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1 Introduction

Ferroalloys are now produced mainly by electric furnace, both in Japan and elsewhere. As a result of the first and second oil crises, the cost of electric power spiralled and in particular, the one in Japan became the highest in the world. Silicomanganese, ferrochromium, and ferrosilicon produced in Japan have accordingly lost competitiveness internationally. This is clearly evident from the steady increases in imports of these ferroalloys, and the fact that current import ratios are roughly 20%, 40%, and 60% respectively.

Although the import ratio of ferromanganese in Japan has been held to only at a level of 3–5%, Japanese ferromanganese also lost competitiveness in the international market, and is expected to fall victim to imports, as the above-mentioned ferroalloys have, in the near future. In addition, in a recently developed steelmaking technology in which manganese ore is added directly to hot metal or molten steel to raise the manganese content, consumption of maganese-based ferroalloys has been reduced. This has forced ferroalloy producers to curtail production.

Under such circumstances, Japanese ferroalloy producers are compelled to change their production process and improve their operations. Mizushima Ferro-Alloy Co., Ltd., located in the Chugoku region, where electric rates are the highest in Japan, undertook construction of a shaft type ferromanganese smelting furnace (SF), the first of its kind in Japan. This type of furnace uses coal based energy instead of electric power, a great advantage as the company is situated within Mizushima Works of Kawasaki Steel, where low-cost coke is available. Effective use of gas generated from the furnace is also possible in the steelworks. The reasons for the smelting furnace adoption are shown schematically in **Fig. 1**.

In February 1984, Mizushima Ferro-Alloy contracted for the new furnace with the Engineering Division of

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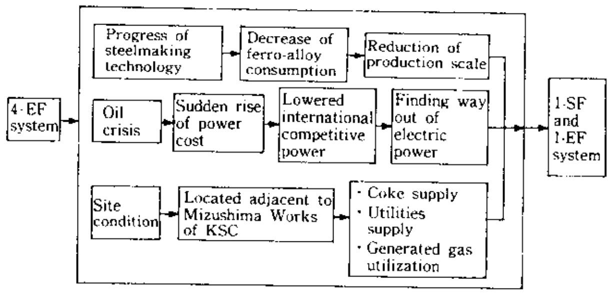

Fig. 1 Background and conception on the adoption of SF

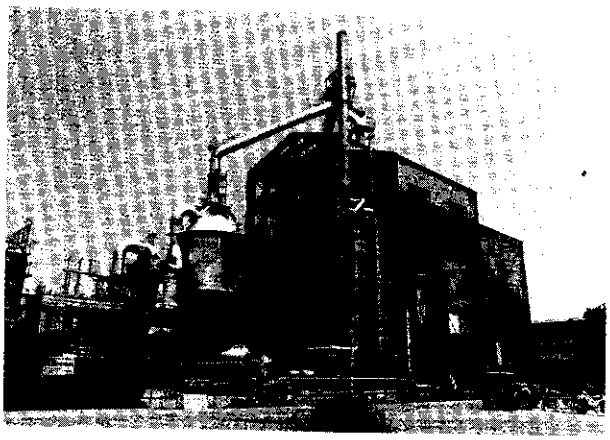

Photo 1 General view of SF

Kawasaki Steel on a full turn-key basis, and construction was completed about one year later. This shaft-type smelting furnace was designed exclusively for use with Fe-Mn. Although based on conventional iron- making technology, the design was drawn up giving consideration to the special nature of ferromanganese production and taking full advantage of the technical capabilities of Kawasaki Steel (**Photo 1**).

This report describes the special characteristics of ferromanganese smelting by the shaft-type smelting furnace and the features of the facility, and also outlines the construction work.

2 Production Setup

Mizushima Ferro-Alloy was established as an affiliated company of Kawasaki Steel in 1964, and is a manganese-based ferroalloy producer. The company formerly operated four electric furnaces. The No.4 furnace was dismantled, and the smelting furnace discussed here was constructed using the existing building and foundation and a portion of auxiliary facilities of the dismantled electric furnace. When the smelting furnace was blown in, the No.1 and No.3 electric furnaces were shut down. Production was reorganized so that the

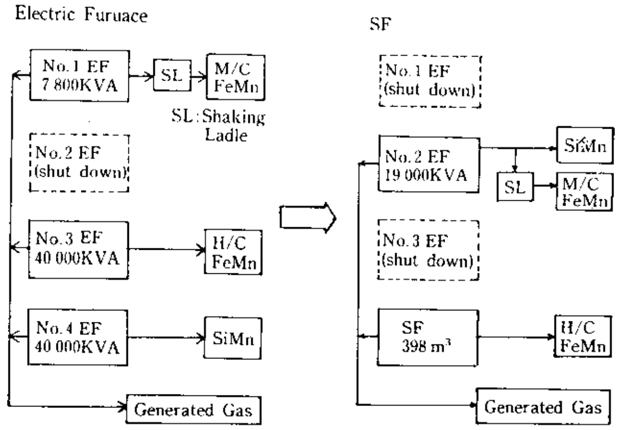

Fig. 2 Conversion of production system at Mizushima Ferro-Alloy Co., Ltd.

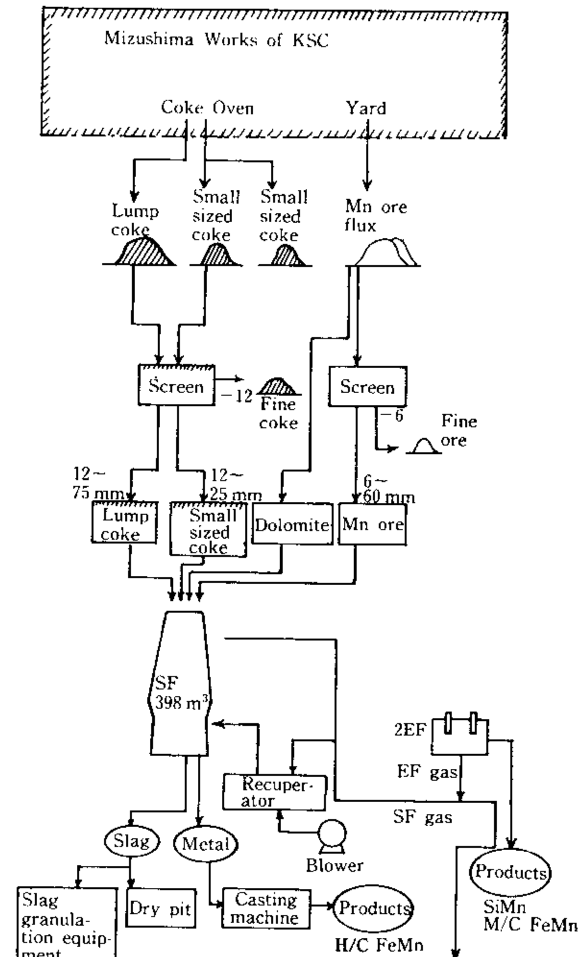

Fig. 3 Materials flow at SF

smelting furnace would produce H/C Fe-Mn steel, while the No.2 electric furnace would produce silicomanganese and M/C ferromanganese. The production capacity of the smelting furnace is about 90 000

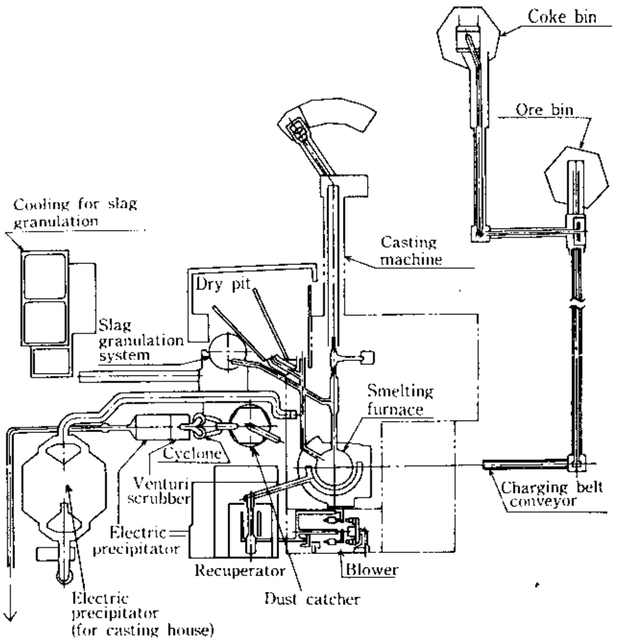

Fig. 4 Layout of SF

t/year. A comparison of the new production setup after adoption of the SF process and the conventional production setup is shown in **Fig. 2**, the production flow chart for the smelting furnace, in **Fig. 3**, and the overall structure of the smelting furnace, in **Fig. 4**.

3 Features of Ferromanganese Smelting by Shaft Type Furnace

To produce a ton of ferromanganese by electric furnace, 2 400 kWh of electric power and about 360 kg of coke are required, but with the shaft type furnace, the requirements are about 200 kWh and about 1 500 kg of coke. The main operational specifications of the smelting furnace are shown in **Table 1**. The following describes the features of ferromanganese smelting in comparison with those of the pig-iron blast furnace.

(1) High Coke Rate

The most outstanding difference between pig iron making and Fe-Mn making is that, in the former, Fe can also be produced through indirect reduction of FeO by CO gas, while, in the latter, the indirect reduction of MnO by CO gas does not occur and Mn is produced only through direct reduction by C (**Fig. 5**). Consequently, CO utilization efficiency in the furnace is lower, and both latent and sensible heats of the top gas become very high. In addition, the energy requirement for reduction to Mn is higher than that for reduction to Fe.

These facts means that the consumption of fuel and coke in the smelting furnace increases to 1 200 to 1 500 kg/t relative to only 450 to 500 kg/t in pig-

Table 1 Operational conditions for design of SF

Items	Specification
Inner volume	398 m^3
Production	230 t/d
Blast volume	450 Nm^3/min
Oxygen enrichment	7~8%
Blast temperature	860°C
Mn content in metal	74.5%
Coke rate	1 500 kg/t
Productivity	0.58 $t/m^3 \cdot d$
Slag rate	580 kg/t
Top gas volume	4 890 Nm^3/t

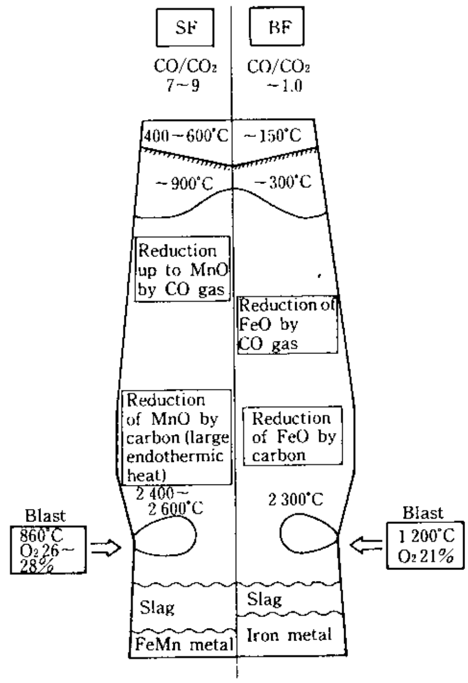

Fig. 5 Comparison of metallurgical reaction between SF and BF

iron making.

(2) Low Productivity

Productivity of pig iron is 1.8 to 2.2 $t/m^3 \cdot d$, but that of ferromanganese drops to 0.58 to 0.68 $t/m^3 \cdot d$ because, in ferromanganese smelting, the coke rate is high and the unit consumption of generated gas in the furnace is also high due to high coke combustion in front of the tuyere.

(3) High Top Gas Temperature

Because reduction of MnO_2 and Mn_2O_3 by CO, which is a significant exothermic reaction, occurs in the upper furnace and, further, because of the high coke rate, the top gas temperature rises to 400 to 600°C compared with the approximate 150°C of the pig-iron blast furnace. Top gas temperature is controlled to 300 to 350°C by spray water for protection of the unit.

(4) High Dust Rate
The dust rate (dry dust + wet dust) in the smelting furnace is 100 kg/t or above compared with about 20 kg/t in the pig-iron blast furnace, for the following reasons:
(a) Manganese ore frequently develops thermal cracking and generates a great deal of powder.
(b) Since the combustion zone temperature and the inner temperature are high, fine powder dust such as SiO_2 is apt to be generated in front of the tuyere.
(c) The volume of top gas generated in the furnace is great due to the high coke rate; also, due to the high top gas temperature, the apparent gas volume and the gas flow velocity in the throat increase.

(5) High Theoretical Flame Temperature (TFT) at Combustion Zone
As manganese has strong affinity with oxygen, manganese oxides are difficult to reduce. Therefore TFT, which improves manganese yield, is set to 2 400 to 2 600°C, compared to the TFT of the pig-iron blast furnace of about 2 300°C. The smelting furnace uses a continuous heat-exchanger-type metallic recuperator instead of the conventional hot stove. Since the blast temperature is as low as 860°C, TFT is maintained and controlled by oxygen enrichment.

(6) High Heat Load
Due to the high coke rate and high TFT discussed above, the inner temperature of the smelting furnace is higher than that of the pig-iron blast furnace. According to temperature measurements by the shaft gas sampler, the temperature at the side wall at a level about 1 m below the stock-line exceeds 800°C. Due to this high heat load and the high refractory erosivity of MnO slag, as well as the fact that raw materials charged into the furnace are higher in alkali content than those of the pig-iron blast furnace, the life of the furnace lining is estimated to be shorter than that of the pig-iron blast furnace.

(7) High Alkali
Since manganese ore contains more alkali than iron ore and the coke rate is three times as high as that of the pig-iron blast furnace, unit consumption of K_2O charged into the furnace is about 12 times as high as that of the pig-iron blast furnace, and even if correction using the productivity coefficient is made, the smelting furnace requires four times as much K_2O as the pig-iron blast furnace. K_2O not only erodes the furnace lining but also adheres to the gas cleaning system, affecting it adversely.

4 Specifications and Features of the Furnace Facilities

Main specifications of the furnace facilities are shown in **Table 2**, and the features of the facilities are described below.

4.1 Protection of Facilities against High Heat Load

The coke rate of the smelting furace is about three times that of the blast furnace, and the heat capacity of the bosh gas also increases due to an increase in carbon burned at the tuyere zone. The MnO_2 and Mn_2O_3 contents in manganese ore are reduced easily to Mn_3O_4 by a comparatively lower-temperature CO gas. These are significant exothermic reactions and warrant particularly careful attention in facility planning. Countermeasures adopted to protect the furnace against the high heat load and high top gas temperature are as follows:

(1) High density arrangement of furnace cooling plates **(Fig. 6)**
(2) Expansion of furnace cooling area (cooling plates installed up to the lower edge of wearing plates, Fig. 6)
(3) Water cooling of wearing plates and adoption of cooling plates for the wearing-plate protection

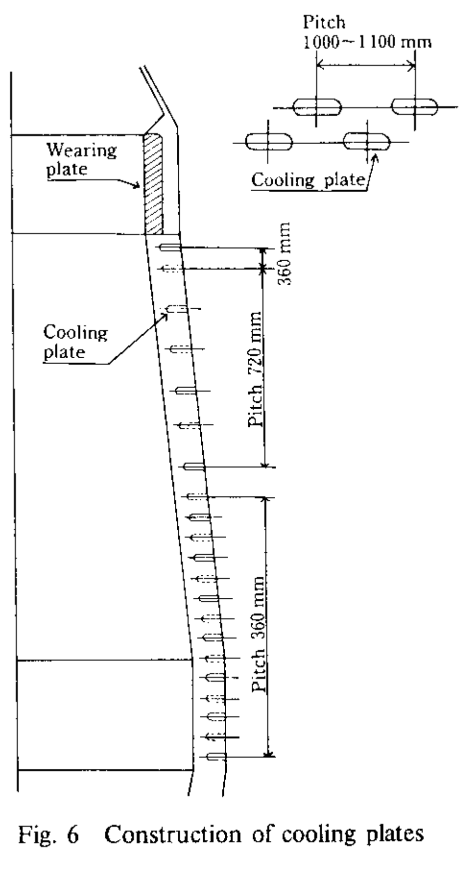

Fig. 6 Construction of cooling plates

Table 2 Main specifications of SF equipment

Item	Specifications
Furnace proper	
Inner volume	398 m^3
Furnace support	Free standing type
Cooling system	
Shaft and Bosh	Cooling plates
Hearth	Water spray
Refractories	
Up. and mid. shaft	High alumina brick
Lower shaft	SiC brick
Hearth	Carbon brick
Tuyere	
Number	13
Type	Eccentric high flow rate water cooling type
Tap hole	1
Cinder notch	1
Cast house	
Tap hole opener	
Number	1 set (air driven)
Effective length of opening	3 000 mm
Mud gan	
Number	1 set
Mud capacity	0.1 m^3
Filling	Driven by hydraulic pressure
Rotation	Driven by electric power
Iron trough	Non hot metal storage type Mono-stage skimmer
Molten iron treatment	1-casting machine Max. 4.3 t/min
Slag treatment	2-dry pits 1-slag granulation system
Furnace top equipment	
Charging pattern	Standard charging (C ↓ O ↓ and C ↓ C ↓ O ↓ O ↓), C-O mixed charging, coke two-size separate charging, etc.
Type	One hopper type new bell-less top (CTBL)
Distribution chute	Electric drive
Seal valve, flow control valve	Hydraulic drive
Hot blast generator	
Type of recuperator	Radiation and convection
Number	1 set
Blast temperature	860°C (max. 900°C)
Gas cleaning system	
Dust catcher (DC)	Gravity settling type
Cyclone (CY)	Centrifugal type
Venturi scrubber (VS)	1-stage venturi throat variable type
Electric precipitator (EP)	Wet type, 2-rooms
Stock house	
Coke bin	55 m^3 x 14 bins
Ore bin	60 m^3 x 12 bins
Blower	
Type	Electric drive
Blower revolution	13 400 rpm
Motor	1 400 kw x 3 580 rpm
Blast volume and pressure	535 Nm^3/min x 1.3 kg/cm^2

(4) Water cooling of bell-less drive unit (rotating frame and distribution chute ring)

(5) Adoption of a high-flow-rate-water-cooled-type-tuyere (tip velocity: 20 m/s)

(6) Castable lining which covers internal surface of both external cylinder and bottom hopper of dust collector

(7) Furnace top water-spray facilities

4.2 Furnace Body Lining

Manganese ore, compared with iron ore, has high content of alkalis such as K_2O and Na_2O. The MnO content of the furnace slag is about 8% even in the final slag, and $SiO_2 \cdot Al_2O_3$ refractories are highly susceptible to reaction with MnO slag. In the smelting furnace, careful attention is paid to resistances against alkali and against high MnO slag, and SiC-based bricks are used in an area extending from the shaft bottom to the tuyere. The philosophy of refractory selection for the smelting furnace proper is shown in **Fig. 7**.

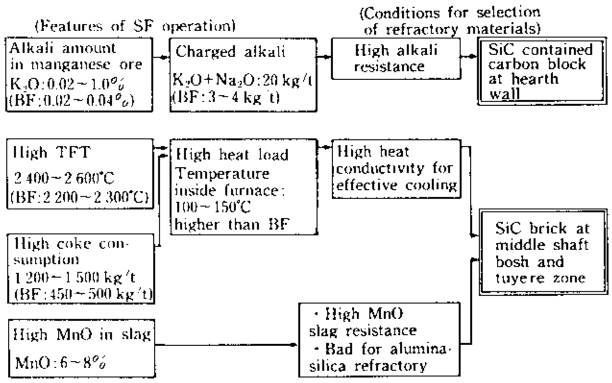

Fig. 7 Conditions for selection of SF refractory materials

4.3 Hot Blast Generation Equipment

For the first time in the field of ironmaking, a continuous heat-exchanging radiation type metallic recuperator was used in place of the conventional heat-accumulation type hot stove. In introducing this recuperator, special attention was paid to the life of the radiation tube at high temperatures, thermal efficiency, wide operation range, combustion controllability, and maintainability. One year has passed since the start-up of the recuperator, and to date its stability and controllability have been excellent. Heat efficiency is maintained at 84%. The structure of the recuperator and its operational range are shown in **Figs. 8** and **9** respectively.

Blast air is first preheated in the convection section and then supplied to the radiation section via a connecting tube. After being heated to a prescribed temperature in the radiation section, the blast air passes through the hot blast tube and is supplied to the furnace. The maximum blast temperature is determined by the heat-resis-

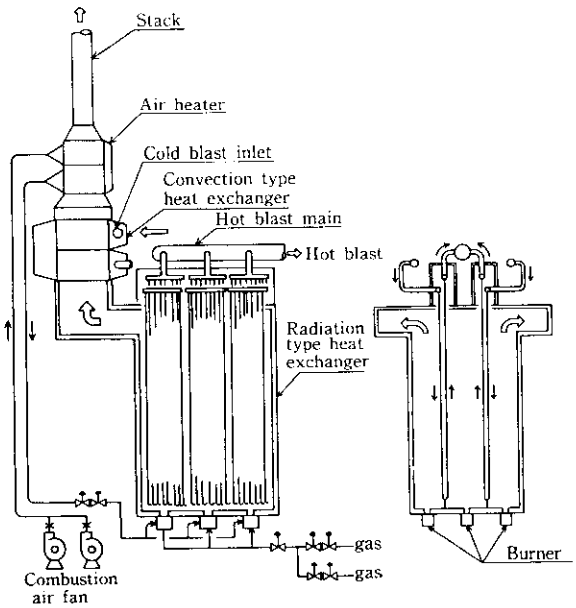

Fig. 8 Structure of recuperator

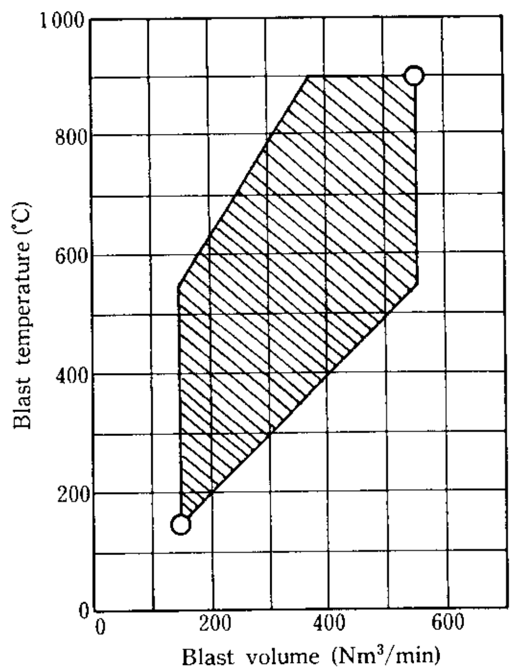

Fig. 9 Operational range of recuperator

tance of the heat-transfer tube in the radiation section, and can reach 900°C, the highest level for this type of facility. Incidentally, the recuperator burns M gas exclusively in the start-up operation after blowing down, but uses a blend of M-gas and SF-gas after operation is stabilized.

4.4 Furnace Top Charging Facilities[1,2]

To stabilize ferromanganese operation by control of the distribution of the furnace-top charge and to cope

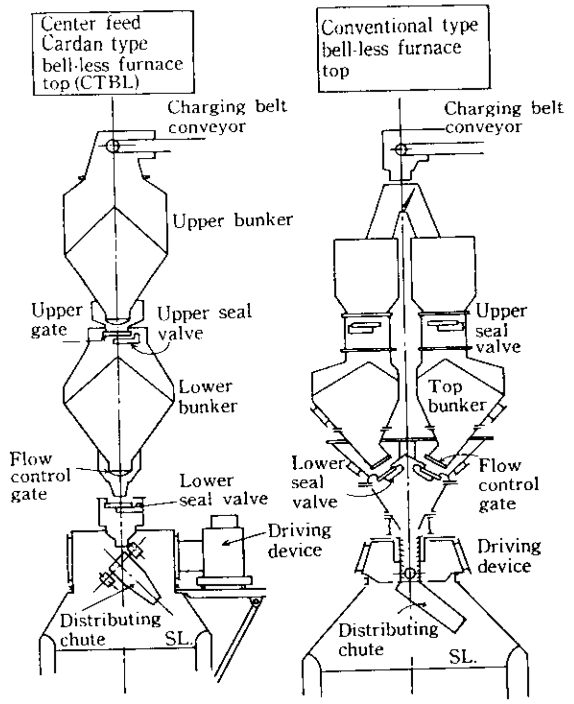

Fig. 10 Comparison of CTBL construction with conventional type

with the high top-gas temperature, a one-hopper center-field Cardan type bell-less furnace top (CTBL) was adopted.

After blow-in, smooth trouble-free operation of this furnace top was achieved, in spite of its being used in a high top-gas temperature and high dust environment. A comparison of the construction of the new bell-less top and the conventional PW type bell-less top is shown in **Fig. 10**. Characteristic of the new Cardan type bell-less top is the horizontal installation of the distribution chute drive unit outside the furnace. The drive unit, thus, is not directly exposed to the high-temperature furnace top environment. Further, the rotating-frame which supports the distribution chute is water-cooled by a water-cooling jacket, as shown in **Fig. 11**.

To describe the distribution chute mechanism in detail, the trunnion of chute is set into the V-groove of the double-pronged portion at the tip of the rotating frame and locked, and the chute is driven from outside the furnace. This mechanism is shwown in **Fig. 12**. To drive the distribution chute, the swing movement of lever (A) causes rotation of the rotating frame and reciprocating motion of link (B), thus giving a rotating motion to the chute. The inclination angle (θ) of the chute is changed by elevation of shaft (C).

4.5 Gas Cleaning Equipment

In the smelting furnace operation, dust collection and disposal are very important because a much greater volume of dust is generated than in blast furnace

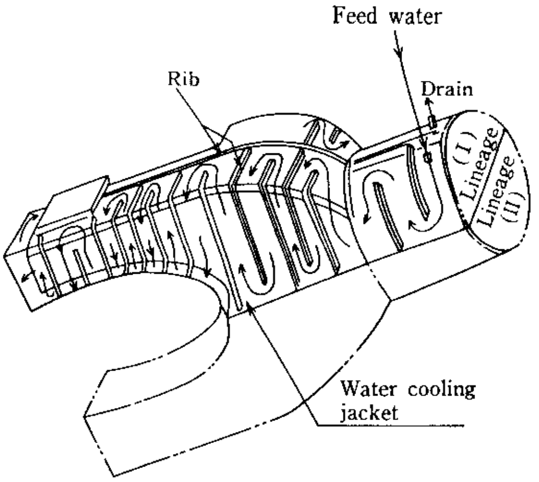

Fig. 11 Cooling water flow in CTBL rotating frame

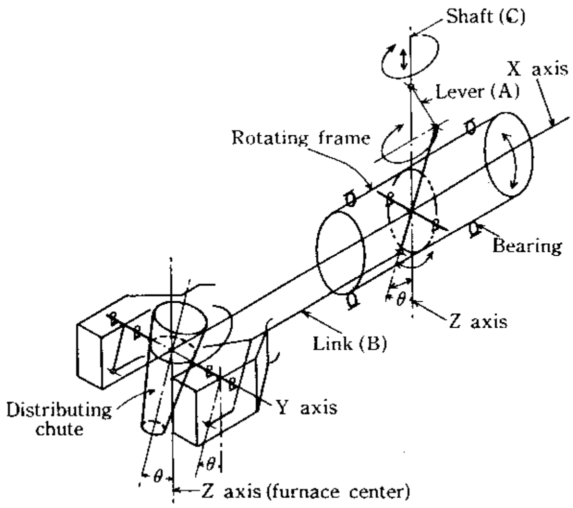

Fig. 12 Drive mechanism of CTBL

operation. Further, there are dust properties such as stickiness and micrograins which are peculiar to the ferromanganese smelting operation. To lower the dust load on the wet-type dust disposal facilities (VS/EP), dry dust collection equipment was augmented by installing a cyclone at the downstream of the dustcatcher.

5 Construction Work

Immediately upon receiving the order for smelting furnace construction work from Mizushima Ferro-Alloy, Kawasaki Steel organized an SF Project Team in its Engineering Division, centering around the Blast Furnace Relining Technology and Planning Sec. in the Iron and Steel Making Technology Dept., and undertook the task of constructing the optimum facility.

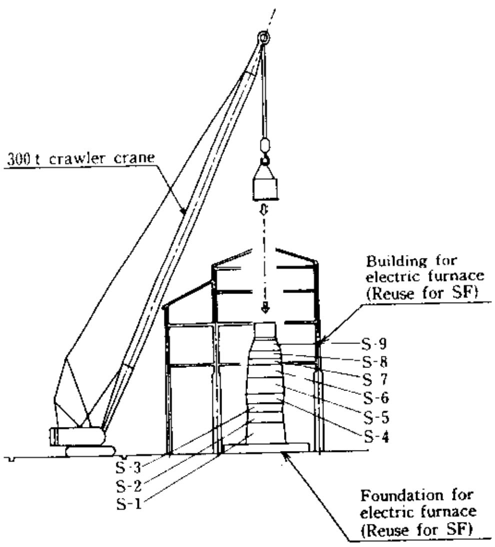

Fig. 13 Erection of SF furnace shell

In the construction, the foundation, building, pipelines, equipment, and power source panel of the No.4 electric furnace were fully used to minimize construction costs. The furnace proper was a close fit in the electric furnace building, and the electric-furnace building and foundation were usable without modification (**Fig. 13**).

To shorten the construction period and ensure safety, a large block process was adopted. In the furnace shell assembly work, the lateral shift process, using a 200-t carrier, and the ring mounting process, using a 300-t crawler crane, were adopted (Fig. 13).

The No.4 electric furnace was shut down on September 4, 1984, and dismantling work was begun. Following dismantling of the electric furnace, building remodeling work and foundation work were done, and the smelting furnace shell erection work commenced in November 1984. The downcomer connecting furnace shell and the dustcatcher was installed on May 8, 1985, completing the erection of the main portions.

For Mizushima Ferro-Alloy Co., Ltd., the smelting furnace was the first instance of new facilities replacing a conventional electric furnace. For this reason, Kawasaki Steel sent an operation and maintenance technique guidance team to Mizushima Ferro-Alloy in April 1985 to perform operations preparatory to blowing in, such as recuperator drying, SF drying, and raw material charging operations, and to guide the startup operation after blow-in and advise in maintenance techniques.

During the construction work, a general safety and health administration system was established. The construction work was executed on a safety-first principle and the construction work was completed without accident or injury (total work hours: 377 000 h). The

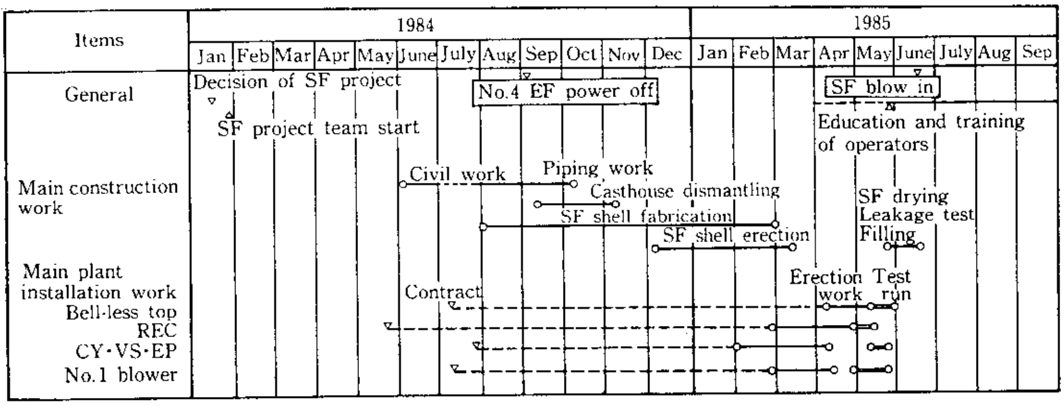

Fig. 14 Construction time schedule of SF

overall timetable of the construction project is shown in **Fig. 14**.

6 Startup Operation

The new smelting furnace was blown in on June 24, 1985. The first tapping was 30 t of pig iron on June 25. The foundry pig-iron making operation was conducted for a week. The production of ferromanganese began 2 days later. The start-up operation was carried out smoothly, without any serious trouble, and since September 1985, the smelting furnace has performed consistently as originally planned.

7 Conclusions

A ferromanganese smelting furnace was constructed at Mizushima Ferro-Alloy Co., Ltd. and blown in on June 24, 1985. This new smelting furnace has the following features:

(1) Strengthened cooling of the furnace body and water cooling of wearing plates to cope with high heat load due to high coke rate.
(2) Adoption of refractories having alkali resistance and high-MnO slag resistance properties.
(3) Adoption of continuous hot-blast generating equipment using a radiation-type metallic recuperator in place of the conventional heat-accumulation-type hot stove.
(4) Adoption of a water-cooled center-feed type bell-less furnace top capable of excellent charge distribution control.
(5) Installation of gas cleaning facilities consisting of a dust catcher, cyclone, VS, and EP to cope with the high volume of dust generated by this type of furnace.

The construction work, in which the furnace shell was assembled by the large block process using ring mounting, was achieved on without accident or injury seven days ahead of schedule. At present, the smelting furnace has overcome start-up problems and is in smooth operation.

Finally, the authors would like to express their deep appreciation to the staff concerned for their warm support and kind cooperation rendered in the course of executing this SF project.

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