

New Technology for Continuous Casting Machine

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In pursuit of high productivity, energy saving, steel-type versatility, and more stringent quality, each engineering company of steel making equipment has made a variety of unique development and improvements of continuous casting machines since its full-scale practical applications in the 1960s. Kobe Steel has newly developed an optimal support mechanism for a large tundish, and a highly precise weighing device for tundish cars, which are closely related to safety and workability. In addition, the company has newly developed a structure, capable of maintaining high rigidity and movements without backlash for an extended period of time, for the mold oscillator and supporting roll stand, which can significantly affect the quality of cast blooms. This paper introduces these technologies, which have been employed in the continuous bloom casting equipment for special steel—equipment that was delivered to Kobe Steel's Kakogawa Works in January 2017.

Introduction

Continuous casting equipment is used to continuously cool and solidify molten steel, and its apparatuses must demonstrate stable performance in a high temperature environment.

In the periphery of the continuous casting machine (CCM), which is located the farthest upstream, there are large apparatuses such as a ladle turret, tundish, and tundish car, which slew, lift, and/or travel in a three-dimensionally interlacing manner. The No. 6 continuous casting equipment at Kobe Steel's Kakogawa Works, recently delivered by Kobe Steel, includes a casting machine that handles a ladle containing 240 tonnes of molten steel. Any trouble with the casting machine during the handling of molten steel can lead to a serious accident. Hence, each apparatus must have excellent workability and high reliability.

In the main CCM equipment (e.g., mold, mold oscillator, and supporting roll stand), which is located in the downstream of the pig bed, a primary solidified shell is formed in the mold, and the solidified shell is grown by spray cooling in the secondary cooling zone to continuously produce semi-finished slabs. In order to manufacture a high-quality slab without any hazardous cracks on the surface or inside, no strain exceeding the allowable limit should be applied to the slab during solidification. The mold, mold oscillator, and

supporting roll stand are required to have structures with high rigidity and to move without backlash so as to allow each slab to be accurately drawn along the track even under high-temperature high-load conditions.

Kobe Steel has conducted development and improvement in various manners to meet customer requests, not only for apparatus reliability but also slab quality. This paper introduces the technologies adopted to the continuous casting equipment for producing special steel blooms that was delivered to Kobe Steel's Kakogawa Works in January 2017.

1. Tundish car

1.1 Role of tundish car

A tundish car (hereinafter, a "TD car") is a self-propelled carriage that transports a tundish (TD), which has the role of distributing molten steel poured from a ladle into a plurality of strands. **Fig. 1**¹⁾ shows a conventional TD car with a TD mounted on it. Each TD is heated to a high temperature by a heating apparatus at a standby position and transported to the casting station by the TD car immediately before casting begins.

In addition to the traveling function, a TD car comprises a lifting function for inserting a submerge nozzle arranged at the bottom of each TD into a mold, a centering function for adjusting the position of the submerge nozzle, and an automatic molten-steel-level control function for keeping molten steel

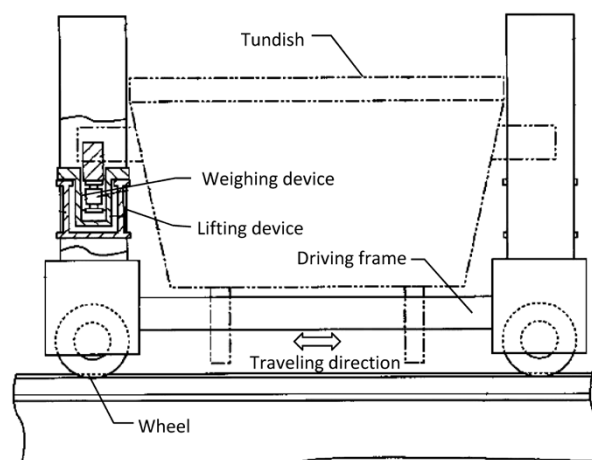


Fig. 1 Conventional tundish car with tundish mounted¹⁾

at a constant level to separate impurities by flotation. One of the important devices of the automatic molten-steel-level control is a weighing device, which is required to measure the weight of molten steel in each TD with high accuracy while the weight changes from time to time.

The size of the TD car is usually increased as the number of strands increases, and the interference with adjacent apparatuses becomes tighter. Therefore, it must have a mechanism that is lean in terms of structure dynamics.

1.2 Problems of conventional technology

The multi-strand bloom continuous casting equipment recently delivered by Kobe Steel has a large TD whose total weight exceeds 200 tonnes. The TD is surrounded by a ladle above, a ladle turret on its side and a mold below it. In this limited space, it must accomplish the functions of traveling, elevating, centering and weighing. In addition, the operators must be able to safely perform their work around the ladle, TD, and mold.

A Kobe Steel's conventional TD car with lifting and weighing functions generally adopted a method of supporting the trunnions at both ends of a TD. However, when applied to a large, long TD for multi-strands, as in this case, Kobe Steel's conventional structure causes large bending stress in the TD itself due to its own weight. Hence the rigidity of the TD must be increased, which has turned out to be difficult to achieve within the limited space.

1.3 New technology

1.3.1 Main frame construction of new TD car

The new TD car consists of a carriage frame, wheels, a lifting frame, a saddle frame, a lifter, a weighing device, a saddle-frame actuator, and a driving unit. Fig. 2 shows the new TD car with a TD mounted on it. The right side of the figure shows the lifter in a raised position, while the left side shows the same in a lowered position. The latter is the position during the casting operation.

The new TD car comprises a carriage having a rectangular-frame structure, a wheel attached under each corner of the carriage, and a hydraulic-cylinder type lifter placed on top of the carriage. Furthermore, a rectangular lifting frame is mounted on the rod tips of these hydraulic cylinders. Each rod tip is made to coincide with the corresponding corner of the frame, and a load cell is placed between them. The saddle frame is placed so as to surround

the two sides of the rectangular lifting frame, and both ends of the saddle frame are placed on the receiving rollers provided at the four corners of the lifting frame. A TD is placed on the four receiving parts provided on the saddle frame. The new TD car also employs a hydraulic cylinder for driving the saddle frame.

Each trunnion of the hydraulic cylinder is connected to the lifting frame, while each clevis is connected to the saddle frame, so that the saddle frame can be moved to the horizontal direction relative to the lifting frame. In other words, each TD can be moved in the direction orthogonal to the traveling direction of the TD car, so that the respective submerge nozzle can be adjusted to the center of the mold.

It should be noted that the greater the distance between a TD and mold, the greater the potential energy of the molten steel to be discharged from the TD, which makes the submerge nozzle longer and is not desirable. Therefore, the space between the TD bottom and the mold-top end is made narrow. The middle portions of the carriage frame, lifting frame, and saddle frame must traverse this narrow space, which has been enabled by the structure shown in Fig. 2.

1.3.2 Supporting mechanism of new TD

The new TD car supports a TD at the point where the deformation of the TD is minimized. The bending stress occurring in the TD itself is kept low by having both ends of it overhang the car. A structure was also devised in which the wheels, carriage frame, hydraulic lifting cylinder, load cell, and lifting frame are arranged in a vertical line to prevent a bending load from acting on the carriage frame.

An optimum support mechanism for a large, long TD has been realized by incorporating these ideas.

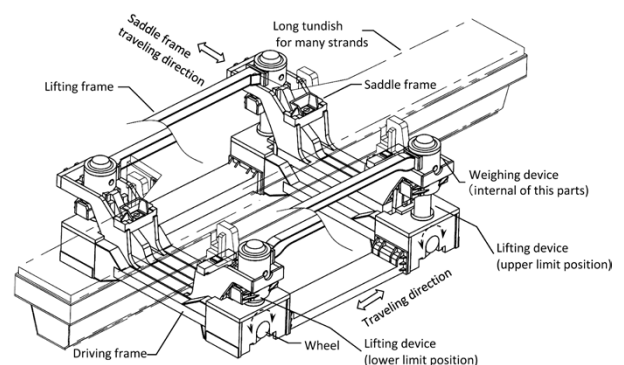


Fig. 2 New tundish car with tundish mounted (right: lifting state, left: lowering state)

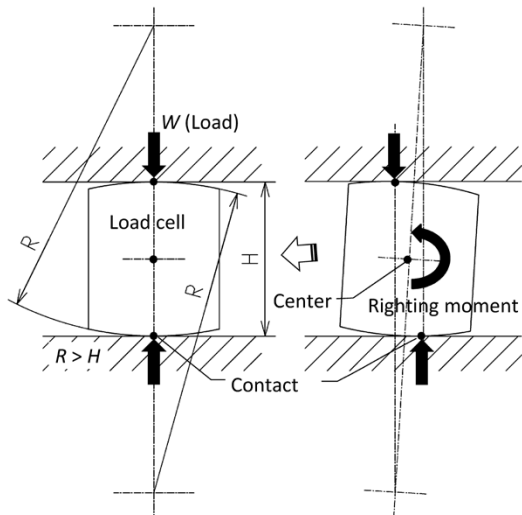


Fig. 3 Restoration principle of load cell

1.3.3 Weight measurement mechanism of new TD

In order to improve the accuracy of weight measurement using a load cell, it is necessary to devise an ideal mechanism for supporting the load only in the vertical direction. In order to increase the measurement accuracy, Kobe Steel employs a double-convex-type load cell. When a vertical load acts on a double-convex-type load cell in an inclined state, the load cell itself rolls in the vertical direction like a self-righting doll (Fig. 3). It is a characteristic of the load cell that the greater its inclination, the greater the resilience to the vertical (upright) direction becomes, and the lifting frame placed on the load cell swings like a cradle. When a traveling TD car accelerates or decelerates, a force is generated in the horizontal direction in the lifting frame to tilt the load cell, whereas, when it travels at a constant speed or is stationary, the load cell is restored to the upright position. This property was exploited in eliminating the lifting guides for restraining the lifting frame, and other restraints that can deteriorate the measurement accuracy. This, as a result, has secured an extremely favorable measurement accuracy.

2. Mold oscillator

2.1 Role of mold and mold oscillator

The mold is a primary cooling apparatus for forming an initial solidified shell that is healthy and homogeneous. In the mold, molten steel comes in contact with a copper plate the back of which is water cooled. The mold oscillator is an apparatus which oscillates the mold in the pulling direction of the slab to prevent adhesion between the mold

and the surface of the solidified shell. Here, the oscillation typically has a sinusoidal waveform. When a lateral displacement of the oscillating mold occurs, the fluctuation of the molten surface becomes so large that it adversely affects the formation of the initial solidified shell in the meniscus portion, which is formed in every cycle of mold oscillation. In other words, disturbance occurs in the oscillation mark, causing surface defects. In order to secure the surface quality of slabs, it is very important to suppress the lateral displacement of the mold oscillator.

2.2 Problems with conventional technology

Fig. 4 shows a typical mold oscillation mechanism commonly used today. The oscillating table is supported by a pair of links, each configured in a parallelogram shape, which creates a pseudo circular movement along the profile of the apparatus when a vertical movement is provided at the end of a driving lever. Hydraulic cylinders or electric motors with eccentric shafts are used for the driving source of the vertical motion. This mechanism has the advantages of allowing the placement of the oscillation source in a favorable environment remote from the mold, avoiding thermal influence, facilitating maintenance, easily responding to amplitude change, etc. On the other hand, this mechanism has a plurality of joints connecting the links, and each joint engages in repetitive forward and back movement. Since the oscillation amplitude is rather small with respect to the link length, the rolling angle of each bearing, built in the corresponding joint part, is very small, and the rolling angle of the roller in the bearing becomes extremely small. Therefore, it has the drawback that the lubrication oil film is not formed on the rolling surface of each roller, causing the bearings to wear prematurely, and the favorable oscillation

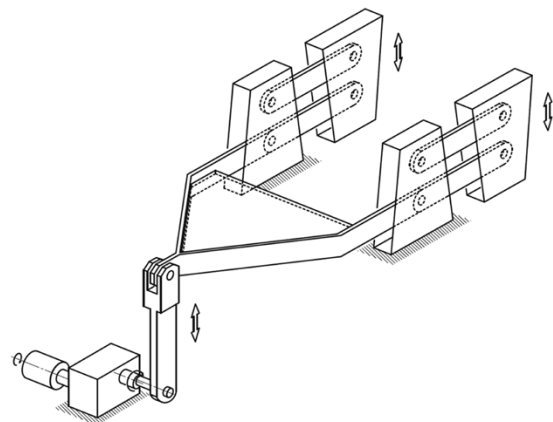


Fig. 4 Lever-type mold oscillator

state cannot be maintained for an extended period of time. Furthermore, the gaps existing in the joints may cause lateral displacement during oscillation.

2.3 New technology

2.3.1 Construction of new mold oscillator

As shown in Fig. 5,²⁾ Kobe Steel's new mold oscillator³⁾ comprises a pair of eccentric shafts supported by corresponding fixed bearing boxes on the upper side of a fixed oscillation table in the form of a rectangular frame, wherein each eccentric shaft is driven by a common electric motor via reduction gears. Each of the eccentric shafts has two movable bearing boxes attached via bearings.

The movable bearing boxes support the four corners of the rectangular-frame-shaped oscillation table from below through thin sheet-like connecting plates that are placed vertically. Each spring plate has both ends supported by the fixed table, while the center part of the spring plate is connected to the oscillation table.

2.3.2 Oscillation mechanism causing no lateral displacement

Kobe Steel has developed a mechanism, as described below, for the new mold oscillator that causes no lateral displacement. The spring plates, bending and deforming in the vertical direction, permit the vertical displacement of the oscillation table. Meanwhile, the spring plate regulates the lateral displacement of the oscillation table.

Along with the rotation of the eccentric shaft, the movable bearing box causes an orbital motion that centers on the rotation center axis of the eccentric shaft with the radius of the eccentricity. For the orbital motion of the movable bearing box, the thin sheet-like connecting plate transmits

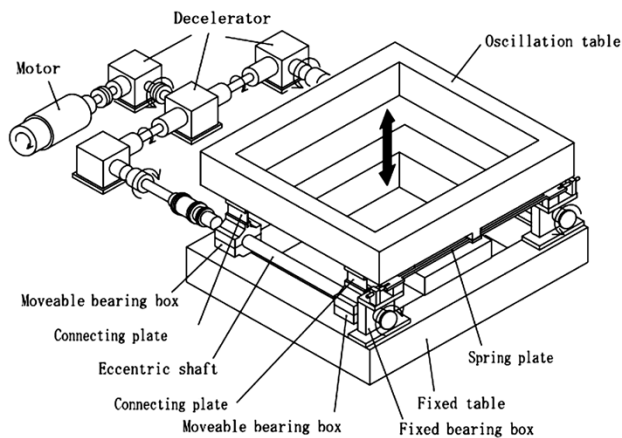


Fig. 5 New mold oscillator

only the vertical motion of the orbital motion to the oscillation table. The horizontal direction displacement of the orbital motion is absorbed by the bending of the connecting plate. Fig. 6 is an operation diagram of this motion.

The connecting plate and spring plate are subjected to bending deformation alternating in every other cycle of the mold oscillation; however, the stress caused by this deformation is set to be less than their fatigue limits. The weights of the mold and oscillation table, the frictional force generated between the mold and the slab, and the acceleration during the oscillation act as compressive forces on the connecting plate. Increasing the thickness of the connecting plate increases its resistance to buckling, but increases the bending stress. Conversely, decreasing the thickness reduces the bending stress, but decreases its resistance to buckling. Kobe Steel's connecting plate achieves the optimal degree of both bending stress and buckling strength, which are in a trade-off relationship.

2.3.3 Maintaining high precision oscillation performance

The oscillation mechanism devised by Kobe Steel, as described above, has eliminated all the pivot points of forward and reverse rotation; the pivot points have caused problems in the conventional technology. This has enabled high-precision oscillation to be maintained for a long period of time. No lateral displacement occurs during the oscillation because the horizontal direction is regulated without a gap by the spring plate. In addition, all the bearings rotate 360° in one direction without causing any problems associated with the repetition of forward and reverse rotations. Even when there is a small gap in a bearing part, the gap is kept pressed downward by the weight of the mold, causing no disturbance in the oscillation waveform. Any difference in the eccentric phases of the two eccentric shafts would cause a lateral displacement of the

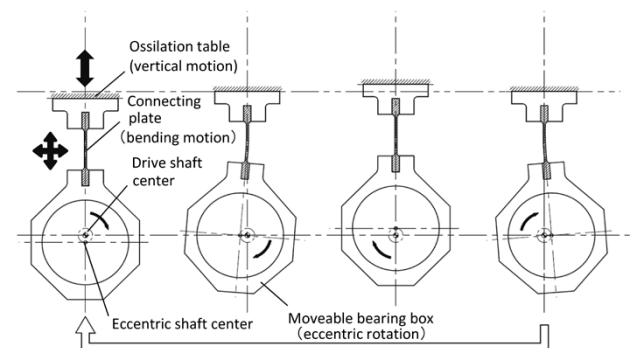


Fig. 6 Motion of connecting plate

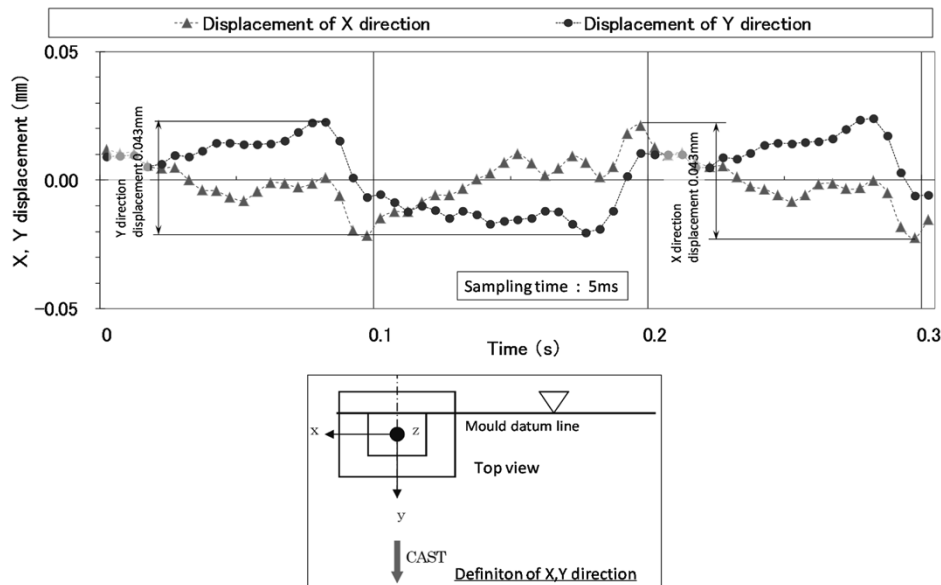


Fig. 7 Oscillation test results (X, Y displacement) of new mold oscillator

oscillation table; however, no difference in eccentric phase should occur, thanks to the two eccentric shafts that are driven by reduction gears branched from one electric motor. Also, the two eccentric shafts are rotated in opposite directions so that the horizontal forces generated at the time of oscillation cancel each other out. Furthermore, the stress generated by the alternating bending deformation is set to be less than the fatigue limit, which ensures the long-term durability of the connecting plates. The fixed table can be detached from the dedicated mount, enabling the mold oscillator to be taken out as a unit for offline maintenance, which has eliminated the need for online maintenance. The connection between the reduction gears and the eccentric shafts via drive shafts allows the placement of the vibration source in a favorable environment remote from the mold.

As a result of various measures, including ones for extending the service life, the amount of lateral displacement during oscillation was confirmed to be 0.05 mm or less, as shown in Fig. 7.

3. Supporting roll stand

3.1 Role of supporting roll stand

A supporting roll stand serves to guide a slab consisting of a shell filled with unsolidified metal by means of a set of rolls arranged in a predetermined profile. Solidification is promoted by the spray water cooling in the secondary cooling zone, where the slabs are completely solidified, and their quality is determined. A supporting roll stand plays major roles; for example, it suppresses the bulging that

may occur in the solidified shell due to the static pressure of the molten steel pool inside the slab, reduces the roll gaps to match the slabs' thermal contraction, and decreases strain caused by bending and unbending. Therefore, a supporting roll stand is required to have a rigidity high enough to withstand the deformation due to the heat and force received from slabs.

3.2 Problems with conventional technology

As shown in Fig. 8, a conventional supporting roll stand (hereinafter "conventional stand") comprises a lower frame, a set of lower rolls, an upper frame, a set of upper rolls, and a connecting member for connecting the lower frame and upper frame. In both the lower frame and upper frame, a plurality of rolls are attached at predetermined intervals via bearings, and the connecting member joins the upper and lower frames such that the lower rolls and upper rolls face against each other.

During casting, the slab is held between the lower and upper rolls, and the forces due to the static pressure of molten steel and straightening reaction act to stretch the connecting member. In addition, other forces act to bend the lower frame and upper frame. Furthermore, each member of the supporting roll stand is subjected to complicated thermal deformation during casting due to the increase in atmospheric temperature and radiant heat from the slab. As a result, each roll is displaced from its predetermined profile and causes misalignment.

The misalignment can cause internal cracks in the cast slab. Increasing the rigidity of the construction elements (the upper frame, lower frame, and

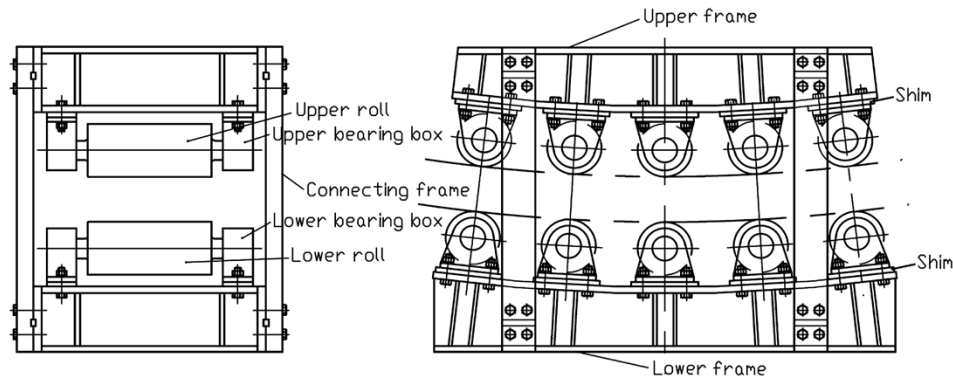


Fig. 8 Conventional supporting roll stand

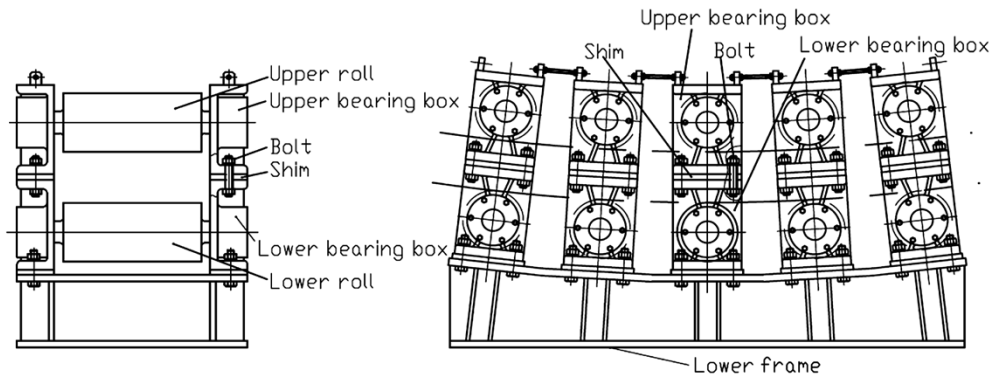


Fig. 9 New supporting roll stand

connecting member) may solve this problem. However, there is a limit in terms of the weight and cost of the stand. In addition, the fluctuation of the roll alignment due to the temperature change in the members cannot be avoided even by increasing the rigidity. For this reason, it was difficult to resolve the issue of roll misalignment in the conventional stand structure.

3.3 New technology

3.3.1 Construction of new supporting roll stand

The new supporting roll stand⁴⁾ comprises a lower bearing box supporting a lower roll and an upper bearing box supporting an upper roll, in which the lower and upper bearing boxes are connected pair by pair so as to eliminate the upper frame that was indispensable in the conventional stand. Fig. 9⁵⁾ depicts the new supporting roll stand. The lower surface of each lower bearing box is fastened by bolts to the lower frame via a shim for alignment adjustment. Furthermore, an upper bearing box is stacked on the lower bearing box via a shim to adjust the gap between roll surfaces, and both the boxes are fastened by bolts.

3.3.2 Advantages of new supporting roll stand

The structure of the new supporting roll stand is less susceptible to the influence of stretch deformation and thermal deformation, which, in the conventional stand, would occur in the upper frame and the member connecting the lower frame and upper frame. The displacement of rolls is minimal because the static pressure of molten steel and straightening reaction force, both acting on the rolls, are limited by the elastic deformation of a small area in the bearing box. In addition, the upper and lower bearing boxes are internally water cooled and are less susceptible to the temperature change in the surrounding area. This has enabled the initial roll gap and roll alignment to be maintained with high accuracy even when the surrounding environment is changed.

The assembly of the conventional stand required the following steps: First, the rolls on each of the upper frame and lower frame were assembled. Next, the upper frame was turned upside down so that its roll surfaces faced those of the lower frame, and the upper and lower frames were connected with tie rods. Then, the gap between the roll surfaces was adjusted to a predetermined dimension by means of shims placed between the bearing boxes and the frames. The new supporting roll stand, on the other

hand, has a structure in which each upper bearing box is mounted on a corresponding lower bearing box, and the upper and lower bearing boxes are fastened by bolts. This has made the assembly work safer and easier.

Conclusions

Continuous casting machines came to be in wide practical use in the 1960s, and since then, various R&D and improvements have been made in pursuit of high productivity, energy saving, steel-type versatility and quality improvement. This paper has introduced a tundish car, which is closely related to safety and workability, a mold oscillator, which is closely related to slab quality, and new technologies having to do with the supporting roll stand.

Kobe Steel will strive to continue development

and improvement to respond to customers' more advanced needs, including the improvement of apparatus safety and reliability, and further improvement of slab quality.

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