Proposal of Robot Application for the Ladle Slide Gate Brick Replacement

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Abstract

The new ladle slide gate (LSG) for robot application and prototype system using the general-purpose robot equipped with several sensors to enable automatic brick replacement have been developed and confirmed that the prototype system succeeded to carry out a series of actions for the LSG preparation work in laboratory basis. Putting the system into the actual field trial service at a mini mill in Japan, the combination of the new LSG system and the robot system verified to be able to cover the skill needed for slide gate brick replacement work.

1. Introduction

In recent years, automation devices using industrial robots are widely spread to manufacturing sites due to the significant improvement of the robot control technology including the peripheral sensors being incorporated in the system, consequently, robot replaces complex human tasks in order to improve the consistent operation and work place safety in addition to labor saving.

The automation devices using robots are gradually spreading in steelworks where the robot application is seemed to be very difficult and limited to the process after rolling where the effects of heat and dust are relatively small. However, with the background of recent robot utilization, robots are applied to simple operations of converter floor and cast floor, and the practical examples are increasing with which labor saving, work stabilization and site safety are realized.

According to the situation of such robot application, it was thought to apply the robot to the ladle slide gate (abbreviated to LSG) brick replacement after casting and to realize labor saving, operation stabilizing and safety of the replacement work. In the past, although there was a joint work[1)-2)] of steelworks and refractories manufacturers in Japan and Europe to apply the robots to slide gate brick replacement work, the stage of practical application has not yet been achieved.

In the present investigation, the verification regarding the necessary element technology to be involved and the brick replacement work by robot control has been carried out in three steps: first, preliminary verification of the elemental technology by the computer simulation with CAE approach, next verification by prototype development, and finally, verification under the actual field trial. Through the three steps verification, it was clarified that the LSG brick replacement by robot was feasible and the details are described below.

2. Verification Method

2.1 Elemental Technology Development

2.1.1 Computer simulation

The concept image created by 3D CAD is taken into the simulator as shown in **Fig.1**. A robot is placed on the working deck in lieu of the operator who is in charge of all the works carried out on this deck. Under this virtual layout, general purpose robot is operated and extracted the newly required elemental technologies as per the next paragraph.

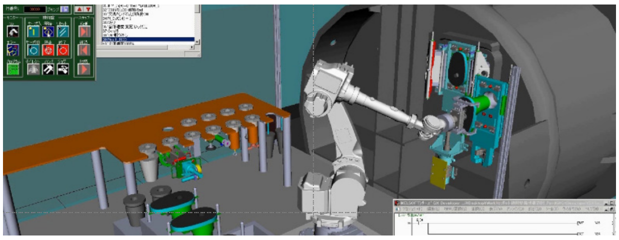

Fig.1 Verification of replacing operation by simulator.

2.1.2 Newly required elemental technologies

(1) LSG system

Existing LSG is designed on the assumption of the manual brick replacement, so the frame opening angle is around 100° [3)] which is insufficient to robot access, therefore, the new hinge mechanism has been designed to expand to 180° opening angle.

Also, new plate clamping mechanism (locking by latch) has been designed which allows single push in action for plate placing in LSG frame by robot.

(2) Robot hand

Several kinds of hand were studied to carry out each task i.e.: the LSG frame open/close, plate hanging/handling, and status check to eliminate any errors.

(3) Plate brick configuration

To fit the above hand and clamping mechanism, metal clad configuration was applied. Thus, the back face of the plate brick was covered by the metal in shape to fit both the robot hand and new clamping mechanism in the LSG frame. Lower plate and lower nozzle were consolidated into one body to simplify the work itself and the resultant weight gain was not a problem because of robot work. **Fig.2** shows the newly devised plate brick configuration.

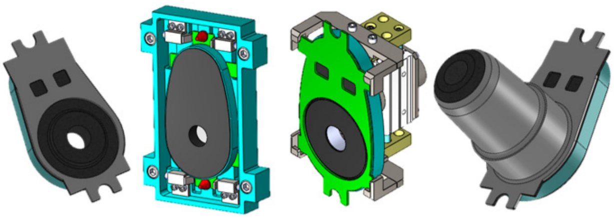

Fig.2 Plate brick configuration.

(4) Image processor

The device is mounted on the robot and has functions to detect and correct the target position and to control the position of the entire system. The image data of the target caught by camera is fed to the selected image processing software, then the adjusted data is fed to the robot as shown in **Fig.3**. The effectiveness of the device has been confirmed by using image processing software.

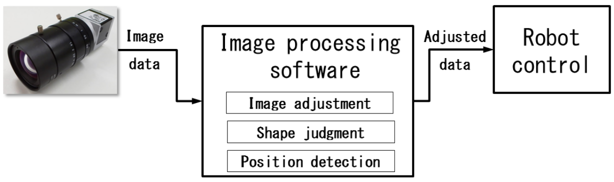

Fig. 3 Flow of image processing and position correction.

In the above (2) and (3), three kinds of test pieces have been made, and the best one have been decided.

2.2 Prototype Development

The above new elemental technologies are simulated and confirmed that each one work well in the virtual space.

Then, prototype system has been designed and manufactured to confirm that the entire system works as just like an actual operator. In the prototype system, the following two major items have been studied.

(1) LSG

- LSG being used at mini mill has been modified to incorporate the new hinge and clamping mechanism.
- Handles for the LSG frame opening/closing and the marking for position detection are added as the counterparts of the robot hands and camera of the image processing.

(2) Robot and its operation

a) Robot

- The robot has been selected in consideration of the operation plan, automatic control including the image processing and force control, and the layout between LSG, robot, and miscellaneous members.

b) Robot hand

Two types of hand have been developed, one is for the frame opening/closing and the status check, and the other is for brick handling.

c) Human-robot collaboration

- Intervention of operator seems to be inevitable, therefore, the operation plan has been designed so as to enable the collaborative work.
- The various safety sensors are studied and incorporated into the system to protect operators from any incidents led by robot motion.

d) Miscellaneous

Brick stand for mortar application and air supply source including piping to deliver cooling air to protect robot from high temperature atmosphere in actual field.

The prototype system consists of the above unit and consideration have been manufactured and placed as per the field trial layout, then, cold tested as designed in the automatic control plan and confirmed whether the entire system can carry out what real operators are doing in laboratory basis as shown in **Fig.4**.

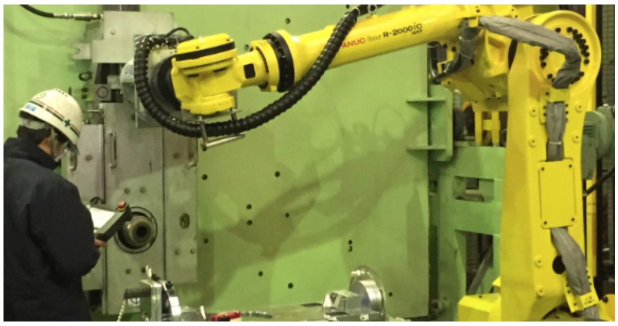

Fig. 4 State of prototype verification.

2.3 Actual Field Trial

As a first stage, only the LSG system has been put into the actual field trial to confirm the all new mechanisms incorporated does work under the actual field conditions by manual operation.

The trial of LSG alone has performed in one campaign (46 heats) and completed without any problems.

Then, another equipment such as robot, brick stand, control panel, etc. have been installed on the working deck at ladle preparation area of the mini mill. After installation, cold test run has been made based on the operation plan under the automatic control. The actual field trial has been started March 2018 and continued to the end of April 2019 with a total of 48 chances. **Fig.5** shows state of actual field trial.

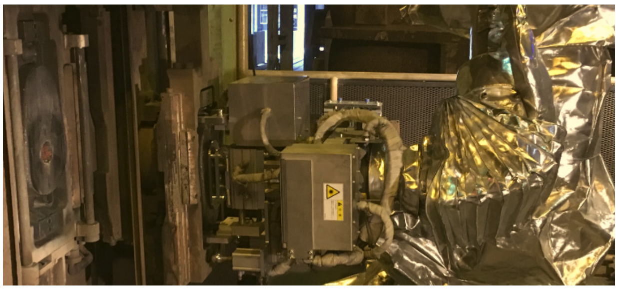

Fig. 5 State of actual field trial.

3. Result and Discussion

It is thought that the big difference between the laboratory basis verification and the actual field trial is heat, dust, brightness which continues to change all the times and affect to the system performance.

The result of a total of 48 chances is shown in the **Table 1**. Each work is described in the left column according to the operation procedure in which the inevitable human operations are included.

The result is divided in two by the vibration applied for the upper plate setting, so the second column shows the first 34 chances without vibration and the right column shows the later 14 chances with vibration.

Various issues have been come out and adjusted, finally, a total of 27 modifications are required. The major items and their adjustment and countermeasures are as per follows.

(1) Position error

Issue and estimated causes

- The prepared image processing control can not detect the target to be photographed.
- The estimated causes are the contamination of the target to be photographed for position correction or the influence of the brightness which changes due to the lighting in the plant. Also, dust has been seen on the surface of the glass which protects the camera lens.

Adjustment and countermeasures

- The camera exposure and detection settings have been adjusted and the image processing control has been also reviewed.
- Regular cleaning of the camera lens and the target surroundings by air flow has been taken in the process.
- By the above countermeasures, the image processing control does work to detect the target to be photographed. Furthermore, the error in the correction value has become smaller.

(2) Difficulties on the upper plate placing

Issue and estimated causes

- The upper plate placing is insufficient and stopped before latch is being in engaged.
- The estimated cause is mortar setting being faster than expectation. The upper nozzle surface is being hot and the mortar applied on the upper plate dowel has been hardened before placing due to the less speed and less pushing force of robot hand and this may lead the upper plate pushing to be difficult.

Adjustment and countermeasures

- The motion control such as pressing force, pressing speed, pressing number, etc. have been reviewed and the number of successes have been gradually improved.
- However, there is a limit to improvement with robot alone, therefore, the vibration has been introduced in the hand from the 35'th trial. With the vibration, plate setting has been improved significantly.

  Without vibration: 6 successes out of 34

  With vibration: 10 successes out of 14

  Currently, the degree of vibration is being adjusted depending on the mortar amount applied, moisture added, and so on in order to clear this issue.

Table 1 Operation procedure and time and rate of success of each robot motions in field trial

Operation procedure	First 34 chances		Later 14 chances	
	No vibration		vibration	
	Success			
	Times	Rate %	Times	Rate %
① Human operation 1 Attach hyd. cylinder Clean metal with oxygen	–	–	–	–
② Open frame				
Adjust pos. open/close	28	82	12	86
Open spring box	33	97	14	100
Open slide frame	33	97	14	100
③ Detach plate				
Adjust pos. replacement	30	88	14	100
Detach lower nozzle plate	27	79	14	100
Detach upper plate	27	79	14	100
④ Human operation 2 Apply mortar to upper plate Cleanig around frame	–	–	–	–
⑤ Attach plate				
Attach lower nozzle plate	29	85	14	100
Attach upper plate	12	35	12	86
Check plate attachment	23	68	14	100
⑥ Human operation 3 Lubricate plate surface Lubricate liner	–	–	–	–
⑦ Close frame				
Close slide frame	30	88	14	100
Close spring box	27	79	14	100
Check face pressure	28	82	14	100
⑧ Human operation 4 Clean nozzle hole Detach hyd. Cylinder	–	–	–	–
Series of operation	6	18	10	71

Also, four times human operation totally were carried out in one brick replacement work, and no incidents occurred during the actual trial, so, the safety system for human-robot collaboration incorporated was thought to be sufficient.

4. Conclusion and Future Subject

It was confirmed that the combination of the new ladle slide gate (LSG) and the general purpose robot could substitute the LSG brick replacement work i.e. face pressure loading/unloading, plate brick replacement, and the status check of the LSG being ready to go the next service currently being carried out by the skilled operator.

As the next step the study of the automation of the heavy task such as the cylinder attach/detach and upper nozzle replacement has been started in consideration as countermeasure for the decreasing of the skilled workers.

In addition, the service life judgement of the LSG with use of AI and big data is important subject to practice for avoiding the breakout incident in future.

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3) Toshihiro Imahase, Akira Otsuka, Junichi Funato, Nobuyuki Yokoi and Haruyuki Ohba : AISTech 2016 Conference Proceedings (2016) pp.1661-1671.