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Technology for Prolonging Campaign Life of Blast Furnace

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Technology for Prolonging Campaign Life of Blast Furnace*

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Synopsis:

The Chiba No. 6 blast furnace with an inner volume of 4 500 m^3 has operated for 16 years without intermediate relining since June 1977. It has achieved a record of long campaign life and accumulated iron production to the class of 4 000 m^3 inner volume. This record has been established with a new furnace design, total instrumentation and control system, operation control technology and good maintenance. Lower shaft of the furnace was protected with lower thermal heat load by burden distribution control with Paul Wurth bell-less top charging facility. Upper shaft was rather damaged, and water-cooled panels (like stave coolers) were installed to keep good furnace profile and smooth furnace operation. Erosion of hearth brickwork was estimated with the application of a hearth erosion model using boundary element method (BEM). No severe erosin is found. More than 19 years of service life is expected with stable furnace operation.

1 Introduction

As of July 1993, Chiba Works No. 6 blast furnace was in operation as Kawasaki Steel's longest continuously-operating BF, with a single-campaign record of more than 16 years since blow-in on June 17, 1977. Operating results to date include a cumulative pig iron output of approximately 48.2 million tons, or in terms of output per unit of inner volume, more than 10 700 t/m^3.

Prolongation of blast furnace campaign life has been the subject of diligent study from the viewpoint of improved return on equipment investment capital. As a result, campaign life increased from 5-6 years with blast furnaces of the 1960s and 70s to more than 11 years in the early 1980s. Blast furnaces blown in more recently show a trend toward even longer campigns, as illustrated by the Sumitomo Metal's Kashima Works No. 3 (13 years, 4 months), Nippon Steel's Oita No. 1 (13 years, 5 months) and Hirohata Works No. 4 (16 years, 4 months).

Kawasaki Steel has also promoted the development of technologies for blast furnace operation, equipment diagnosis, and repair with a view to furnace body protection. The campaign life record established at Chiba No. 6 BF was made possible by the synergistic effect of these technologies. This report describes the technology for prolonging blast furnace campaign life which was applied at Chiba No. 6 BF.

2 Concept of Construction of Chiba No. 6 BF

The furnace body profile of Chiba No. 6 BF is shown in **Fig. 1**. It is a large-scale blast furnace with an inner volume of 4 500 m^3, a throat diameter of 10.5 m, a hearth diameter of 14.1 m, four tap holes, and 40 tuyeres, and is capable of producing 10 000 t/d of iron. It was blown in in 1977 as Kawasaki Steel's largest existing blast furnace. In the construction of No. 6 BF, study was given to measures for achieving a campaign life longer than the average 8–10 years prevailing at the time, as discussed below.

(1) Furnace Support Structure
With free-standing blast furnaces, shaft brackets are provided for use during emergencies. As blast furnaces were scaled up, throat bracket supports, lintel supports, and shaft bracket supports were adopted in large number at Kawasaki Steel's Mizushima Works and other companies. However, with the shaft bracket support and lintel support, the shell is under constraint at high thermal load parts of the shaft and belly, and the use of expansion joints in the

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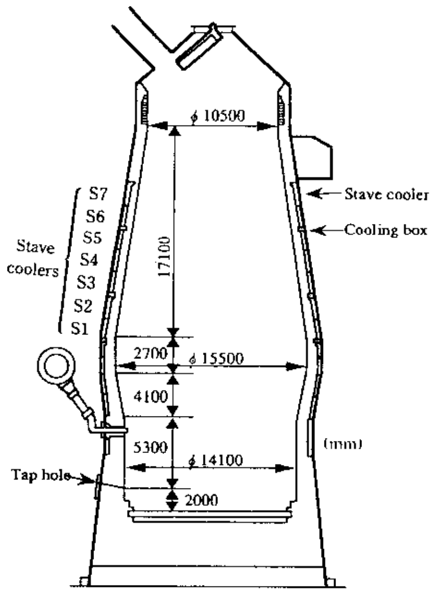


Fig. 1 Blast furnace profile

structure may cause cracks in the shell and other problems. As a countermeasure, the free-standing type was adopted, but with the shaft bracket support used, the load of the shell is locally supported by lower furnace columbs when the shell buckles.

(2) Furnace Profile

The furnace profile was decided on the basis of actual results obtained with Mizushima No. 4 BF, from the viewpoint of the profile and operating results, furnace body refractory wear, stable operation, and other characteristics of large-scale blast furnaces in Japan. As one noteworthy feature, the height of the lower part of the furnace below the belly is great. The bosh angle of No. 6 BF was set at 80° based on the finding that, in dismantling research with previously blown out furnaces, the erosion angle of the bosh was 68°-80°, and the finding reported in the Babarykin study that a funnel-shaped loosely packed bed exists between the deadman and the bosh and has a stabilized angle of 79°- 80°. Also based on the Babarykin report, the distance from the belly to the iron notch was increased from that used in the past, and the belly height, bosh height, and hearth height were set at 2.7 m, 4.1 m, and 5.3 m respectively.[1]

(3) Shell

In the past, SM50 has been used as the BF shell material in consideration of tensile strength,[2] but in this case, SM41 B and C were mainly used based on a report by the Subcommittee on Prevention Method for Blast Furnace Shell Crack of the Japan Iron and Steel Institute[3] that SM41 C offers superior material characteristics in the shell.

(4) Structure of Hearth Brick

The results of an investigation of the damage of hearth bricks in previously blown out blast furnaces confirmed that hearth brick erosion substantially stops at the upper row of carbon bricks. Based on this finding, an all-carbon brick hearth structure was adopted at No. 6 BF. The brickwork consists of one run of brick for furnace-bottom adjustment and five runs of large carbon bricks. As a countermeasure for hearth corner erosion, the surface area of chamotte brick was decreased, and the carbon bricks at the outer circumference were made thicker. In order to prevent a circular flow of molten materials, the depth of the disk (distance from iron notch to upper surface of the hearth bricks) was increased over that used in the past, to 2 m.

(5) Furnace Cooling Equipment

To reinforce the refractory supports at the furnace shaft, a joint-use method was adopted for the staves and copper cooling box in the layout of shaft cooling equipment, as shown in Fig. 1. To reinforce the shaft support function, Γ type stave coolers were used in the past as brick supports for the shaft. However, Γ type stave coolers have a short service life and may suffer damage within several years after blow-in, thus failing to provide an adequate brick support function. For this reason, cooling boxes were inserted between the stave coolers in order to stably maintain the brick support function over the long term.[4] This BF has twelves rows of stave coolers, but Γ type staves are used only in the top row. Cooling boxes are installed at three rows. Forced-circulation using demineralized water are applied as the cooling method, improving the cooling function.

(6) Furnace Body Refractories

The refractories in the bosh, belly, and lower part of the shaft were the first SiC bricks to be adopted by Kawasaki Steel. In the past, high alumina bricks were used in these positions in consideration of oxidation resistance and strength characteristics, but at No. 6 BF, SiC bricks were adopted for their outstanding hot modulus of rupture, heat conductivity, and resistivity to alkali corrosion.

(7) Top Charging System

No. 6 BF was the first 4 000 m^3 class large-scale blast furnace in Japan to be equipped with a Paul Wurth (PW) type two parallel bunker bell-less top. There was some anxiety concerning the lack of actual operating results in comparison with those available for bell-movable armor type charging systems, but based on the extremely large degree of operating flexibility with the bell-less top and the belief that bell-less systems represent the mainstream of the future, this type was adopted, aiming at early establishment of burden distribution control technology for bell-less systems with large-scale blast furnaces. As a bell-less top had already been adopted at Chiba No. 2 BF (4th campaign), the operational results obtained with that unit formed the basis for burden control at No. 6 BF.[5]

3 Operating Technology for Prolonging Campaign Life

3.1 Operational Trend of Chiba No. 6 BF to Date

The operational results of Chiba No. 6 BF from blow-in to the present time are shown in **Fig. 2**, and may be divided into six periods of operation having the features described below.

Period 1 (June 1977–Nov. 1980)—High Production Rate/Low Fuel Rate[6)]

- Operation with oil injection (monthly low-fuel rate record, 418 kg/t-p)

Period 2 (Dec. 1980–June 1983)—Low Production Rate/Low Fuel Rate

- End of operation with oil injection, switch to all-coke operation

Period 3 (July 1983–Sep. 1987)—High Production Rate/High Fuel Rate

- Implementation of high fuel-rate operation considering the Works' energy balance following start-up of a new power station

Period 4 (Oct. 1987–May 1991)—Low Production Rate/High Fuel Rate

- Reduced output operation in line with consolidation of production affecting Chiba Works

Period 5 (June–Dec. 1991)—High Production Rate[7)]

- High production rate operation during relining of Chiba No. 5 BF
- Pulverized coal injection operation following start-up of PCI plant

Period 6 (Jan. 1992–present)—Low Production Rate/Ultra-high Fuel Rate[8)]

- Ultra-high fuel rate (≧ 530 kg/t-p) in consideration of Works' energy balance

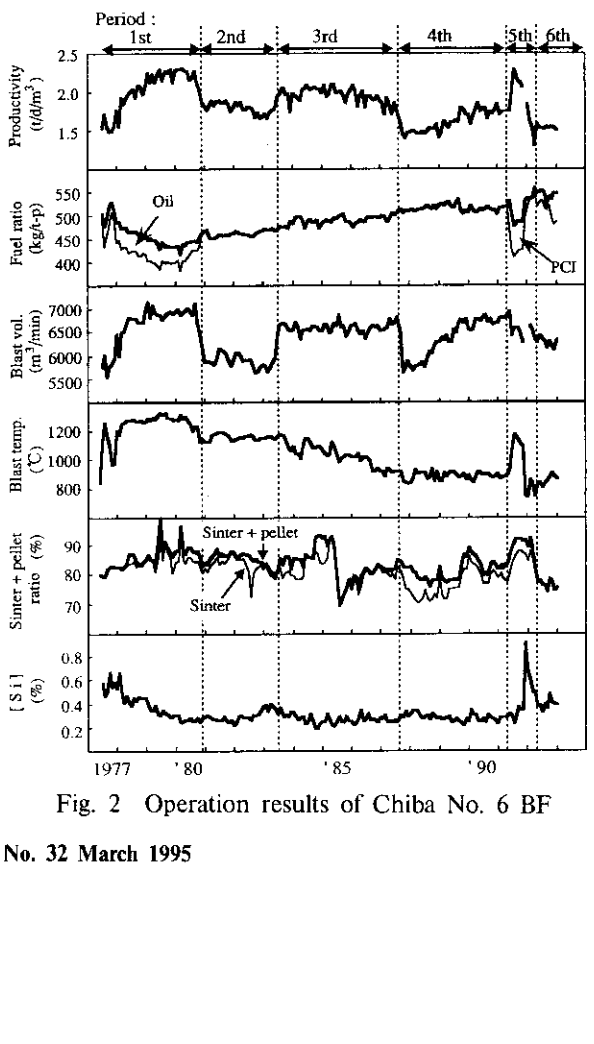


Fig. 2 Operation results of Chiba No. 6 BF

Main operating trends since blow-in have included the initial period of operation with oil injection, all-coke operation after the 2nd Oil Crisis, and a shift to high fuel-rate operation with the start-up of a new power plant. Pulverized coal injection began in 1991, and was followed by ultra-high fuel-rate operation beginning in 1992. Particularly in terms of the fuel rate, the operation of No. 6 BF has changed with current energy balance requirements, from a minimum of 418 kg/t-p in the first period to a maximum of 545 kg/t-p in the sixth period. The production rate has also swung from 1.46 $t/d \cdot m^3$ during the production cuts made in the fourth period to a high of 2.30 $t/d \cdot m^3$ during the fifth period. The fact that it was possible to achieve a maximum production rate of 2.30 $t/d \cdot m^3$, 14 years after the furnace was blown in, is particularly worthy of note. In spite of all these changes in operating conditions, stable operation has been maintained and furnace body wear held to a minimum by developing and establishing operational control techniques represented by burden distribution control using the bell-less charging system.

3.2 Techniques for Long-Term Stable Operation

To achieve a long blast furnace campaign life, it is essential to maintain stable operation. First, this report will describe the stable operation techniques by which furnace body protection was achieved at Chiba No. 6 BF.

3.2.1 Instrumentation system and operating control system

The original instrumentation at Chiba No. 6 BF[9)] was a leading-edge system of the time, which made full use of digital control system and tele-control technologies. Although now considered conventional, it is a central monitoring system in which field signals from sensors at the site are taken up by DCSs (digital control systems) and PLCs (programmable logic controllers) at the local level, and all signals are concentrated at the process computer (**Fig. 3**). With this system, it is possible to control virtually the entire blast furnace and hot stove operation with a process computer. The process computer can also monitor the temperature of the furnace body and various types of cooling water at about 300 points, and control of equipment abnormalities has also become possible.

Adopting a system which performs centralized monitoring using a process computer made it possible to promote a shift to computerized control of the blast furnace operation function, which in the past had involved

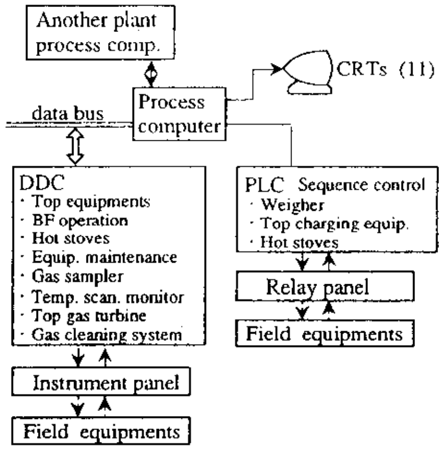


Fig. 3 Instrumentation and process computer of Chiba No. 6 BF

an extremely large number of items dependent on operator experience. A representative example of computerized control is the GO-STOP operation control system using an on-line computer.[10] The GO-STOP is not simply a model which grasps one-dimensional phenomena, but rather is a system which organizes information obtained from a variety of measurements on the basis of blast furnace process theory, further selects factors which are judged to critical to the operation, and on this basis, evaluates operating conditions. Values of approximately 20 main process factors are divided into eight categories, and primary judgments are made of each. The results are then combined and classed synthetically into one of three steps called GO, STOP, and Back, and blast volume reduction and other indications are given to the operator. Operations have been conducted at No. 6 BF since blow-in using the GO-STOP system, which has played a key role in maintaining normalized operations. As special features of this system, the furnace body temperature and heat load on the stave coolers are included among the factors used in judging operating conditions, thus constituting a system which has from the first given consideration to furnace body protection.

3.2.2 Burden distribution control techniques

As mentioned in Sec. 3.1, the operational mode of No. 6 BF has changed greatly since blow-in in response to economic necessity. The most crucial technology established for maintaining normalized operation during this entire period was the burden distribution control technology taking advantage of the bell-less top charging system. At Kawasaki Steel, the fundamental technology had been established at Chiba Works No. 2 BF, but a variety of control techniques for the large-scale blast furnace were then developed on the basis of this fundamental technology. Representative techniques include the following:

(1) Control technique for measuring burden particle size segregation in ore bins and furnace top bunkers[11].
(2) Technique for achieving a uniform burden distribution in the furnace circumferential direction[12]
(3) Technique for setting an appropriate ore/coke layer thickness ratio[13]

In the original technique for controlling burden particle size segregation in the ore bins and top bunkers, a study was made of particle size characteristics during discharge from the top bunkers. A stone box was installed to minimize particle size segregation during discharge, and improvement in CO gas utilization was achieved. This work made it possible to set the record for the minimum fuel rate. The order of raw material dishcarge from the ore bins and dishcarge behavior at the top bunkers was also investigated. Segregation during discharge from the top bunkers was prevented by blending materials on the charging conveyor. Use of these techniques made it possible to achieve the mass use of small sinter (100 kg/t-p and over).

Second, for the technique of achieving a uniform burden in the furnace circumferential direction, it was necessary to clarify the relationship between circumferential O/C segregation, which is an equipment-related characteristic of the two parallel bunker type bell-less top, and fluctuations in hot metal temperature and composition between tap holes. Control of ore and coke assignment changes and the rotational direction of the revolving chute made it possible to develop a technique for preventing differences in hot metal temperature and composition and slag rate between tap holes and secure stable a tapping condition.

Third, the setting technology for the layer thickness ratio (L_O/L_C) of the ore and coke layers is a technique for controlling the heat load on the shaft by appropriately controlling the gas flow in the furnace (peripheral gas flow). **Figure 4** shows the trend in the heat load on the body stave coolers, and indicates that it was possible to stably control this index to a low level for more than 10 years after blow-in.

Figure 5 shows the target furnace-wall L_O/L_C relationship for various operating conditions as obtained from actual operating results at Chiba No. 6 BF. Here, the furnace wall L_O/L_C is the thickness ratio of the ore and coke layers at the furnace wall calculated from charging level measurement. From these results, if the gas volume is increased (increased production) or if the heat

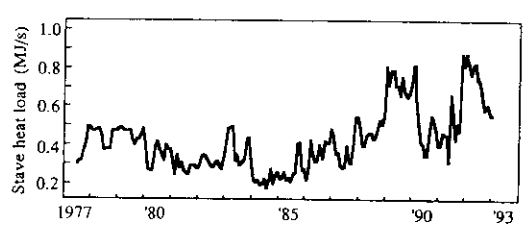


Fig. 4 Transition of stave heat load

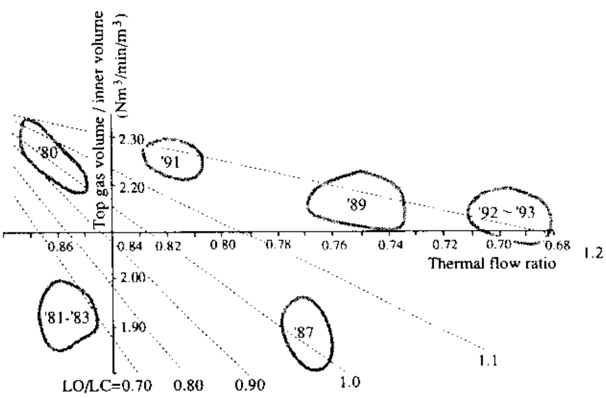


Fig. 5 Optimum L_O/L_C diagram on the various furnace operating conditions

flow ratio is decreased (high coke rate), some surplus will exist in the heat exchange in the furnace, increasing the heat load on the furnace wall, and it is therefore considered necessary to increase the L_O/L_C at the wall (suppressed peripheral flow). In addition, during periods of reduced production, when the gas volume decreases, or in operation with a low coke rate and high rate of oxygen enrichment with a high heat flow rate, the peripheral flow must be increased by reducing L_O/L_C in order to prevent the formation of an inactive zone at the wall. This type of furnace wall L_O/L_C control is basically conducted using the tilting angle of the chute during each revolution (charging pattern), and in some other cases by changing the stock line or the charging sequence. In this manner, close control of only the furnace-wall L_O/L_C has made it possible to control the trend in stave cooler heat load stably to very low levels.

Figure 6 shows the shape of the estimated cohesive zone during the representative periods shown in Fig. 5

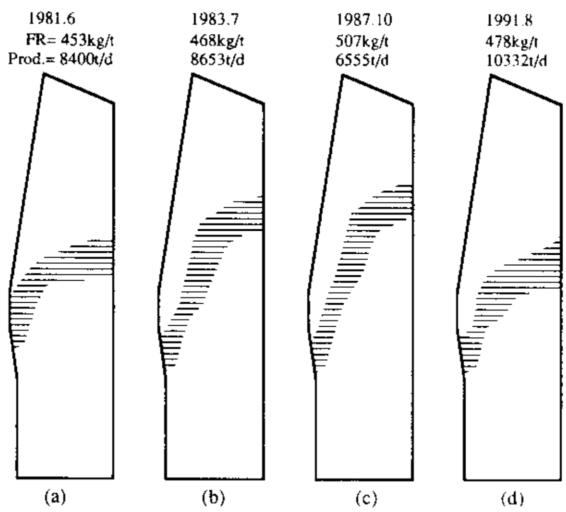


Fig. 6 Shape of estimated cohesive zone by mathematical model

as calculated with a predictive model for cohesive zone shape. As can be understood from these calculated results, there is very little change in the position of the cohesive zone at the wall. Ordering the burden distribution on the basis of Fig. 5 has made it possible to stabilize the heat load on the furnace wall at a low level under a wide range of operating conditions. It should also be noted that the bell-less charging system is an exceptionally good type of equipment for close control of burden distribution.

3.2.3 Operating control of hearth

Surgical repair techniques which can be applied during operation are available for damaged parts of the shaft, but this is not the case where hearth brick damage is concerned. Moreover, adequate control is necessary, because the degree of hearth brick damage can have a decisive effect on the campaign life of the blast furnace.

Where hearth brick damage is concerned, erosion of the hearth corner section was formerly a problem. This type of erosion was attributed to the circular flow of molten materials at the hearth. As a measure to prevent this circular flow at No. 6 BF, the vertical temperature difference (ΔT; shown **Fig. 7**) at the center of the hearth bottom is controlled to avoid inactivity in the deadman. Lowering the temperature difference at the center of the hearth bottom is considered to reduce thermal flux at the hearth bottom center and to promote a circular flow by forming a solidified layer at the hearth center. As a countermeasure for this problem, it was possible to secure a stable central gas flow by burden distribution control. **Figure 8** shows the control results for hearth bottom ΔT. Using burden distribution control, it was possible to maintain ΔT by stably securing the central flow.

On the other hand, a quantitative grasp of hearth refractory wear conditions is needed. For this reason, the number of installation points for hearth thermometers, which was formerly 14, was increased to 81 in 1987,[14]

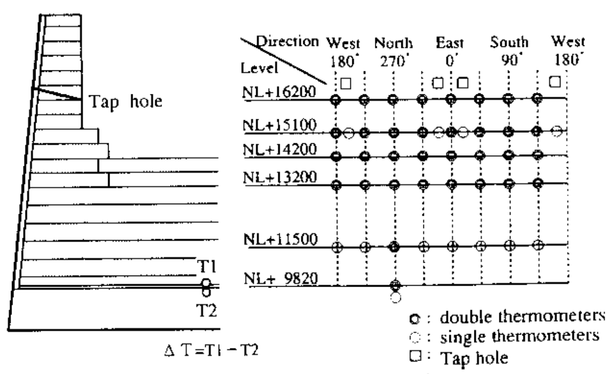


Fig. 7 Arrangement of the hearth temperature-measuring points

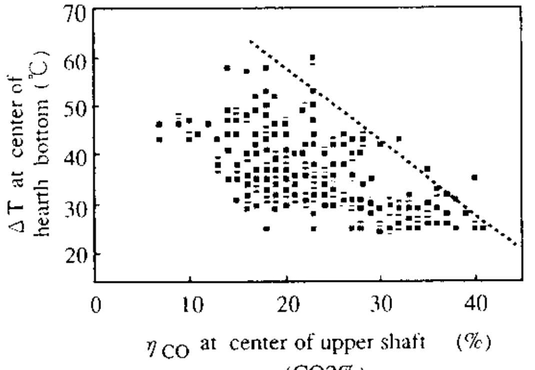


Fig. 8 Relationship between η_{co} at the center of upper shaft and ΔT at center of hearth bottom

to reinforce hearth brick temperature control. The arrangement of hearth thermometers after the increase is shown in Fig. 7. The number of thermometer installation points was increased to include eight cross-sections in the circumferential direction and five rows in the wall-height direction. Using this hearth temperature data, the maximum hearth brick erosion line and solidified layer line have been estimated periodically using the boundary element method.[15] In this method of estimating the maximum erosion line from the maximum temperature in the temperature history of each measurement point and estimating the solidification layer line corresponding to changes in temperature, the estimated results are output once each month for hearth solidified layer control. **Figure 9** shows estimated results of the maximum erosion line at Chiba No. 6 BF. At the present stage, the hearth bricks do not show abnormal erosion. The fact that there is no major damage to the hearth is attributable to the large depth of the hearth and suppression of the circular flow at the hearth by control of the vertical temperature difference ΔT at the center of the hearth bottom.

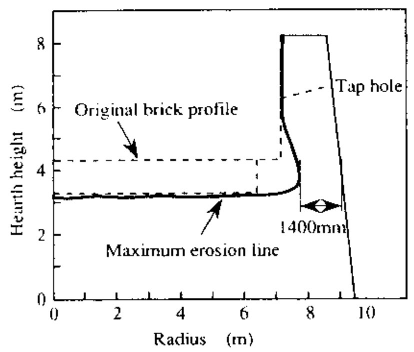


Fig. 9 The maximum erosion line estimated by boundary element method

4 Plant Engineering Countermeasures for Prolonging Campaign Life

Damage appears in all furnace body parts after 10 or more years of service. Damage is particularly noticeable in the area between the upper shaft and the throat. This was because, although adequate study of the campaign life, which was estimated at 8 to 10 years at the time of construction, was given to the lower shaft and hearth brick, a full study of measures to extend campaign life had not been made for the upper shaft (in the past, blast furnaces were blown out due to problems developed in the lower shaft or hearth brick). However, campaign life prolongation measures were implemented because factors detrimental to stable operation had appeared due to progressive damage of the upper shaft. The following describes the campaign life prolongation measures taken to date.

4.1 Campaign Life Prolongation Measures for Shaft

Because the previously described operation for furnace-wall protection using burden distribution is based on the precondition of stable burden distribution control, the furnace profile must be sound in the throat and upper shaft. Related operating and plant engineering technology will therefore be discussed.

4.1.1 Armor plate damage

In the furnace throat, the shelf supporting the armor plate had suffered heat deformation due to wear of the upper shaft refractories, the lower stage of the wearing plate had been pushed into the furnace, and part of the wearing plate had fallen off. In 1985, a cooling box designed to support the shelf was installed around the entire circumference of the shelf, and armor plate retainers were installed where necessary to secure parts of the armor that had dropped off or sagged dan-

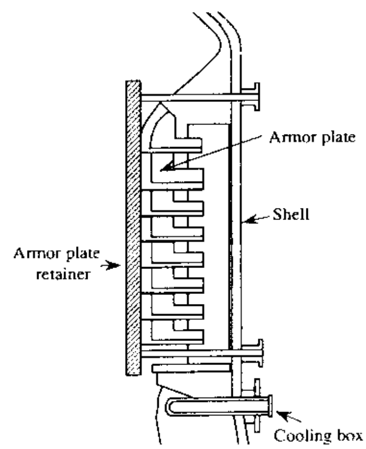


Fig. 10 Schematic drawing for protection of armor plate

gerously.[16] These measures are illustrated in **Fig. 10**.

4.1.2 Upper shaft refractory damage

Progressive wear of the upper shaft refractories caused changes in the gas flow distribution, as shown in the example in **Fig. 11**. After 1988, when upper shaft wear had become conspicuous, the peripheral gas flow increased (and the central flow decreased) even when an identical charging method was used. At the same time, it became difficult to secure a stable central flow, and fluctuations became excessive. In response to this problem, the coke charging position was moved toward the center of the furnace by changing the bell-less charging pattern. This measure was successful in controlling the peripheral flow and securing the central flow, but it was not possible to reestablish the gas flow distribution existing before 1987, and the peripheral flow continued to be excessive. From this, it can be understood that there is a relationship between upper shaft refractory damage and control of a stable gas flow. This phenomenon is attributed to be the formation of a mixed layer due to locally irregular descent of the burden caused by irregularities in the profile of the furnace wall.[17] The increased peripheral flow due to this type of decreased controllability of the gas flow distribution invites an increased heat load on the furnace body, and is therefore a major problem from the viewpoint of furnace body protection. Moreover, the fact that it is difficult to secure a stable central flow invites inactivity in the deadman, which would be a serious problem for continuing stable operation. To solve these problems, repairs were made to restore the profile of the upper shaft with the aim of recovering gas flow distribution controllability.

As a plant engineering countermeasure for upper shaft refractory wear, the cooling panels shown in **Fig. 12** were installed over a space of 4.2 m between the bottom of the wearing plate and the upper row of staves.[14] In the installation work for the water-cooled panels, the furnace was stopped on six occasions for preliminary work, and material interfering with the placement of the panels (i.e. remaining brickwork) was removed. The actual panel installation required 76 hours.

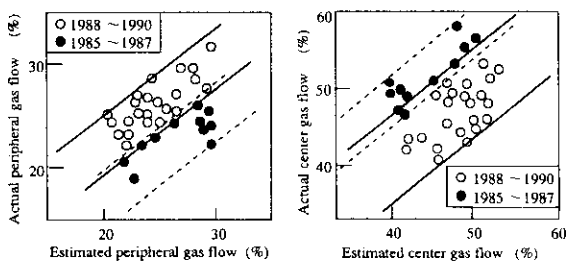


Fig. 11 Transition of gas flow after wearing of upper stack

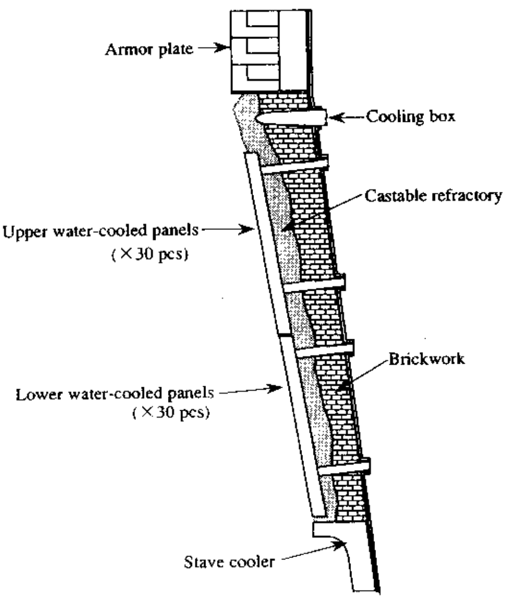


Fig. 12 Schematic drawing of upper shaft lining repair

4.1.3 Stave cooler damage

Long-term control of the heat load on the stave coolers to a low level, achieved by appropriately controlling the thickness of the ore layer at the furnace wall, was reported in an earlier section. However, after more than 10 years of operation, the heat load on the stave coolers showed a steady increase from 1986 onward due to progressive damage of the refractories at the front surface of the stave coolers and reduced burden distribution controllability due to damaged throat refractories. This problem resulted in a higher heat load on the furnace body.

Figure 13 shows the trend in damage to cooling-panels in blast furnaces blown out at Chiba Works. To date, damage to the cooling system of No. 6 BF has

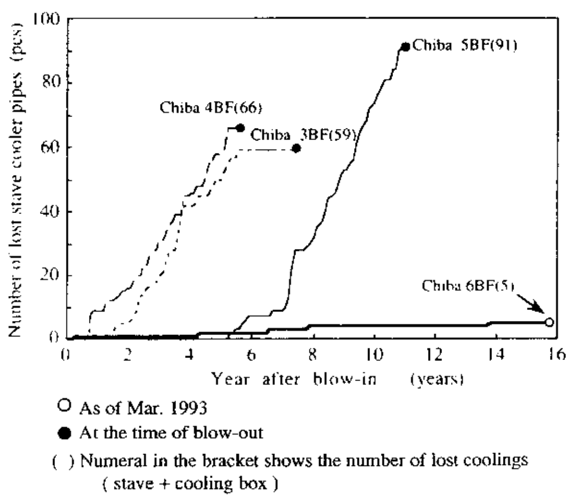


Fig. 13 Transition of number of lost cooling pipe lines

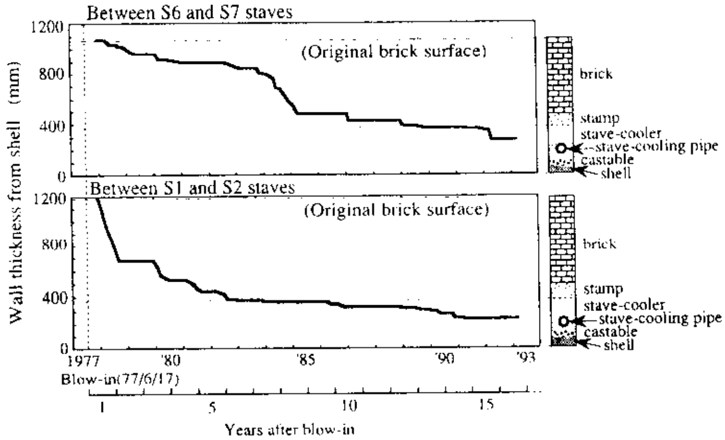


Fig. 14 Transition of shaft wall thickness (No. 6 BF)

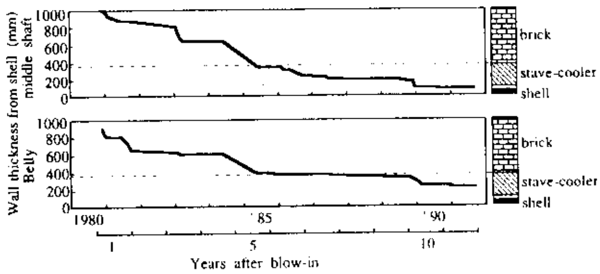


Fig. 15 Transition of shaft wall thickness (No. 5 BF)

been limited to two copper cooling boxes and three stave cooling pipes, which is extremely small number of problems in comparison with those suffered by blast furnaces in the past. **Figure 14** shows the results of an estimation of the remaining brick thickness in the furnace. Here, the minimum value up to the time at which the thickness of material attached to the wall was measured is assumed to be the residual brick (stave cooler) thickness. Meausrements were made at stave corners. It was possible to verify that bricks remained in the lower shaft nine years after blow-in, and in the upper shaft, until 12 years after blow-in. **Figure 15** shows the measured results for remaining shaft wall thickness at Chiba No. 3 BF (3rd campaign). Refractory wear was extremely fast at No. 3 BF because it was not equipped with cooling boxes, and at a point in time only five years after blow-in, no stave-front bricks remained anywhere in the furnace. In the eighth year of the campaign, cracks developed in the shell, and in the terminal phase of operation, operating conditions were severely restricted by the countermeasures taken for shell cracking. This experience with No. 3 BF highlights the marked superiority of the concept of furnace body protection during construction and an operation technology which gives consideration to operation for furnace body protection. Examples of these two policies at No. 6 BF include improvement of the refractory support function using the cooling box and optimum control of the heat load on the furnace body using the bell-less charging system.

However, in the current condition of No. 6 BF, the stave-front refractory material has already disappeared in both the lower shaft (S2 stave level in Fig. 1) and the upper shaft (S6 stave level), and wear of the cast stave material is progressing. In addition, hot spots have been observed on the shell between stave coolers at the middle and upper shaft level. It will therefore be necessary to inject castable refractories between the shell and stave coolers during a blow-down and strengthen operational practices for furnace body protection in the future.

4.2 Equipment Control Countermeasures to Prolong Campaign Life

When a blast furnace campaign is extended, the plant becomes more susceptible to equipment problems due to the aging of auxiliary facilities, with a potentially grave impact on blast furnace operation. Early detection and countermeasures for equipment abnormalities and failure by improved equipment control are therefore essential. In 1988, a network system was put in place using remote equipment-monitoring devices and optical cables to create a remote equipment monitoring system.

One example is the monitoring system for the bell-less drive unit shown in **Fig. 16**. As a means of monitoring wear of the large bearing used to hold and revolve the rotating chute, a displacement sensor was installed outside the rotating drive device for remote monitoring of the displacement of rotating and tilt of

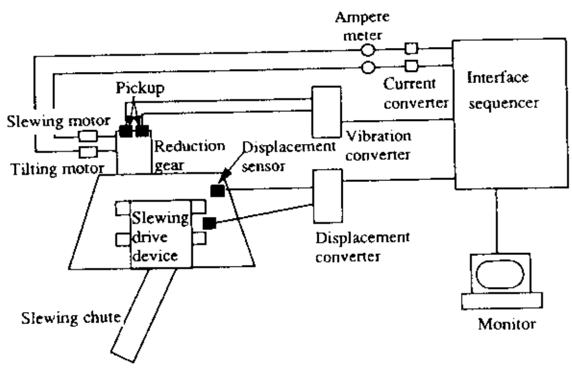


Fig. 16 Monitoring system for the bell-less drive unit

the large bearing. A vibration sensor for the upper reduction gear was also installed to monitor vibration of the reduction gear input bearing. Remote monitoring for the presence of equipment abnormalities is possible by boundary and trend value control of signals from these devices, preventing equipment failures and avoiding disturbances of the normalized operation.

5 Recent Tasks for Achieving Normalized Operation

The preceding sections have reported the measures taken to date to prolong the campaign life of Chiba No. 6 BF. However, these measures are intended to restore locally damaged parts. General furnace body damage is also progressing, and problems which affect the operation have emerged. One example is described below.

Progressive wear of the cast stave cooler material has been confirmed from the results of furnace body damage presented in Fig. 14. From the actual results with Chiba No. 5 BF, increasing damage to the stave cooler cooling-water pipes is expected in the future. New furnace wall-thickness sensors for the belly and bosh were therefore installed to strengthen furnace body protection control (**Fig. 17**).

Figure 18 shows the condition of damage in the shaft. Four years after the water-cooled panels were installed in the throat, these parts began to show deformation. On the other hand, wear of the stave cooler castings was also becoming progressively worse. These problems were producing large irregularities in the vertical profile of the shaft. Circumferential irregularities were also becoming more serious. **Figure 19** shows the variations in the temperature of lower furnace body parts when the furnace body was sound and at the current level of wear. As can be understood from the figure, furnace body temperature variations have increased due to the

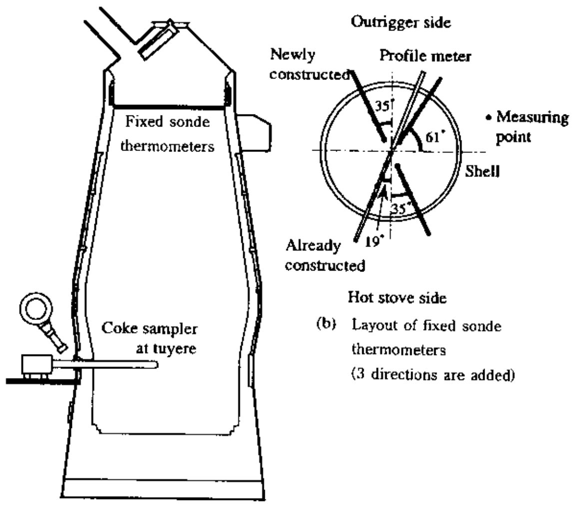


Fig. 17 Configuration of recently installed sensors

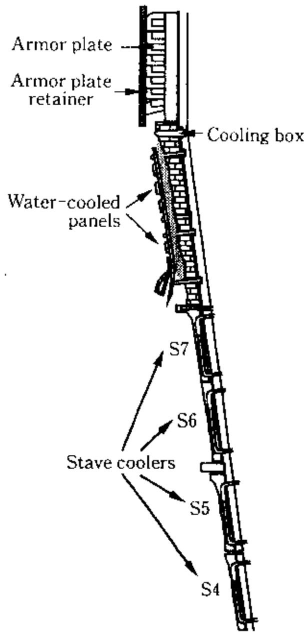
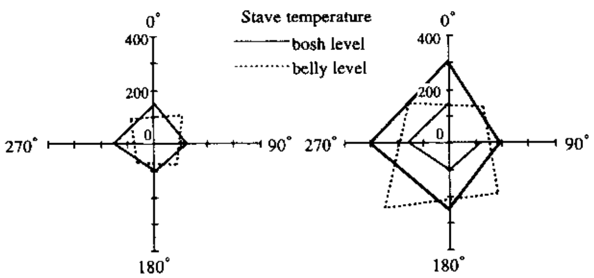


Fig. 18 Schematic illustration of upper shaft profile



(a) Normal shaft wall profile (b) Irregular shaft wall profile

Fig. 19 Comparison of stave temperature variation

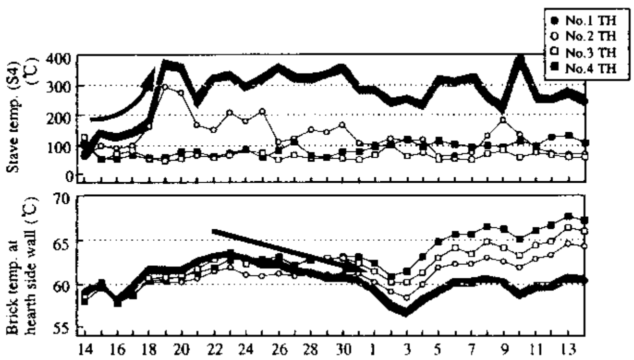


Fig. 20 Relationship between stave temperature (S4) and brick temperature at the hearth wall side

increasing irregularity of the furnace profile, and circumferential deviations in gas flow have occurred. **Figure 20** shows the correspondence between the stave temperature at S4 and the temperature at the hearth side wall. When the stave temperature increases, the temperature at the hearth side wall decreases. Moreover, deviations between tap holes in the temperature and composition of tapped hot metal and in the slag rate tend to increase simultaneously with drops in hearth wall temperature.[17] Scale model experiments have confirmed that when wall profile irregularities are large, as they are in this case, the coke layer tends to segregate toward the wall below a convex irregularity, while the ore layer tends to segregate toward the center.[17] This problem does not occur in sound furnaces. Measurement of in-furnace conditions caused by local segregation of raw materials during burden descent will show an increase in the gas flow rate near the wall, together with an increase in the temperature of the furnace body, as a result of the formation of a coke layer at the wall. On the other hand, it is thought that segregation of the ore layer allows unreduced iron ore to descend through the furnace, resulting in the formation of a solidified layer of ore and a low temperature coke area at the hearth (shown by the reduced temperature at hearth side wall). The observed deviations in hot metal and slag characteristics are assumed to be caused by changes in the flow of molten iron and slag attributable to this mechanism. As a countermeasure for this problem, the top bunker assignment changes are actively used when a stave cooler temperature increase is noted before the deviation in tapping characteristics occurs, preventing the deviation. However, with the BF in its present state of deterioration, it is extremely difficult to control the gas flow using the burden distribution techniques which were established when the furnace was in sound condition. The number of fixed sonde thermometers were therefore increased (from the former one direction to four directions) to strengthen operating control by providing a grasp of the gas flow distribution in the circumferential direction. To measure conditions at the deadman, operational control equipment was augmented by installing tuyere coke samplers and other measures (Fig. 17).

To avoid operating problems due to equipment abnormalities, seriously deteriorated electrical and instrumentation equipment will be replaced, and the equipment monitoring system will be upgraded for closer control of equipment by both operating and maintenance personnel.

6 Conclusions

Chiba Works No. 6 BF has been in continuous long-term operation since June 1977, when the unit was blown in for its first campaign. The following measures were taken to achieve this long-term operation:

(1) Incorporation of new design features to prolong campaign life.
(2) Implementation of operational control practices aimed at prolonging campaign life using the bell-less top charging system and GO-STOP operating control system.
(3) Elimination of obstacles to stable operation from the equipment side by installing water-cooled panels and an equipment control system.
(4) Identification of the state of hearth brick damage using the boundary element method.

However, general damage to the furnace wall profile has affected operations, and new sensors were therefore installed to strengthen operational control of this long-campaign blast furnace.

No. 6 BF must remain in stable operation until a relining which is scheduled for 1998. Although this furnace has now been in service for more than 17 years, it continues to be an extremely important facility at Chiba Works in terms of both iron supply and energy supply. Moreover, additional cost reductions are required even with this long-campaign unit. For these reasons, operating and equipment control will be strengthened further in order to maintain stable operation until the scheduled relining.

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