entire process is performed during operation by displaying the condition of the coal preparation process (**Photo 5**) and the coke transport process (Photo 3), usually on two respective CRTs. Necessary information is displayed on screen by numerals, graphs, and color, with data updated every 10 seconds. Furthermore, alarm messages are displayed on the same screens in case of any abnormality in equipment. In addition, the latest information on related equipment operating conditions is displayed, along with

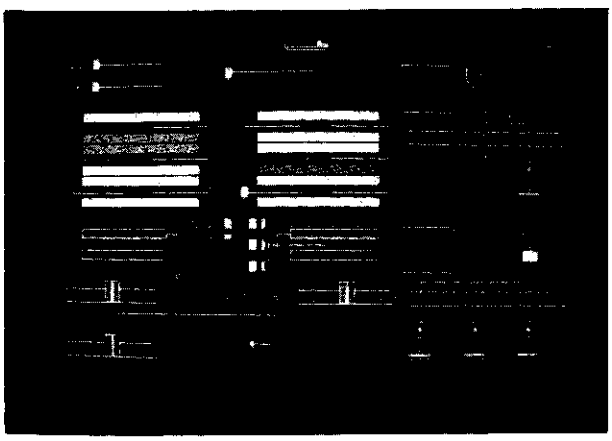


Photo 5 Coal preparation process display

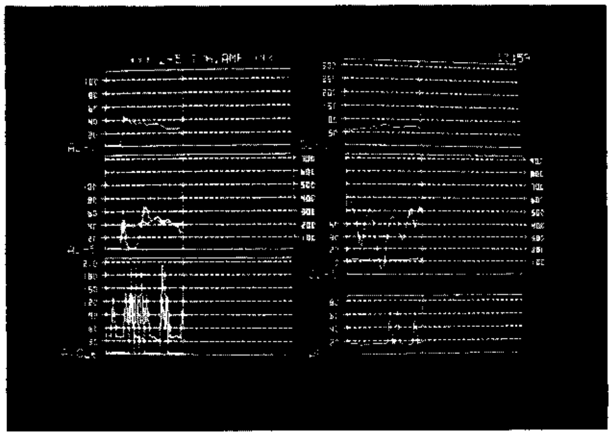


Photo 6 Conveyor load trends display

that on subsequent operating condition changes, in time series (**Photo 6**) to facilitate monitoring by the operator.

4.2 Bedding Control

Bed longitudinal quality variation $V(X)$, is given by the following equations.[3,4]

$$V(X) = \sigma_Q^2 + \sigma_P^2 \quad \cdots\cdots (7)$$

$$\sigma_Q^2 = \frac{Av}{B} \sum_{i=1}^{m} F_i \sigma_{X_i}^2 \quad \cdots\cdots (8)$$

$$\sigma_P^2 = \left(\frac{Av}{B}\right)^2 \sum_{i=1}^{m} X_i^2 \sigma_{l_i}^2 \quad \cdots\cdots (9)$$

where

- A: Average stacking rate of the stacker (t/h)
- B: Bed size (t)
- v: Average traveling speed of the stacker (h/layer)
- X_i: Quality characteristic value of coal brand (%)
- m: Number of coal brands blended
- σ_{X_i}: Standard deviation of quality characteristic value of coal brand (%)
- σ_{l_i}: Standard deviation of the number of stacked layers in the longitudinal direction for coal type (layers)
- σ_Q: Quality variation in the longitudinal direction of the bed, which is a function of σ_{X_i}
- σ_P: Quality variation in the longitudinal direction of the bed, which is a function of σ_{l_i}

The σ_Q- and σ_P-values of ash in coal were investigated and it was found that, as shown in **Table 3**, the contribution of σ_P is great. This is because σ_{l_i} takes a certain value between 0 and 1 since the starting and finish positions for bedding any coal type are random. Therefore,

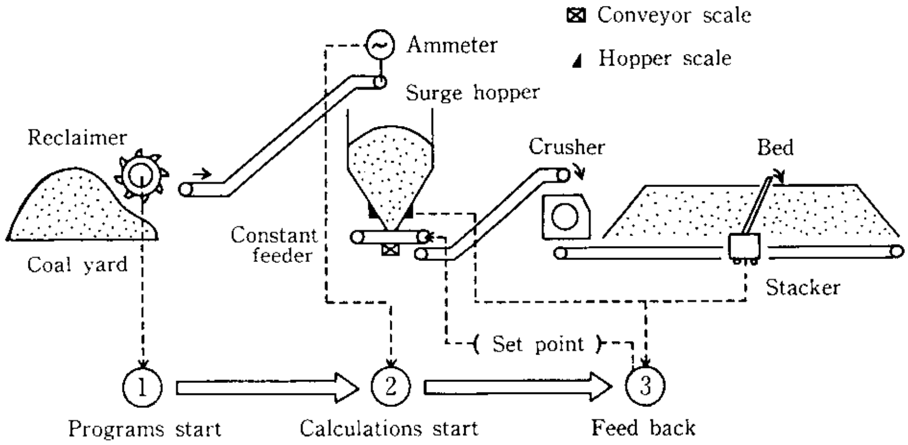


Fig. 5 Control system for final stacking position[4)]

Table 3 Calculated σ-values (%) of coal ash in the longitudinal direction of a bed

Stacking method	σ_Q	σ_P	$\sqrt{\sigma_Q^2+\sigma_P^2}$
Random stacking	0.023	0.059	0.06
Controlled stacking	0.023	0.020	0.03

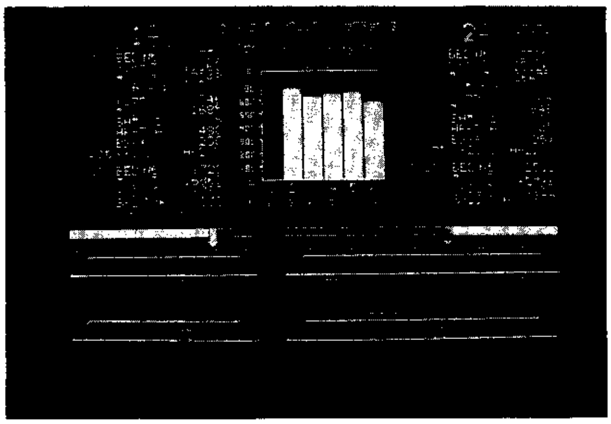


Photo 7 Yard blending process display

theoretically σ_P is zero if the starting and finish positions are controlled to the bed ends.

The following system was developed based on the above-mentioned considerations:

(1) Circuit for automatically moving the stacker to the bed end at the start of bedding

(2) Circuit for temporarily stopping the stacker travel when the coal amount becomes insufficient during stacking, so as to prevent a forming of a discontinuous layer

(3) Control system for setting the bedding finish position at the bed end (see **Fig. 5**)

This finish position control starts when a predetermined quantity of coal has been reclaimed from the coal yard. Calculations are made from the position and travel direction of the stacker and surge hopper stock, and surge hopper discharge settings are automatically changed so that the finish position corresponds to a bed end. The stacker position is reset to zero at the turning point and the rotation of wheels is converted to pulse values for calculation. The travel direction is judged from signals sent from the turning points at each end. **Photo 7** shows an example of a CRT screen for monitoring bedding conditions, including stacker operation. The value of σ_P decreased to 0.020% as coal ash after the introduction of this system (see Table 3).

4.3 Document Preparation

The greater part of documents necessary for quality control and operation control is now prepared by computer, and manual work has been substantially reduced. Monthly reports such as matrix analysis of equipment and equipment problems, power consumption tables for each operation, conveyor idle time tables, are contributing to a decrease in maintenance problems and to better electric power savings results.

Chemical coating instructions for coal stockpiles are described as an example in daily scheduling jobs. A surface-hardening agent, a filmforming agent, and a water penetration inhibitor are applied by a chemical spraying car. Spraying operations are divided by purposes into the spraying of the above-mentioned three chemicals by stages just after the receiving of coal, spraying work carried out at constant intervals thereafter to repair deteriorated films, and spraying work for exposed surfaces each time coal is reclaimed. Because the coal storage yard stores 70 to 80 lots, daily work instructions are given by the computer so that chemicals use will be appropriate and economical. Information on each lot in the coal storage yard, such as history of past sprays, stock, delivery plans, exposed surfaces formed by dis-

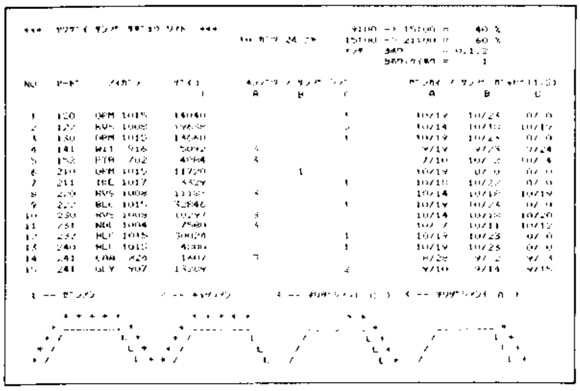


Fig. 6 Stockpiles spraying instructions issued by the computer

charge and predictions of rain and wind on the following day, is necessary for giving work instructions. Results of spraying are entered through the CRT each day after the completion of work and are then used in the spraying history. Stock, delivery plans, and the existence of exposed surfaces are judged from retrieving operation data. Weather conditions at Mizushima Works are predicted using a discriminant function based on the weather forcasts of the Okayama District Meteorological Observatory. An example of work instructions is shown in **Fig. 6**.

5 Conclusions

In October 1983, Mizushima Works completed a quality and operation control system, using process computers, for the coal preparation and coke transport processes. The system has since been operating smoothly. The computer system includes the following software functions:

(1) Coal blending planning using a coal quality evaluation model, a coke strength prediction model, and a model for programming crushed coal sizes
(2) Setting of operation conditions and process monitoring
(3) Automation of data preparation and issuing of work instructions

Owing to the adoption of this computer system, it has become possible to stabilize quality and operation, to save electric power, and to adopt one-man operation of the control room, covering both coal blending and operation planning.

At present, Mizushima Works is improving the level of quality and operation control in these processes by adding the new function of coke-oven combustion control and, in addition, a personal computer network to this system.

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