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Instrumentation in Ironmaking Process

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Instrumentation techniques in ironmaking process, mainly some unique function of sensors developed by Kawasaki Steel Corporation, are described as follows: (1) Yard: Ore bin level meter, automatic operation of yard machines, and quality monitoring system (2) Sinter plant: Raw material moisture meter, waste gas analyzer, heat pattern measurement, and waste gas volume pattern measurement (3) Blast furnace: Gas distribution measurement, burden profilemeter, burden surface monitor, vertical distribution measurement, circumferential distribution measurement, burden distribution control, equipment monitoring system, and instrumentation for hot metal handling.

The body can be viewed from the next page.

Instrumentation in Ironmaking Process*

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(1) Yard: Ore bin level meter, automatic operation of yard machines, and quality monitoring system

(2) Sinter plant: Raw material moisture meter, waste gas analyzer, heat pattern measurement, and waste gas volume pattern measurement

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1 Introduction

Since ironmaking comes at the start of the production process in an integrated steel work, a stable supply of pig iron is required first of all. Since energy consumption in ironmaking reaches about 75% of the whole consumption in the steel works, efficient operation of the ironmaking process is essential and greatly affects profitability.

Problems common to all stages of the ironmaking process consist of difficulty in making a quantitative analysis of the operation of the respective stages and the lack of the simple and clear-cut means of conveying the dynamic phases of the process. Recently many studies have been made in an effort to grasp the nucleus of the process including the one represented by the furnace body dissection survey.

In addition, findings from the above studies led to the development of new instrumentation techniques and computer-aided information processing techniques, contributing greatly to visualizing various phases of the ironmaking process. In sintering, product quality has been stabilized, and a low SiO_2 and low FeO operation challenged; in the blast furnace operation which has also been stabilized, fuel ratio has been reduced drastically, with the service life of all types of equipment prolonged.

This report mainly describes sensor techniques used in the ironmaking process, introducing some special features found useful in operation improvement and interesting from the viewpoint of instrumentation techniques.

2 Instrumentation in Raw Materials Processing

The material flow in the iron and steelmaking starts at the raw materials yard. Therefore, it is necessary to stabilize the supply of raw material to succeeding processes, that is, sintering plant and blast furnace, and to improve and stabilize the quality of raw materials. Further, it is essential to have an efficient operation of huge yard machines and extensive and complex conveyer system.

Consequently, accurate grasping of the quantity of raw materials has become the essential point of instrumentation, and strenuous efforts have been made to increase the accuracy of the belt conveyer and bunker level meter. Efforts toward computerization have also been directed for some time in grasping the quantity of inventory, controlling the quality of raw materials, and optimizing conveyor scheduling[1,2]. Recently, automatic or remote operation of yard machines has been successfully accomplished[3,4] for labor saving by combining yard machines with various kinds of sensors and microcomputers.

Since the sintering process treats more than 70% of main materials to be supplied to the blast furnace, the quality of the sinter product has a substantial influence on the blast furnace operation. Energy consumption

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** Chiba Works
*** Mizushima Works

in this process accounts for about 10% of the total in the steel works, and therefore, reduction in coke consumption and unit fuel consumption in the ignition furnace pose serious problems. Compared with other processes, this process is required to have a more strict environmental consideration involving desulphurization and denitrification of waste gases.

Kawasaki Steel Corporation adopted DDC (Direct Digital Control) of the sintering process some time ago[5] and established an efficient instrumentation system concerning desulphurization and denitrification. Recently emphasis is laid on developing an advanced instrumentation system for closer grasping of the sintering process itself.

2.1 Automation of Yard Machines

Kawasaki Steel has long been working toward automatization of various machines on the vast raw materials yard so as to release operators from field work, thereby saving labor.

The first accomplishment was operation of the blast furnace ore bin. Complete operation of the ore bin was attained[2] by using self-travelling level meter[6] utilizing ultrasonic waves and data communication between the blast furnace process computer and the yard process computer.

At the West Plant of Chiba Works, existing 4 stackers and 5 reclaimers were automated[3,4]. The main points of the automation are as follows, being performed in the system as shown in **Fig. 1**:

(1) Remote control of stacker and reclaimer operations from the yard operation room (unmanned operation)
(2) Full automation of stackers after presetting
(3) Automatic "feeding" of raw materials after they are landed on the stack by remote control operation.

Features incorporated in sensors are 5 ITVs mounted on machines, an ultrasonic level meter, an electrostatistic capacity type level switch, and a collision preventing equipment using microwaves. This system saves 20 persons in manpower with no loss in handling capability compared with manual operation of the machines.

This automation system is significant not only in its development as to automation itself but also in its contribution to blast furnace operations through

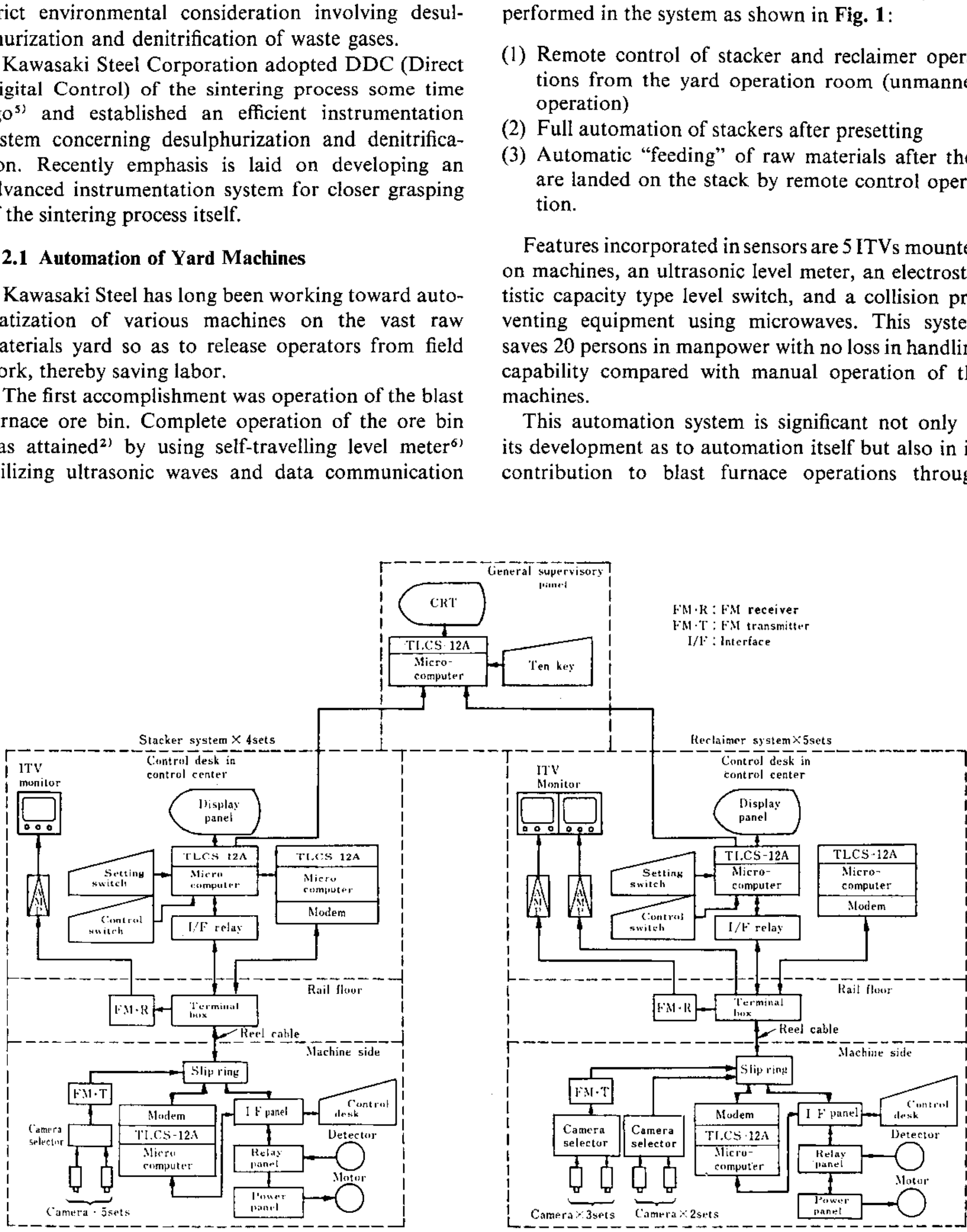


Fig. 1 Automatic control system of stackers and reclaimers

prevention of particle size segregation of raw materials for the furnace by the use of the ore bin level control.

2.2 Improvement in Sintering Process Instrumentation

2.2.1 Improvement in moisture measurement of raw materials

The measurement of moisture in raw materials and coke is extremely important for improving the accuracy of blending ratio and for maintaining required permeability. Conventionally, a neutron moisture meter was used, but since it posed problems in radiation and measuring accuracy, an infrared ray type moisture meter has been newly developed. Of a two-wave-length comparison type, the new moisture meter gives accurate measurements with small influence by colors or surface condition of the materials to be measured or the intensity of the light source. **Fig. 2** compares measured values between the infrared ray type moisture meter and the drying method.

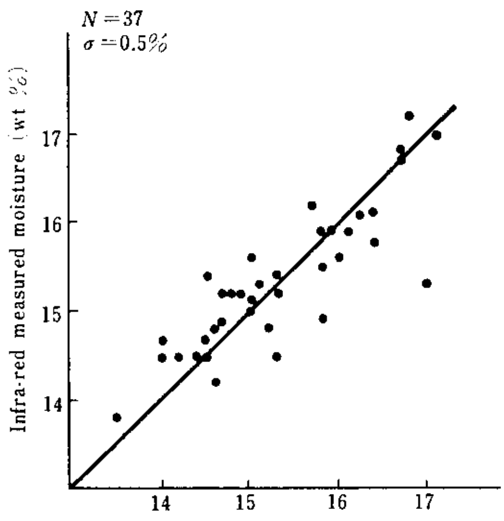


Fig. 2 An example of coke moisture measurement performance by infra-red type moisture meter in comparison with conventional manual analysis by drying method

2.2.2 Pressure control of sintering ignition furnace

The ignition furnace has a function important to the progress of sintering reaction in igniting coke laid atop the raw materials and supplying energy and air required for the sintering reaction. In order to save ignition energy, suction pressure control is performed in the ignition furnace[7]. As the result, appropriate surface temperature is maintained, and the fuel gas saved by 1 Nm^3/t-sinter.

2.3 Instrumentation for Analysis of Sintering Process

2.3.1 Waste gas analysis

Waste gases are analyzed to grasp the condition of the chemical reaction in the sintering process. Analyzed value of the waste gas is put into process computer, together with the flow rate, temperature of the waste gas and other data, and utilized for monitoring the sintering process.

2.3.2 Measurement of heat pattern

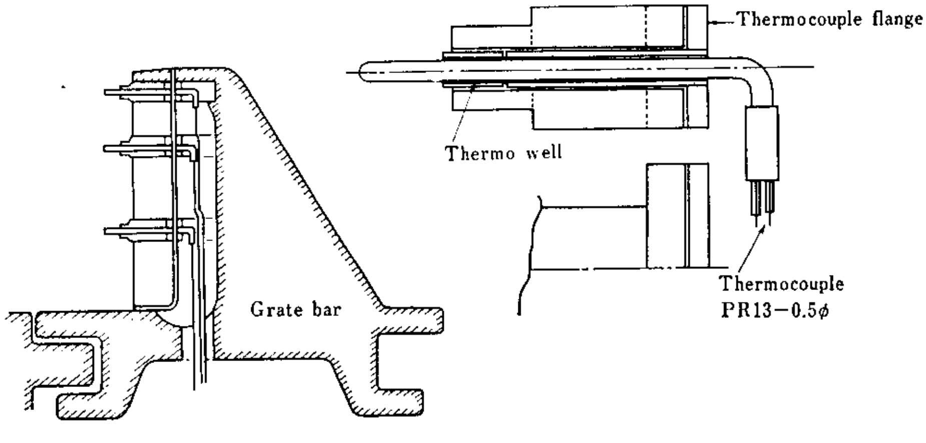
The quality of sintered ore is governed by the chemical composition of raw materials and their characteristics at the high temperature melting zone in the sintering process. Therefore, a heat pattern measuring device was developed to know the temperature distribution in the sintering layer[8-10]. In this device, the temperature inside the layer is measured with three thermocouples each fixed vertically to the specially-prepared edge of the grate bar, and measured values are transmitted by radio. **Fig. 3** (a) shows the schematic drawing of the device. The relation between the index of the heat pattern and the shatter strength is shown in **Fig. 3** (b). Since there is a significant correlation between the heat pattern and the quality of products, it is possible to control the quality of sintered ore by monitoring and controlling the heat pattern.

2.3.3 Measurement of wind volume distribution

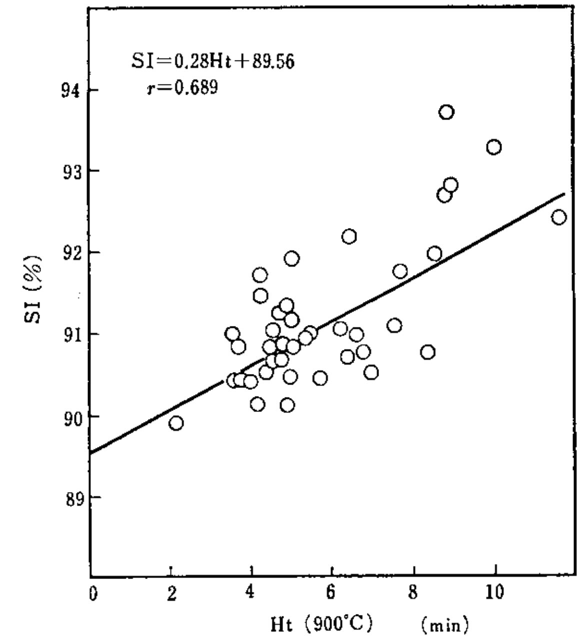
The wind volume in the longitudinal direction of the sintering machine varies with the difference in permeability of the sintering bed. Since the difference is generated by the progress of the sintering process, the in-layer condition can be estimated, though indirectly, through the measurement of the wind volume. Thus, a device for measuring the suction wind volume by the wind box placed on the sintering bed has been developed[11] to prevent the influence of air leakage. The device has two functions of the mechanism; one to obtain stable flow velocity distribution in the wind box, and the other to perform automatic measuring and position returning along with the movement of the sintering machine. **Fig. 4** shows the sectional view of wind box and the flow velocity distribution in the box. A turbulent flow is formed at the measuring point of flow velocity to guarantee stable measured values. The authors are now working on further utilization of wind rate distribution measured for the estimation of in-layer reaction, and for operational control and wind volume distribution control.

2.4 Instrumentation for Quality Control in Raw Materials Processing

As one example, quality monitoring system for iron ore bed is explained as follows. Iron ore for sintering



(a) Measuring device



(b) Relation between shutter index, SI and high temperature holding time Ht

Fig. 3 Sinter heat pattern measuring device and applied data

is stacked in multi-layered beds and cut out by the stacker-reclaimer for achieving a uniform chemical composition. In the quality monitoring system which evaluates chemical composition at this bedding stage, measurement is made of the weight of iron ore stacked for each position in the longitudinal direction of the bed, and the distribution of chemical composition in the bed is found by using individual composition already known. The system has the following features: One of them is that the quality (chemical composition) can be evaluated at the bedding stage, and therefore, quality problems (stacking troubles) can be handled quickly. The other is that no expensive sampler and analyzer are required. **Fig. 5** shows a comparison between actual measurement (analysis) and estimate by monitoring in terms of a chemical component (SiO_2).

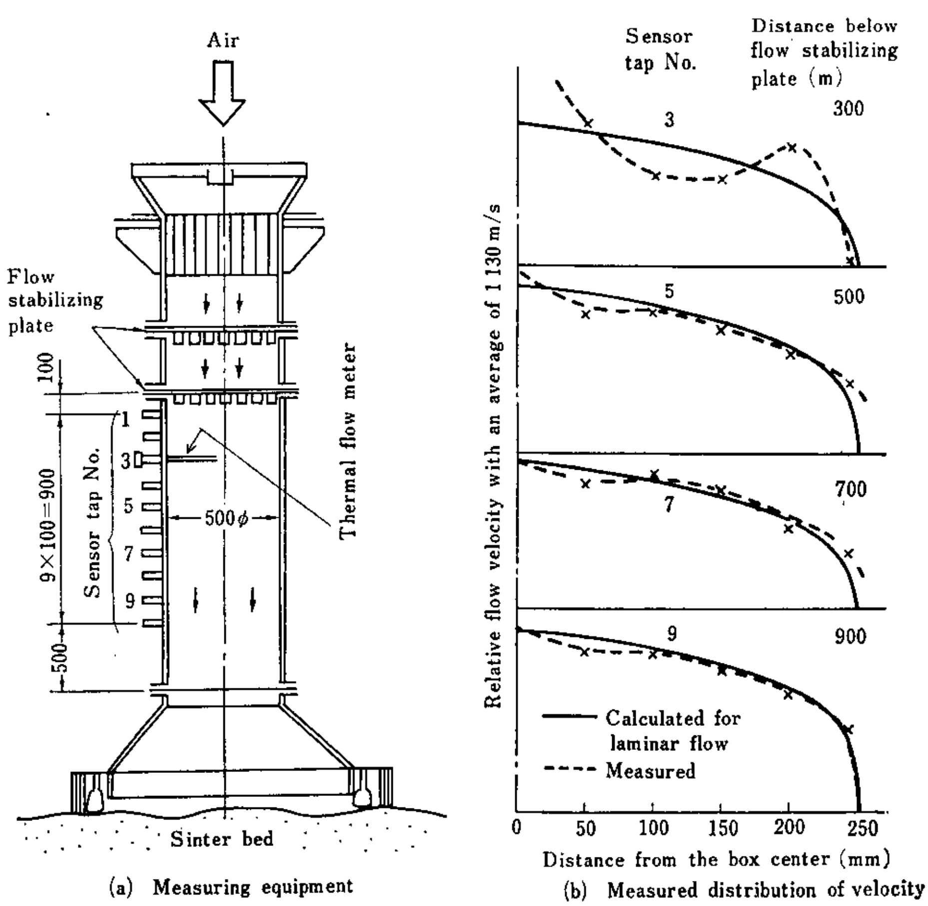


Fig. 4 Gas flow measurement on a sintering bed

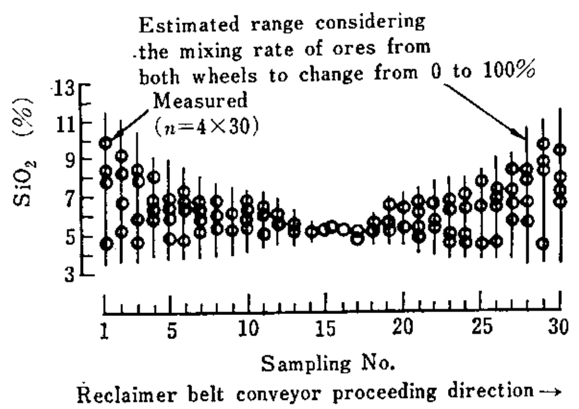


Fig. 5 Comparison of estimated and analyzed content of SiO_2 in ore bed quality monitoring system

3 Instrumentation of Blast Furnace

Recently, the blast furnace is being completed as a designed huge total process, because the furnace itself is designed larger, with various kinds of energy saving equipment joined to it, and anti-pollution and power-saving equipment also upgraded. For an efficient and reliable operation of this large-scale system, instrumentation control has also employed new devices and techniques positively[12], such as development of new sensors, integration of many types of information and attempts at blast furnace total control. **Fig. 6** shows an example at Chiba No. 6 blast furnace, which incorporates digital instrumentation techniques and communication control techniques to a maximum level and aims at blast furnace total control with distributed control of individual subsystems and full consideration of continuity with adjacent operations[13].

Recent major progress in blast furnace operation includes the following:

(1) Establishment of gas flow distribution control and the resultant stable operation at low fuel consumption
(2) Decrease in trouble with blast furnace equipment and marked prolongation of the blast furnace life
(3) Quantitative analysis of blast furnace process and effective use of various types of information.

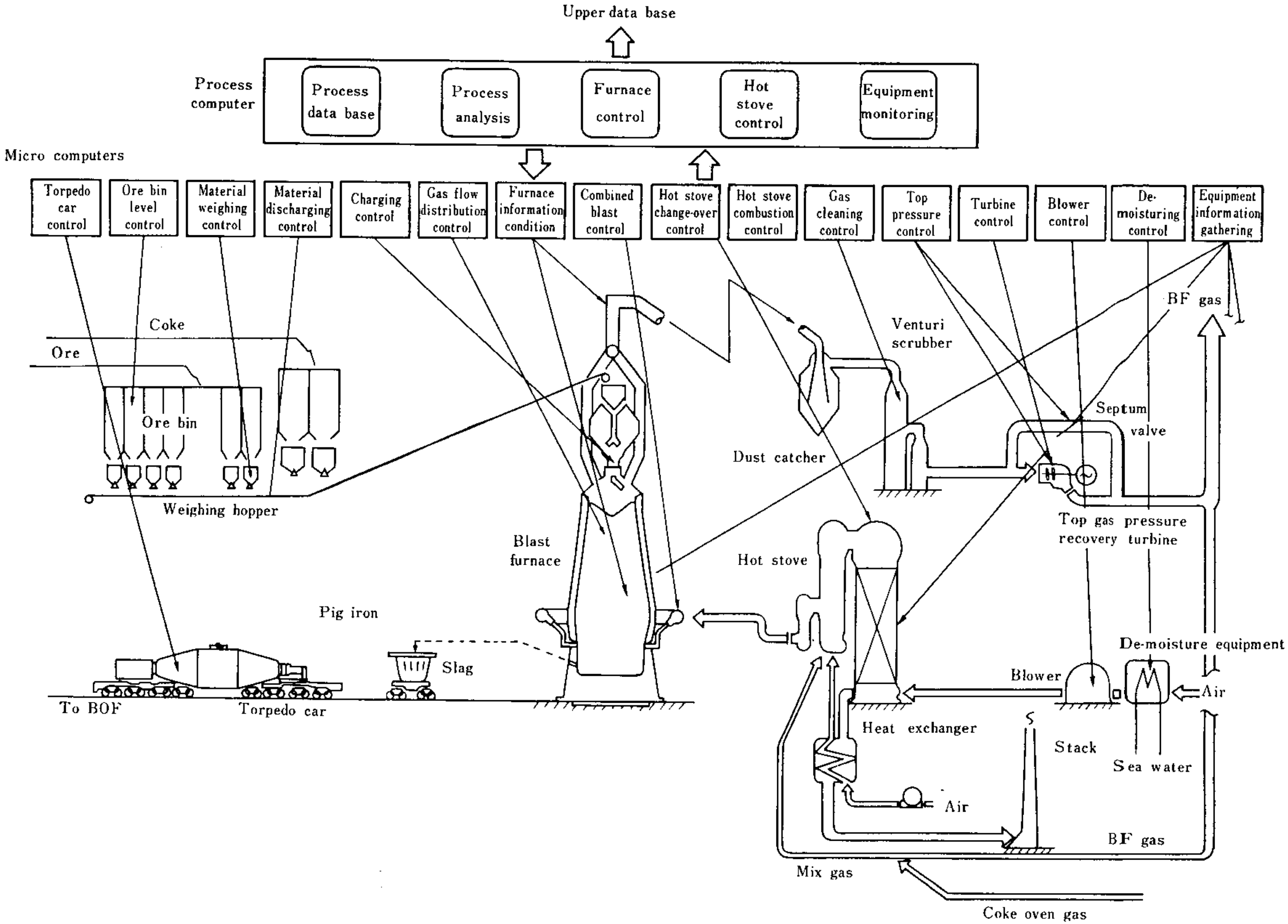


Fig. 6 Advanced control and information processing system of a blast furnace

Instrumentation and operation techniques have progressed interdependently, stimulating each other. On one occasion, the former met the needs of the latter while, on another, the development of the former gave an impetus to the latter.

This chapter mainly describes sensor techniques for the blast furnace as the basis of the above-mentioned progress and one of the most characteristic.

3.1 Instrumentation and Control of Gas Flow Distribution

The gas flow distribution inside the blast furnace is closely related to the operational efficiency of the blast furnace, and appropriate control of the gas flow distribution is extremely important for blast furnace operation[14]. As a result of dissection survey of the blast furnace, the existence of the cohesive zone and many reaction mechanisms in the blast furnace have been clarified, and the relation between these findings and the gas flow distribution are also being revealed gradually[15].

Against this background, the authors have recently taken active steps in developing sensors to measure the dynamic condition of the furnace interior, especially the gas flow distribution[16].

3.1.1 Measurement of gas flow distribution

For the method of gas flow velocity measurement, attempts have been made to use direct velocity measurement by the turbine meter, fluidics flow-meter, etc.[17,18], but the measuring method which is now in practical use is an indirect measurement employing temperature or gas analysis.

The indirect measuring method using temperature is represented by the fixed temperature probe of the throat in which the gas temperature distribution is measured with CA thermocouples placed at intervals in the radial direction.

The indirect measuring method using the gas composition includes the moving sampler that works above or in the burden. The latter has the merit of measuring the gas flow distribution without being influenced by gas flow turbulance at the furnace top, although it requires greater driving power and structural durability.

Fig. 7 shows operation trends at No. 6 BF in Chiba Works, together with typical charging patterns at the following three periods:

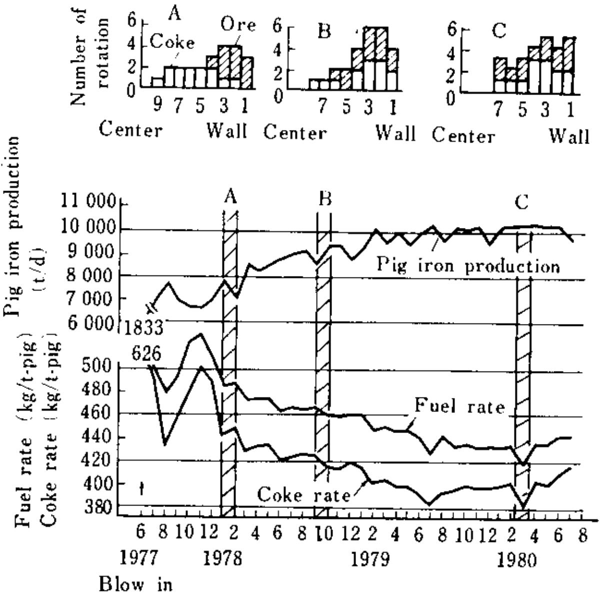
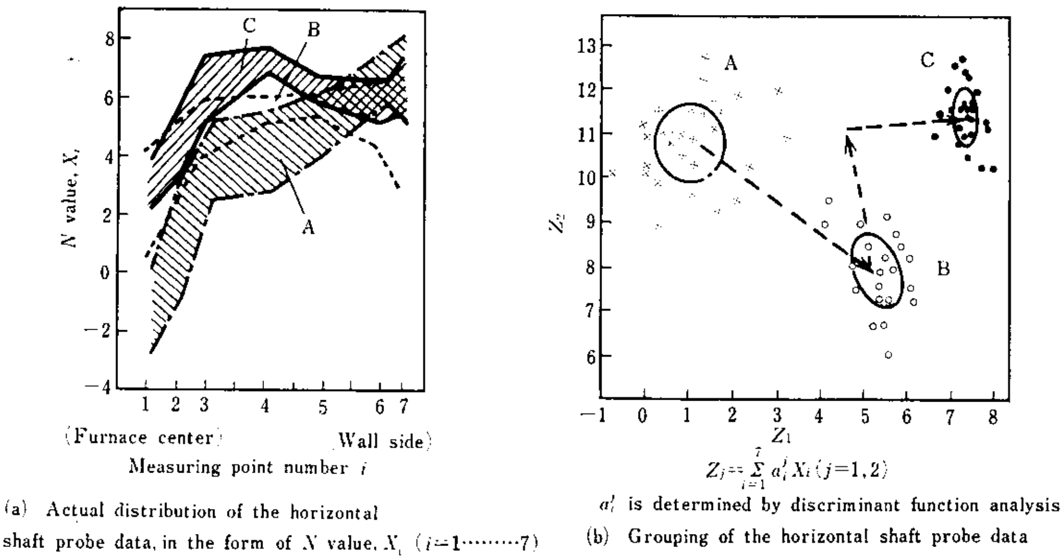


Fig. 7 Operation trend and typical charging pattern of Chiba No. 6 BF



(a) Actual distribution of the horizontal shaft probe data, in the form of X value, X_i ($i=1 \cdots\cdots 7$)

(b) Grouping of the horizontal shaft probe data

Fig. 8 Evaluation of data given by horizontal shaft probe

A: Excessive central flow; frequent tuyere bending troubles

B: Excessive peripheral flow; frequent tuyere melting troubles

C: Accomplishment of low fuel ratio by performing the high processed ore ratio test

Fig. 8 (a) shows the range of dispersion of daily mean values of gas component (expressed in the N value; $N = 18 \times (CO_2\%)/\{(CO\%) + (CO_2\%)\} - 3$) at each period of A, B and C, and large overlapping is formed between the three periods. In **Fig. 8** (b), these data are classified into groups by the discriminant function procedure, and clear separation is observed[19].

From these results, it is clear that the gas flow distribution in daily operation can be sufficiently controlled by the fixed temperature probe or the travelling sampler for gas composition measurement. At this time, it is also important that pattern information obtained from such device should be subjected to an adequate quantitative processing as explained above.

3.1.2 Measurement of burden profile

Gas flow distribution can be controlled by adjusting the layer-thickness distribution in the radial direction of the ore and coke with a movable armor or a PW type bell-less charging device. Therefore, the burden profiles of ore and coke are important as a more direct feedback information with less delay than the gas flow distribution[16]. Kawasaki Steel has been developing three methods in parallel, that is, the mechanical method[20], microwave method[21], and laser method[22], to be applied to this measurement. **Fig. 9** shows a comparison of these three methods and **Fig. 10** examples measured by the respective methods. **Fig. 10** (b) shows the profile movement at the time of stock line changes, measured by the microwave method, and **Fig. 10** (c) shows the profile movement at every rotation of the PW-type rotating chute, measured by the laser method. Both values show interesting results.

Since these three methods have their own merits, the method to be adopted should be determined in consideration of function requirement and its cost.

The authors are now investigating the correspondence between the profilemeter data and operation and it is considered necessary to study redistribution caused by influx of the charged burden into the furnace center.

3.1.3 Monitoring of burden at furnace top

Monitoring units of the burden surface at the furnace top include the unit for monitoring the surface temperature of burden by an infrared-ray camera and the unit for monitoring the movement of burden by a silicon visicon[13,23].

At Mizushima No. 2 BF, a system has been developed which processes 8 level temperature-distribution information obtained by an infrared-ray camera using a microcomputer and can detect burden influx into the center by observing the changes in the sectional area of each temperature zone along the passage of time.

The burden movement monitoring unit displays television pictures of the burden surface at the near infrared-ray zone by means of a silicon visicon. It

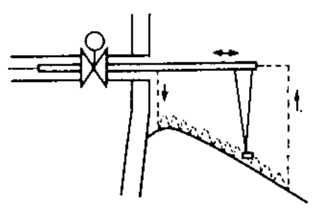
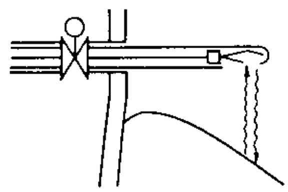
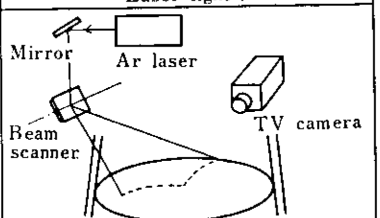
Type	Mechanical	Electro magnetic	Optical
Means	Wire and weight	Micro wave	Laser light
Principle			
Specification	(1) Measuring time 60 s (2) Accuracy ±50 mm (3) Measuring area About 10 points	120 s ±130 mm One radial line	2 s ±50 mm A part of surface
Merits	Low cost and good accuracy	Easy for maintenance Multi-purpose use of probe	High speed measuring Surface measuring

Fig. 9 Outline of three methods of profile meter

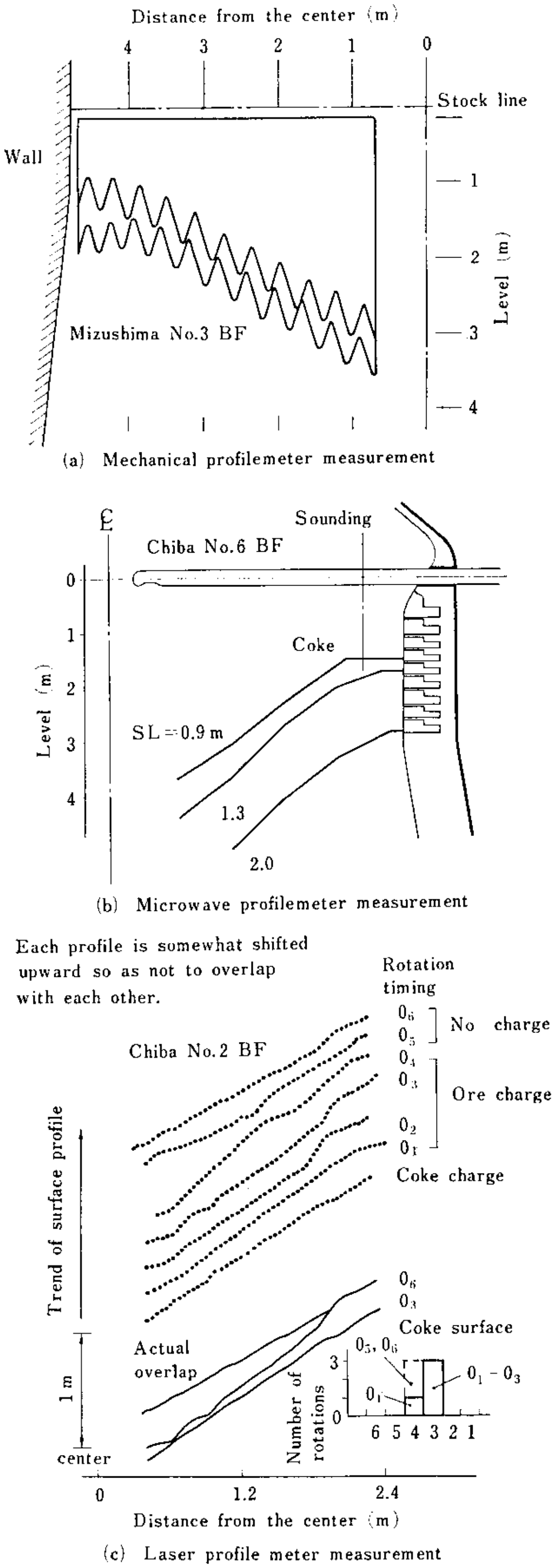


Fig. 10 Examples of burden profile measurement

can directly visualize the movement of raw material lumps themselves on a TV screen and is used for monitoring such abnormal in-furnace conditions as burden influx or "channelling."

Since the blast furnace interior of high temperature and high pressure contains a large quantity of dust, various techniques are applied to washing and protecting the measuring window in both the infra-red and silicon vision type camera. **Fig. 11** shows the configuration of the burden movement monitoring unit.

3.1.4 Measurement of burden distribution in the vertical direction

Changes in the temperature and composition of in-furnace gas in the vertical direction are measured to grasp the reduction and heat exchange process of iron ore inside the furnace, while changes in gas pressure are measured to know changes in physical properties (powdering, softening, fusion, etc.) of burden and its abnormal descent. These measurements were very difficult in the past owing to severe in-furnace conditions. In recent years, strenuous efforts are being made to obtain quantitative clarification of the furnace interior[24]. Measuring methods include a continuous measuring in which the probe is fixed inside the furnace and a batch measuring method in which a detecting probe is inserted along with the descending burden. **Fig. 12** shows an outline of these two methods. For the fixed method, wear of the probe by burden must be considered; therefore, durability of the probe is required. For the insertion method, a horizontal component of the burden movement must be considered for identification of measuring position. **Fig. 13** shows an example of measurement by the three-point type temperature measuring probe[25] used by No. 2 BF at Chiba Works. This figure clearly indicates that thermal reserve zone exists.

For a macro-analysis measuring of the pressure distribution in the vertical direction, shaft pressure is measured, and complete instrumentation for this purpose has already been incorporated in the routine operation. The essential point in this measurement is to maximize the pressure outlet hole and minimize dust inclusions due to the breathing phenomenon in the duct tube. **Fig. 14** shows the method newly adopted by Kawasaki Steel[26]. Fine results have been obtained by this method through the use of a line-mount type pressure sensor.

3.1.5 Measurement of burden distribution in the circumferential direction

Uneven circumferential distribution of the burden is also generated by an untimely tapping of slag and hot metal from the furnace or the influence of depositions on the furnace wall. If the uneven distribution

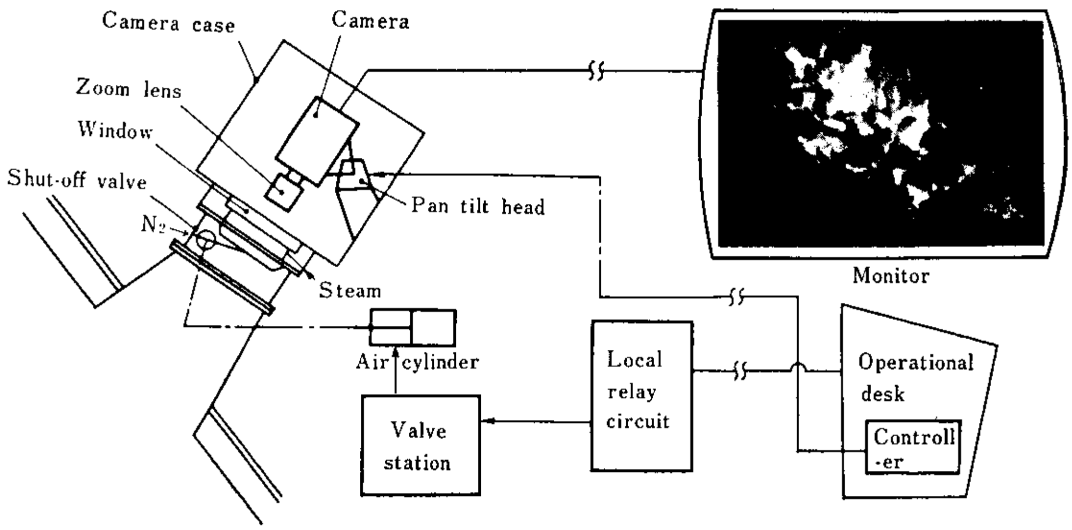


Fig. 11 Configuration of ITV system

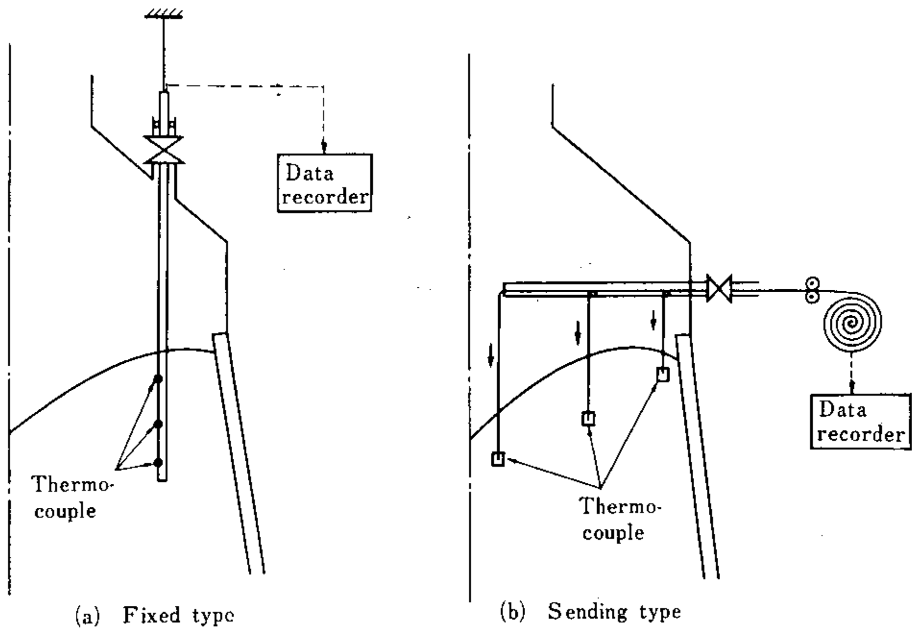


Fig. 12 Two methods of temperature distribution measurement in vertical direction

exceeds some point, it induces the deviation of products quality and quantity by the tap hole, partial hanging, slipping or the damage of a specific tuyere. Therefore, it is necessary to discover such circumferential unevenness in an early stage and remove its cause.

The distribution of blast volume in every tuyere can be used as a means of detecting the in-furnace permeability in the circumferential direction, and is calculated from pressure loss at the bend portion of tuyere branch pipe and a total blast volume[13].

In addition, the distribution of circumferential unevenness can also be estimated from information given by fixed temperature probes described above attached at several positions in the circumferential direction.

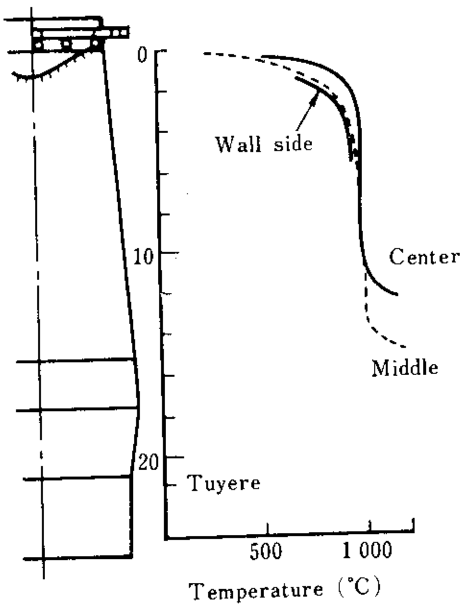


Fig. 13 An example of temperature pattern measured by 3-point sonde

3.1.6 Burden distribution control

Burden distribution is controlled by the position of the movable armor for the bell-type furnace and by the rotational pattern of the chute for the PW type furnace. Changes in the stock line and batch charging sequence are also used as a means of distribution control.

The PW type charging equipment has a higher degree of freedom compared with the bell type, but the former requires strict control of equipment with an increased load of the control device.

Fig. 15 shows an example at No. 6 BF of Chiba Works. As shown in this figure, discharge rate control of raw material is the most important operation, and the discharge rate must be appropriately controlled within a prescribed range to obtain a desired burden distribution. The flow control gate is the operational end of controlling discharge rate, and feedback control based on the measured value of the discharge rate is required for such reasons as changes in the particle size of burden, wear of the liner at the control gate or deposition of powder. Therefore, Kawasaki Steel employs a method in which the opening of the flow control gate is controlled at each charging of burden on the basis of information on discharge rates from the load cell.

3.2 Instrumentation to Detect Equipment Trouble

In order to maintain a stable blast furnace operation, it is essential to detect troubles in important equipment at an early stage and take appropriate measures of preventing serious accidents. This section describes instrumentation to detect troubles generated in the equipment.

3.2.1 Tuyere leakage detection

Leakage of tuyere cooling water occurs owing to tuyere damage arising from the abnormal fall of

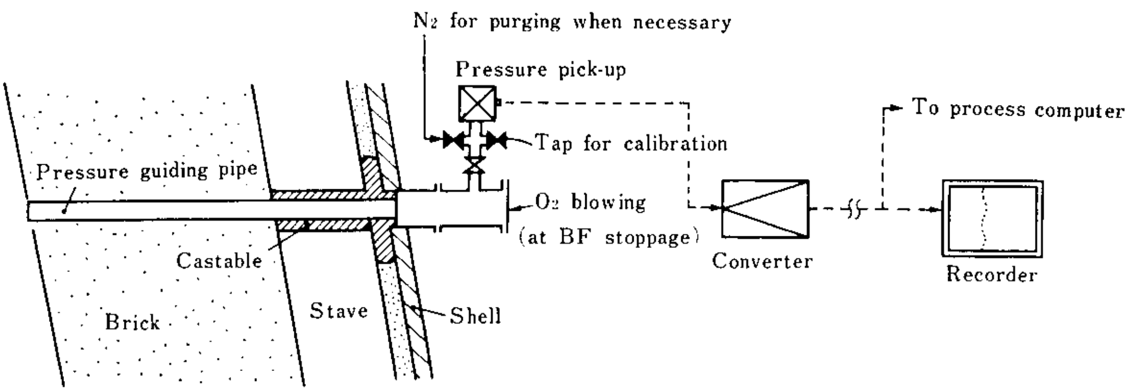


Fig. 14 Configuration of a shaft pressure measuring equipment

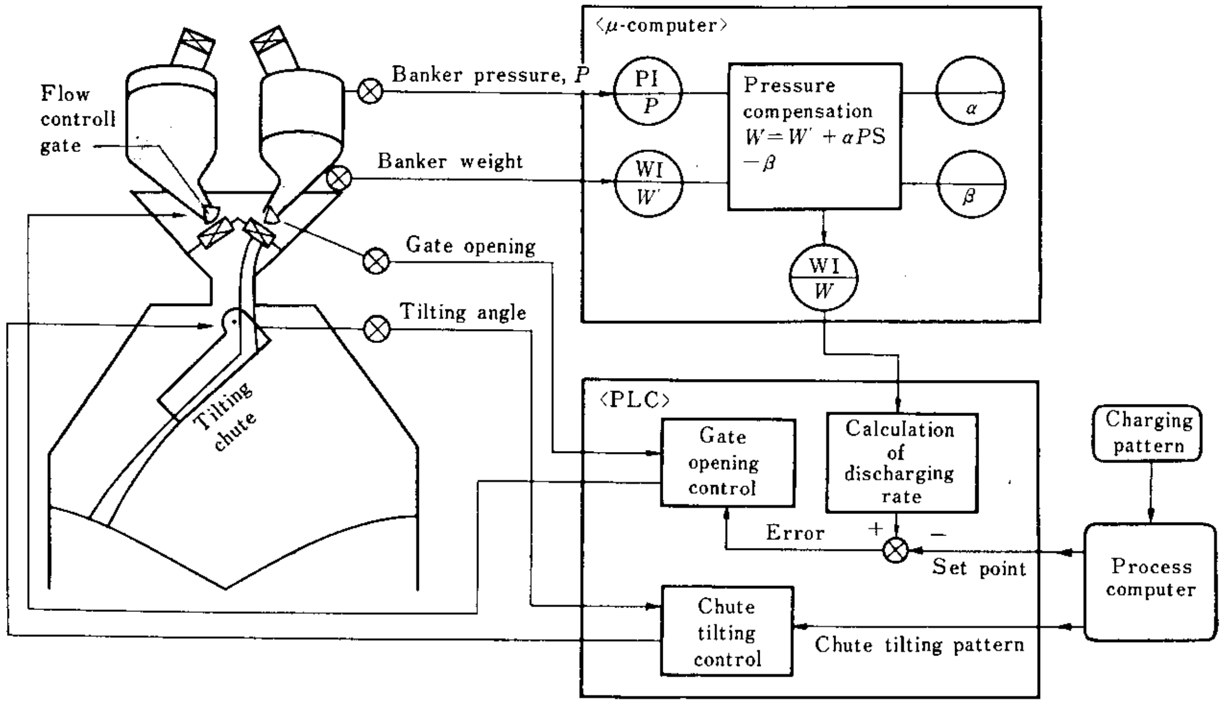


Fig. 15 Charging rate control system

charged burden, and it is important to detect the first sign of leakage and immediately replace the tuyere. Tuyere damage rarely occurs recently except for wear of tuyeres, and therefore, reliability of detection is particularly required. For the method of detecting water leakage, the difference in water flow rate between inlet and outlet, is monitored with a high-accuracy flow meter. An electromagnetic flow meter is most suitable for this purpose because it is free from pressure loss and does not generate an error alarm caused by foreign matters in cooling water.

In No. 6 BF at Chiba Works, the influence of drift is removed by installing a by-pass line for calibration use to the pipeline system, applying the same flow rate to the flow meter for water inlet/outlet and correcting the instrumental error automatically. This correction of the instrumental error doubled the accuracy of differential flow rate to within ± 1 ℓ/min ($\pm 3\sigma$). **Fig. 16** shows an example of leakage detection. The alarm is set at a 3 ℓ/min leakage, and the detection system has been keeping a record of 100% detection and 0% erroneous detection for more than four year operation.

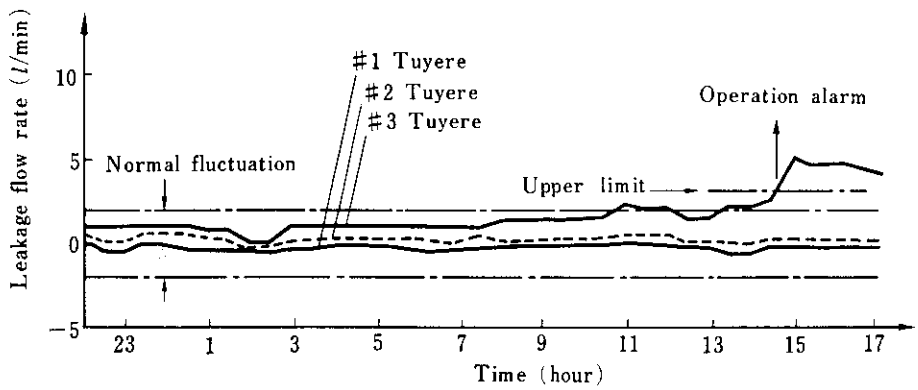


Fig. 16 An example of tuyere leakage detection system

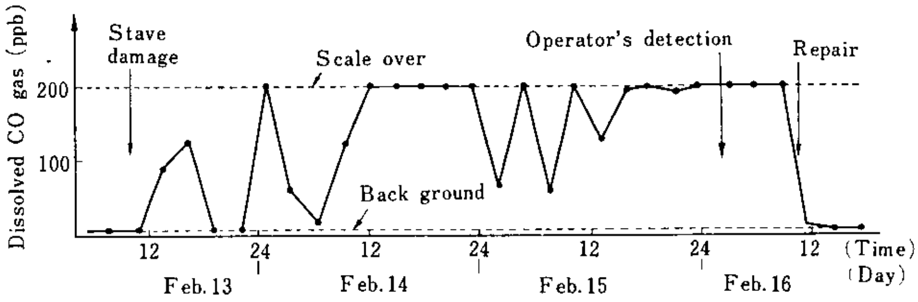


Fig. 17 Record of dissolved CO gas when a stave was damaged

3.2.2 Stave leakage detection

The differential flow rate method used for the tuyere as mentioned above, is not practical for the stave because of high cost as it has many water channels. Therefore, Kawasaki Steel has developed a system which can detect water leakage by measuring the quantity of CO dissolved in outlet cooling water[27]. In this system, outlet water mixed with the furnace gas generated as a result of stave damage is deaerated by carrier gas, thereby measuring the quantity of CO gas contained in the outlet water. This system detected all the three cases of stave damage that occurred during the test period. **Fig. 17** shows variation in the indicated value of dissolved CO at stave damage.

3.2.3 Blast furnace temperature monitoring

A large-sized blast furnace has several hundreds of temperature measuring points scattered over a wide area for monitoring furnace temperatures. If a receiving unit is to be installed for each loop of measuring points, an enormous expense would be incurred. A switching method is, therefore adopted to measure temperatures at many measuring points efficiently. In this method, switching devices are installed at several local places; and temperature signals are switched over and transmitted serially to the central data processing unit. Then the temperature data are transmitted to the supervisary process computer and informed to the operator in a processed form[28].

3.3 Instrumentation for Hot Metal Handling

Grasping the quantity and quality of hot metal is not only necessary for blast furnace operation, but also influential in the transportation of hot metal and the efficient operation of the next steelmaking process. This section describes the hot metal information management system and torpedo car hot metal level meter as instrumentation for hot metal handling.

3.3.1 Hot metal information management system

At the Chiba's West Plant, an unmanned hot metal information management system was developed for the purpose of automatic collection of hot metal information and of improving operational efficiency of the torpedo car[13]. The system performs automatic tracking of torpedo car positions by introducing an automatic torpedo number reading device and also performs automatic weighing on the track weigher by being combined with a reading device. Such information is processed integratedly by No. 6 BF process computer together with the hot-metal analysis transmitted from the analysis computer. **Fig. 18** shows an schematic diagram of the tracking system, and **Photo. 1** the CRT screen displaying the positions of torpedo cars. The system can save labor and improve torpedo car running efficiency (turnover ratio of 3.0 times/day), and has decreased the span of hot metal temperature drop to 130°C (usually 200°C), for a considerable energy saving.

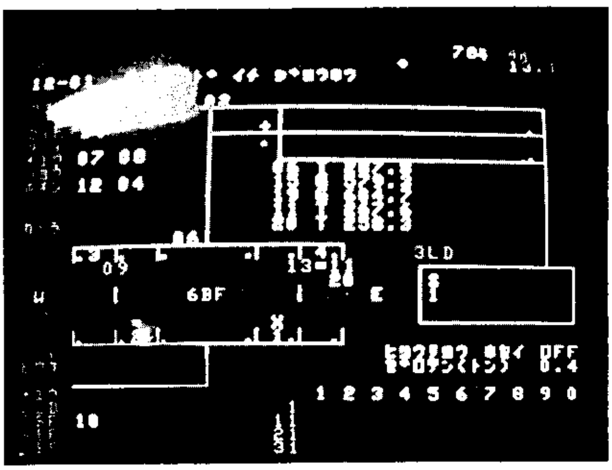


Photo. 1 An example of CRT display of torpedo car tracking

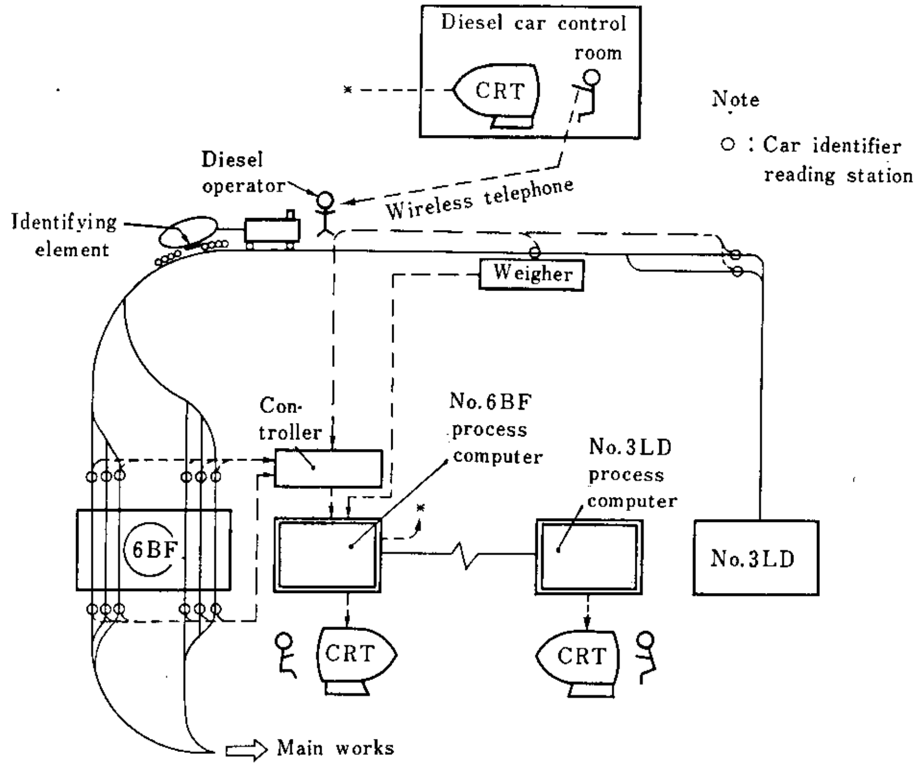


Fig. 18 Torpedo car tracking system at Chiba Works

3.3.2 Hot metal level meter

The cast house work is where automation lags far behind in all the blast furnace operation. Hot metal level monitoring for pouring hot metal upto the prescribed level of the torpedo car is the key point of the automation of cast house work and its automatic monitoring is also strongly demanded from the consideration of safety.

At Kawasaki Steel, electrode-type level meters were used for hot metal ladles in the past[29]. But the application of the level meter to the torpedo car was difficult because the latter's hot metal receiving hole was too small; and therefore, a microwave hot metal level meter was developed at No. 3 BF of Mizushima Works[30]. The surface level of hot metal can be measured with an accuracy of ± 50 mm without obstruction by dust and the like. **Fig. 19** shows an example of level measurement.

Chiba No. 6 BF employs a simplified method in which the weight of the torpedo car is measured through the measuring of the strain of rails for the purpose of level monitoring[30]. The system measures strain applied from wheels to the rail with the strain gage stuck to the rail and achieves a weight accuracy

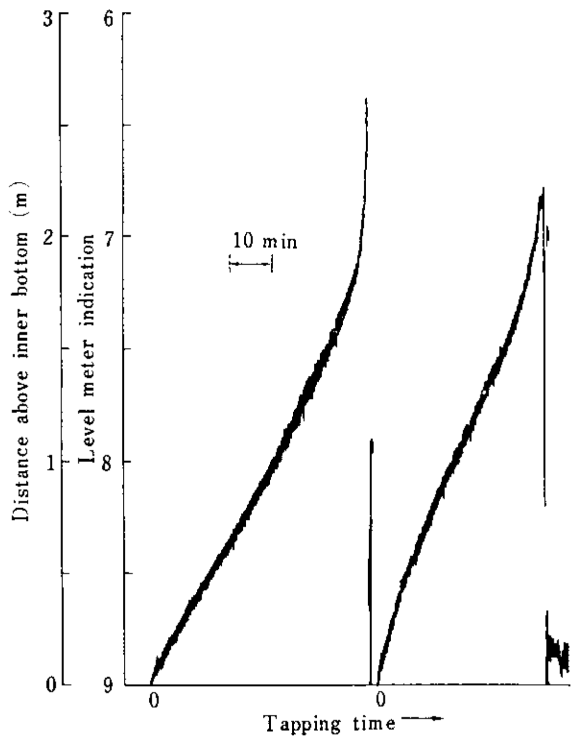


Fig. 19 An example of molten iron level measurement in torpedo car by microwave level meter

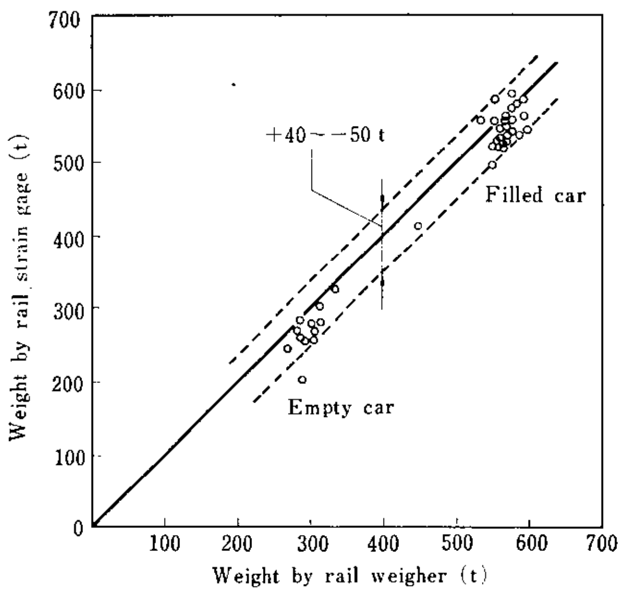


Fig. 20 Accuracy of rail strain gage

of ±5% by correctly adjusting the stop position. **Fig. 20** shows the measured results in comparison with the track weigher.

In the future, the authors hope to enhance the reliability of the level meter by combining the weight system with the microwave system to automate hot metal receiving work.

3.4 Improvement in Standard Instrumentation

This section describes improvements of ordinary instrumentation other than the instrumentation mentioned above.

3.4.1 Coke weigher

The weigher of coke to be charged to the blast furnace is one of the most important instruments and strict management of its accuracy is required. Therefore, the coke weigher is designed to be a direct load cell system, without balancing beams. Double load cells are used for keeping accuracy, and a weight checking device is used for calibration purposes. **Fig. 21** shows the system configuration.

3.4.2 Sampling hopper type coke moisture meter

In order to improve the measuring conditions of the coke moisture, coke to be charged into the weighing hopper is sampled, and charged into the sampling hopper for measuring moisture content[13,28]. **Fig. 22** shows correlation between measured moisture and the drying method value, in comparison with the conventional method. When the total accuracy is evaluated with dispersion $3\sqrt{V_{xy}}$ obtained from the regression this method shows an accuracy of 1.92% compared with that of 2.91% for the conventional one, and it is clear that accuracy is enhanced by the former.

3.4.3 Microwave sounding meter

This sounding meter is obtained by replacing the conventional mechanical system with the microwave system, with features for the measurement during charging, excellent maintainability and driftlessness in principle[23,31]. The microwave sounding meter now can give accuracy no less inferior to that by the mechanical type meter, after the former has been improved by modification of its oscillator and signal processing. **Fig. 23** shows the examples of measurement when the microwave system is compared with the mechanical system. Further, this technique has been applied with satisfactory results to empty furnace blow-off (the conventional method cannot be used).

3.4.4 Annubar flow meter

Annubar flow meters are widely used since they are practically free of parmanent pressure loss due to flow rate measurement and are easy to install and maintain.

In Chiba No. 6 BF, Annubar flow meters are installed at more than 30 places for monitoring purposes[28], and are also used for controlling hot stove combustion air flow rate. When this flow meter was

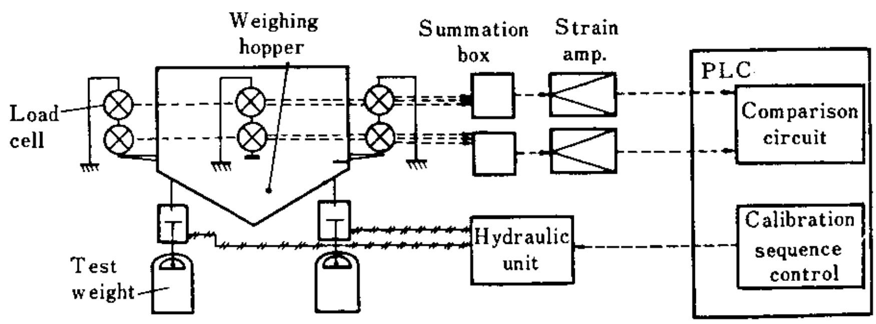


Fig. 21 Coke weighing system

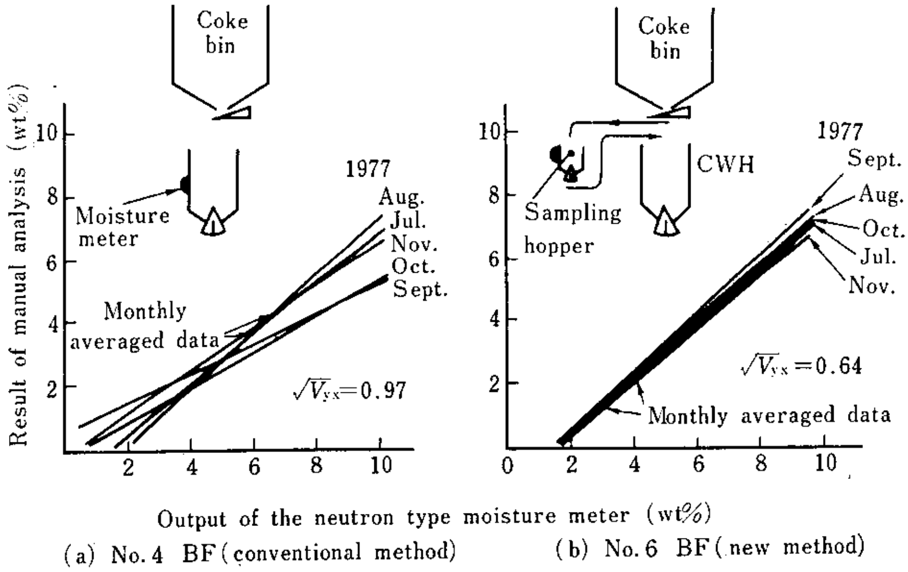


Fig. 22 Comparison of calibration curves between the new and conventional coke moisture measuring systems

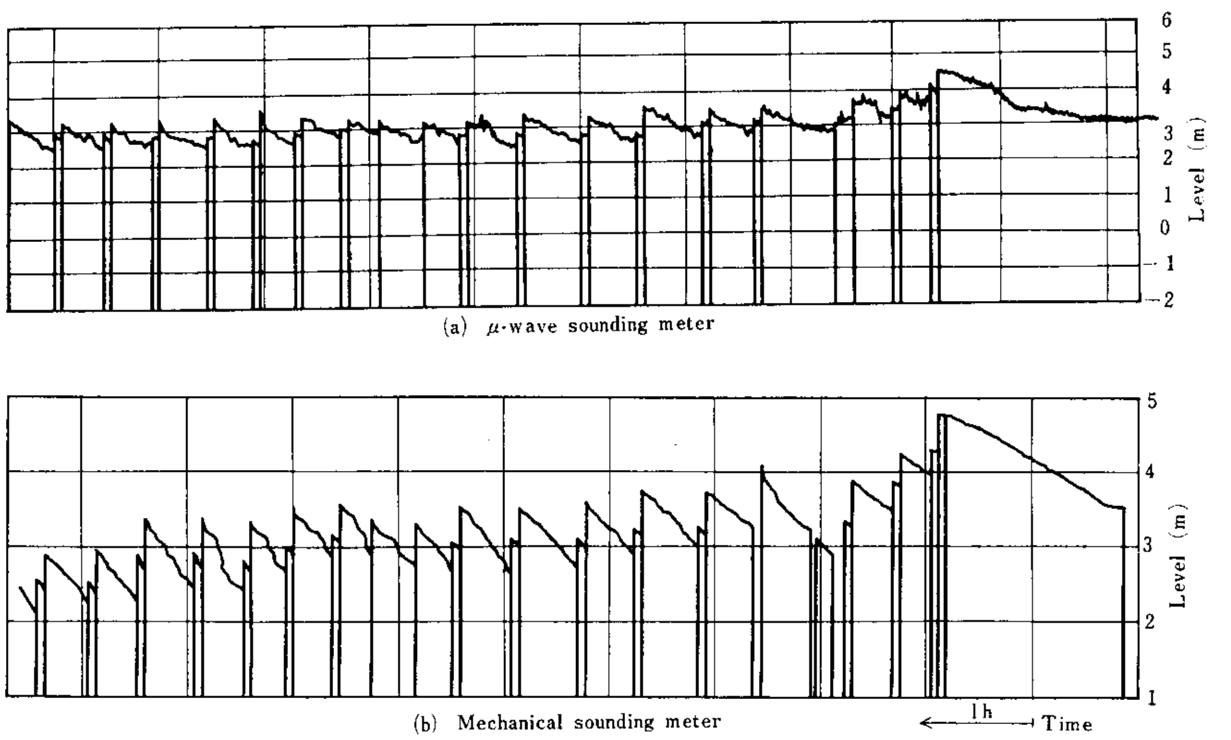


Fig. 23 An example of microwave sounding meter measurement

Table 1 Running cost comparison for measuring combustion air flow rate of hot stove

Running condition			
Measuring points			4
Line flow rate	Q (m^3/h)		1.80×10^5
Specific gravity in line condition	γ_f (kgf/m^3)		0.718
Fan utilization	η_1		0.97
Fan efficiency	η_2		0.80
$\alpha\beta^2$ value of orifice	$\alpha\beta^2$		0.30
Item		Annubar	Orifice
Differential pressure, DP	(mmH$_2$O)	24.4	126.5
Permanent pressure loss, PPL	(mmH$_2$O)	0.732	68.1
Power required to make up for PPL	(kW)	0.448	41.7
Yearly operating cost (yen/year/measuring point)		4.40×10^4	4.09×10^6
Yearly costs saving (yen/year/measuring point)	4.05×10^6		
Total cost saving per year	7 860 000yen/year		

Note : Overall fan utilization is assumed to be 97%.
Only two lines are active simultaneously.

compared with the orifice measuring the blast volume, the difference was kept only within ±2% of the measured flow rate. **Table 1** shows a comparison of operational cost between the annubar and the orifice measuring hot stove combustion air flow rate[32].

3.4.5 Strain gage type pressure sensor

Kawasaki Steel has introduced strain gage type pressure sensors which can be line-mounted, to the pressure measurement loops in blast furnace instrumentation[26]. Compared with the conventional pressure conduction pipe and pressure transmitter system, this pressure sensor has many merits such as the reduction in instrumentation cost, improvement in maintenability, elimination of pressure conduction pipe problems caused by dust and drain, and decrease in signal transmission delay. The authors are planning to increase the number of this sensor in future. In Chiba Works, these pressure sensors have been installed to 42 positions at No. 5 BF on the basis of the test result at No. 6 BF.

3.4.6 Hot stove gas analysis

Kawasaki Steel is making fuel and waste gas analysis for strengthening combustion control in the hot stove[13]. Namely, the authors are using feedforward control, in which blast furnace (B) gas and coke oven (C) gas are analyzed by gas chromatography and a C/B ratio to obtain the required calorie of the mixed (M) gas is set, together with feedback control of the air/fuel ratio of the M gas using the waste gas O_2 meter, thereby improving the hot stove combustion efficiency.

4 Future Orientation

4.1 Instrumentation for Raw Material Processing

Goals for the immediate future in the raw material processing instrumentation are to achieve a higher degree automation of yard machines, improve the accuracy of the inventory system, and make a plant monitoring system for yard machines which are placed over the huge yard. Then the future task that comes thereafter will be to master and control physical and chemical properties of raw materials.

Immediate goals in the sintering process are to promote power saving in present equipment and to put a new sensor to a practical use to clarify the sintering process. The subsequent future prospect lies in developing instruments for correctly detecting Input and Output of the sintering process. It will be necessary to develop on-line measuring methods not only of the properties of raw materials, but also of the reduction disintegration index and shatter strength, which are the indices for product quality, or alternative indices.

4.2 Blast Furnace Instrumentation

Sensors for blast furnace instrumentation whose development is desired are more direct measuring instruments such as instruments that can measure, not indirectly but directly, the shape of the fusion zone, hot metal and slag levels inside the furnace, heat levels inside the furnace, and the quantities of erosion of the furnace wall and hearth.

At the same time, attention should be paid to the reorganization and integration of all the sensors which have been already developed. So far the authors have been endeavoring to develop a large number of direct and indirect sensors with the sole objective to "measure" by any means. Some kinds of information obtained by these sensors are duplicated. Thus the time has come to sort out these sensors positively without waiting for natural selection and choose sensors of true needs.

In the future, the operational target should be changed from the quantity of hot metal to its quality. It will be required to prepare a sophisticated blast furnace model in which a lot of sensor information is incorporated, thereby collecting early stage information even from the tuyere or quality data based on on-line analysis of hot metal and slag. Further, it will be necessary to develop new instrumentation arising from changes in raw material and fuels as shown in the coal injection, and to develop and systematize sensors for the automation of cast house work. It will also be a task which requires examination from a different angle to achieve coordination with the succeeding process, i.e., the steelmaking plant, and the entire steel works in terms of energy control systems.

5 Conclusion

This report outlines instrumentation, mainly on sensors, in the ironmaking process. Since emphasis is laid on sensors developed by Kawasaki Steel and control models are omitted, this report may be somewhat prejudiced.

The ironmaking process is now gradually turning itself into "visible" by the accumulation of technique described in this paper and those developed by other steel makers. A stable operation is now natural for blast furnaces which sometimes fell into the "furnace chilling" state in the past. The target life of the blast furnace is now prolonged to 10 years, and thus the responsibility of future instrumentation techniques will be ever more increased.

Further efforts should be made not only toward development of individual new sensors, but also toward the integration of such sensor information and the systematization of respective processes in the whole ironmaking process.

What is important is not simply to follow the advancing steps of the process, but to make it so that the progress of instrumentation will create a new way of ironmaking process.

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