KAWASAKI STEEL TECHNICAL REPORT
No.43 (October 2000)
Automative Materials and Instrumentation
and Process Control

The Latest Technologies for Process Control and Automation in Blast Furnace

Yunosuke Maki, Akihiro Inayama, Katsumi Ino

Synopsis :
Kawasaki Steel has modernized blast furnace control systems featuring an integrated instrumentation and electrical system for each sub-process, a human-machine interface through a single window, and a distributed process computer system. A furnace diagnostic system, the "GO-STOP system", has been developed into a knowledge-based system that provides appropriate action guidance. For burden distribution control, controllability and flexibility have been improved by the use of a bell-less-top charging device. For hot stove control, the automatic setting of combustion gas flow rate and improved efficiency have been achieved by a fuzzy control system. Furthermore, the recent remote operation of cast house equipment has helped to improve the working environment and efficiency at Chiba Works No. 6 blast furnace.

The body can be viewed from the next page.

KAWASAKI STEEL TECHNICAL REPORT No. 43 October 2000

The Latest Technologies for Process Control and Automation in Blast Furnace*

Yunosuke Maki
Staff Manager,
Equipment Planning Sec.,
Corporate Planning Dept.

Akihiro Inayama
Staff Manager, Plant Control Technology Sec., Plant Control Technology Dept.,
Chiba Works

Katsumi Ino
Staff Manager, Plant Control Technology Sec., Plant Control Technology Dept.,
Mizushima Works

Synopsis:

Kawasaki Steel has modernized blast furnace control systems featuring an integrated instrumentation and electrical system for each sub-process, a human-machine interface through a single window, and a distributed process computer system. A furnace diagnostic system, the "GO-STOP system", has been developed into a knowledge-based system that provides appropriate action guidance. For burden distribution control, controllability and flexibility have been improved by the use of a bell-less-top charging device. For hot stove control, the automatic setting of combustion gas flow rate and improved efficiency have been achieved by a fuzzy control system. Furthermore, the recent remote operation of cast house equipment has helped to improve the working environment and efficiency at Chiba Works No. 6 blast furnace.

1 Introduction

Kawasaki Steel replaced and modernized the control system of the No. 3 blast furnace at Mizushima Works[1] in 1990 and that of the No. 6 blast furnace at Chiba Works[2] in 1998. To diagnose and control furnace condition, the conventional "GO-STOP system" has been advanced to a knowledge-based system and its functions have been extended to include operational guidance. For burden distribution control, the introduction of a bell-less top and corresponding control system has improved the controllability and flexibility of operations and has led to the increased use of inexpensive raw materials. For hot stoves, the revised fuzzy control system has improved the automatic setting of combustion gas flow rate, and it has brought the improved efficiency of combustion control. Furthermore, in the No. 6 blast furnace at Chiba Works, remote operation of cast house equipment has helped to improve working conditions for the operators.

In this paper, the latest technologies on process control and automation for blast furnaces are described, mainly using examples from the No. 6 blast furnace at Chiba Works.

* Originally published in *Kawasaki Steel Giho*, 31(1999)4, 216–221

2 Control System of the Blast Furnace

2.1 Latest System Configuration for Blast Furnace Control

Figure 1 illustrates the configuration of the new control system for the No. 6 blast furnace at Chiba Works. The second campaign began in May 1998 after two months of revamping work. The features of the control system are described below.

2.1.1 Selection of the controller for each sub-process

A blast furnace consists of various sub-processes such as raw material handling, furnace top charging, hot stoves, gas cleaning, and cast house equipment. In terms of control system design, those processes can be classified into the following three groups.

(1) Raw material handling and furnace top charging systems that require fast and large-scale sequence control.
(2) Hot stoves, gas cleaning, and blowers for blast and other systems that need instrumentation-based process control.
(3) Cast house equipment, dust collecting and other sys-

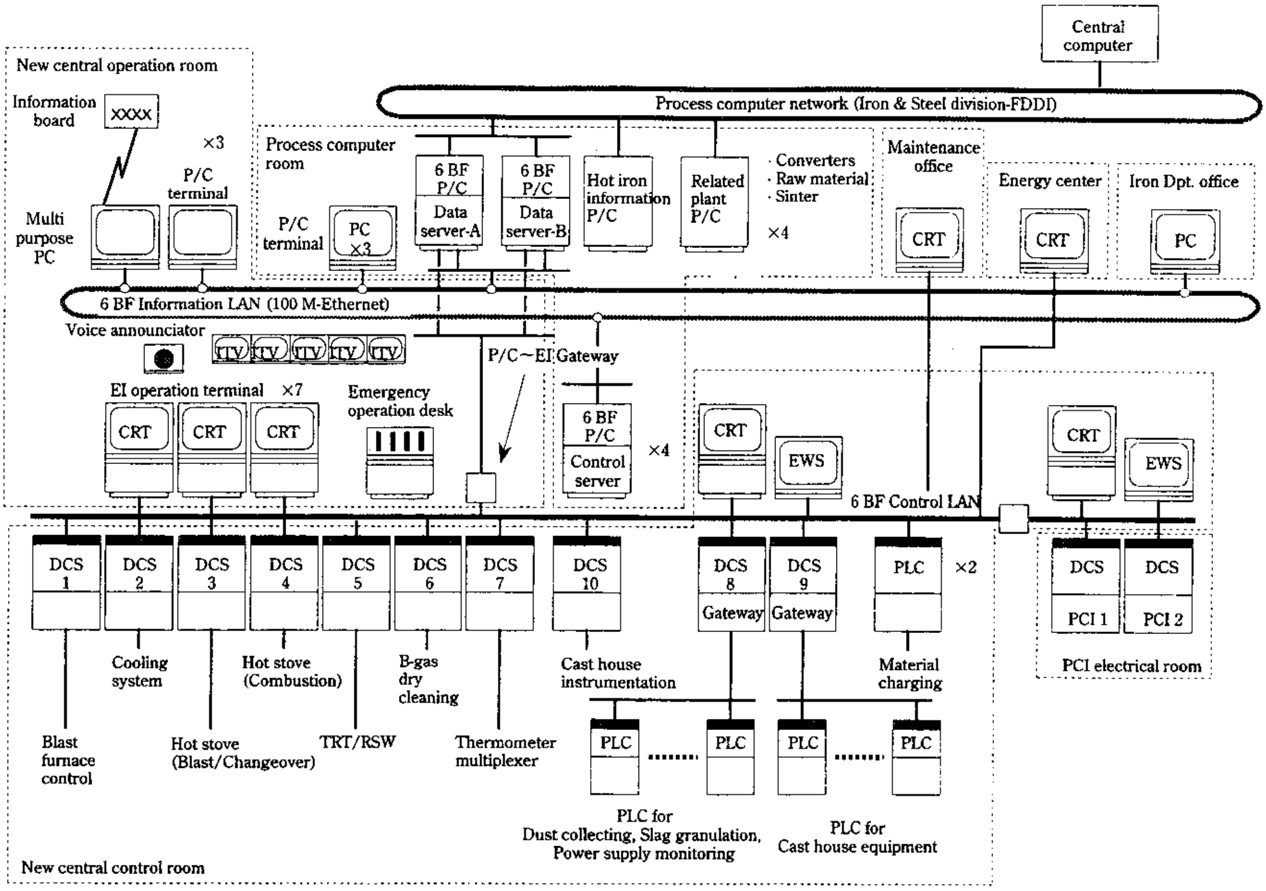

Fig. 1 Control system configuration of Chiba Works No. 6 BF

tems that need intricate factory automation-based control.

Referring to the features mentioned above, large-scale programmable logic controllers (PLC1), distributed control systems (DCS), and small-scale programmable logic controllers (PLC2) were chosen for the respective groups. Generally speaking, a control system is designed according to the features of each sub-process. Every sub-process is monitored and operated from a centralized control room located beside the cast house.

Remote I/O units are widely used and the electrical cabinets equipped with input/output boards are located separately in various local rooms. Hence, the long-distance wiring between the central and the local control rooms could be drastically reduced. These innovations owing to the digital multidata transmission have helped to reduce construction period and wiring costs.

2.1.2 Functional distribution between process computer and EI system

In the past, the assignment of each function, in a process computer (P/C) or in an electrical and instrumentation (EI) system had been always a complicated issue. The functional allocation for the second campaign of the No. 6 blast furnace at Chiba Works is based on the following idea.

The function of automatic process control is implemented in the EI system not in the P/C. The P/C is specialized in the processing of a lot of data obtained from the blast furnace. Hence, the P/C can focus on the information service and decision support for the operators.

Utilizing the commercial software that has been steadily improved, even advanced control functions can be incorporated into the EI system. As a result, all fundamental control functions for the blast furnace, most of which will not be changed significantly in the future, are covered by the EI system.

2.1.3 Integrated human machine interface (HMI) in the EI system

In order to facilitate operations, the HMI terminals are integrated to cover the above-mentioned three types of controllers. In other words, the HMI terminals of the PLC1, the DCS and the PLC2 are integrated under a common local area network (LAN) for control. Therefore, all sub-processes can be operated and monitored in front of any EI-integrated HMI terminal.

2.2 Down Sizing of Process Computer and Distributed Structure

With respect to the functions of the P/C applied to the No. 6 blast furnace at Chiba Works, a comparison

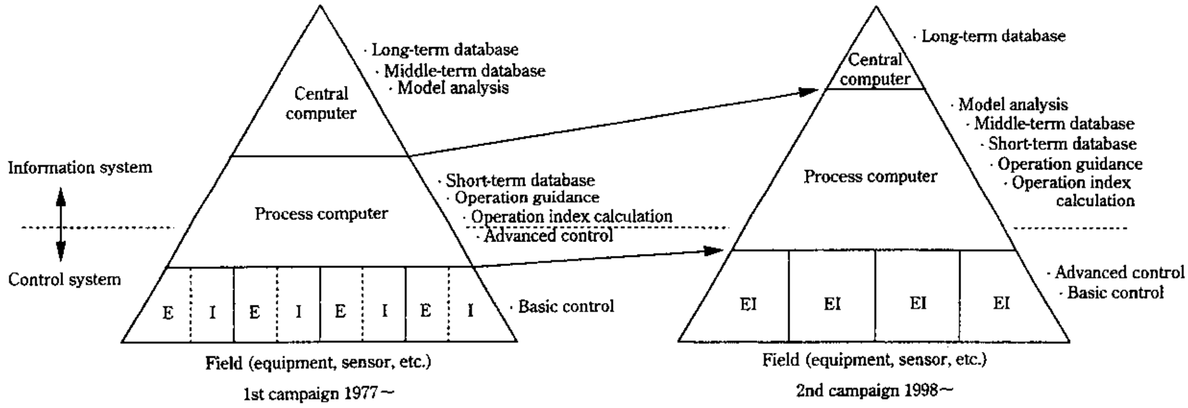

Fig. 2 Transition of functional workshare of Chiba Works No. 6 BF control system

between the first and the second campaign is shown in **Fig. 2**.

The previous P/C was equipped with an advanced control function which could not be realized by the previous EI system. In addition, the regular information processing functions, for example short-term (daily) data-base and data transmission to the upper level computer that deals with the middle- and long-term (monthly, yearly) data base, were included.

The required functions for a blast furnace system are reviewed and classified into information processing and process control. In the meantime, a remarkable progress in the computer hardware such as EWS and personal computers has been observed and it has implied the light and flexible system configuration.

The following are the features of the new P/C for the No. 6 blast furnace at Chiba Works.

2.2.1 Enhanced operational guidance function

Because the pre-installed functions in the latest EI system can cover most of the fundamental control functions for the blast furnace, those functions are all transferred to the lower EI system. As a result, the P/C can improve the function of the information processing by focusing on the operational guidance.

The off-line models such as the internal furnace mathematical model and the furnace corrosion prediction model, which used to be for engineers' batch use, have been converted into P/C codes for the operators. The P/C can now incorporate the above-mentioned models using either past or real-time field data. To enable the execution of those P/C codes, it has become necessary for the P/C to gather and store middle-term data.

2.2.2 Replaceable system

Considering that the life of a control system will become shorter than that of a blast furnace, the P/C system is so designed that it is integrated by multiple and distributed processors of various function named as data server, operator guidance model server, transmission server and other peripherals. Thus, the whole system can be flexibly adapted to various operational needs and its parts be replaced individually as the hardware becomes obsolete.

3 Blast Furnace Condition Control

3.1 Necessity of Control

A blast furnace is a huge reactor filled with physical and chemical reactions, in which the iron ore is melted and reduced into pig iron. Because a furnace is a multi-variable distributed system of high temperature and high pressure, it is difficult to measure its characteristic physical variables and to develop a model that applies control theory. Therefore, the operation of a blast furnace is conducted based on empirical knowledge and various measured process data. For the furnace condition diagnosis and control system, it is essential that decisions be supported by qualitative and quantitative evaluation.

3.2 Conventional System

For the above-described reasons, the "GO/STOP system" was developed and has been used as the furnace diagnostic system since the start-up of the No. 6 blast furnace at Chiba Works in 1977. It quantifies indexes of the furnace conditions for the operators to support their decision-making and has contributed to stable operation. Those indexes are obtained from the measured values in terms of both average and variations. Then the weighted sum of each index is calculated and the results are finally shown as the normalized overall score. It is also expressed as GO, STOP or BACK according to the score, and that is used to support the operator's decision for which direction the blast volume should go.

3.3 Latest System

The conventional system has put much importance on the diagnostic results based on the information gathered from the plant. The latest system has developed to pursuit action guidance rather than diagnosis. In other words, the purpose has been changing from the prevention of catastrophic trouble to stabilizing operation with minimum cost. Since the process modeling of the blast furnace is very difficult and its operation is highly dependent on human judgment, the steel industry has been trying heuristic approaches using knowledge-based technologies such as fuzzy theory, artificial intelligence and so on.

The furnace condition control system developed at the Mizushima Works No. 3 blast furnace[3] is explained below.

The knowledge-base mainly consists of two independent groups such as stationary information, e.g. heat level and tapping balance, and event-based non-stationary information, e.g. variation of blast pressure. The knowledge-base is described by the production-rules. Referring to normal viewpoints by experts, the rules are divided into three groups to enable three-stepwise inference, the process recognition, process analysis and determination of the action. In addition, such structure of rules makes it easy to trace the process of inference back from the output action. Owing to this, the operator can be notified of the reasons why the system orders such action.

The configuration and scale of the knowledge-base are shown in **Fig. 3** and **Table 1**. At Mizushima Works No. 3 blast furnace, the automatic control of the furnace heat level has been achieved in the stationary condition. At Chiba Works No. 6 blast furnace, a similar system was implemented. The parameters can be adjusted by the layered tables that are open to the operators and the system has been utilized by the operators as the advanced GO/STOP system.

4 Burden Distribution Control

The objectives of the raw material charging control are (1) stable operation under a high pig-iron ratio, (2) low coke ratio operation and (3) the use of inexpensive raw materials. In order to achieve these goals, highly accurate burden distribution control by a bell-less top charging device is essential. In the second revamping of the No. 6 blast furnace at Chiba Works[4] and the third revamping of the No. 3 blast furnace at Mizushima Works[5], their furnace top charging devices were replaced by bell-less tops of the three-parallel-bunker type (**Fig. 4**). The two main features of the burden distribution control are as follows.

First, the charging pattern can be designed using the simulation model of burden profile. The predicted burden profile is calculated from the charging pattern and is displayed on the screen of the P/C. Second, the flexibility and the freedom of the control system is significantly improved so that the system can be easily adapted to changes in operation or different raw materials in the

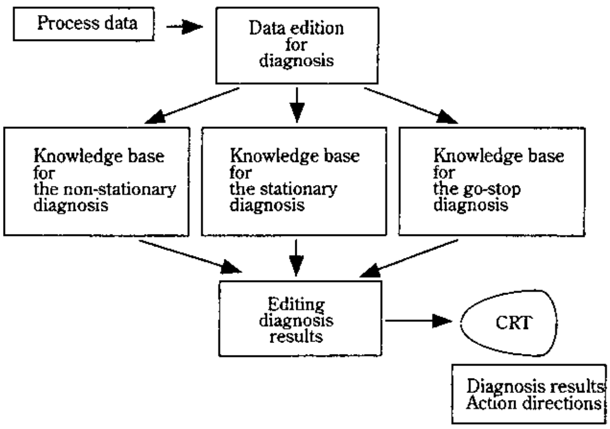

Fig. 3 Configuration of the knowledge base in the blast furnace expert system

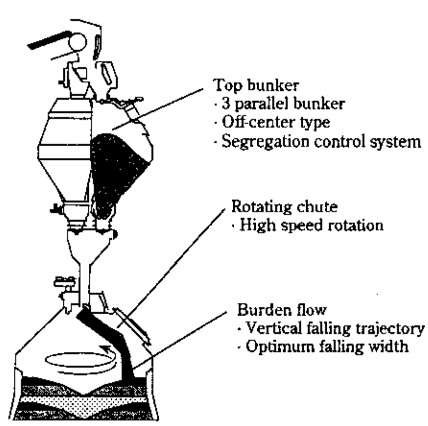

Fig. 4 New top charging system for Chiba Works No. 6 BF (2nd campaign)

Table 1 Scale of the knowledge base

	Number of production rules	Number of knowledge frames	Execution timing
Knowledge base for the stationary diagnosis	508	50	Every 5 min, 15 min, and 1 day
Knowledge base for the non-stationary diagnosis	50	5	Executed by events
Knowledge base for the go-stop diagnosis	37	1	Every 15 min

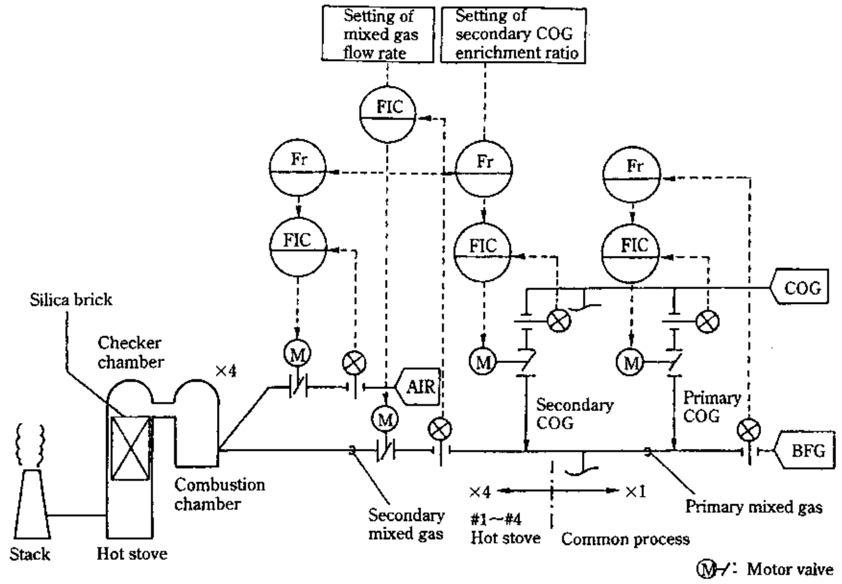

Fig. 5 Gas flow of hot stove combustion process and its control system

future. The following are also considered in the phase of engineering.

(1) Chance free setting of charging schedule
(2) Highly accurate position control of the flow control gate and the charging speed control of the material
(3) Free settings of the rotation speed of the chute

Regarding the operation of the raw material charging, the realization of fully automatic control, except for the change of the charging schedule, has helped to make operation more stable.

5 Hot Stove Control

5.1 Outline of Process and Instrumentation

Figure 5 shows the process flow of the hot stove combustion and its instrumentation system. The fuel gas, a mixture of blast furnace gas (BFG) and coke oven gas (COG), is burnt at the burners with air. The gas is so controlled that it can adjust the deviation of heat level for each stove by the addition of secondary COG at each branched line.

Ideally, the hot stoves should minimize energy costs by heating the air up to the prescribed temperature consuming less gas while controlling the temperature distribution of the checker bricks with a view to brick protection. The trick is how to set the combustion gas flow rate during the combustion period. Before the introduction of this control, the setting of mixed gas flow rate and secondary COG enrichment ratio had been manually conducted at the time of changeover from blast to combustion.

5.2 Fuzzy Control Model and Its Contribution

Kawasaki Steel has developed a model by applying fuzzy theory to the automatic setting of combustion gas flow rate and its calorie that used to be determined from the empirical knowledge of the operators. This automation has greatly contributed to energy-savings; the thermal efficiency has increased by as much as 3%[6].

Figure 6 shows the general flow of this fuzzy control system. Judgments and inference are made based on the heat level of each stove at the end of the blast period measured from the thermometers and the opening of control valves. Considering the heat that must be taken out at the next blast period, the input heat value for the subsequent combustion period is calculated. Finally, the mixed gas flow rate and the secondary COG enrichment ratio are determined giving the set points of those for the next cycle. During the first campaign of the No. 6 blast furnace at Chiba Works and current other blast furnaces, the main portion of the fuzzy control was implemented in the P/C. For the second campaign of the No. 6 blast furnace at Chiba Works, the whole system has been incorporated into the DCS using commercial fuzzy control software. As a result, the more accurate judgment of heat level and quicker response to changes in operating conditions have been achieved and the new system has helped to increase efficiency.

6 Remote Operation and Automation of Cast-house Equipment

Remore operation and automation of the cast house equipment has been a long-term goal to improve working conditions for the operators. In the second revamping work of the No. 6 blast furnace at Chiba Works[7], all mechanical and electrical systems were fully replaced for remote operation and automation. **Figure 7** shows the layout of the cast house and **Table 2** lists the features

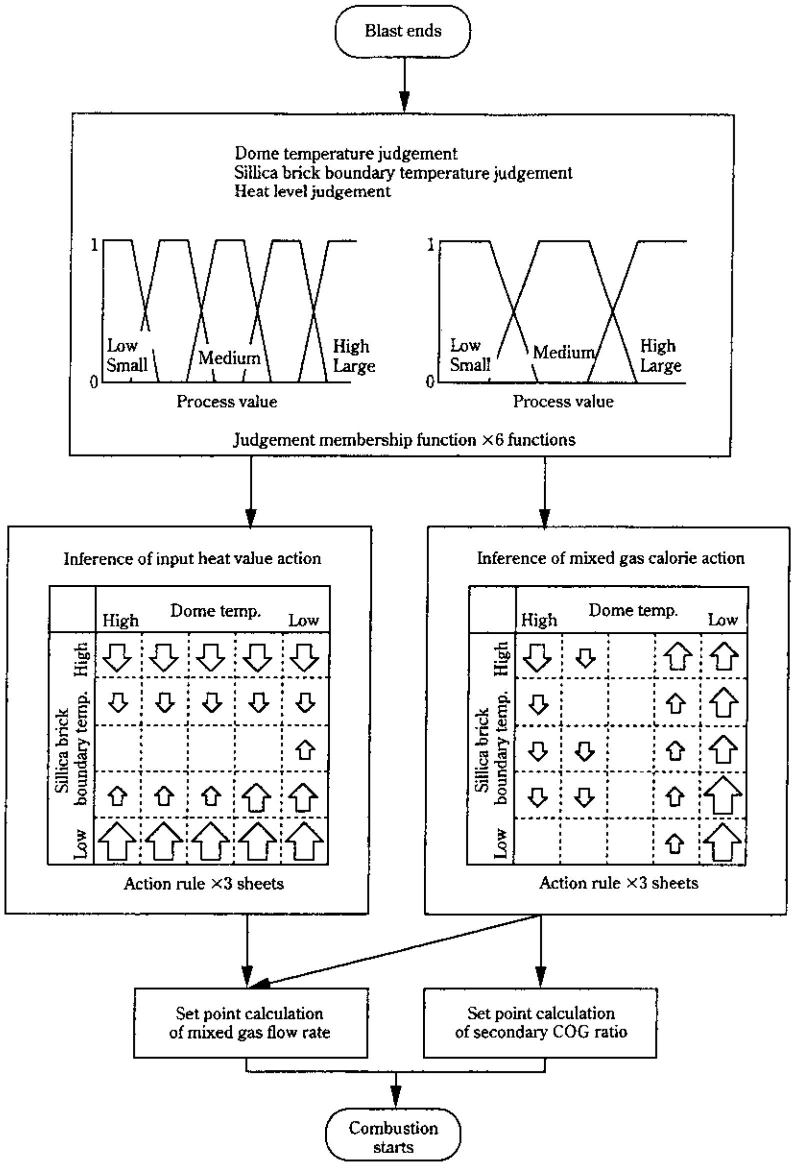

Fig. 6 General flow chart of fuzzy control system (Chiba Works No. 6 BF)

of the new equipment. For the layout, a tilting runner and an opener were installed for use by two tap holes. A new operation room was built beside the case-house. Various improvements have been made on the motion control of cast house machines such as single motion control of mud-guns.

6.1 Remote Operation and Automation of Tap Hole Opening and Closing Work

To increase the efficiency of opening and closing tap holes, a cover traverser in front of two tap holes and a rod changer for an opener were installed. The former works sequentially with the mud gun and the latter works with the opener. These machines used to be operated using a telecontroller, but now they are one-touch operated from the central control room beside the cast house.

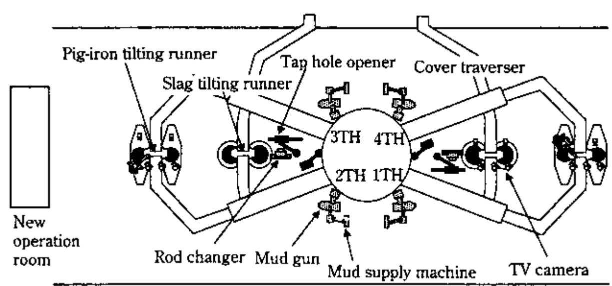

Fig. 7 Layout of cast house

To realize the one-touch operation, the sensors for motion feedback control are important and the sensors,

Table 2 Feature of the renewal on cast house equipment

Name of equipment	Feature of renewal for the 2nd campaign
Mud gun	Fully replaced 1-motion control Increased hydraulic pressure
Top hole opener	Fully replaced Hydraulic system One system for two tap holes
Cover traverser	Newly introduced One system for two tap holes
Rod changer	Newly introduced
Desiliconization equipment	Fully replaced
Slag deformer charging equipment	Newly introduced
Tilting runner	One system for two tap holes
Torpedo weighing machine	Newly introduced; 4 sets

which need to be resistant to harsh thermal conditions, were introduced. Hence, the position of each cylinder and the pressure at the cylinder become measurable, and they are used for the position control of the opener and mud-gun.

6.2 Remote Operation of Tilting Runner

For the filling work of molten metal, torpedo car weighers and a couple of monitor cameras have been introduced in addition to the microwave-type hot metal level meter. By monitoring these measurements and the images obtained from the cameras, the tilting runner can be operated from the central control room. Moreover, the auxiliary machines related to the filling function, which include desiliconization equipment and a deformers-charging machine, have been introduced and they are also remotely operated.

For the filling of slag, monitor cameras are also newly introduced, and the remote operation covering from the tilting of the runner to the motion control of toeing car is realized.

6.3 Improved Data Gathering Function

In the first campaign, reports were hand-written by the operators. It was time-consuming to manually enter information such as amount of pig-iron filled in a torpede car, the used amount of desiliconization and deforming flux, the amount of mud used for the stoppage of the tap holes, the depth of the tap holes opened, etc. Since the second revamping, however, all of the above-mentioned data have been automatically gathered.

6.4 Centralized Operation Room

In addition to the above-mentioned upgrading, the control system for the auxiliary equipment such as slag granulation, dust collecting, and desiliconization was also replaced during the second revamping work of the No. 6 blast furnace at Chiba Works. The operation of such system used to be conducted at independent local panels at different locations in the field. However, all these operation can now be done at the new central control room and the labor efficiency has significantly improved.

7 Conclusions

The plant control technologies that have been applied to blast furnaces are described in this paper, focusing on the examples conducted in the second revamping of the No. 6 blast furnace at Chiba Works.

(1) The EI control system for the blast furnace is composed of an appropriate combination of electrical PLC1, instrumentation DCS and PLC2. The process control functions have been transferred to the EI system while the process computer now specializes in information processing and is developed to a down sizing and distributed system.

(2) In the field of furnace diagnosis and condition control, the system can now give appropriate guidance and timely action through the introduction of knowledge-based system.

(3) For the burden distributin control, a function to improve the controllability and flexibility of the control system has been developed in combination with the introduction of a bell-less top charging device.

(4) For the hot stove combustion control, the automation of gas flow rate setting and improved thermal efficiency have been achieved by the revised fuzzy control.

(5) At the cast house of Chiba Works No. 6 blast furnace, the automation and remote operation of cast house equipment such as tap hole openers and mud guns has helped to improve the working environment.

References

1) T. Iwamura and O. Iida: *Keisou*, **35**(1992)1, 24–28
2) A. Inayama, M. Sakurai, Y. Maki, T. Suzuki, F. Tominaga, and H. Kamano: *CAMP-ISIJ*, **12**(1999), 296
3) O. Iida, S. Taniyoshi, T. Uetani, T. Sawada, M. Hashimoto, and D. Onoda: *Kawasaki Steel Giho*, **23**(1991)3, 210–217
4) T. Suzuki, A. Inayama, Y. Maki, F. Tominaga, H. Kamano, and J. Miyata: *CAMP-ISIJ*, **12**(1999), 295
5) S. Hirose, H. Sugawara, and S. Taniyoshi: *Kawasaki Steel Giho*, **25**(1993)4, 253–257
6) Y. Maki, A. Takashima, H. Obata, O. Iida, K. Nakashima, and T. Sawada: *Kawasaki Steel Giho*, **22**(1990)3, 196–202
7) Y. Morikawa, H. Kamano, T. Kawai, H. Marushima, and T. Matsumoto: *CAMP-ISIJ*, **11**(1998), 896