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Nippon Steel High Speed Variable Width Mold "NS-VWM" for Slab Caster

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Abstract

In slab continuous caster, when slabs of different widths are to be produced, casting has to be stopped in order to change the mold width to the required size. The technique to solve such problem is a variable width mold, which changes the mold width during casting. Nippon steel developed the high speed variable width mold "NS-VWM" which permits a shift mold width changing speed to higher speed with a combination of changes of a narrow face taper and parallel movement. In this paper, the features and effects of this equipment are outlined.

1. Introduction

When slabs of different widths were to be produced by continuous casting (CC), in the early days of the technology, it was necessary to stop the operation of a caster to change the mold width to a required size. For eliminating the shortcoming, the technology of changing the mold width (variable width mold: VWM)[1-4] was developed, wherein the positions of narrow faces of a mold are changed during casting operation without having to stop it. The technology made it possible to cast slabs of different widths without operation interruption and, as a result, the ratio of sequential CC was remarkably increased.

Meanwhile, the direct connection of the CC and hot rolling processes became widely practiced and as a result, the requirements for making the width of cast slabs synchronize with the sequence of hot rolling and decreasing the crop loss of tapered slabs occurring during width change came to be intensely felt. Thus, strong demands for rapid width change arose.

In 1984 Nippon Steel Corporation's Sakai Works proposed a new philosophy to change the mold width by combining the taper change and parallel shifting of mold narrow faces, and developed the technology to change the mold width at high speeds (Nippon Steel Variable Width Mold: NS-VWM). The new technology raised the width changing speed, which had conventionally been less than 60 mm/min in total of both the sides, to a maximum of 200 mm/min and, as a result, it became possible to change slab width even during casting at a speed as high as 1.4 to 1.8 m/min without slowing down. At present, NS-VWM is commercially used in most of Nippon Steel's large CC machines at Kimitsu, Oita and other Works.

This paper reports the features and construction of NS-VWM and the effects brought about by the high-speed variable width mold.

2. Principles of Conventional VWM

Table 1[5-7] shows conventional methods of VWM, in any of which the speed of width change is limited. The principles of the conventional width changing methods and the restriction on the width changing speed therein are explained below.

By the conventional method C, the mold width is changed in three steps as shown in **Fig. 1**. In order to minimize the force required for driving the mold narrow faces and the air gap between the narrow face and solidification shell during the parallel shifting (step II), the narrow faces have to be tilted to a taper angle so as to follow, at a moving speed V_m, the narrow face of a cast slab moving downwards at a casting speed of V_c, as shown in **Fig. 2** and equation (1) in the figure. The narrow faces are tilted to the taper angle and returned to an original angle in steps I and III, respectively.

The higher the parallel shifting speed of a narrow face V_m, by this method, the larger the change of taper angle ΔT has to be, which means a longer time to reach the required tilting angle. This method, however, has the problems that the air gap becomes large unless the taper change is done quickly, and that when the taper changing speed is increased for making the taper changing time shorter, the defor-

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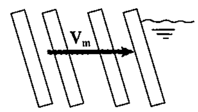
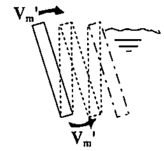
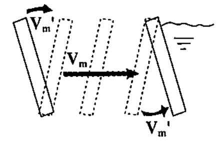
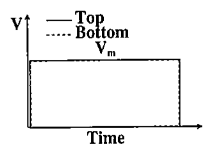
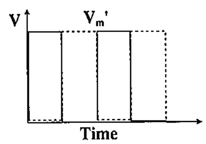
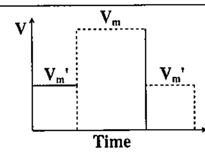
Table 1 Conventional width changing methods and width changing speed

Method		A	B	C
Characteristic		Parallel movement	Taper change	Parallel movement and taper change
Narrow-face movement				
Velocity diagram of top and bottom of narrow face				
Width changing speed (one side) (mm/min)	Width decrease	5	20	32
	Width increase	15	20	6.5

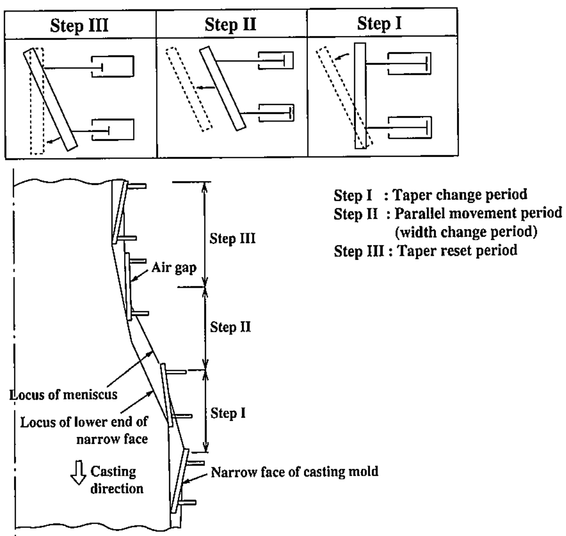


Fig. 1 Conventional width changing method

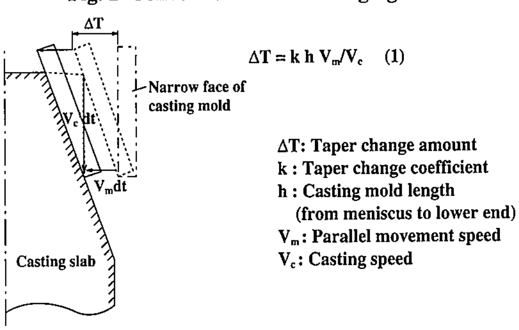


Fig. 2 Taper angle during parallel shifting of narrow face by conventional method

mation resistance of the cast slab increases. For this reason, there is a natural limit in the parallel shifting speed V_m, and this fact has been an obstacle to the enhancement of the productivity and yield of the CC process.

3. Construction and Main Specification of NS-VWM

3.1 Construction of NS-VWM

Fig. 3 shows the construction of NS-VWM developed by Nippon Steel. Electro-hydraulic stepping cylinders are used for driving the narrow faces for the width change, and one unit of them is provided at each of the upper and lower ends of a narrow face.

3.2 Main Specification of NS-VWM

The main specification of NS-VWM is given in **Table 2**.

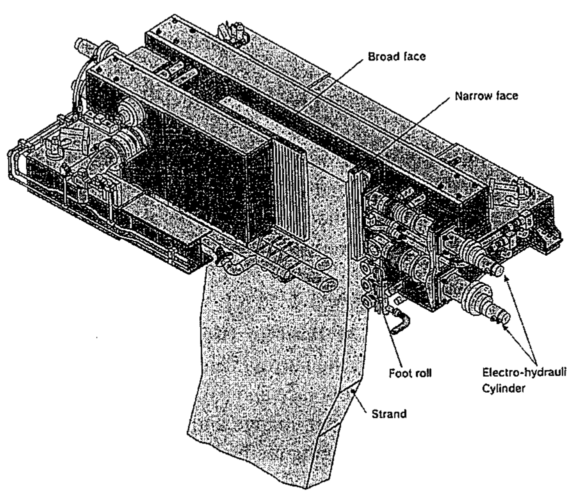


Table 2 Main specification of NS-VWM

Cast radius		Curved(7,500-12,500mm)/ vertical/ vertical-bend
Slab size	Thickness	150-400mm
	Width	508-2,200/ 900-2,240mm
Mold length		Min. 800mm, max. 1,100mm
Casting speed		0.4-2.5m/min
Type of drive		Four electro-hydraulic cylinders, two (top and bottom) for each narrow-face
Foot roll (narrow face)		2 rolls/ 3 rolls
Hydraulic fluid		Water glycol/ mineral oil/ fatty acid ester/ phosphate ester

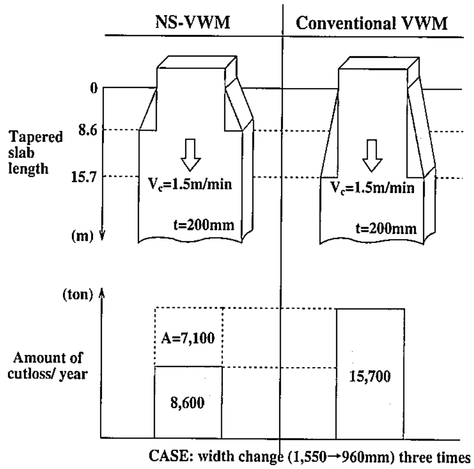


Fig. 4 Comparison of cut loss in different width changing methods

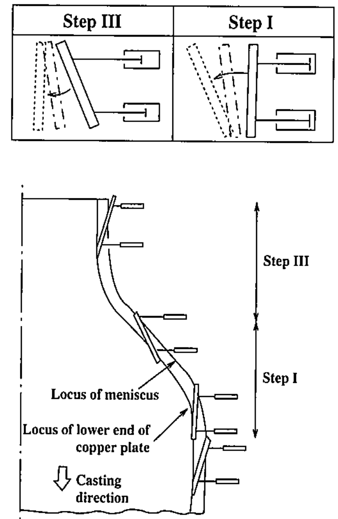


Fig. 5 Width changing method of NS-VWM

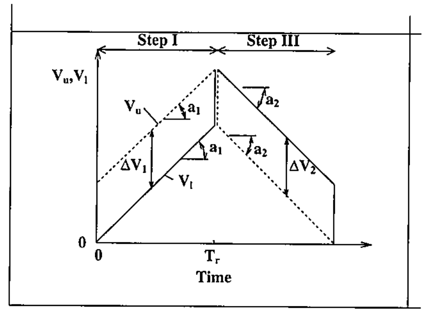


Fig. 6 Relation of width changing time with shifting speeds of upper and lower ends of narrow faces

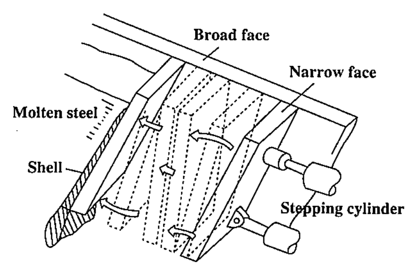


Fig. 7 Movement of narrow face during width reduction by NS-VWM

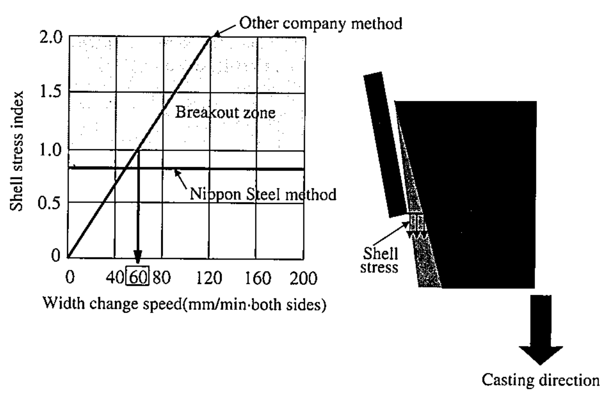


Fig. 8 Comparison of shell stress during width change

4. Effects of NS-VWM

NS-VWM is effective for remarkably enhancing production yield. **Fig. 4** shows the cut loss at the width change portion of a cast slab. The width changing time of NS-VWM is shorter than that of other similar methods and, therefore, the cut loss at the width change portion is significantly reduced. For example, when the width of a 1-strand CC machine is changed from 1,550 to 960 mm under a condition of a casting speed of 1.5 m/min and a slab thickness of 200 mm and if the width change takes place 3 times a day, the cut loss is reduced by 7,100 t/year. NS-VWM also brings about the following advantages:

- The slab width can be changed without lowering the casting speed and, for this reason, the fluctuation of slab quality is reduced.
- Production yield is increased as a result of the slab production in compliance with the quantity, product dimension and steel grade of orders.
- Casting operation is started using only one dummy bar head and the slab width can be changed quickly thereafter to a required one without having to change another dummy bar head and, thus, operation preparation time is reduced and productivity is increased.

5. Characteristics of NS-VWM

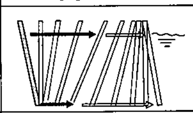
5.1 Narrow Face Change Method for High-speed Width Change

Nippon Steel developed the narrow face change method to keep the contact between the narrow face and solidification shell constant by means of the combined taper change and parallel shifting of the narrow faces. The width changing method of NS-VWM is shown in **Figs. 5, 6 and 7** [9,10,11]. The method is characterized by changing the taper angle of a narrow face and shifting its position at the same time. **Fig. 8** shows the force imposed during width change on the solidification shell of a cast slab in relation to the speed of the width change. This narrow face shifting method eliminates the air gap between the solidification shell and the mold copper plate of the narrow face during the width change and keeps the force imposed on the shell stably at a low level. These functions realize a width changing speed amounting to 200 mm/min in total of both the sides, preventing the occurrence of breakout and slab defects. Some of the characteristics of NS-VWM are explained in comparison with those of other similar technologies in **Table 3**.

5.2 High Positioning Accuracy of Narrow Faces

Nippon Steel developed electric motor types and electro-hydrau-

Table 3 Comparison between NS-VWM and other variable width mold technologies

	NS-VWM	Other technology
Narrow face movement		
Width changing speed	200mm/min (both sides)	60mm/min (both sides)
Air gap	0mm	2-5mm
Shell stress	Constantly low	Fluctuates from low to high
Breakout	None	Occurs when accelerating
Shell defect	None	Occurs when accelerating

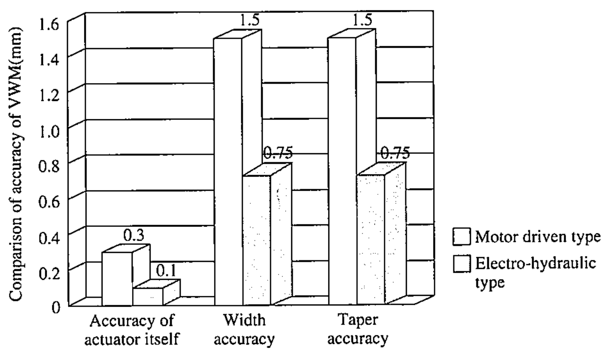


Fig. 9 Comparison of width changing accuracy between electro-hydraulic stepping cylinder drive and electric motor drive

lic stepping cylinder type driving systems of the narrow face and, after a series of performance evaluation tests in commercially operated casters, finally elected the electro-hydraulic stepping cylinder type drive for use in NS-VWM for the reason of high positioning accuracy in the shifting and taper setting of the narrow face. The electric motor type and electro-hydraulic stepping cylinder type drives are compared in **Fig. 9** in terms of the accuracy of the width change. In the case of the stepping cylinder type drive, since the actuator proper has a high movement accuracy and there are few components to cause mechanical play, it is possible to position the narrow faces in strict accordance with the commands from a control system, and therefore breakout and slab defects are effectively prevented from occurring.

5.3 Easy Maintenance

The maintainability of the width changing equipment is shown in **Table 4**, comparing the electro-hydraulic stepping cylinder type and the electric motor type. Since the electric motor type equipment requires many component items for converting the rotation of the motor into the stroke movement to drive the narrow face, its maintainability is poor and the accumulated mechanical play of the components makes it difficult to secure high positioning accuracy. The construction of the electro-hydraulic stepping cylinder type equipment, on the other hand, is very simple, comprising only one mechanical and two electric components, and hence it is excellent in maintainability. An outside view of the electro-hydraulic stepping cylinder type equipment of NS-VWM is given in **Fig. 10**.

Table 4 Comparison of maintainability between electro-hydraulic stepping cylinder drive and electric motor drive

	Nippon Steel	Other technologies
Number of mechanical parts	Only one (stepping cylinder)	Many (spur gear, worm gear, trapezoid screw, bearings, etc.)
Number of electrical parts	Two (stepping motor, motion detector)	Many (electric motor, position transducer, electricmagnetic clutch, electricmagnetic brake, etc.)
Construction	Simple	Complicated
Maintainability	Excellent	Poor

5.4 Width Change Control System

In order to realize the high-speed width changing operation, a high-speed programmable logic controller (PLC) is used in the core part of the control system of NS-VWM. **Fig. 11** shows the diagram of NS-VWM's control system. The PLC calculates the positions and shifting speeds of the upper and lower ends of the narrow faces in real time from the positions and actuating speeds of the upper and lower stepping cylinders, decides the control values for optimum shifting speed patterns of the cylinders, and outputs the commands of actuating speed to the stepping cylinders in real time. Even if casting speed and other operation parameters change during the course of the width change, this control system makes it possible to continue the width changing operation in accordance with new operation parameters.

The control system of NS-VWM decides the width changing speed pattern best suited to the casting operation conditions (original width, taper, and casting speed) and target width and taper after width change, and controls the entire width changing sequence fully automatically. Therefore, an operator's complicated intervention is totally unnecessary. The width changing speed and current width and taper are displayed on an operation panel from time to time so that operators can periodically monitor the conditions of the mold at any time during the width change as well as during constant width casting. In the event of a failure of an electro-hydraulic stepping cylinder during the width changing operation, a failsafe function intervenes so as to shift the narrow faces at positions not to cause casting interruption. A high level of safety of the width changing operation is thus secured.

5.5 Long Service Life of Mold Copper Plates

Since the introduction of VWM, short service life of mold copper plates has been one of its major problems. **Fig. 12** shows the typical defects occurring to the copper plates. Most of the surface defects of the copper plates are seen in the areas near the meniscus and their lower ends. Among these, the defects in the area near the meniscus are caused by the friction between the broad and narrow

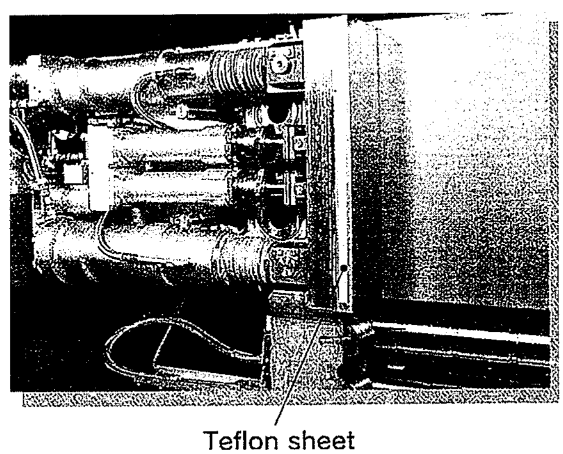


Fig. 10 Outside view of electro-hydraulic stepping cylinders used in NS-VWM

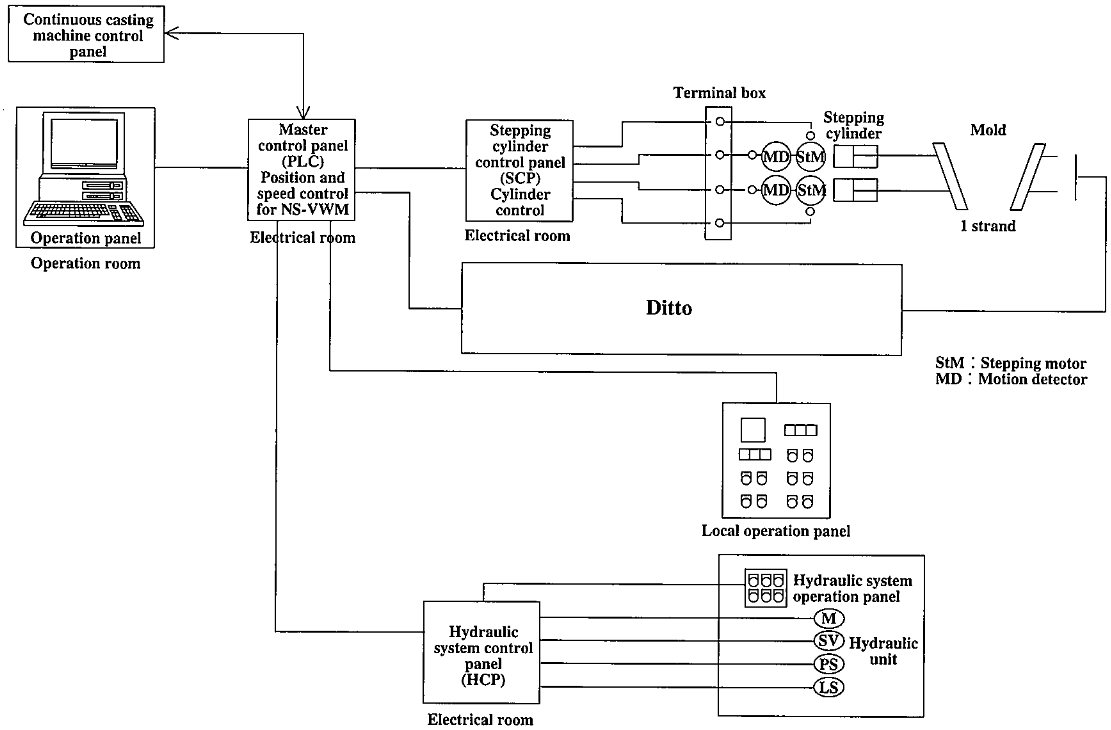


Fig. 11 Control system diagram of NS-VWM

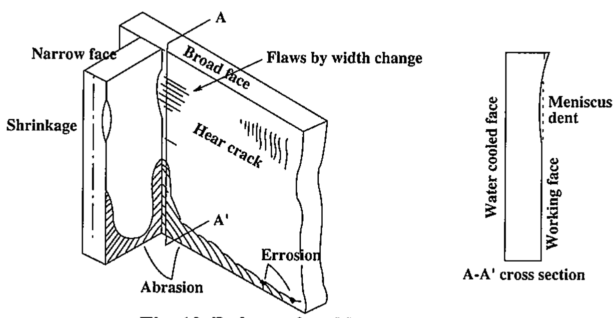


Fig. 12 Defects of mold copper plates

faces during the shifting of the narrow faces.

The following options are provided in NS-VWM for making the service life of the copper plates longer.

5.5.1 Teflon Sheets

Fig. 13 shows an NS-VWM mold in which Teflon sheets are inserted in grooves machined in the sliding surfaces of the narrow faces. This lowers the friction coefficient during the shifting movement of the narrow faces to prevent the defects near the meniscus from occurring (see also Fig. 10).

5.5.2 Mechanism for Controlling Narrow Face Clamping Force

The force for clamping a narrow face can be optimally controlled at any time in accordance with operation conditions such as slab width, casting speed and width changing speed, which change from time to time, by providing a hydraulic cylinder having a function to adjust its pressure at an end of each clamping shaft. **Fig. 14** shows the mechanism for controlling the friction force caused by the clamping force by means of the pressure adjusting function of the hydraulic cylinders.

These measures improve the service life of the copper plates, decrease the frequency of their change and re-machining and thus lower the costs of maintenance. **Fig. 15** shows the effects of these

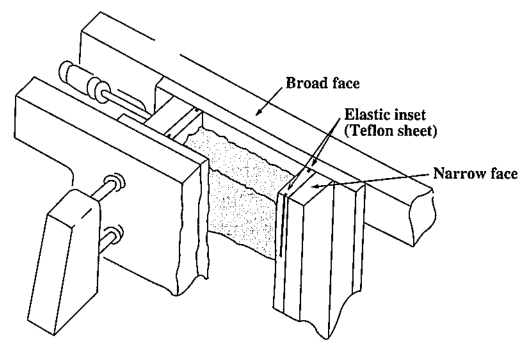


Fig. 13 Mold with Teflon sheets inserted in narrow faces

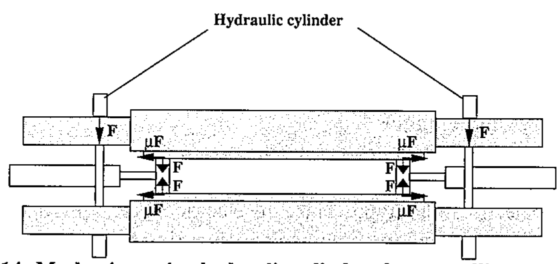


Fig. 14 Mechanism using hydraulic cylinders for controlling narrow face clamping force

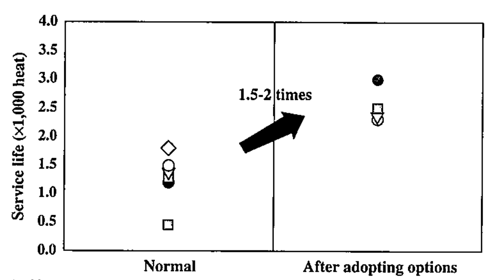


Fig. 15 Effects to extend service life of copper plates of NS-VWM

measures to extend the service life of the copper plates.

6. Summary

NS-VWM has the following advantages.

- The cut loss at the width changing portion of a cast slab is reduced and the production yield is increased as a result of high-speed width change up to 200 mm/min in total of both the sides. A slab caster is enabled to cope with a rolling schedule of a large capacity hot strip mill producing small lots of widely varied products without significantly lowering the production yield.
- The occurrence of breakout and slab defects is kept under control as a result of the high narrow face positioning accuracy of electro-hydraulic stepping cylinders used for driving the narrow faces.
- Equipment construction is simple and its maintenance is easy as a result of direct driving of the narrow faces by the electro-hydraulic stepping cylinders.
- The service life of mold copper plates is improved by the use of Teflon sheets and a mechanism for controlling the clamping force on the narrow faces.

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