KAWASAKI STEEL TECHNICAL REPORT
No.24 (April 1991)

Computer Control System for Ore Yard Operation at Mizushima Works

Shuichi Taniyoshi, Tsunehiro Kaneda, Teruo Tamura, Daisuke Onoda, Yasuharu Miyazaki, Tsuyoshi Ikeda

Synopsis :
At Mizushima Works, ore yard control systems of electric equipment were renewed. This is the second step of iron marking department information system. New belt conveyor control for energy-saving and staking control for quality improvement have been applied. Control technologies such as knowledge engineering, fuzzy control, and self-tuning control have been applied. The systems have been achieving great effects in what was difficult to obtain with a conventional way, and are working with no problem at all since April 1987.

The body can be viewed from the next page.

Computer Control System for Ore Yard Operation at Mizushima Works*



Shuichi Taniyoshi
Staff Deputy Manager, Plant Control Technology Sec., Mizushima Works

Tsunehiro Kaneda
Staff Deputy Manager, Ironmaking Technology Sec., Mizushima Works

Teruo Tamura
Plant Control Technology Sec., Mizushima Works



Daisuke Onoda
Plant Control Technology Sec., Mizushima Works

Yasuharu Miyazaki
General Manager, Plant Control Technology Dept., Mizushima Works

Tsuyoshi Ikeda
Manager, Hot Rolling Plant Control Sec., Plant Control Technology Dept., Mizushima Works

Synopsis:

At Mizushima Works, ore yard control systems of electric equipment were renewed. This is the second step of iron making department information system. New belt conveyor control for energy-saving and staking control for quality improvement have been applied. Control technologies such as knowledge engineering, fuzzy control, and self-tuning control have been applied. The systems have been achieving great effects in what was difficult to obtain with a conventional way, and are working with no problem at all since April 1987.

1 Introduction

The electric control equipment of the Mizushima Works ore yard was first put into operation in 1967, then expanded in stages corresponding to the construction of blast furnaces. However, the electric equipment control system began to show distinct deterioration, mainly caused by corrosion and vibration, and functional obsolescence originating from the contact-operating wired logic system.

In the meantime, an ore yard information system was put into operation in 1984 as a part of the ironmaking information system. This ore yard system was introduced as phase 1 for an upper-rank information system, and as such consisted of a central computer and process computer.[1)]

Next, the electric control system was refurbished in phase 2 during the period from 1985 to 1987, and a CRT operation system based on PLC (programmable logic controller) control was completed. The master controller was linked to the central computer and process computer, permitting automatic operation linked directly to the operation plan.

Further, several new techniques which could not be introduced earlier due to the functional limitations of the old control equipment have now come to be adopted. With the aim of achieving energy-savings, quality improvement, and labor-saving automation, upgrading of the level of ore yard control was thus planned, using control techniques such as knowledge engineering, fuzzy control, and self-tuning control. In this latest refurbishment, the specification examination, preliminary investigation, incorporation of the new system into existing control circuits, change-over to the new master control devices, and trial-run were completed within two years, and the new control system was commissioned in April 1987.

This report describes the application of these control techniques and the results achieved with the new system.

* Originally published in *Kawasaki Steel Giho*, 22(1990)1, pp. 6-11

2 Outline of Ore Yard Electric Control System Hardware

A composition diagram of the ore yard electric control system is shown in **Fig. 1**. As controllers, a two-hierarchy composition of the master controller and PLC is used in the upper rank. Full-scale CRT operation using a light-pen was adopted at the operator level. System features are described below.

(1) The ore-yard electric system is linked to the already completed phase 1 ore yard system, permitting fully automatic operation of the belt-conveyors (BC) in direct linkage to the operation plan of the host computer.
(2) As the master controller, a minicomputer is used; functions such as the interface between the PC and the process computer, automatic operation control of the BC system, and fuzzy control are assigned to the minicomputer, forming a control hierarchy of simple but highly reliable software composition.
(3) Through the use of an ITV system installed on a chimney 200 m above the ground, it has become possible to monitor the extensive ore yard layout from the central control room.
(4) The database for equipment malfunctions is linked to a personal computer. The efficiency of maintenance work has been improved by this equipment monitoring system.
(5) Through adoption of a PLC with a dual-CPU composition and a data-way as well as an optical remote I/O, the reliability of the system has been improved.

Refurbishment has eliminated the limits of the control function due to obsolescence of the wired logic element controller and other difficulties associated with aging equipment, which had long been problems. Further, it has become possible to decrease the burden of operation and maintenance work, supporting stable, trouble-free operation even under high-capacity production.

As a result of improvements in the control function, the level of ore yard control has been upgraded with positive results in terms of energy-saving, automation, and quality improvement. In the following, these upgraded control functions are described.

3 Control System Functions

3.1 Energy-Saving Control

The ore yard at Mizushima Works consists of 26 sections and covers an area of 1 million m^2; its ore storage capacity is about 2.3 million tons. The yard is serviced by 30 yard machines, 460 BC groups, 3 sizing plants, and 150 relay hoppers. Efficient, coordinated operation of all these units is important for energy-saving.

The basic control functions of transport are as follows. Especially from the point of view of energy-saving, upstream sequential start and unloaded stopping control have been adopted as new functions.

(1) Start Control (**Fig. 2**)
Downstream Sequential Start: Sequential starting at prescribed time intervals, beginning with downstream units.
Upstream Sequential Start: Material is time-tracked and sequential starting is initiated with upstream units.
(2) Stop Control
Simultaneous Stopping: Equipment in the entire system can be stopped simultaneously.
Unloaded Stopping: Material is time-tracked and operations are sequentially stopped beginning

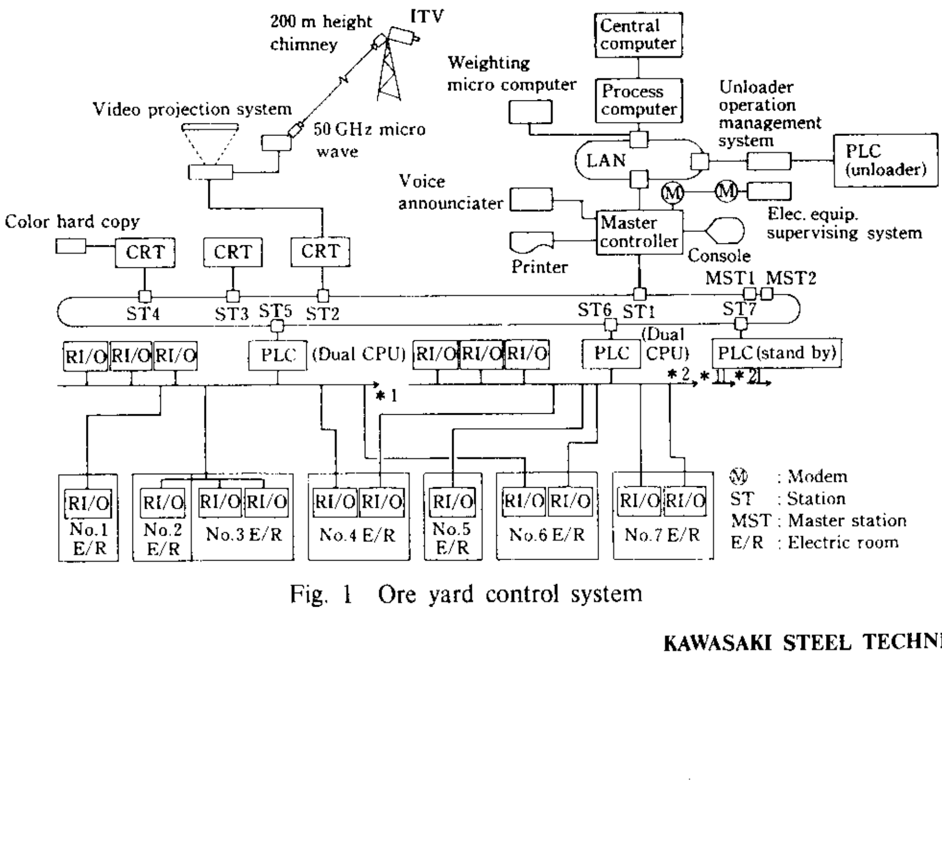

Fig. 1 Ore yard control system

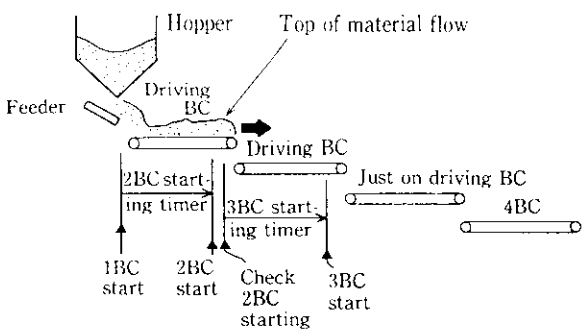

Fig. 2 Conveyor starting from upper side

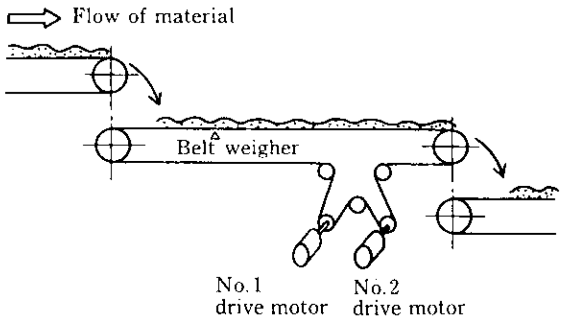

Fig. 3 Number control of driving motor

with the upstream equipment.

Sequential Stopping: Sequential stopping begins with upstream units and proceeds downstream at prescribed time intervals.

(3) System Switching Control

System Switching during Operation: Two-line downstream BCs which serve common upstream equipment are automatically switched during operation.

In addition, the energy-saving control measures described below have been implemented.

(1) Control of BC Drive Motors (**Fig. 3**)

The number of drive motors of BCs driven by motors is controlled as required by changes in load quantities at the time of transporting.

(2) Residual Quantity Mode

Through the use of the load detector or instant values of the belt weigher corresponding to each hopper, empty BCs are detected and the system is stopped by unloaded stopping control.

(3) Stopping and Re-starting by Belt Weigher

Interruption of material transportation is detected by the belt weigher, and the downstream BC is stopped as required by unloaded stopping control. Sequential upstream starting is resumed upon detection of loading.

(4) Cumulative Transportation Mode

Using values provided by the belt weigher, the BC is automatically stopped when the end-target belt-weigher has reached a predetermined cumulative

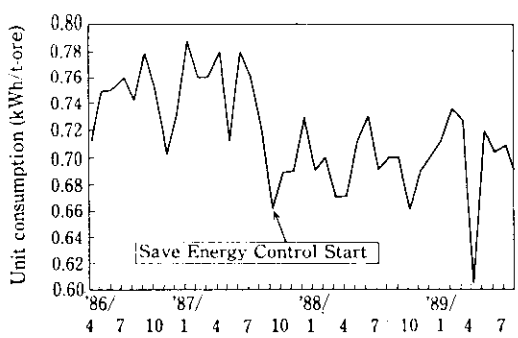

Fig. 4 Transition of electric energy consumption

tonnage.

This energy-saving control has resulted in an electricity saving of about 10% (**Fig. 4**).

3.2 Remote Automatic Control of Sizing Plant (Application of Fuzzy Control)

The values used in evaluating sized products are the lump ratio and the size distribution analysis of the lump ore. These evaluation values vary with the clearance of the crusher and screen mesh and size distribution of the ore. On the other hand, the main value used for evaluating operation is processing efficiency (quantity processed per unit of time). In the past, crusher clearance and the feed rate of the apron feeder (AF) were set to satisfy the evaluation standards based on the empirical judgment of field operators. Automatic control functions for crusher clearance and AF feed were therefore developed using fuzzy control with the aims of labor saving and energy-saving.

Clearance control and AF feed control are shown in **Fig. 5**, and a composition diagram of the automatic control system is shown in **Fig. 6**. This control system has plural evaluation values, as mentioned earlier, and uses multiple inputs and outputs, making it difficult to apply precise numerical models. In addition, operation has conventionally been carried out based on the experience of field operators. For these reasons, it was

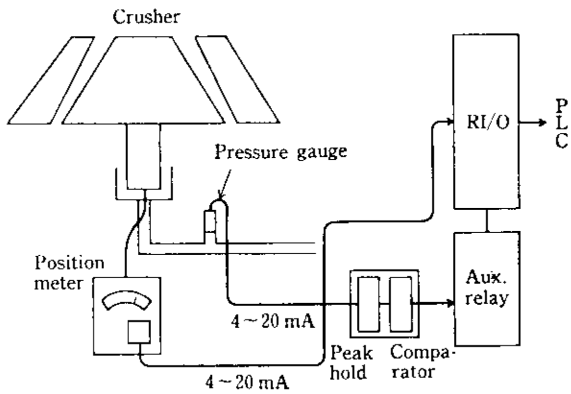

Fig. 5 Remote crusher's position control

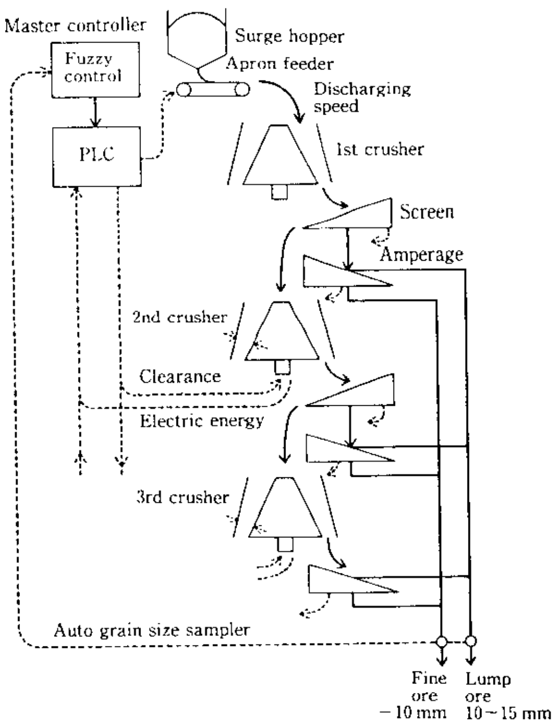

Fig. 6 Remote control system of sizing plant

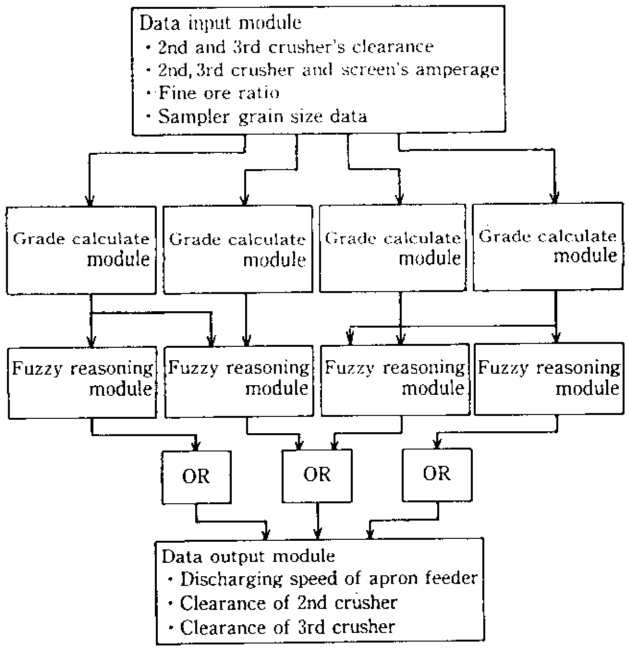

Fig. 7 Example of fuzzy module combination

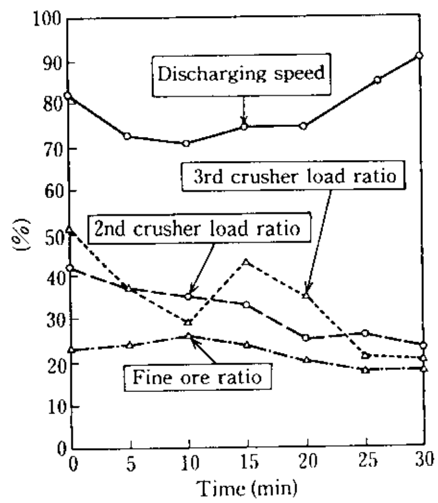

Fig. 8 Result of automatic sizing plant control

decided to apply fuzzy control.

In general, fuzzy control is carried out in the following four steps: (1) Evaluation of measured values ("large," "small," etc.), (2) fuzzy estimation of the evaluation of measured values on the basis of control rules, (3) composition of results of various fuzzy estimates, and (4) calculation of output values based on composite estimate results. To permit easy, flexible compilation and modifications of the control logic, these respective steps are made into modules (the steps are considered subroutines), so that the control logic can be compiled as combinations of modules. An example of a fuzzy module combination is shown in **Fig. 7**.

Development of the fuzzy control system involved the following four steps: The development of a crushing-state estimate model using the electric current value and electric power value, preparation of a control logic based on operator knowhow, testing of the control logic, and parameter tuning.

The control logic incorporates fuzzy theory, and is composed of an energy-saving logic (over-crushing prevention control, maximum efficiency control) and quality control logic. The energy-saving logic functions preferentially when product size is controlled within a range and the quality control logic functions preferentially when the size is outside the range.

The results of automatic sizing plant control are shown in **Fig. 8**. Although the load on the crusher changes with fluctuations in the ore size distribution, it has become possible to consistently maintain the load ratio at the target value by automatic control of the crusher clearance and AF feed. Further, by controlling the clearance of the final-stage crusher on the basis of size-distribution after crushing, it has also become possible to cosistently maintain the size distribution of crushed products within specified values.

3.3 Ore-Bed Stacking Homogenization Control

Stabilization of the feed from ore bunkers situated upstream of the ore bedding process constitutes a basic condition for averaging the stacking quantity in the lengthwise direction of the bed. Constant feed from the ore bed bunker, which was introduced as part of this

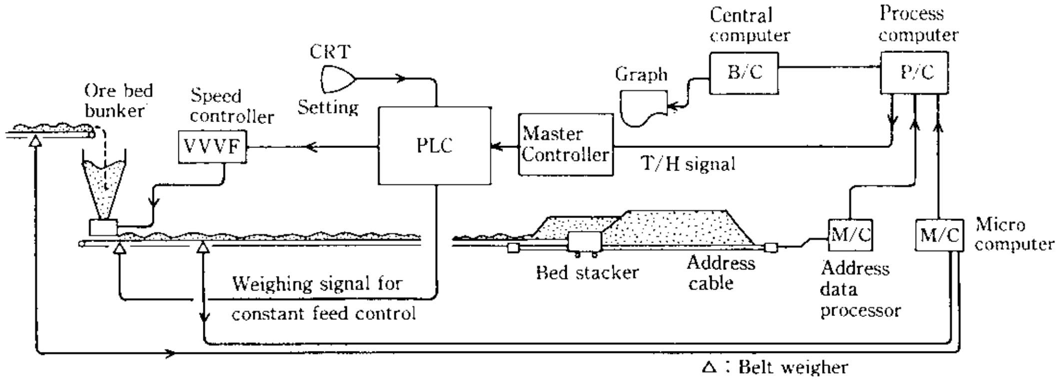

Fig. 9 Bed quality control

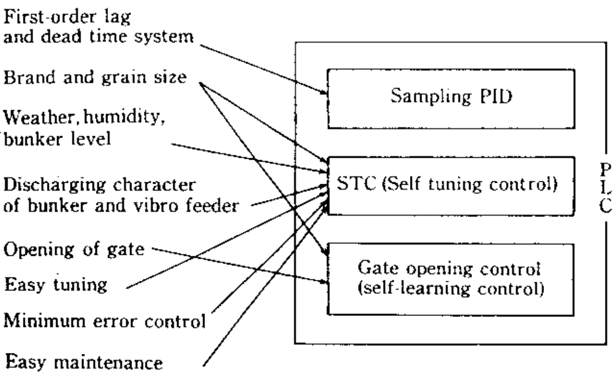

Fig. 10 Function of bed quality control

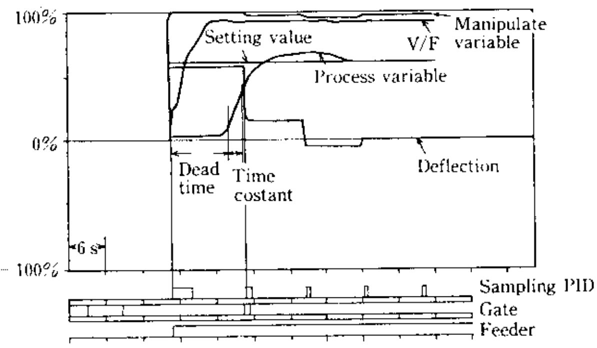

Fig. 11 Starting characteristic

project, is a method of controlling the number of revolutions (VVVF control) of the motor-driven feeder. The composition of this system is shown in **Fig. 9**, and the control logic is shown in **Fig. 10**.

Sampling PID, self-tuning control (STC), and self-learning control are expanded in the PLC, and form a closed loop with the external VVVF and belt weigher.

For STC, a system structure for stepped drive was developed, and consists of a 1-step influence signal method, a 2-step seeking signal method, and a 3-step deviation signal method. The tuning process and parameter adjusting process of the drive are carried out in parallel, so that the quantity control system can respond at any time. This configuration also makes it possible to adopt an asymptotic convergence process, in which drive performance improves as the adaptive process progresses.

The chart in **Fig. 11** indicates starting characteristics. The target-following capability is 30 sec, and external disturbance suppression is within ±1% or below.

3.4 In-hopper Homogenized Stacking Control

The BF ore-storage hoppers and sinter-blending hoppers have the important roles of connecting the ore yard to subsequent processes. Though various attempts have been made to stabilize material quality (size distribution and segregation of chemical composition), the initiation of charging in the conventional ore charging method was based on hopper inventory or simple time intervals, and examples of control of by in-hopper charging position were rare. In the following, the various charging control methods adopted in the new system are outlined:

(1) SS (Super-static) Charging

This charging method is used with the sinter-blending hopper. The conventional charging method was one-point charging into the hopper at a certain time interval. However, this charging method caused coarse grains of the ore to accumulate at the edges of the hopper due to sizing segregation. Ore fed from the hopper changed over time, with an adverse effect on the stability of the sintering operation, which is the subsequent process. To solve this problem, a continuous-running charging method has been adopted. Travel-speed control by VVVF is applied to the tripper on the blending hopper, and ore charging is distributed over the lengthwise direction of the hopper, preventing size segregation. **Figure 12** shows the concepts of conventional charging and SS charging, and the difference in the operational results of the two charging methods.

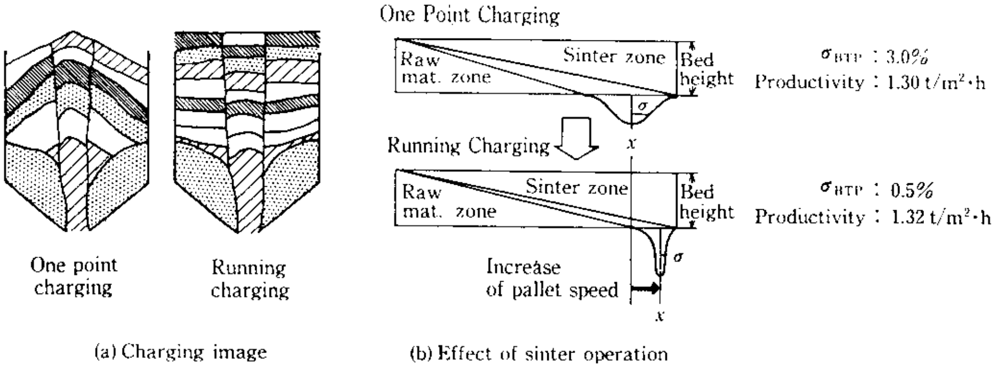

Fig. 12 Distinction of conventional charging and super static charging

(2) SD (Super-dynamic) Charging

This charging method has been introduced at the storage hoppers of all blast furnaces. Powdering suddenly increases as the head of fall increases during lump ore charging. To suppress excess powdering during charging, it is necessary to secure the collective storage quantities of all hoppers at a prescribed level and simultaneously to secure the storage quantity level of each hopper at a constant level or above. SD charging is a system for control of the charging system which minimizes differences in the ore storage levels of the storage hoppers of all blast furnaces.

Beside the above-mentioned control methods, other charging control methods have also been adopted. In S (static) charging, designated hoppers are charged for a certain time (for both storage hoppers and blending hoppers), while D (dynamic) charging prevents powdering of sintered ore by eliminating differences in the ore storage quantities of the storage hoppers of individual blast furnaces.

3.5 Knowledge Engineering Method Conveyor Control

The sequence of BC transportation control constitutes a complex world governed by operational rules which include equipment conditions, operating conditions, mutual positional relations of BC units, transportation quantities, brands, priorities, success rates, and rates of fatal influence. In the new system, the knowledge engineering method is used with these operation rules as a basis, and is applied to operation control of the complicated connecting parts of the BC system. Because knowledge engineering does not suffer the limitations of the conventional standardized sequences which characterizes procedure-type language, it has now become possible to develop a flexible BC transportation system.

As shown in **Fig. 13**, the system can perform a lump sum processing by making full use of respective features of the knowledge engineering (KE) method and PLC, including DDC (direct digital control of BC) as an

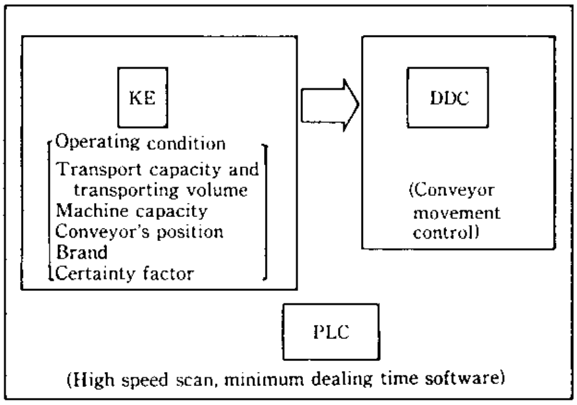

Fig. 13 Conveyor control of knowledge engineering style

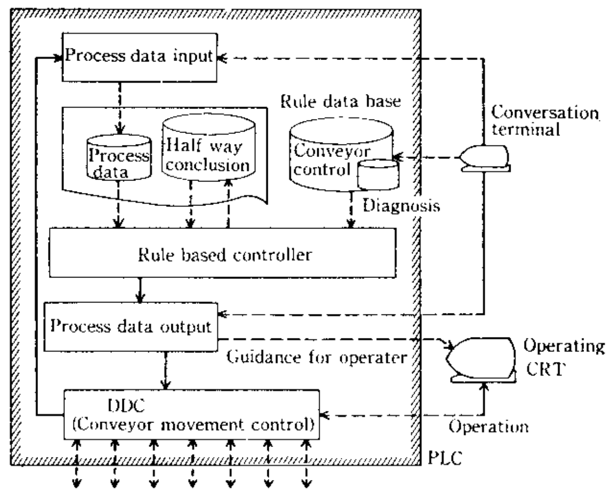

Fig. 14 System block diagram

inherit feature of PLC.

A system block diagram is shown in **Fig. 14**. The features of the present system are as follows:

(1) The system is a forward-looking (forward-linking and event-driven type) production system ("if LHS

then RHS").

(2) It uses certainty factor (c.f.) and expresses human priority judgments and success probability rates.
(3) It utilizes the two-stage inference process of intermediate conclusion ⟶ final conclusion, expressing the intermediate coclusion by evaluating the inter-BC connecting states at three levels (A, B, and C).
(4) The number of rules totals 106 (including system diagnostic rules and operation guidance rules).
(5) Compared with the conventional procedure-type language program, this system has the following features in respect of the compilation and maintenance of software: ① The system is bright and easily programmable, ② software maintenance is easy, ③ it is possible to cope flexibly with changes in operating conditions, and ④ simulation and debugging are easy.

4 Personal Computer System for Electric Equipment Supervision

As a part of the new system, a personal computer system for equipment supervision has been developed with the aim of remote-control maintenance. A system composition diagram is shown in **Fig. 15**, and a function diagram in **Fig. 16**. In response to the requests of maintenance people and on the basis of past problems, a principle of the system design was that it be closely related to the work site condition. The system features are as follows:

(1) Free access to data by personal computer ensures that data in the master controller and PLC is readily available.
(2) As a result of preventive maintenance, the system has improved the supervisory functions for total equipment operation time, the number of instances of sensor actuation, and the electric current values of important equipment.

5 Conclusions

As part of the modernization of the iron-making information system at Mizushima Works, the ore yard electric control equipment control system has been refurbished to improve the energy-saving performance of the BC and ore stacking systems. The results of this project are given below.

(1) A two-tiered controller consisting of the master controller and PLC was incorporated into the ore yard electric control system, and CRT operation using a light pen was adopted.
(2) Through efficient control of the BC, represented by the upstream sequential starting and unloaded stopping control functions, electric power savings of 10% have been achieved.
(3) Application of fuzzy control to the Sizing Plant has resulted in the development of an automatic control system incorporating the practices of expert operators.
(4) Through the adoption of ore bed stacking homogenization control and in-hopper homogenized stacking control, the effects of brand segregation and size segregation during ore transportation have been reduced.
(5) Through the adoption of belt conveyor control using knowledge engineering, automatic operation control of complicated BC connections has been made possible.
(6) Personal computer-based equipment supervision has enhanced the maintainability of electric equipment.

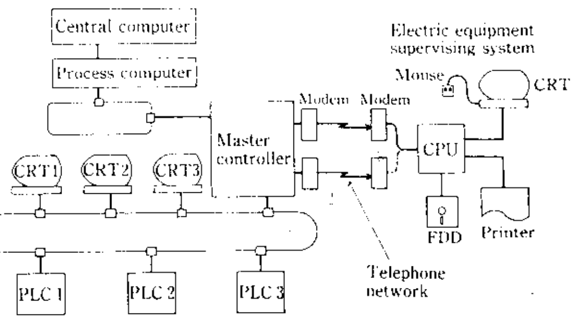

Fig. 15 Ore yard electric equipment supervising system

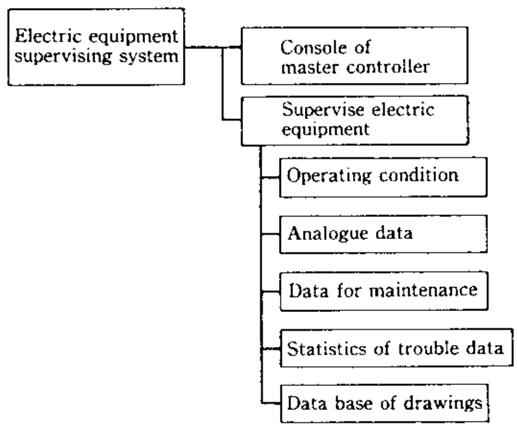

Fig. 16 Function of electric equipment supervising system

The authors have introduced a new control system aimed at improvement in energy-saving, automation, and quality and have achieved significant results in all three areas.

References

1) S. Yamana, S. Nigo, H. Obata, T. Fukagawa, N. Morinaga, M. Ukita: *Kawasaki Steel Giho*, **16**(1984)3, 155