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COMPUTER CONTROL OF BLAST FURNACE

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I. INTRODUCTION

The data which directly indicates the level of blast furnace operating techniques are coke rate and pig iron rate. A comparison of the average values for these in Japan over the last 10 years is given below.

Item \ Year	1953	1958	1968
Coke rate (kg/t)	840	675	504
Pig iron rate (t/m^3)	—	0.82	1.73

It can be seen that considerable progress has been made in operating techniques. One of the reasons behind this progress has been the advances made in the facilities themselves. However, the biggest reason has been the drive toward centralization, automation and other forms of rationalization of even supervision and control, as well as the realization of more precise, more reliable measurement and control. Looking back on the history of blast furnace instrumentation, the instruments which measured blast volume, pressure, and temperature, and top pressure and stoke line level sounding and ore cutting measurement of ten or so years ago gradually become more numerous and sophisticated with the increased complexity of furnace operations until centralized control using a number of panels mounting a large number of meters and installed in a control room was reached. We have now progressed to a type of instrumentation which includes [control] and is by the development of new blast temperature control and oil injection control, in addition to blast volume, pressure, and temperature control, and top pressure control and which has elminated only [metering] from instrumentation and automatic compounding of materials, automatic insertion, hot blast stove combustion and automatic switching control, etc.

In addition, the development of a reliable process use electronic computer accompanying the rapid growth of digital techniques in the next few years will permit centralized control of the complete blast furnace installation, including furnace control having a complex interrelationship, through the utilization of expanded data processing capabilities. Fuji Electric has installed a number of blast furnace computer control systems starting with the No. 3 furnace of the Nagoya Iron Works of Fuji Iron and Steel. This article gives a detailed description of of this system based on our experience.

II. OUTLINE OF PLANT

The blast furnace is a vertical type furnace which produces pig iron by reduction of iron ore. The iron ore, coke, limestone, manganese ore, etc. is inserted from the top hopper in suitable grain size and compounding ratio. Hot air is forced into the furnace from a hot blast stove and reduction of the iron ore is performed at a temperature of 1,600~1,700°C. An outline is shown in *Fig. 1.*

The blast furnace plant can be roughly divided into:

(1) Raw material cutting and insertion system
(2) Blower and hot blast stove system
(3) Furnace unit

Control and metering of these systems is performed for:

(1) Stable operation
(2) Increased pig iron
(3) Reduced operating costs
(4) Stable product quality
(5) Safe operation
(6) Research and development on new techniques

III. OBJECTIVE AND CONSIDERATIONS RELATED TO INTRODUCTION OF COMPUTER CONTROL

The necessity for computer control of the blast furnace plant has been recognized for many years, but since the large number of difficult problems involved in furnace control made the design of a perfect system impossible, large scale systems were never introduced. However, there are a large number of cases in which special computers have been introduced in the raw materials system and for logging.

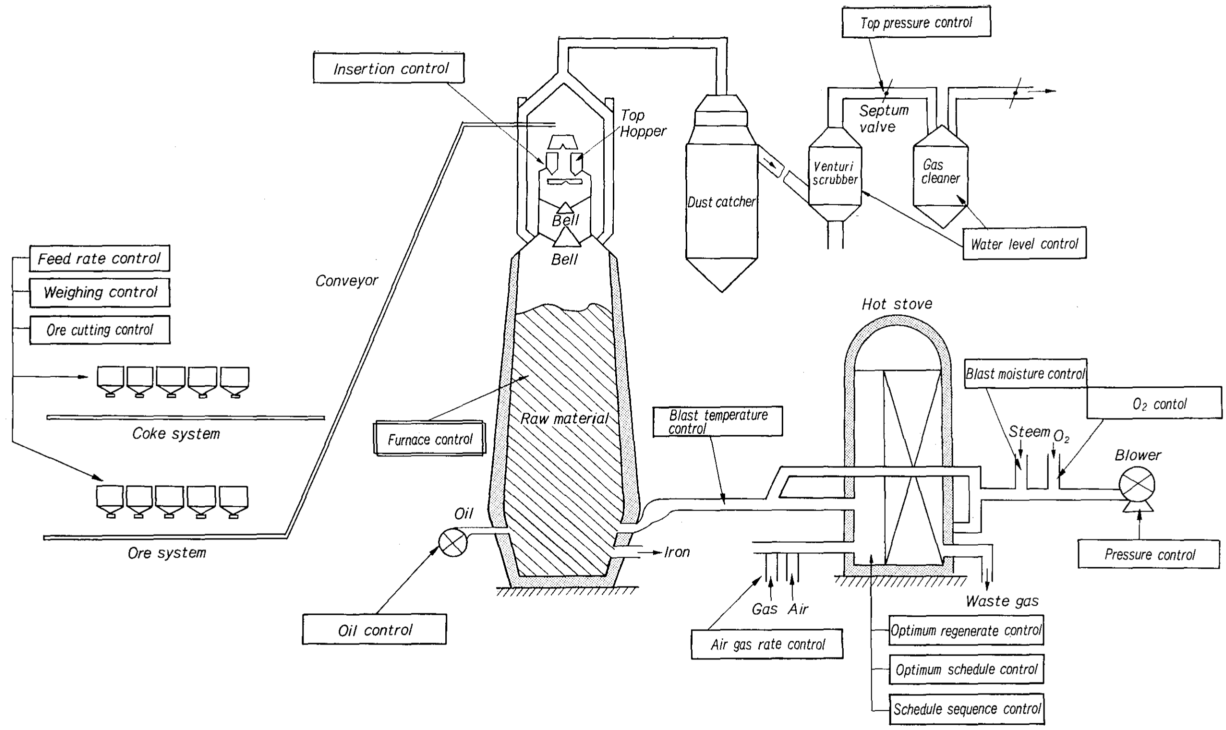

Fig. 1 Schematic diagram of the blast furnance control system

The development of suitable computer hardware and software in recent years has made on-line analysis through the use of actual data possible even for furnace control. This method has been recognized as a furnace control and analysis shortcut and the introduction of computer systems into large scale and high pressure blast furnaces has been recently given consideration. The main objectives of introduction of computer control are stable operation, large volume, high quality pig iron, and reduced costs. A list of items required would be:

(1) Collection and storage of data
(2) Plant supervision and operator guide
(3) Sequence control
(4) Plant control by computer
(5) Perfect furnace control through plant analysis and preparation of mathematical models.

Complete computer control including all these items is possible, but since sufficient result can be expected even if only only one of these items is performed, the items to be performed must be amply studied and decided in the system planning stage.

The method of introducing a computer into the plant will now be discussed. As previously mentioned, the blast furnace can be roughly classified into:

(1) Raw materials cutting and insertion system
(2) Hot blast stove and blower system
(3) Furnace unit.

The two methods shown in *Fig. 2* (*a*) and (*b*) can be considered when introducing computer into each of these systems.

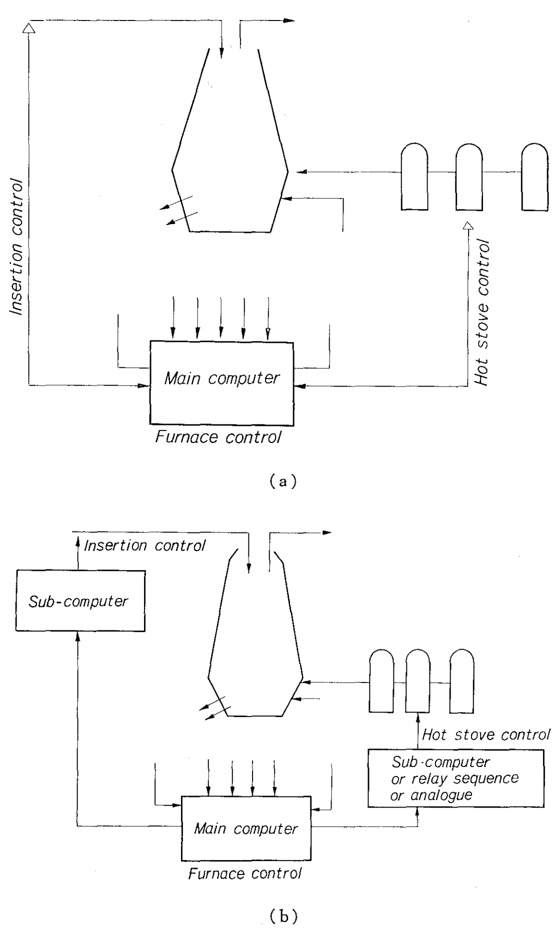

Fig. 2 Computer control system of the blast furnace

The method shown in *Fig. 2* (*a*) is a system in which the raw materials system, hot blast stove, and furnace unit are individually controlled by computer. Since furnace control is fairly difficult, there are a large number of cases in which computer control is first introduced into the raw materials system and then into the furnace later. However, since these systems are not mutually independent, their relationship as a whole must be amply studied. The method of *Fig. 2* (*b*) shows the case of introduction of a single computer for the complete system.

The method most suitable for any particular case is difficult to choose, but the present trend is toward the method of figure (*a*) when introducing the computer into an existing blast furnace in order to provide control equipment suitable for the raw materials system and hot blast stove, while the trend is toward overall control of the blast furnace using the method of figure (*b*) in the case of new construction. However, since reliability is extremely important when considering the quality of the blast furnace plant, careful consideration must also be given to back-up, etc.

IV. COMPUTER CONTROL

Since the major objectives have already been given, a detailed description of each system will be given in the following.

1. Raw Materials Cutting and Insertion System

The raw materials cutting and an insertion system are vital in supplying raw material to the blast furnace. Moreover, since a large amount of materials is supplied, variations in quality, composition, water content, amount, etc. will distrub the blast furnace and thus disturb stable operation. In addition, since material balance is one of the most important items in the furnace control described later, insertion, cutting, etc. must be perfectly controlled. It is for this reason that a computer is introduced into this system first.

The major objectives of introduction of computer control into the raw materials system are :

(1) Material ratio control
(2) Weighing control
(3) Cutting and insertion sequence control
(4) Cutting and insertion data collection and management

A detailed description of each of these objective is given in the following.

(1) Material ratio control

The compounding ratio of the materials required at the blast furnace side is determined to obtain the lowest costs with the ore currently on hand. Since the amount of raw materials used is large, a reduction in cost in this way is fairly important.

In actual practice, these are still problems points concerning control conditions, etc. which must be solved, but examples of their solution using LP techniques have already been reported. A block diagram is given in *Fig. 3*.

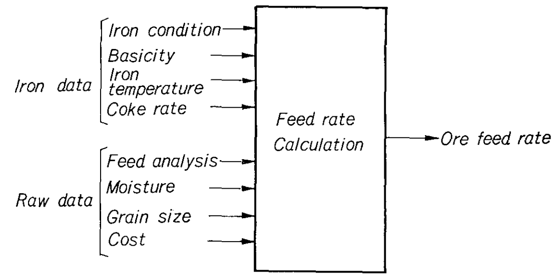

Fig. 3 **Block diagram of the material ratio calculation**

(2) Weighing control

Weighing control automatically weighs the raw materials cut at the ratio determined by ratio control, compensates for errors in the insertion amouut, and inserts the raw materials into the blast furnace without disturbing the furnace. Generally, the materials are discharged in accordance with a specified schedule after the specified amount of material has been inserted into each hopper. However, the specified amount is not necessarily discharged due to the flow, clinging to the hopper, etc. Consequently, the full amount and the empty amount after the materials have been discharged are read into the computer, the remaining amount and flow amount produced during discharge are automatically compensated, and the overall cutting amount is made constant by a type of integrating control which changes the cutting amount by changing the setting value when the amount exceeds a certain specified value.

(3) Insertion sequence

Positive control of the average discharge pressure valve and other head devices must be performed at the set sequence for insertion of the discharged raw materials without disturbing the state of the blast furnace. Introduction of a computer into this section will also result in system simplification, ease of operation changes, etc. However, since the top section is also an important field and incorporation of a sequence considering semi-automatic and manual operation is generally employed in Japan at the present time, there are very few cases of sequence control performed by computer. However, the instroduction of a computer in this area is sure to be considered in the future.

(4) Data collection, recording, and management

The importance of management of raw materials data in a blast furnace has already been mentioned.

For this reason, the collection, recording, and management of this data is performed at each insertion charge and in hourly and daily units. Furnace control has been recenly studied and its method of management has become fairly complex.

2. Hot Blast Stove

The demand for stable operation of the hot blast stove has accompanied the increased size of blast furnaces and the development of high temperature, high pressure blast furnace operation and other blast furnace operating techniques. Since operation of the hot blast stove also disturbs the operation of the blast furnace the same as the raw materials system, precise control is demanded. Control of the hot blast stove has already been accomplished using analogue controllers, relay circuits, etc. However, this is one field in which introduction of a computer will result in better control.

The objectives of the introduction of computer control into the hot blast stove are:

(1) Determing the ideal switching schedule
(2) Ideal combustion control
(3) Blast temperature control
(4) Switching sequence control
(5) Introduction of a DDC system

(1) Determining the ideal switching schedule

As described in Section II, the hot blast stove performs a mutual " combustion " " blast " cycle. If we consider efficient use of the hot blast stove in this case, the " combustion " must be suppressed by continuing the " blast " for as long as possible after completion of regeneration.

The blast system generally used in the past has been the single blast system shown in *Fig. 4* (*a*). In this system, since the regeneration of the stove immediately after switching to " blast " is large, the the temperature of the hot air is higher than the temperature required at the blast furnace side. Consequently, the temperature is lowered by mixing cold air. For this reason, when the temperature at the stove outlet drops below the temperature required at the blast furnace side, the " blast " is stopped and operation is switched to " combustion ". The latest method to be used to lengthen the " blast " period is the parallel blast system shown in *Fig. 4* (*b*). As shown in the figure, in this system parallel blasting is performed by mixing the stove having the lower temperature of the two stoves in the same manner as the cold air of the single system. In this way, the outlet temperature of the stove is within the " blast " even when the temperature of the stove outlet drops below the specified temperature

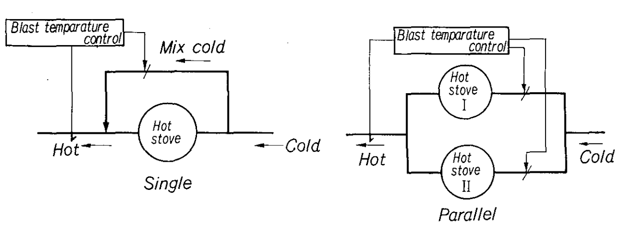

Fig. 4 Schematic diagram of the hot blast furnace blower system

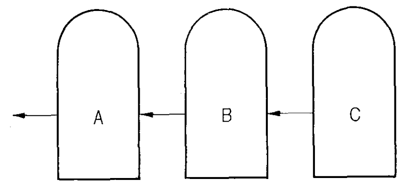

Fig. 5 Block diagram of hot blast furnace

of the blast furnace side and heat exchange efficiency is increased.

In order to perform good control with this system, the regeneration and heat dissipation completion period of the stove must be predicted and the ideal switching schedule given.

For example, if " *A* " and " B " are assumed to be in " blast " and " *C* " is assumed to be in " combustion ", the period required for " *A* " to complete its " blast " (" *C* " is assumed to have completed regenaration at this time) and up to the completion of regeneration by switching to combustion is predicted (refer to *Fig. 5*). If this is made T_{AH}, " *B* " and " " *C* must perform " blast " during T_{AH}. For this reason, prediction of period T_{BCF} at which blasting is possible with " *B* ", " C " blast temperature *t* and flow *F* and switching of the stoves at time $T_{AH}=T_{BCF}$ is permissible.

In this way, an ideal switching schedule can be determined by predicting the time up to regeneration completion when switched from " blast " to " combustion " and the period " blast " is possible by means of the amount of regeneration retained by the stove.

(2) Ideal regneration control

When the regneration completion time is determined by a switching schedule, ideal regeneration control is performed by manipulating the air fuel ratio and combustion gas volume so that regeneration is completed in accordance with the schedule.

In order to accomplish this, a mathematic model which simulates the hot blast stove must be prepared. This becomes possible with the introduction of a computer.

(3) Blast temperature control

Both the single and the parallel blast systems shown in *Fgi. 4* must be controlled so that the temperature of the hot air at the blast furnace side remains constant. In the case of the single system, feedback control in which the amount of cold air is controlled in accordance with the hot air temperature is generally used. However, when disturbances are produced, such as when the hot blast stoves are switched, sufficient control cannot always be expected due to the measurement delay of the thermocouples, etc. and there are cases in which predictive control is also performed by computer. In the case of the parallel system, if the temperature of the two stoves is made T_I, T_{II}, the blast volume is made F_I, F_{II}, and the specified temperature of the blast furnace is made T, then control of the flow of each stove can be controlled by computing F_I and F_{II} from,

$$(F_I \cdot T_I + F_{II} \cdot T_{II})\ (F_I + F_{II}) = T \cdots\cdots\cdots\cdots (1)$$

$$F_I + F_{II} = F \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (2)$$

(4) Switching sequence control

Sequence control in switching the hot blast stoves from " combustion " to " blast " and from " blast " to " combustion " is fairly complex and is generally performed by relay sequence. However, switching sequence control by computer will result in a reduction in costs, simplification of the system, etc. However, in this case, operation in the case of manual operation, semi-automatic operation, etc. must be thoroughly studied.

(5) Introduction of a DDC system

Introduction of a DDC system into the hot blast stove has been considered in newer systems. This is also economically advantageous, but since the combustion and blast cycle of the hot blast stove changes at a fairly high frequency, stable control of the transient state, that is, start up and shut down, can be expected with computer control.

3. Furnace Unit

Since full scale computer control of the furnace unit involves the problem of furnace control and numerous other difficult problems, it will be discussed later. However, the control system currently in use and considerations required in the introduction of computer control will be discussed here.

The following control loops can be considered (refer to *Fig. 1*)

(1) Pressure control
(2) Oxygen addition control
(3) Blast moisture control
(4) Oil control
(5) Top pressure control
(6) Gas washer water level control

Typical examples of these will be described in the following.

(1) Pressure control

The blast to the blast furnace is heated in the hot blast stove and then sent to the blast furnace. Since the hot blast stove is a regeneration type, it must be switched at fixed intervals. At this time, the " blast " to the furnace is temporarily disturbed. In other words the hot blast stove which has been newly switched is at almost atmospheric pressure. Air has been blasted up to the blast tube side. For this reason, the hot blast stove that has been newly switched is filled only up to the pressure of the blast tube and if fed at a fixed air flow, then the flow to the blast furnace naturally decreases. Pressure control is performed to prevent this drop in air volume.

The introduction of computer control permits predictive switching of the hot blast stoves and processing in response to switching of hot stoves and continuous blasting without disturbance.

(2) Oxygen addition control

Oxygen addition control at the blast furnace serves to restore the state of the funance, which tends to cool, by rising the orifice tuyere precombustion temperature. Perfect dissolution of the fuel and dissolution heat compensation ahead of the orifice tuyere during the oil injection operation can be expected. The effect of the oxygen addition operation has been theorectically clarified, but since oxygen was expensive it has not come into use until recently. In recent years, however, exygen has been made cheaper by advances made in oxygen generation facilities and its use has become popular. The introduction of computer control can also be considered in oxygen addition, etc.

(3) Blast moisture control

The moisture content must be maintained constant by injecting steam into the main cold air line. Detection of the moisture content is generally performed by means of lithium chloride, but the problems of measurement delay and measurement accuracy are involved. Moreover, since disturbances due to blast pressure, flow, etc. are numerous, good results cannot be expected with conventional analog control. However, improved control characteristics can be expected when control is performed by the introduction of a computer.

(4) Oil control

Oil injection is one of the blast furnace fuel injection techniques and the injection of air from the orifice tuyere of the blast furnace and the injection of oil into the furnace contribute to the regeneration reaction of the iron ore. The purpose of oil injection is to reduce the coke rate and increase the pig iron. Since this leads to a reduction in the cost of the iron, its effect is considerable. Since the oil injected into the blast furnace contributes to the regeneration reaction of the iron ore, the amount injected must be controlled in accordance with the pig iron and blast volume. Moreover, since it has a group purge and injection and other special control modes, more suitable control can be expected through the introduction of computer control.

(5) Top pressure control

The top pressure is controlled by an septan valve installed at the end of the primary washer. This control system receives large disturbances when the materials are inserted and is relatively stable at other times. However, since it changes widely with the operating state, in high pressure operation, control suitable to operation is desirable and computer control utilizing decision by the computer can be considered.

4. Furnace Control

Furnace control is control of the temperature and composition at the pig iron at the target value and all iron and steel manufacturers are actively engaged in the developement of models. However, a positive system has yet to be established. This is because:

(1) The state of the bottom of the furnace prior to pig iron cannot be directly measured and indirect contact must be grasped from the gas content at the top or must be predicted from the melted iron data when pig iron extraction is performed in batches and the bottom of the furnace must be simulated using some suitable method.

(2) Since there is about a 10 hour delay from insertion of the raw materials to melting and pig iron extraction, this time delay must be amply considered in material insertion control and pig iron extraction control.

(3) Since top gas analysis, composition of the inserted materials, furnace temperature and pressure, and other errors are included in the measurement input, the true value cannot be measured and these inputs must therefore be judged and corrected.

(4) A solution cannot be found from only the theory of chemical reaction inside the furnace, state of dropping of the physical materials, heat dissipation from the furnace wall, state of the molecules of the slag, dust content, reaction heat, etc. and there are are many unclear points.

Therefore, establishment of a model is difficult. At the present time, we have progressed to the point where the blast furnace process is known and analysis of current blast furnace operation has been improved as one approach to a perfect mathematical model. Analysis of blast furnace operation is performed by fiinding the interrelation between the actual plant and the gas flow inside the furnace, orifice tuyere temperature, pig iron composition, and pig iron amount, etc. by solving them theoretically by means of equations. Moreover, the injection of oil, oxygen addition, and increasing the pressure inside the furnace are performed to accelerate the regeneration reaction and the composition and amount of raw materials, blast temperature, etc. are equalized to prevent external disturbances to the blast furnace to improve blast furnance operation. However, in the final analysis, the aim of computer control is perfect predictive control of the furnace and a mathematical model must be prepared.

The procedures used to accomplish this are shown in *Fig. 6*.

(1) Calculation of material balance

A material balance expression of relation inside the blast furnace is prepared and the degree of material balance is studied through actual measurement. In this way, the deviation between the measured values and the absolute values are assumed, the iron yield is estimated, the duct system is estimated, and the material balance equation is revised.

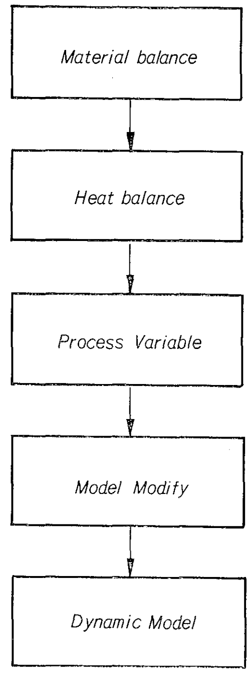

Fig. 6 General flow of the mathematic model construction

(2) Calculation of heat balance

A heat balance expression of relation inside the blast furnace is prepared, the heat balance which can be realized is studied using measured values, the chemical reaction equation, reaction heat, slag formation reaction process, molecular composition of the iron at pig iron extraction, heat loss from the furnace wall, etc. are estimated and the thermal balance equation is revised.

(3) Determining operating variables

Sensitivity analysis of the effect of the pig iron composition and temperature which become the objective function by changing the various amounts which become the operating variables is performed from the materials balance equation and the thermal balance equation. The operating variables which have a large effect on the objective function is found from this and the operating variables which have no effect are lumped into a single variable and an abbreviated model equation is constructed.

(4) Revision of the model with actual data

The material balance and thermal balance equations are collated with the actual plant data, the coefficient of the statistical model is revised from the results, and a static model coinciding with the actual furnace is prepared.

(5) Preparation of a dynamic model

A dynamic model based on the static model is prepared by entering time elements.

5. Plant Supervision and Operator Guide

Since the interior of the blast furnace cannot be directly supervised, changes in the interior state of the furnace, that is, hanging, slip, etc. supervision and prevention has normally depended upon operator experience. Since the differences in the skill of the operators has a direct effect on the product, standardization of supervision and operation is required. The introduction of a computer in this area easily satisfies this demand by combining pattern recognition, logical decision, etc. and suitable operator guidance is also possible.

At the same time, supervision of the furnace, for example, furnace body and furnace floor temperature, cooling water leakage, etc. is possible and the operator can be alerted of any trouble.

6. Data Collection and Management

The amount of data in the raw materials system, hot blast stove, and furnace unit is large. The computation and processing of this data in the form required for overall centralized operation is one field in which the computer excels. Generally, the following data processing is performed.

(1) Raw materials system

Raw materials composition, cutting and inserting amount, name, etc. is processed and printed at each charge. Moreover, the total by name are printed out in the required format either at fixed intervals or at any arbitrary time.

(2) Hot blast stove system

The amount of fuel used, switching interval, air fuel ratio, etc. are printed at switching and in the necessary format at fixed periods or at arbitrary times.

(3) Furnace system

Raw materials dropping speed, furnace body temperature, blast temperature, pig iron composition and amount, top gas composition, and other data required for operation are printed out at uniform periods. Inputs which vary, such as gas component input and flow from a gas chromatograph, are not only calculated as average values but smoothing of the data and distribution of the data are considered and the data processed by mathematical techniques coinciding with its input.

(4) Changes in state and alarms

Changes in furnace pressure, pig iron, air increase, and other furnace states are printed out periodically. Moreover, when the furnace wall temperature, blast flow, and other inputs vary from the specified values, supervision of operation is performed by printing the value, time, etc. Recently, a total system which controls the overall plant has come to be adopted and data collected at the blast furnace is exchanged with the computer using a communications lines and a paper tape system and greater overall data collection and management can be expected.

V. CONCLUSION

An outline of computer control of a blast furnace has been given in the above. However, since there are still a number of points, such as furnace control, which must still be solved, complete computer control is impossible. However, the introduction of the computer covered in this article is a short cut and since improved control, data management, and supervision functions in its process are anticipated, the introduction of a computer into the blast furnace plant has blossomed in recent years. Fuji Electric is also endeavoring to development software to aid iron and steel producers.