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The purpose of controlling technique on the gas distribution for a stable furnace condition is to maintain an adequate peripheral gas flow and a sharp center gas flow, for preventing a scaffold (ansatz) at wall side and for improvement in the discharge of Zn from the furnace top. The gas distribution of a furnace equipped with a bell-armour in comparison with that of the bell-less top has a tendency to be flat owing to the difference in size segregation behavior in the radial direction, thus posing a problem in micro-control of burden distribution. The authors have recently developed a new method of burden distribution control by the movable armour and introduced it to No.5 BF. This method is aimed at promoting large particle size segregation at the center and wall side by controlling the bell stroke and speed.

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The gas distribution of a furnace equipped with a bell-armour in comparison with that of the bell-less top has a tendency to be flat owing to the difference in size segregation behavior in the radial direction, thus posing a problem in micro-control of the burden distribution. The authors have recently developed a new method of burden distribution control by the movable armour and introduced it to No. 5 BF. This method is aimed at promoting large particle size segregation at the center and wall side by controlling the bell stroke and speed.

1 Introduction

The burden distribution control in the blast furnace operation has achieved a great stride, with the introduction of bell-less top and the development of various in-furnace sensors, thus resulting in the improvement of the blast furnace operation[1-3]. In view of the recent trend toward the reduction of production level and the all-coke operation, the concept of optimum burden distribution has taken much importance because the blast furnace operation is affected by the scaffold (ansatz) made at the wall side and the zinc content in dust.

On the other hand, the advent of the bell-less top characterized by the effective control of burden distribution has induced an active discussion on comparative merits and demerits of the blast furnace equipped with the bell armour, and on the burden distribution control using Movable Armour (abbreviated to MA). For this reason, it has been urgently required to establish the methods for burden distribution control in the bell type blast furnace and to elucidate the problems involved.

Under these circumstances, in Chiba Works having both types of blast furnace, positive efforts have been made for establishing the technique of burden distribution control through MA since blowing-in of Chiba No. 5 BF, bell armour type, with furnace throat diameter of 8 m and inner volume of 2 584 m^3. Consequently, the techniques for controlling large bell stroke and stroke speed have been developed as a means for improving the particle size distribution in the radial direction in the conventional bell armour blast furnace, and satisfactory results were obtained. As a result of application of this technique, the burden distribution control comparable with that in the bell-less blast furnace has been available in the bell armour blast furnace.

The present report will concern the progress of development and the results of application.

2 Features of Bell-armour Discharging Equipment

2.1 Operational Conditions of Chiba No. 5 BF

A schema of the furnace top equipment in Chiba No. 5 BF which is a medium-sized furnace of 3-bell type equipped with the MA of Kawatetsu* type, is shown in **Fig. 1**. The MA of Kawatetsu type is characterized both by the prevention of dust accumulation by the use of the vertical drive shaft and the effective distribution control through the vertical fine adjustment of the drive shaft. For controlling the

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** Chiba Works

*** Research Loboratories

* Abbreviation of Kawasaki Steel Corp.

burden distribution, an armour of stone box type is installed between the large bell and the wearing plate and the burden is allowed to hit at the armour so as to adjust the falling positions in the radial direction. The MA set positions are defined as point 0 at the furnace wall and points 1-6 at 54 mm intervals toward the furnace center from 460 mm inside the wall. A specified amount of raw materials is charged at once through the 2-batch 1-charge system, based on the single charge system with both coke and ore allowed simultaniously to charge until a given stock lines.

The distribution control is evaluated by the zinc content in dust emitted from the furnace top and the stave temperature index[4]. The index is a sum of scores corresponding to readings of thermometers installed on staves at various stages: the greater the index is, the more activated the furnace wall. As shown in **Fig. 2**(a), zinc content in dust decreases with the drop in temperature measured by the probe fixed at center and also the temperature of molten metal drops with the periodic fall of ansatz. The relationship of stave temperature index to slip is shown in **Fig. 2**(b). When the stave temperature index is lowered too much, the burden descent tends to become irregular. This suggests that under the extensively reduced production in the all-coke operation, the irregularity of burden descent owing to inactivation at the furnace wall must be avoided[5], and the furnace top gas temperature

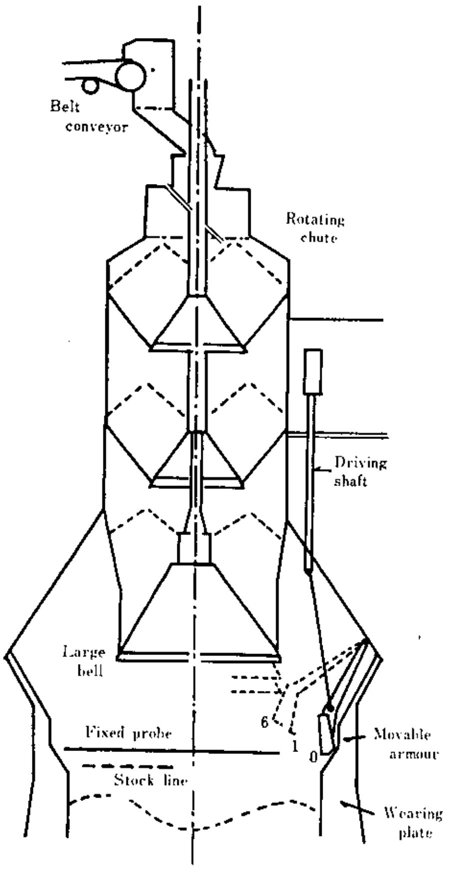


Fig. 1 Schema of discharging equipment of No. 5 BF

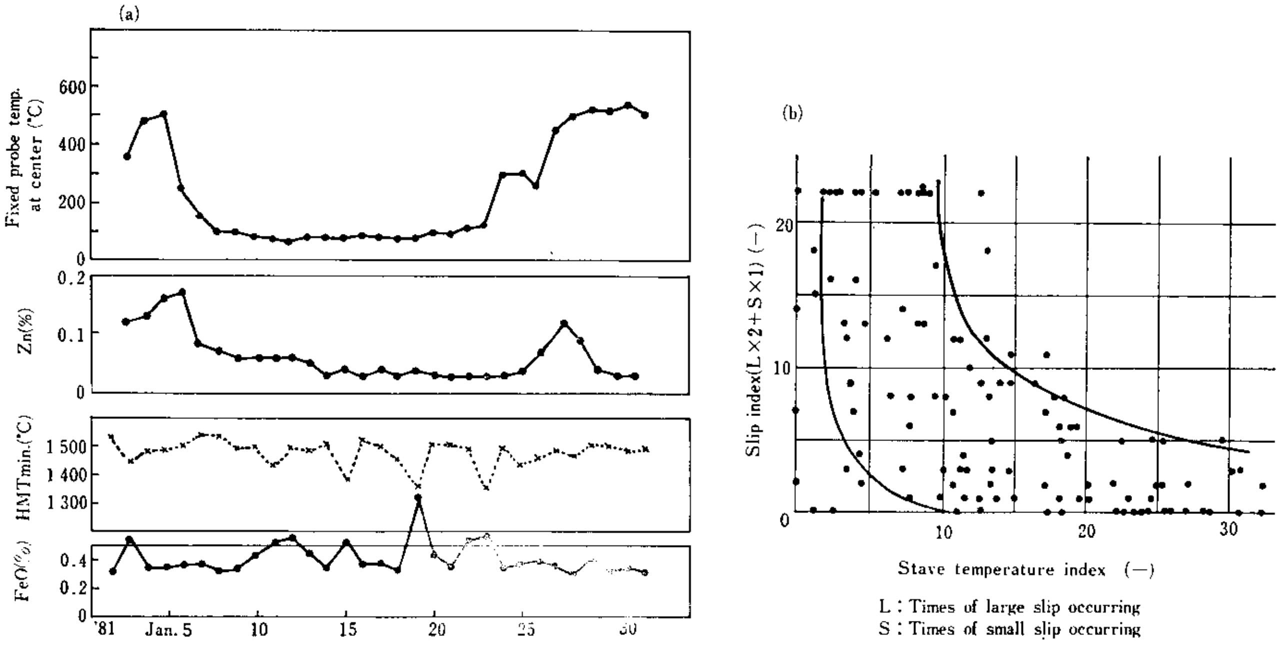


Fig. 2 Effect of the fixed probe temperature at center and Zn percent in dust on hot metal temperature (a), and relation between slip and stave temperature index (b)

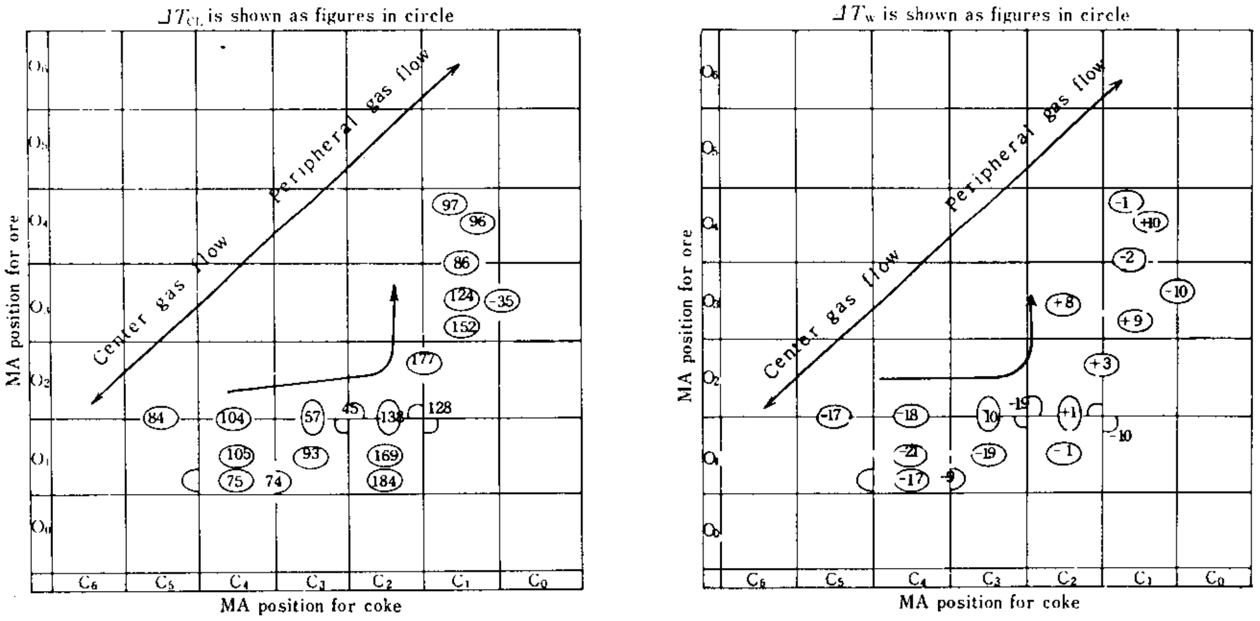


Fig. 3 Transition of ΔT_{CL} (sharp center gas flow) and ΔT_{W} (peripheral gas flow) on every MA notch at No. 5 BF

must be held at a level required for the discharge of circulating zinc in the blast furnace[6,7]. On the basis of these findings, MA positions were controlled to satisfy these two requirements. So long as the zinc content in dust is 0.2% or higher, coke is mainly to be charged toward the furnace wall in order to keep active at the wall side and ore mainly charged toward the furnace center so as to secure sharp distribution of the high temperature gas region limited at the center. **Figure 3** shows the transition of MA patterns at Chiba No. 5 BF, and changes in ΔT_{CL} (gas temp$_{\cdot\mathrm{center}}$ − gas temp$_{\cdot\mathrm{intermediate}}$), representing the sharpness of gas flow at the center by use of fixed probe, and in ΔT_{w} (gas temp. $_{\mathrm{wall}}$ − gas temp. $_{\mathrm{intermediate}}$), representing the intensity of gas flow at the furnace wall area. Setting MA toward the furnace wall when charging coke and toward the furnace center when charging ore tended to secure ΔT_{w}, but contrarily reduced ΔT_{CL}. This constitutes the technical problem of distribution control in the MA system. The difficulties in the distribution control by MA are shown in **Fig. 4**. The slip increased as the stave temperature index fell. In order to move the MA position toward the furnace wall at the time of coke charging, therefore, the MA pattern was changed from C_1O_3 to C_0O_3, where C_mO_n means placing MA at point m when charging coke, and at point n when charging ore. Unexpectedly, this resulted in lowering of fixed probe center temperature and failure of zinc discharge. The distributions of fixed probe temperature in phases (A) and (B) in the figure are compared in **Fig. 5**.

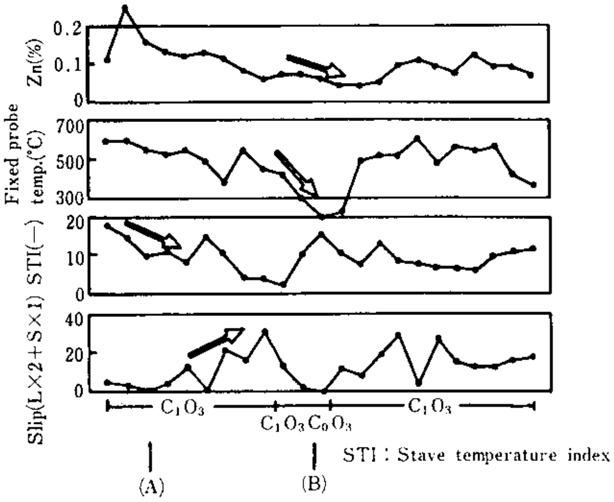


Fig. 4 Operational data on gas distribution control by the use of MA at No. 5 BF

On the other hand, the operational transition of bell-less pattern at Chiba No. 6 BF equipped with the

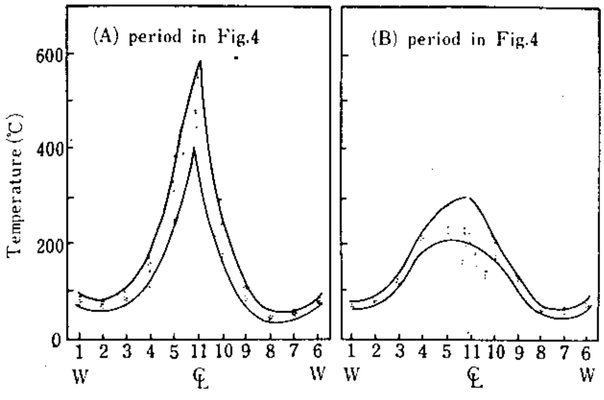


Fig. 5 Comparison of gas temperature distribution measured by fixed probe in radial direction

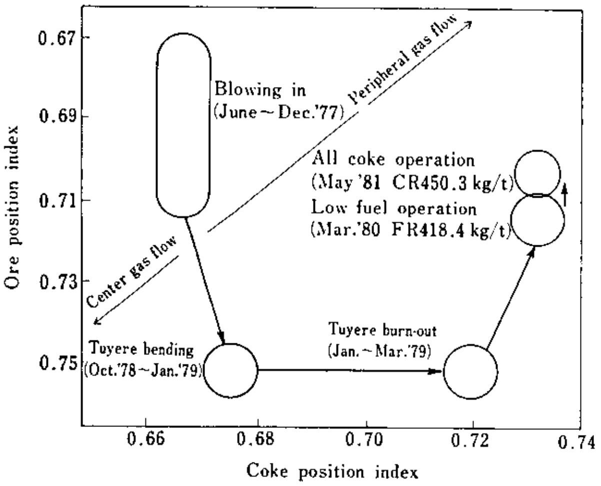


Fig. 6 Transition of bell-less pattern under typical operation at No. 6 BF

bell-less top is shown in **Fig. 6**. Indices on both axes in this figure represent the average distance of burden charge from the furnace center when defined the radius of furnace equal to 1, so as to quantitize the pattern involving multiple tilting position[2-8].

Since blowing-in, the coke charge position has been changed toward the furnace wall between the period of 'tuyere bending[9]', where there is excessive central gas flow and that of 'burnout of tuyere bodies[9]', where there is excessive peripheral gas flow. The ore charge position has also been changed toward the center during the both periods of low fuel rate and all coke. This ensured the stable furnace conditions, through optimizing the gas flow at the furnace wall and sharpening it at the center[1].

Namely, the target gas distribution of MA system was pursued through the same course as the burden distribution control of bell-less system on the basis of common distribution concept of how to strengthen the central gas flow and to secure the stable gas flow at the furnace wall, nevertheless it could not be achieved. In order to solve the problems described above, therefore, it is indispensable to develop the technique to secure the optimal peripheral flow and to strengthen the central gas flow, in the MA system.

2.2 Comparison between Bell-less and MA Methods

Keeping an appropriate gas flow distribution means to control the layer thickness and particle size distribution in the radial direction of furnace. The bell-less system is compared below with the MA system from these points of view.

Schematics of bell-less and bell armour equipment are shown in **Fig. 7**. With respect to charging conditions, the two systems differ in the following points.

(1) Discharging behavior from hopper,
(2) Falling trajectory in respect of charging plane,
(3) Number of dumpings (number of burdens charged one after another), and
(4) Burden charging rate.

These factors cause differences in burden profile, particle size segregation, percolation and mixed layer formation. It has generally been known that the particle size segregation in the radial direction of furnace is less extensive in the bell armour blast furnace than in the bell-less furnace[10].

2.3 Improvement of Particle Size Segregation in Bell Armour Blast Furnace

It has been known that the particle size segregation can be improved in the bell armour blast furnace either ① by separate material charging[11] or ② by size-segregated sinter charging[12]. In the former, the particle size segregation at the center of furnace is improved by increasing the number of dumpings or reducing the charging rate in each dumping, and in the latter, by purposely charging coarser particles into the furnace center.

The authors contrived the method to reduce the charging rate which seemed to be most effective for improving the particle size segregation. It was reported in the actual size test with Chiba No. 2 BF equipped with the bell-less equipment that the particle size segregation was improved by reducing the flow control gate opening[9]. In order to afford the bell MA blast furnace the same function as the flow control gate in

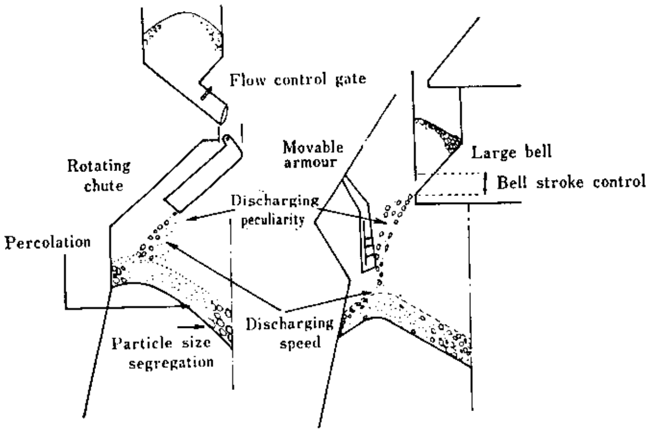


Fig. 7 Schema of discharging equipment of bell-less type and bell armour type

the bell-less blast furnace, the technical development for controlling large bell stroke and stroke speed was attempted.

3 Development of New Method for Distribution Control with MA

3.1 Distribution Survey with Scale Segment Model

Since no measured data are available with regard to the distribution of material particle size and layer thickness, it has been attempted by various steelmakers to quantitize the distribution, even partly, using reduced scale or actual size model[11,13,14]. Before introducing the technique of changing bell stroke and stroke speed to actual furnace, the distribution was surveyed with scale segment models. **Figure 8** shows a 1/15 model of the furnace top equipment in Chiba No. 5 BF, which is sectioned in half and has the front face covered with transparent glass plate. The position of the armour can be changed by turning it around a fulcrum O. The particle size composition of the test sample is shown in **Table 1**. With the material charged uniformly on the large bell, air was fed into the lower tuyere at the rate of 1.2 m^3/min, the large bell was lowered to a specified bell stroke at a specified bell stroke speed and the material was charged. After having charge, the burden was removed from the bottom exit to lower the furnace content to a given stock line. With this operation repeated a few times, the profile and gas flow rate in the radial direction of furnace were measured. Finally, a metallic frame with the cross-sectional area divided into 9 equal parts was driven into the charging plane to take samples for the particle size analysis.

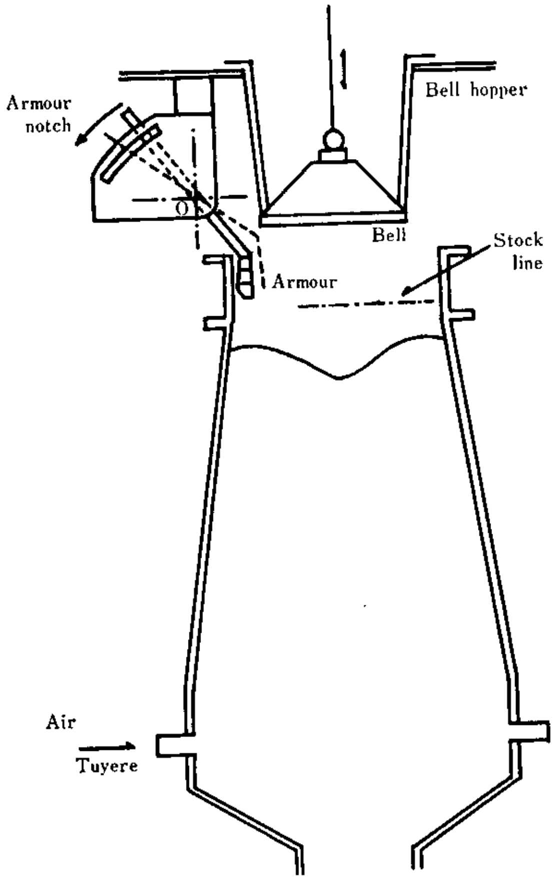
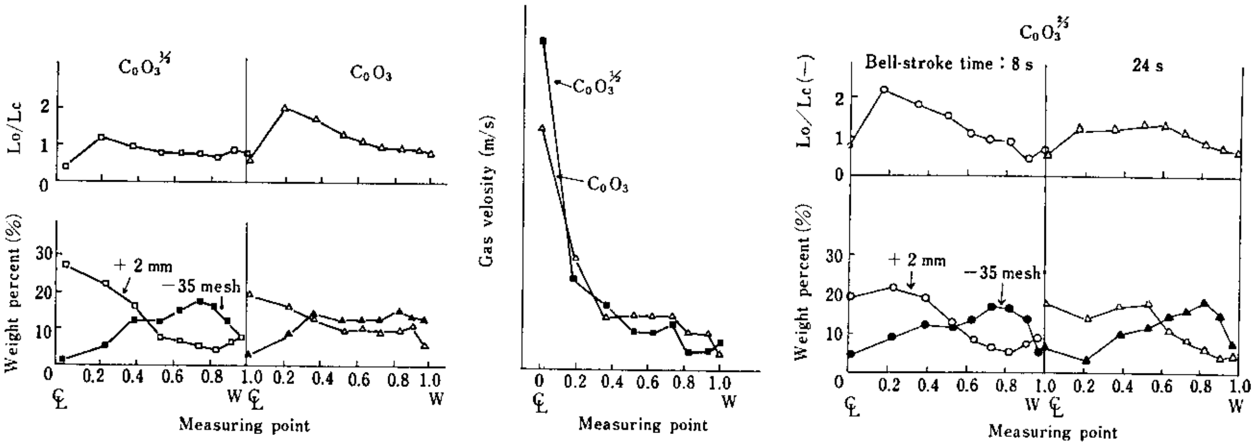


Fig. 8 1/15 scale segment model of No. 5 BF

Table 1 Comparison of particle size

	No.5BF		1/15 scale segment model	
	Particle size (mm)	Weight percent (%)	Particle size (mm)	Weight percent (%)
Ore	+50	4.7	4-3	4.2
	50-35	5.5	3-2	10.1
	35-30	4.1	2-1.5	9.1
	30-25	5.3	1.5-1.0	17.1
	25-20	8.6	1.0-0.6	33.1
	20-15	12.3	0.5-0.4	14.4
	15-10	25.8	0.4-0.2	12.0
	10-5	28.7		
	-5	5.0		
Coke	+100	0.0	6-4	27.5
	100-75	6.5	4-3	32.5
	75-50	43.2	3-2	40.0
	50-25	48.4		
	-25	1.9		



(a) Effect of bell stroke on the particle size segregation in radial direction

(b) Effect of bell stroke on the gas distribution in radial direction

(c) Effect of bell stroke speed on the particle size segregation in radial direction

Fig. 9 Results of investigation on burden distribution at 1/15 model

The results are shown in **Fig. 9**, where (a) the layer thickness ratio in the radial direction of furnace (thickness of ore layer L_o/thickness of coke layer L_c) and the segregation ratio (coarser particles ($>$ 2 mm)/ finer particles ($<$ 35 mesh)), and (b) the gas flow rate distribution in the radial direction of furnace are compared when the bell stroke was changed from full stroke to 1/2 stroke under the condition of fixed bell stroke speed. The particle sizes $>$ 2mm and $<$ 35 mesh correspond to $>$ 30 mm and $<$ 5 mm in the actual furnace, respectively. It is evident that reducing the bell stroke has not only the layer thickness ratio L_o/L_c in the vicinity of center reduced, but also the segregation of coarser particles at the center and periphery of the furnace markedly improved. Consequently, the gas flow rate in the radial direction of furnace increases at the center and periphery of furnace, as shown **Fig. 9**(b). The particle size distribution when the stroke speed was changed from 8 sec. to 24 sec. under the condition of fixing the bell stroke at 2/3, is shown in **Fig. 9**(c). When the bell stroke speed is slowed, the concentration of fine particles in the vicinity of center is reduced. On the basis of these findings, it is evident that changes in the large bell stroke and stroke speed affects not only the layer thickness ratio in the radial direction but also the particle size distribution.

3.2 Application to Actual Furnace

Figure 10 shows the control system for the large bell stroke and stroke speed in the actual furnace. The stroke is controlled by the position of limit switch installed at the bell rod, and the stroke speed by the flow control valve in the hydraulic cylinder piping.

Figure 11 shows the result of measuring the falling trajectory from the large bell at the time of scheduled shutdown. When the large bell stroke is set to 2/3, the material discharged from a higher position falls toward the center, as shown by broken line in the figure. Accordingly, at point O where MA is not used, the material is charged toward the furnace center in case of 2/3 stroke rather than in case of full stroke. For 2/3 stroke at points 1–2, the main stream of material is charged toward the furnace wall side in comparison to the case of full stroke which corresponds to MA. At points 3–4, the effect on the falling position in the radial direction of furnace is thought to be small because the MA is of stone box type.

On the basis of these findings, the bell stroke was controlled by changing patterns in the order of $C_1O_3 \rightarrow C_1O_3^{2/3} \rightarrow C_1O_4 \rightarrow C_1O_4^{2/3}$ in view of peripheral particle size segregation described above, or $C_1O_3 \rightarrow C_1^{2/3}O_3 \rightarrow C_0^{2/3}O_3 \rightarrow C_0O_3$ in view of coke falling position, for the purpose of increasing the peripheral gas flow. The stroke speed control was applied to the actual furnace for the purpose of accumulating coarser particles at the center so that the permeability is not affected and the central gas flow is not excessively controlled when increasing the peripheral gas flow.

3.3 Improvement of Operation

Figure 12(a) shows an example of increasing the peripheral gas flow by setting the armour position to point 3 and the large bell stroke to 2/3 at the time of charging ore, and (b) shows another by setting to point 1 and 2/3, respectively, at the time of charging coke.

On the other hand, (c) is an example of obtaining a sharp central gas flow by changing the large bell stroke speed from 12 to 24 sec/750 mm for coke and from 8 to 16 sec/550 mm for ore.

Thus, it became possible to control the central gas flow which tended formerly to be of flat distribution, and to secure stable peripheral gas flow by controlling the bell stroke and stroke speed.

The effects of some representative operational factors to the operational conditions in Chiba No. 5 BF are compared in **Table 2**. The stave temperature index and the zinc content in dust were adjusted to appropriate values by controlling the bell stroke and stroke speed, and consequently, extreme falling of

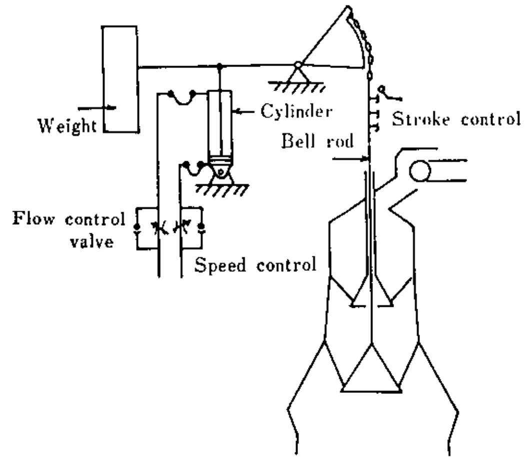


Fig. 10 Control system of bell stroke and bell speed

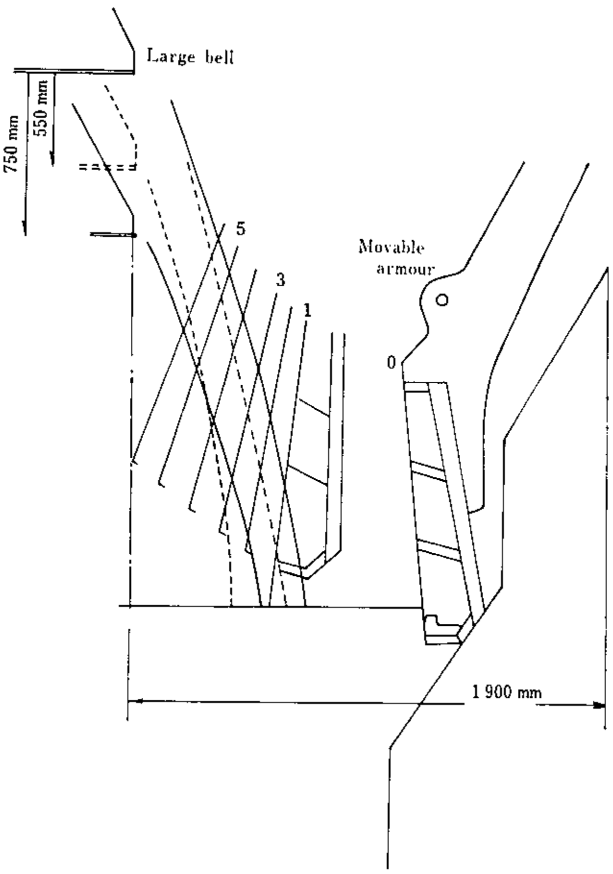
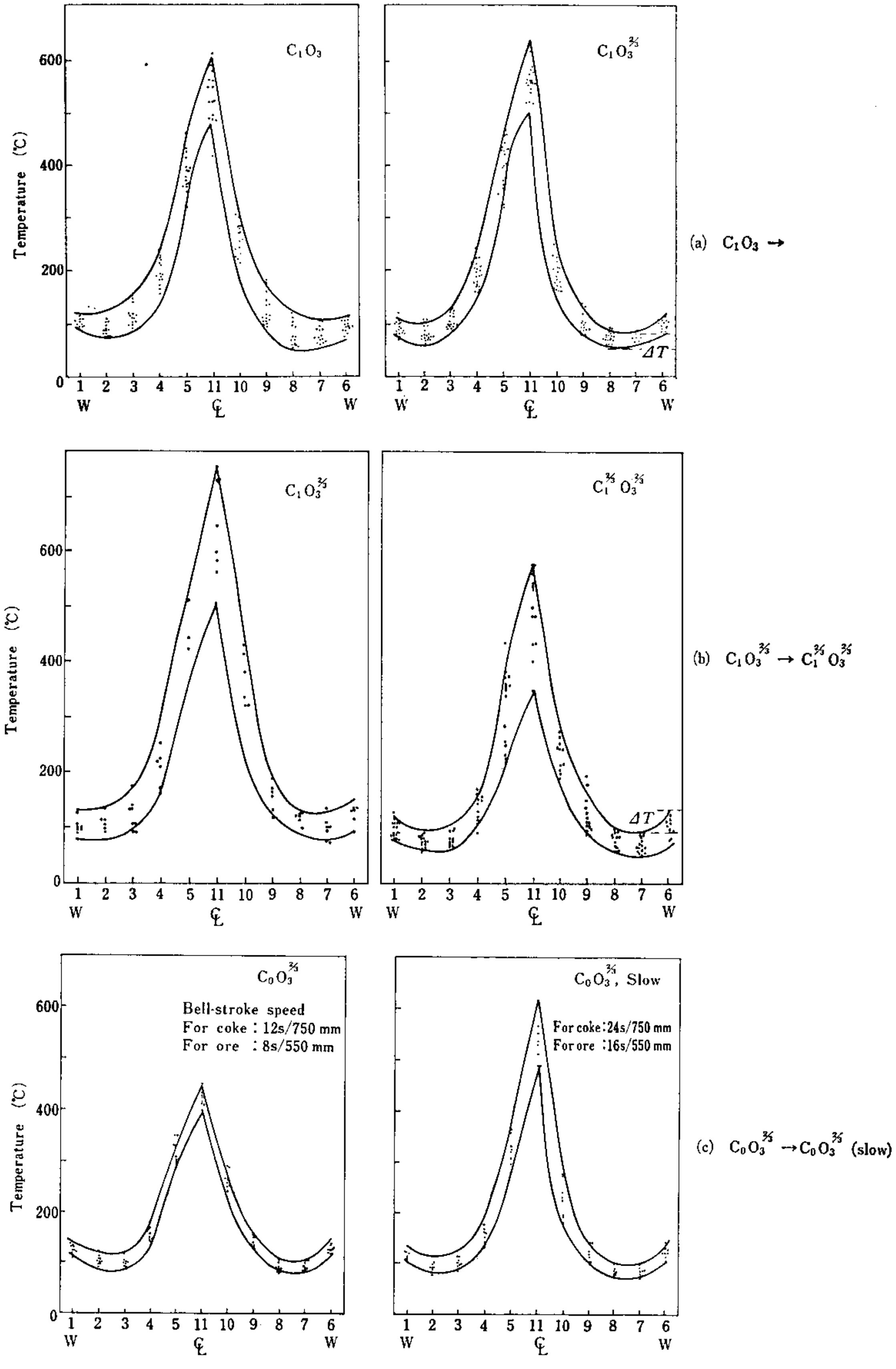


Fig. 11 Discharging behavior from large bell measured at scheduled shut down of No. 5 BF



(a) $C_1O_3 \rightarrow$

(b) $C_1O_3^{3/5} \rightarrow C_1^{3/5}O_3^{3/5}$

(c) $C_0O_3^{3/5} \rightarrow C_0O_3^{3/5}$ (slow)

Fig. 12 Change of the gas temperature distribution by bell stroke control

Table 2 Comparison of typical factor on the blast furnace operation

	Jan. '81	Oct.	Dec.	May. '82	Sept.
Zn percent in dust (%)	0.07	0.22	0.11	0.36	0.23
Stave temperature index (−)	43.4	15.7	9.6	13.3	22.6
Total slip number (L,S)	15,36	115,95	102,72	32,15	14,15
Permeability (−)	0.69	0.75	0.71	0.67	0.66
Hot metal temp. min. (C°)	1 428	1 403	1 463	1 465	1 473
Typical MA notch	C_1O_0	C_4O_1	C_1O_3	$C_0O_3^{2/4}$	$C_0O_3^{2/4}$ (slow)

hot metal temperature was eliminated and the number of slip was reduced, contributing to stabilizing the operation[15].

4 Conclusions

A new method of controlling the burden distribution was established through a 2-year experience after the blowing-in of Chiba No. 5 BF equipped with the movable armour equipment of Kawatetsu type. The results obtained are summarized below.

(1) Both bell-less and bell armour furnaces require identical burden distribution target for making the central gas flow sharper and securing appropriate peripheral gas flow, which are necessary for the stable blast furnace operation.

(2) The burden distribution target described above is to secure the gas flow distribution suited for preventing the forming of the scaffold at wall side and discharging circulating zinc in the blast furnace.

(3) The technical problem in MA is to secure sharp gas flow at the center of furnace while optimizing the peripheral gas flow. The gas flow distribution is extensively affected by the particle size distribution tion in the radial direction of furnace.

(4) In order to improve the particle size segregation in the radial direction of furnace, the technique of controlling the bell stroke and stroke speed was developed. The technique allowed to ensure sharp gas flow at the center while optimizing the peripheral gas flow, and contributed to stabilizing the furnace conditions and expanding the operational repertories under the recent circumstances of reduced production.

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