NIPPON STEEL TECHNICAL REPORT No. 66 JULY 1995

UDC669.184.125:62-52

Development of Converter Relining Robot System

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Abstract:

The relining of converters at steelmaking plants calls for large amounts of labor and time. In recent years, the number of skilled bricklayers has declined to making it difficult to gather the necessary number of bricklayers to reline the converters. A converter relining robot system was developed and commercialized to solve this problem. The system consists of two intelligent robots and an automatic brick transfer machine. Each robot has a visual function and a flexible hand-like mechanism, and can lay bricks in the same way as a skilled bricklayer does. The automatic brick transfer machine has a roller conveyor and lifter, and can transfer a pallet of bricks to the position where the robot can easily handle the bricks. The robotic system has sharply cut down the labor component of converter relining, and has greatly improved the converter relining work environment.

1. Introduction

Japan's steel industry has enhanced its international competitiveness by introducing automation and labor saving initiatives into its main production process. Auxiliary tasks, such as equipment maintenance, are slow to be automated, partly due to their diversity and complexity. Not only in the steel industry, but also in every other industrial sector, labor shortages are serious enough to shake the foundation of Japan's industrial structure. To overcome this situation, the authors have applied robotics and other factory automation (FA) technologies to achieve labor savings in auxiliary tasks.

This article presents the automation of converter relining as an example of such efforts.

2. Present Situation and Problems of Converter Relining

The relining of converters at steelmaking plants requires considerable labor and time. In recent years, many workers have come to shun poor working environments, and the resultant shortage of skilled bricklayers has made it difficult to secure the required number of bricklayers to reline the converters.

The converter is lined with two layers of heat-resistant bricks to protect its steel shell against the intense heat of the molten steel

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it produces. The lining bricks are badly damaged by the extreme heat inside the converter and must be replaced by new bricks at certain intervals. As shown in **Fig. 1**, normally only the inner layer of bricks in the fire brick structure of the converter are replaced.

To replace the worn bricks, a working platform with a lifter similar to a hydraulic pantograph lifter is brought through the mouth into the converter as shown in **Fig. 2**. Bricks are placed on a pallet and carried into the converter by a crane. The bricklayer manually lays each brick into the lining of the converter. The bricks are placed without using mortar. They must be laid so tightly that their dislodgment is prevented by the friction between them. To increase the bricklaying efficiency, the inner layer

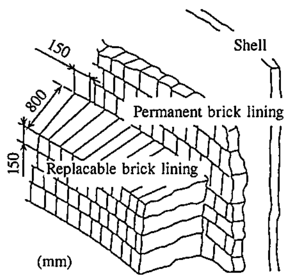

Fig. 1 Fire brick structure of converter

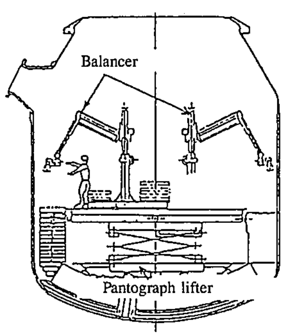

Fig. 2 Conventional fire brick laying work

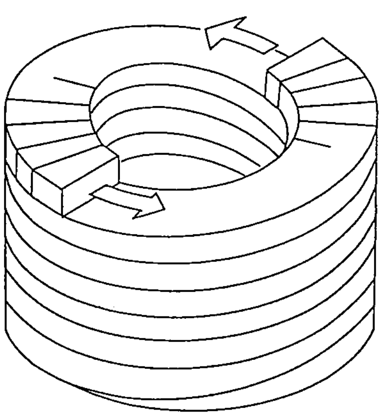

Fig. 3 Double-spiral bricklaying method

bricks are sometimes laid in double spirals as shown in **Fig. 3**.

The double-spiral bricklaying method has the following advantages:

(1) There is no need to adjust the gap between the bricks in each circle.

(2) The bricks can be laid in two positions at a time for higher efficiency.

One key problem with converter bricklaying is the poor working conditions. The workers handle refractory bricks within the confined space of the converter and are constantly exposed to dust.

In recent years, longer bricks have been used to prolong furnace lining life. Some bricks weigh as much as 50 kg apiece as shown in **Fig. 4**. Bricklaying is a heavy physical task involving the handling of heavy bricks. Bricklaying is also only performed once every three to four months. This cyclical nature makes it all the more difficult to secure the necessary number of workers for relining the converter as required.

To solve these problems, local exhaust fans and simple hand cranes, called balancers as shown in **Fig. 2**, have been introduced, but these devices have not brought about substantial improvements in working conditions.

3. Outline of Converter Relining Robot System

Converter relining towers have been traditionally used for automatically transferring bricks to laying positions in the converter. This structural tower is equipped with a work platform and a chain conveyor or spiral slider rails to bring bricks one by one into the converter. When assembled, it exceeds 20 m in height. This large structure is passed through the mouth into the converter and used to lay bricks in the converter. A space large enough to move and install the tower must be available above and around the converter. The relining towers are very difficult to apply to old converters built before their appearance or at converter facilities not specifically designed for their use. Since the relining tower calls for bricks to be manually loaded, it does not improve the poor working environment within the converter.

A new type of converter relining robot system was devised for converter facilities lacking ample space above their converters. As shown in **Fig. 5**, part of the detachable converter bottom is removed, and bricks and bricklaying devices are brought through the opening into the converter. The bricklaying robots are installed on the telescopic platform to automatically lay bricks in the lining of the converter. The system is divided into four main blocks as described below.

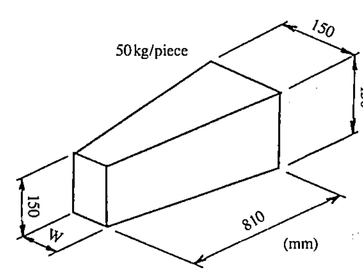

Fig. 4 Replacable brick for converter lining

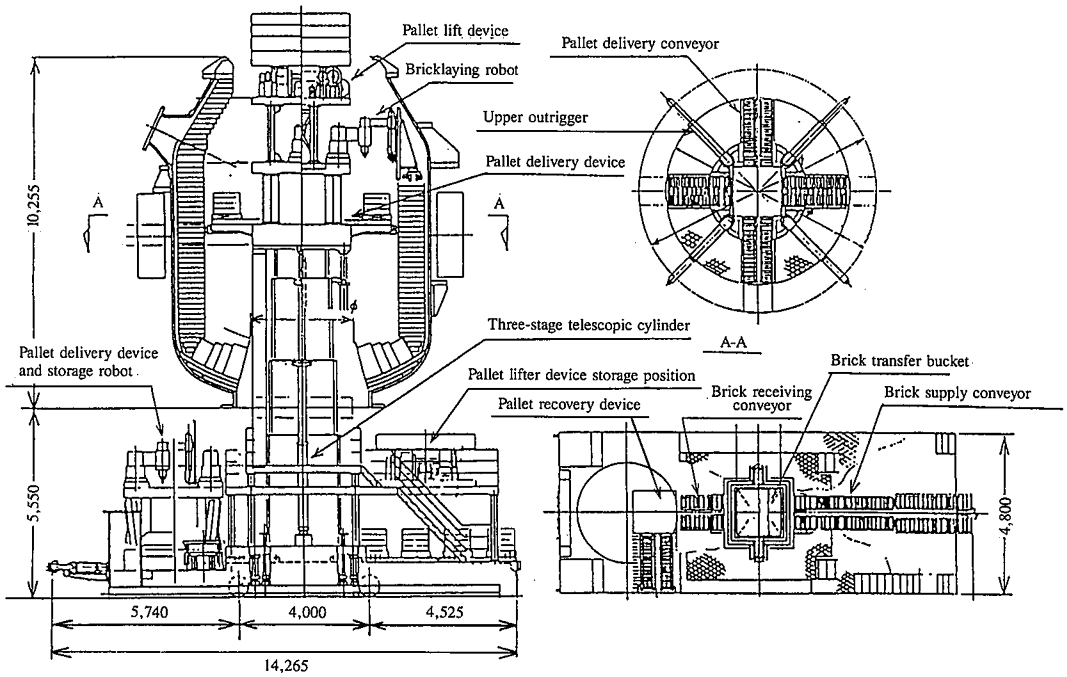

Fig. 5 General view of converter relining robot system

(1) An elevating guide that contains a brick transfer lifter device and is moved up and down by two hydraulic cylinders.
(2) A bricklaying unit that contains a collapsible brick delivery conveyor and two bricklaying robots.
(3) A winch unit that drives the brick transfer lifter.
(4) A tower car that carries the above units as well as control panels. The component units on the tower car are drawn by a diesel locomotive into the position below the converter and are assembled by an overhead crane above the converter.

The technical features of the relining tower and bricklaying robots are described below.

3.1 Relining tower

3.1.1 Brick transfer function

Bricks are transferred by the relining tower as described below.

(1) A pallet of bricks is placed by a forklift onto the receiving roller conveyor at the end of the tower car.
(2) The pallet of bricks is conveyed onto the lifter device installed inside the elevating guide.
(3) The pallet of bricks is raised by the lifter device to the delivery deck where the robot is located.
(4) The lifter has a turntable and can deliver the pallet to a position where the robot can easily pick up the bricks.

The above series of brick transfer operations is automatically performed, using sensors installed in the specific units and a control computer.

3.1.2 Lifting function

The bricklaying unit can be automatically moved to the optimum vertical position where the bricklaying robots can properly handle and lay the bricks. The two hydraulic cylinders are each equipped with stroke detection sensors. The hydraulic oil flow rate to each cylinder is controlled on a real-time basis according to the sensor information, lest the elevating guide should be tilted by the stroke difference between the two cylinders. The stroke difference between the two cylinders is always controlled to a maximum of 1 mm.

3.2 Bricklaying robot

A special robot was developed to automate bricklaying. The bricklaying robot was designed and built to operate over the entire inside area of the converter and to carry heavy bricks for efficient installation. As shown in **Fig. 6**, it has four operating axes, is horizontally articulated, and features a maximum reach of 3,850 mm and a load capacity of 300 kg. This large robot must be passed through the opening in the bottom as part of the bricklaying unit. Its operating axis layout and arm operating angle are optimally designed for compactness.

As shown in **Fig. 7**, two such robots are arranged to cover the entire work area without moving them within the bricklaying unit. By operating two robots simultaneously, bricklaying speed is increased.

3.2.1 Flexibility-controlled hand

To install bricks with as much precision as skilled bricklayers, a bricklaying hand was developed as illustrated in **Fig. 8**. This hand is characterized by its ability to apply the optimum force to each brick to lay the brick flush with the adjacent brick as performed by a skilled bricklayer. Three bricks are picked up at a time by three rubber vacuum pads attached to the bottom surface of the hand and are each held by direct-acting bearings, air cylinders and the like. The bricklaying hand has seven degrees of freedom, and its flexibility can be controlled by adjusting the air pressure. It can simultaneously pick up and lay three bricks without any gaps between them.

3.2.2 Method for controlling bricklaying robot without teaching

The control characteristics of the bricklaying robot are described here. Conventional industrial robots repeatedly operate among several taught points (this control method is called the teaching playback method). The bricklaying robot must lay each brick at a different position, therefore it is impossible to teach the bricklaying robot about 2,000 positions where it must install bricks in the lining of a converter. A new control method was developed whereby the bricklaying robot is only taught the first bricklaying position. It then measures and memorizes the first bricklaying position, and computes the next bricklaying position from the first bricklaying position already measured and memorized. This control method has enabled the bricklaying robot to operate after the first bricklaying position without teaching, and has helped to prevent the occurence of brick laying errors.

3.2.3 Robotic vision

Because bricks are delivered to the designated positions by the relining tower, the bricklaying robot can be taught to pick up each brick by the teaching playback method. Should the bricks shift position when being transported on the wooden pallet, supply accuracy will decrease. The bricklaying robot can accommodate brick supply errors up to ±50 mm with the flexible functioning of its hand. If the robot is supplied with bricks considerably out of position, it processes the images of the bricks from two television cameras installed at the bottom surface of the hand and senses the positions of the individual bricks. Using this data, the robot can then move itself into a position over the bricks. This visual function allows the bricklaying robot to accommodate brick supply errors of up to ±100 mm.

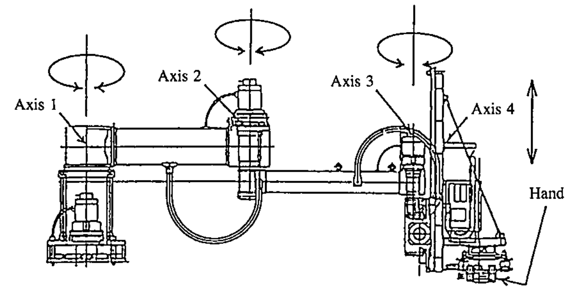

Fig. 6 Bricklaying robot

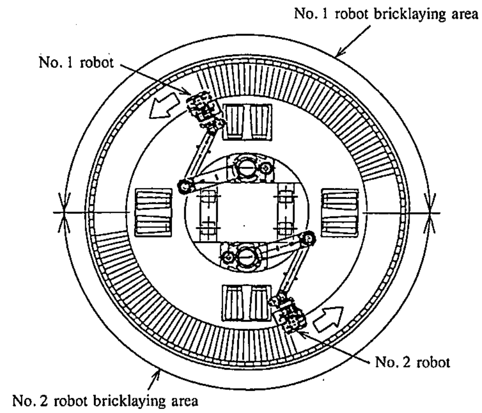

Fig. 7 Robot arrangement

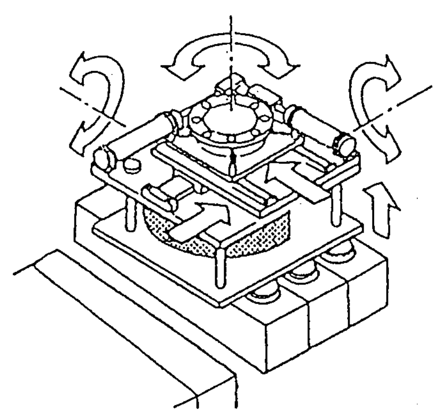

Fig. 8 Bricklaying robot hand

4. Benefits of Converter Relining Robot System

The operation of the converter relining robot system calls for one worker on the relining tower car to monitor the transfer of bricks, two on the upper deck to monitor the operation of each robot, and several others to operate the forklift, handle the pallets, and perform other incidental tasks. Sizable labor savings are achieved by obviating the need for skilled bricklayers. Bricklaying work in a poor environment is also eliminated; another great advantage.

5. Conclusions

The following devices and control method were developed to automate the relining of converters:

(1) A new type of relining tower that can be installed through the bottom opening of the converter for use at converter facilities that lack adequate space above the converters.

(2) A bricklaying robot for automatically laying bricks in the sidewalls of converters.

(3) A flexibility-controlled hand.

(4) A teaching-free control method.

(5) Robotic vision.

The above method and devices have made it possible to automate the relining of converters that was difficult to do so in the past.

Conventional industrial robots can only perform simple repetitive tasks. The factory automation technologies introduced here are capable of making such robots intelligent and applying them to more complicated equipment maintenance. Efforts will continue to research and develop technology for automating more diversified, complicated, and demanding tasks.