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Introducing the No.3 Continuous Slab Caster at Chiba Works

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Synopsis :
The No.3 continuous slab caster of Chiba Works, Kawasaki Steel Corporation has been operating satisfactorily since its start in April, 1981. In order to cast slabs of sound internal quality at high speed, this machine has a 3-meter-long vertical portion, a progressive bending and unbending profile and small roller pitches with divided rollers. The machine also has an equipment for a quick test scarfing to see if slabs are good for charging hot into the heating furnace. Hydrogen content of steels melted by Q-BOP are rather higher than those by LD; posing problems of slab surface defects which, however, are now solved by improvement in Q-BOP operation.

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Introducing the No. 3 Continuous Slab Caster at Chiba Works*

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The No. 3 continuous slab caster of Chiba Works, Kawasaki Steel Corporation has been operating satisfactorily since its start in April, 1981. In order to cast slabs of sound internal quality at high speed, this machine has a 3-meter-long vertical portion, a progressive bending and unbending profile and small roller pitches with divided rollers. The machine also has an equipment for a quick test scarfing to see if slabs are good for charging hot into the heating furnace. Hydrogen content of steels melted by Q-BOP are rather higher than those by LD; posing problems of slab surface defects which, however, are now solved by improvement in Q-BOP operation.

1 Introduction

At the No. 3 Steelmaking Shop of Kawasaki Steel's Chiba Works where two Q-BOP units are in operation, construction of No. 3 slab caster was started in November, 1979, and operation commenced in April 2, 1981, and the machine has since been operating smoothly.

Types of steel continuously cast are mainly slabs for hot and cold rolled carbon steels and plated steels. In order to obtain slabs having sound internal quality even during high-speed casting, the slab caster has a vertical progressive bending and unbending profile, as well as divided rolls particularly designed to reduce roll pitch. Further, for a direct warm slab charging, the slab caster was provided with a torch-cut slag remover and a finishing yard equipped with a quick test-scarfing equipment.

This paper outlines the operating condition of the No. 3 slab caster and its related facilities.

2 Fundamental Concept of Constructing No. 3 Slab Caster

In constructing the slab caster, the fundamental concept of "supplying the succeeding steps with defect-free slabs" was established, with the following guidelines:

(1) To construct a highly efficient machine capable of casting high-quality slabs.
(2) To aim at a non-conditioning and warm slab charging.
(3) To have all the operating unit to be thoroughly automatic and manpower saving.
(4) To achieve thoroughgoing operational and maintenance control through fully-equipped instrumentation.
(5) To prepare the plant layout so as to facilitate the addition of future facilities.

Table 1 shows various measures taken for achieving high efficiency and high quality. **Table 2** shows facilities necessary for the non-conditioning warm slab charging.

For automation, labor saving and instrumentation, a separate report[1] has been given.

3 Outline of Facilities

3.1 Layout

Fig. 1 shows the layout of the No. 3 slab caster. Various yards and cranes for the No. 3 slab caster were designed so that they would commonly be used by No. 4 slab caster to be constructed in the future. The slab yard for No. 3 slab caster was laid out mainly with the warm slab charging in mind. Its slab finishing yard was provided with caisson-type slab cooling equipment

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Table 1 Particulars for achieving high productivity and high quality

For high quality	For high productivity
1) Vertical-bending profile	1) Dummy bar top charge
2) Small roller-pitch by divided roller	2) High speed casting
3) Large capacity tundish	3) Automatic mold width change during casting
4) Shrouding between ladle and tundish	4) Quick change stand
5) Automatic level control of tundish and mold	5) Tundish immersion nozzle change system during casting
6) Automatic control of slab surface temperature	
7) Automatic mold powder feeder	

Table 2 Auxiliary equipment for assuring slab surface free of conditioning in the cooled state

1)	Hot slab marker
2)	Torch dross removal equipment
3)	Hot slab scarfer
4)	Slab cooler for quick scarfing test
5)	Equipment for quick sulfur print

and a warm scarfer for a quick test-scarfing and the conditioning part of the slab.

The above-mentioned layout was so designed as to permit efficient jointing with No. 4 slab caster and No. 3 hot strip mill to be constructed in the future. To be more specific, it was planned that No. 4 slab caster would be placed near to the north side of the existing No. 3 slab caster for a possible common use of the yard and the concentration of electricity rooms, and that finishing of slabs from No. 4 caster would also be processed at the finishing yard to be installed this time for the No. 3 slab caster. It is also planned to feed hot slabs to No. 3 hot strip mill to be constructed in the future.

3.2 Features of Slab Caster

The fundamental specification of the No. 3 slab caster and features of the major facilities are shown in **Tables 3** and **4**. The profile of the slab caster is shown in **Fig. 2**.

3.2.1 Roll profile

Fig. 3 shows the roll profile; **Fig. 4** illustrates how the casting speed affects inclusion accumulation comparing the vertical-bending and a fully-curved type slab casters[2]. The vertical bending machine is capable of reducing inclusion accumulation to a lower level

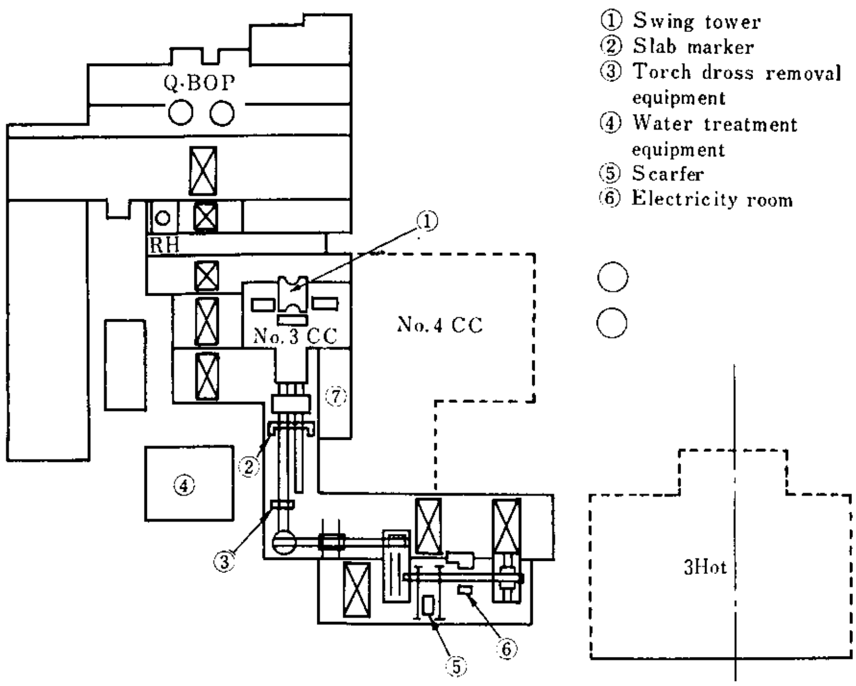

Fig. 1 General layout

Table 3 Principal specification of Chiba No. 3 slab caster

Item	Specification
Furnace	230 t Q-BOP
Machine type	Vertical-progressive bending-progressive unbending
Number of strands	2
Strand distance	6 200 mm
Length of vertical portion	3 000 mm
Metallurgical length	36.5 m
Casting velocity	2.2 m/min for 230 mm thick slab 1.7 m/min for 260 mm thick slab
Casting radius	9 350 mm
Casting floor level	FL+13 700 m
Pass line	FL+800 mm
Mold length	900 mm
Roller type	Combination of divided and full face rollers
Slab size	230 $t\times$(800-1 900) $w\times$(5 000-9 000*) ℓmm 260 $t\times$(800-1 900) $w\times$(5 000-9 000*) ℓmm * 12 000 in future
Machine maker	Hitachi Shipbuilding & Engineering Co.,Ltd.

even during high-speed casting. **Fig. 5** shows the relation between the length of the vertical portion and the amount of inclusions. As clearly seen from the figure, the adoption of the 3-m-long vertical portion made it possible to reduce the amount of inclusions to a level almost equivalent to that of a perfectly vertical type machine. For this reason, the No. 3 slab caster employed a progressive bending and unbending profile

Table 4 Main features of some facilities

Item	Specifications
Swing tower	Ladle weight measuring with 4 load cells
Tundish	Capacity Max. 75 t Bath depth Max. 1 400 mm
Mold	Soft clamp type mold Automatic width change Watt link type oscillation with max. frequency of 200 cycle/min
Segment change	Segment extracting crane
Dummy bar	Short dummy bar Top charge system

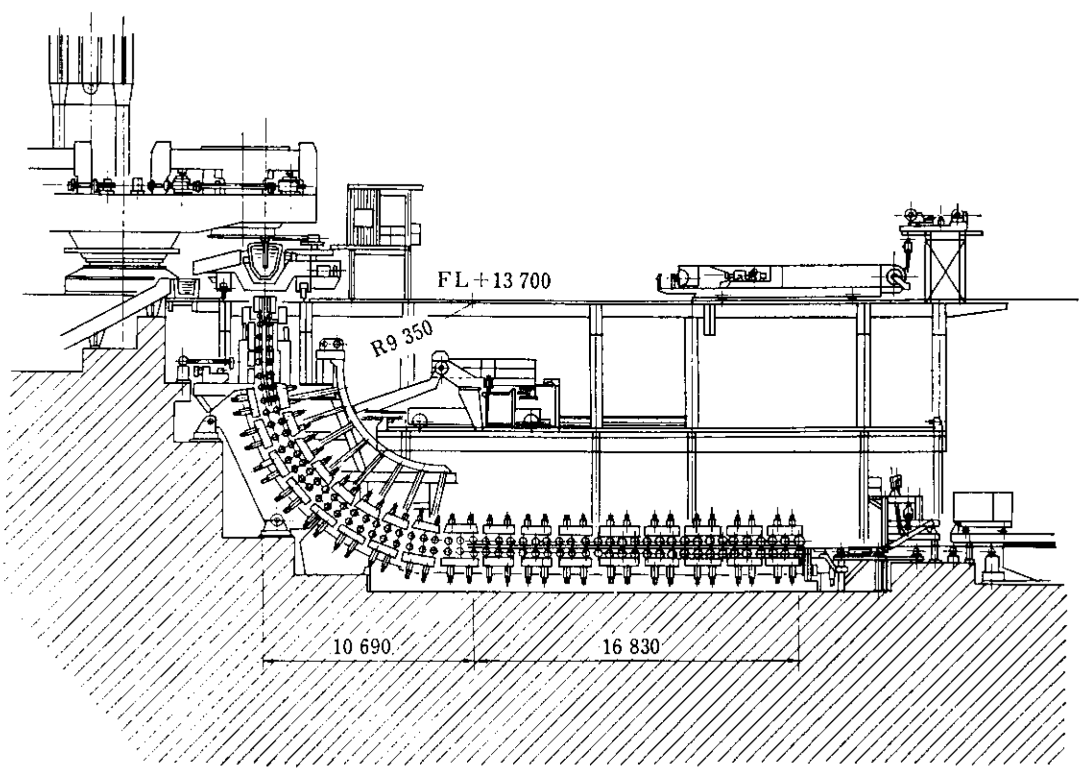

Fig. 2 Cross section of No. 3 caster

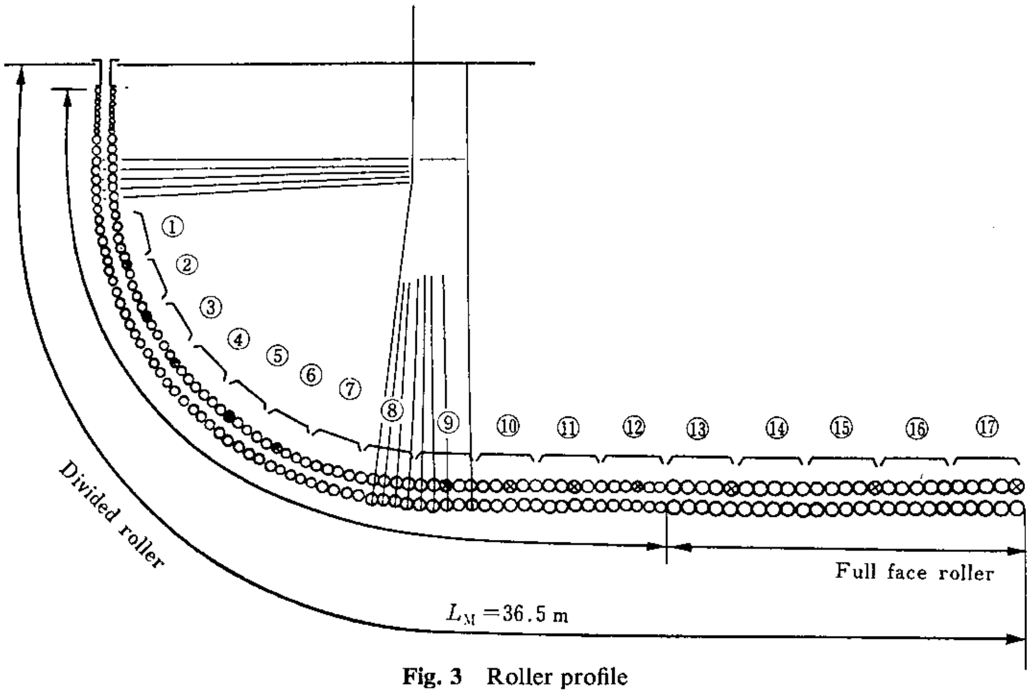

Fig. 3 Roller profile

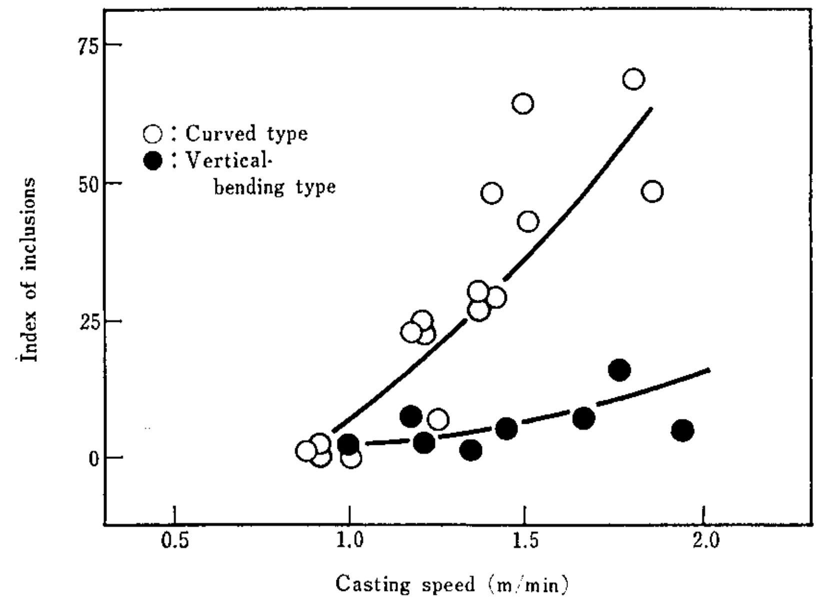

Fig. 4 Influence of casting speed on index of nonmetallic inclusions in accumulating zone

having a 3-m-long vertical portion and attained smaller roll pitches through the use of divided rolles in order to prevent internal cracking of the strand. The divided-roll construction was applied to all driving- and non-driving rolls up to 12 segments.

In determining the roll pitches, internal strain due to bulging was calculated by using a calculation model[3] taking elasto-plasticity and creep into consideration, and a pitch was employed in which maximum strain would be reduced to 0.3% and under. The results of this calculation are shown in **Fig. 6.**

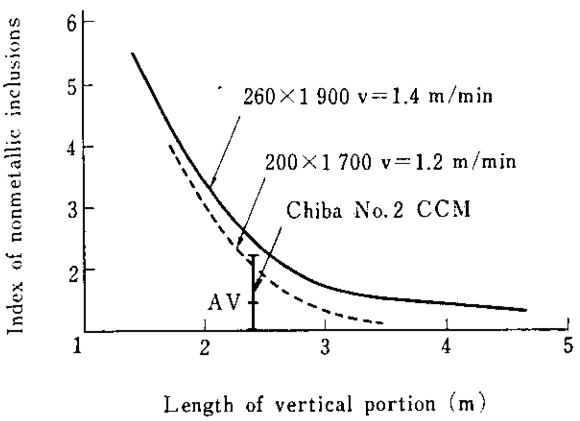

Fig. 5 Influence of the length of vertical portion on index of nonmetallic inclusions

3.2.2 Adoption of large-capacity tundish

Even in high-speed casting in the past, casting speed was reduced at ladle changing, in order to prevent slag inclusions in the tundish due to a drop in the molten steel level. In the Chiba No. 3 slab caster, however, a large capacity tundish having a sufficient molten steel depth (maximum quantity of molten steel: 75 t; molten steel depth: 1 400 mm) was adopted, so that ladle changing would be continued without decreasing the casting speed.

In order to make quick repairs, a sliding nozzle replacing buggie is also provided which permits changing of refractories of the tundish sliding nozzle while the tundish is still in the upright position.

3.2.3 Mold-width changer

Fig. 7 shows a schematic diagram of the mold width changer. In this equipment, the top and bottom supporting points of the narrow face of the mold are driven independently from each other so that slab-width changing speed can be increased during casting, thereby, permitting the taper of the narrow face to be changed during the width changing operation. The narrow side support roll under the mold is also designed to be driven independently, with excellent effect in supporting the narrow face of the strand during high-speed casting operation.

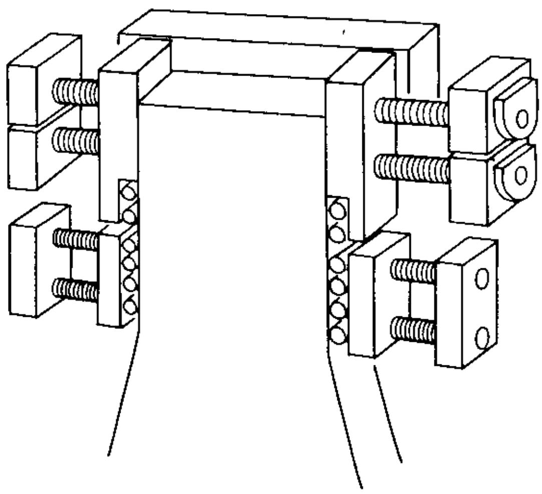

Fig. 7 Schema of mold width change equipment

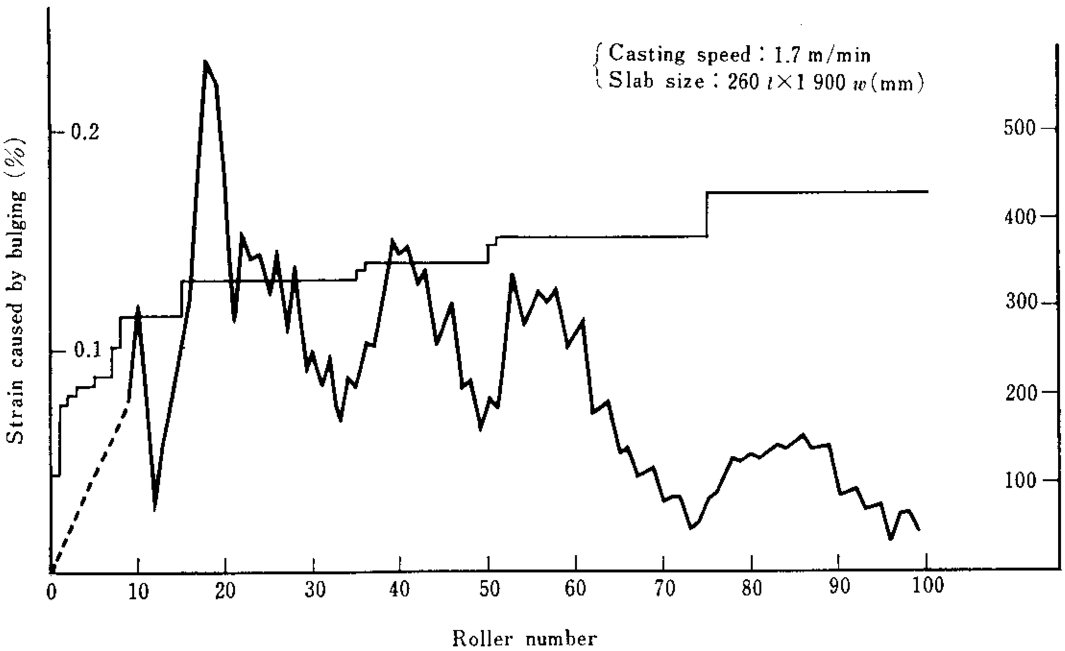

Fig. 6 An example of calculated inner strain caused by bulging at Chiba No. 3 caster

3.2.4 Dummy bar top insertion system

To shorten casting intervals, a "dummy bar top insertion system" is employed, whereby the dummy bar is inserted from the top of the mold while the previously-charged strand is being pulled out.

3.2.5 Secondary cooling water facilities

Facilities related to water treating is based on the fundamental principle of "securing the supply of water whose quality is so good as to avoid clogging of any spray nozzles used for secondary cooling," and the conventional spray cooling water systems were separated into the one for secondary cooling and the other for the cooling of external surfaces of machines located after the torch table. Therefore, scale sluices, scale pits and water treating facilities were provided in 2 channels, and secondary cooling water of the best conceivable quality is secured to prevent nozzle clogging. Since the amount of secondary cooling water which requires intensive treatment has been reduced, saving of construction and running costs has been achieved.

In the scale pits, a fully automatic scale pit crane is employed for unmanned discharging of scale to the hopper.

3.3 Specifications for Transporting and Finishing Facilities

Major specifications of transporting and finishing facilities and the slab flow are shown in **Table 5** and **Fig. 8**, respectively. Slabs which have been cut at prescribed lengths by the torch cutter, with their marking, torch slag removed and their weight measured, are piled by the piler-traverser and then loaded into the slab buggie by using the automatic crane equipped with a slab lifter or piled up at a prescribed location in the slab yard. Meanwhile, slabs to be used for test scarfing or to be conditioned are transported to the conditioning line by the buggie equipped with a table. Slabs which have undergone test scarfing or which have been conditioned in the warm state are transported to the slab yard, loaded on the slab buggie with other slabs of the same charge and transported to the next process.

3.3.1 Slab marker

In order to transport slabs in hot state, a stencil spray marker system using easy-to-read characters was employed for slab marking. This system was an improvement on the slab marker which was developed by Kawasaki Steel.

3.3.2 Torch cut slag remover

Fig. 9 shows a schematic diagram of the equipment. In the conventional torch cut slag remover, it was difficult to remove slag quickly and with sufficient reliability. The slag remover employed at Chiba Works can remove slag almost completely by the cutter system in which water is sprayed on the slag. For a thorough removal of slag from the cutter surface, a system is used in which the cutter is rotated while slag is washed away with water.

3.3.3 Slab quality assuring system

In order to feed detect-free warm slabs to the subsequent step, it is important to establish an automatic system to identify abnormal slab resulting from abnormal operating conditions and machine irregularities. In the following, the slab abnormality finding system is outlined:

(1) Automatic detection of strand at operational abnormality

Table 5 Main specifications of slab delivery and slab conditioning equipment

Item	Specification
Slab marking	Automatic slab marker —stencil type
Removal of torch dross	Automatic torch dross removal —knife edge type
Slab cooling	Caisson slab cooler
Slab piling	Piler and traverser
Hot/cold scarfing	2 face scarfer
Slab handling	Full automatic crane with slab lifter

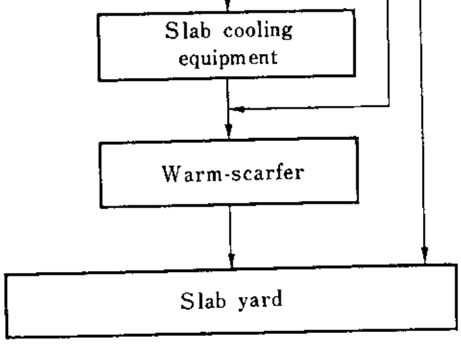

Fig. 8 Schematic flow of cast slabs to yard

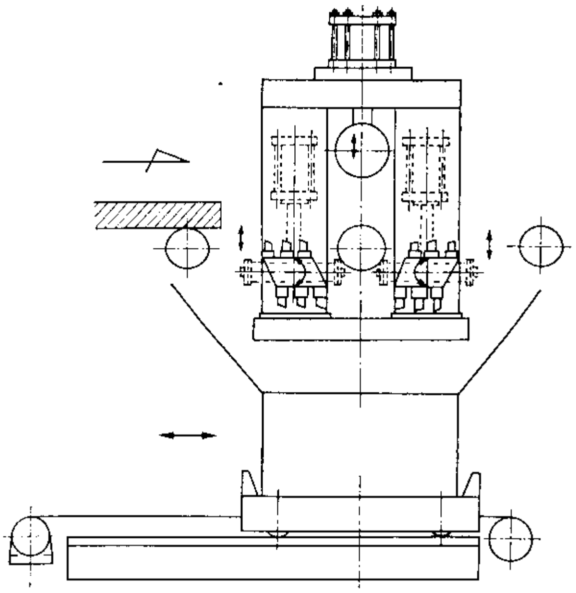

Fig. 9 Schema of torch dross removal equipment

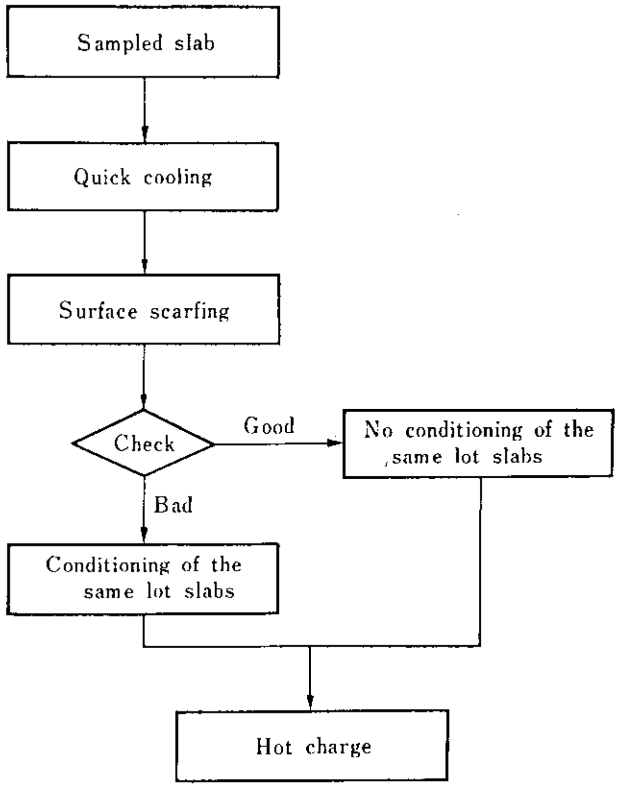

Fig. 10 Configuration of check-scarfing system

A system has been established which can automatically detect an abnormal slab, when such operational factors as sudden changes in the meniscus during casting operation exist, adversely affecting the quality of the slab.

(2) A sample scarfing system

For ensuring non-conditioning warm charging of slabs of crack-sensitive steel, a sample scarfing system is adopted whereby a slab piece sampled out of those taken from a given strand is tested to see if the slabs are acceptable to non-conditioning warm charging. For this purpose, a caisson-type slab cooler and a double-face type scarfer are installed. These units make it possible to obtain the sample scarfing results within 45 minutes after completion of torch cutting. Even if a slab is found to require conditioning, this can be done by the double-face scarfer in a hot state so that slabs can be charged warm to the next step. When a hot slab is conditioned, scarfing fins occur, thereby obstructing warm slab charging, but this problem has been solved by installing a fin generation preventing equipment. **Fig. 10** shows the flow chart of the sample scarfing system.

(3) Quick S-print

In order to guarantee slab quality, detection of internal defects of slabs due to casting machine abnormality is necessary, but this is not so easy. In the No. 3 slab caster, machine condition is monitored by equipment for measuring load on the roll, gap and roll alignment, but as an ultimate test, the slab S-print method is used to check the internal quality of the slab. The slab finishing yard is provided with polishing and grinding equipment and a darkroom. These facilities make S-prints quickly after completion of torch cutting, and feedback the S-print information to the continuous slab casting operation, thereby effectively working to assure slab quality.

3.4 Energy Saving

The slab caster employed AC motors for all its power sources, and VVVF (variable voltage variable frequency) control was applied to the portions requiring variable speed for which DC motors were used in the past. The use of AC motors led to improved maintainability and electrical efficiency, thereby resulting in energy saving. Further, VVVF control is applied to the following equipment with the aim of energy saving:

(1) Main blower for environmental dust collector
(2) Main blower of electric precipitator for finishing facilities
(3) Secondary cooling water feed pump adjustable water quantity in the width direction and discharging pressure.

4 Operation

Since the start of operation, main facilities have exhibited smooth start-up without any mechanical trouble. One-shift operation was carried out for one week after the beginning of hot run, then two-shift operation for three weeks, and finally full three-shift operation commenced.

Automatic units started operation smoothly for the most part and various other operations were also carried out smoothly, including the mold powder feeder and level controllers (for tundish and mold) as well as newly developed units such as the automated device for unsteady-state operation including the start and the end of each series of casting, torch cut slag remover, and automatic crane for hot slab handling.

Fig. 11 shows the transition of production since the start of the hot run. This figure indicates a satisfactory start-up operation as a result of early accomplishment of automation. Steel grades of slabs cast by the machine are mainly materials for hot and cold rolled strip, most of which have a narrow width, as shown in **Fig. 12**, and thus are low in casting efficiency. In spite of this fact, the machine showed excellent operation, primarily because of the early accomplishment of automation, among others, of slab-width changing operation during casting.

Fig. 13 shows the transition of the number of slab-width changing operations during casting.

As mentioned in a separate report[1], this equipment can also be used effectively for correcting slab-width decreases at the casting-start and casting-end portions which are peculiar to continuously cast slabs.

Load cells are also installed at the bending and

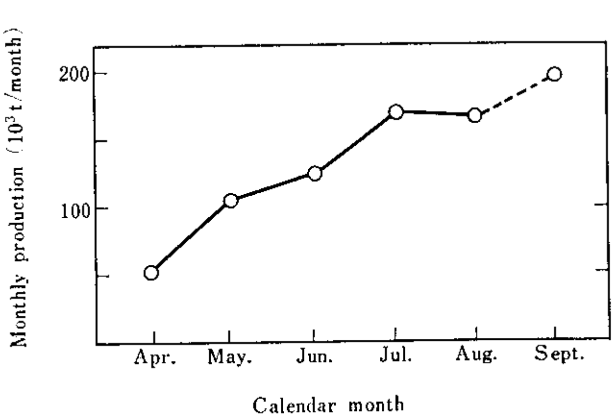

Fig. 11 Trend of monthly production of No. 3 CCM in 1981

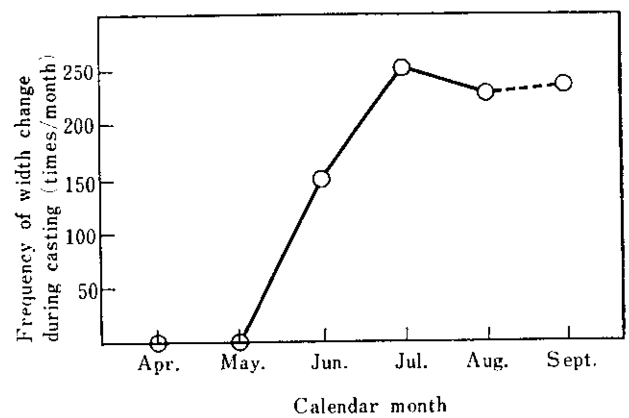

Fig. 13 Trend of width change frequency in 1981 during casting

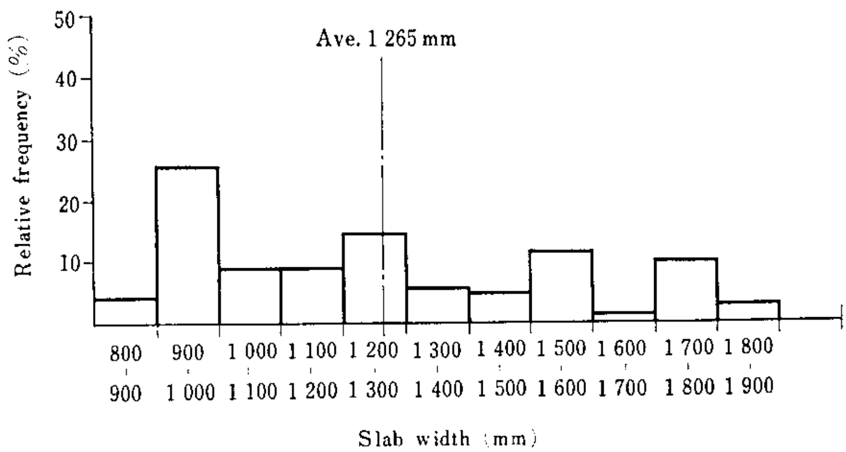

Fig. 12 Distribution of slab width

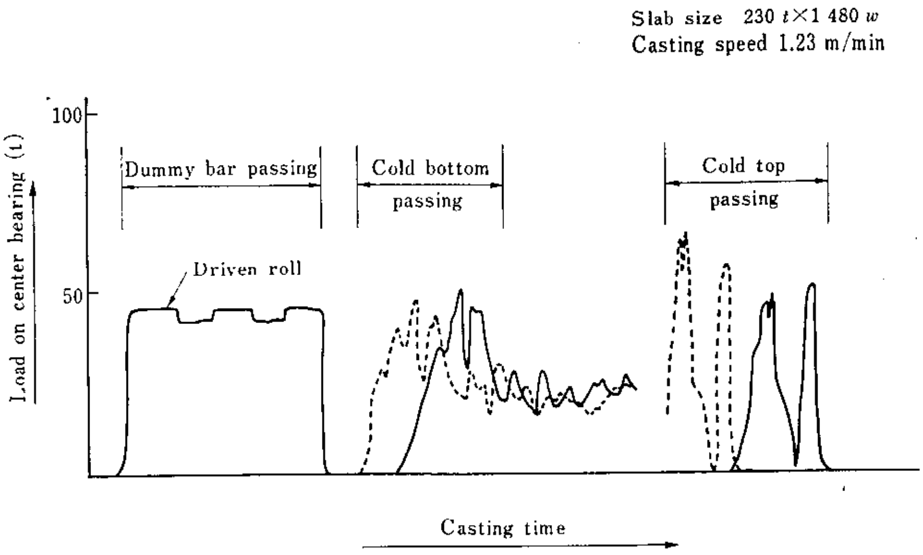

Fig. 14 Measured load on center bearing during casting

unbending portions to continuously measure load applied to rolls during casting. Since the casting machine employs divided rolls, load cells are installed not only on the bearings at both ends but also at the center bearing, so that load distribution in the slab-width direction can be measured. Through the use of these load cells, load that is applied during steady-state casting and abnormal load are measured and roll strength is checked, thereby increasing roll life and improvements on operating conditions. An example of measurement results is shown in **Fig. 14**. This figure indicates that at the time of steady-state casting, force nearly corresponding to ferrostatic pressure is at work and load of 2 to 3 times normal is at work at the time of cold-bottom and cold-top passing. Load distribution in the width direction shows a measured value almost equal to that of uniformly distributed load at the steady-state operation.

5 Quality

Because the No. 3 slab caster aimed at continuous casting of Q-BOP steels for the first time in Japan, it was feared that surface defects due to hydrogen might occur, but through the improvement in the converter operation method[4], not only hydrogen in steel is reduced, but also high Al recovery is achieved.

5.1 Surface Quality

Through the above-mentioned improvement on the converter operation method, generation of surface defects mainly in blowholes was prevented, and the material subjected to Ar-bubbling in the ladle after tapping gave products which are equal or superior to those obtained by conventional facilities in surface quality.

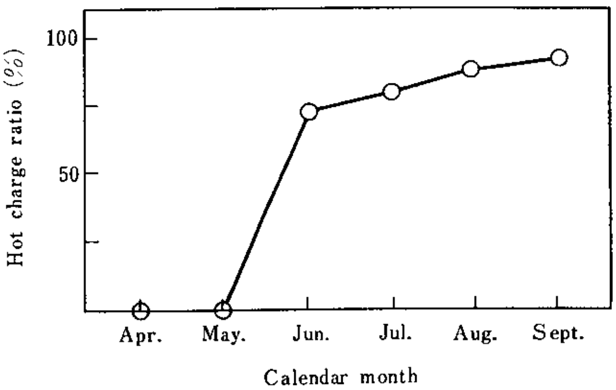

Fig. 15

Fig. 15 shows the transition of the warm slab charging ratio. This figure indicates that after completion of each product quality confirmation test, the warm slab charging ratio has greatly increased, thus significantly contributing to energy saving.

5.2 Internal Quality

The casting machine has a 3 m-long vertical portion below the meniscus, and thus the distribution of nonmetallic inclusions shows identical trends to those of the distribution in Chiba No. 2 continuous slab caster[5], completely eliminating inclusion accumulating zones.

Photo. 1 shows an example of S-prints. There is no problem in internal cracking or center segregation owing to the progressive bending and unbending profile and smaller roll pitch.

The employment of a large-sized tundish has particularly contributed to operation stabilization and product quality improvement through favorable effects such as uniform positioning of the crater end through stabilization of casting speed, the effect of inclusion surfacing in the tundish, and prevention of tundish slag inclusion into the mold.

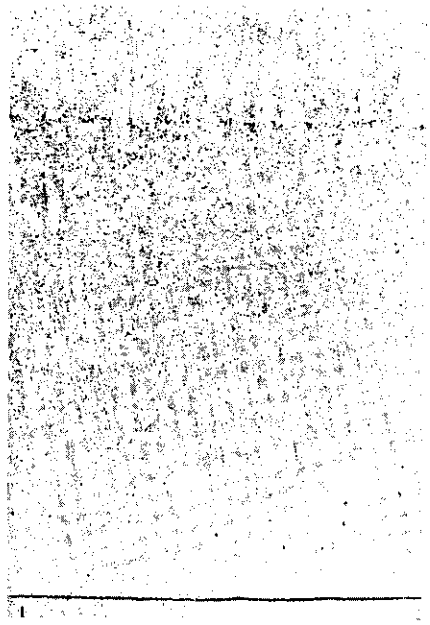

Photo. 1 Sulfur print of continuously cast slab with casting speed of 1.5 m/min and thickness of 260 mm

6 Conclusion

Vertical-bending type No. 3 slab caster at Chiba Works incorporating various measures for high efficiency and high product quality has shown a smooth operation since its start and has marked stabilized, excellent results in operation and product quality.

Its automated facilities have also completed their start-up at an early stage and are contributing to stabilized operation of the slab caster. Kawasaki Steel Corporation will seek to attain a yet higher quality and higher efficiency operation and to achieve a warm slab charging ratio of 90% which is the present target aimed at by Kawasaki.

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