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Development of Coke Oven Machine Automation Technology

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Abstract:

To improve the labor productivity and working environment of coke ovens in the coking process, Nippon Steel developed and implemented automation technology for operating coke oven machines unattended and reducing work on the oven top. In 1992, an automatic system was introduced for unmanned coke oven machine operations at the Oita Works' No. 3 and No. 4 coke oven batteries. An automatic constant-position stop mechanism and automatic mechanisms for coke oven machines capable of faithfully following the oven body profile were developed. Ascension pipe and coking chamber decarbonizing devices were also introduced to reduce the labor required for oven-top tasks. In the automatic operation system of the Yawata No. 5 battery, the second of its kind, the operating sequence was improved by developing and applying a cycle time simulator. Cycle time was shortened by decreasing the manual intervention rate. As a result, a high push rate of 140 ovens per day was accomplished.

1. Introduction

The coke plant constitutes a poor working environment compared with other plants at integrated steelworks and traditionally has been a priority area for automation and labor savings to improve labor productivity and to secure the necessary labor in the future. Coke oven machine operators must finely adjust and check the operation of a range of coke oven machines that vary in profile and hardware details (such as installation error). The automatic operation of individual coke oven machines has already been implemented, but the automatic operation of the complete set of coke oven machines is yet to be achieved (see **Fig. 1**). Mannesman of Germany automated coke oven machines at its

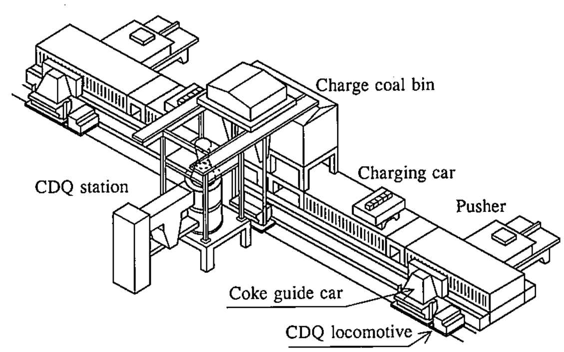

Fig. 1 Composition of coke oven machinery

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Huckingen coke plant. In the German example, however, the coke oven machines are manned for operational monitoring. During the 1980s, Nippon Steel started developing automation technology for application to the coke oven machines of existing coke oven batteries, including old ones. In 1992, the first automatic operation system was installed at the Oita Works' No. 3 and No. 4 coke oven batteries. In 1994, the second automatic operation system was introduced at the Yawata Works' No. 5 coke oven battery. With the Yawata battery automatic operation system, the pusher alone was operated from a return on investment point of view, and the other coke oven machines were monitored. The Yawata system achieved a high push rate of 140 ovens per day. In 1995, an automatic operation system of the Yawata design was implemented at the No. 4 and No. 5 coke oven batteries of Nippon Steel Chemical Co., Ltd.'s Kimitsu Works. This article describes the automatic operation systems of coke oven batteries and the techniques developed and implemented to achieve high push rates of coke ovens.

2. Problems with Implementation

2.1 Follow-up of ovens by automatic equipment

The coke ovens and their auxiliary devices, such as the ascension pipes, individually vary in dimensions and positions with deterioration in age, operating factors such as availability, and environmental factors such as temperature difference and weather. In coke oven machine automation, it is important that automatic devices follow these dimensional and positional variations of the coke ovens and function reliably. The automatic devices must be provided with such functionality and flexibility as required to follow up these variations of the ovens and their auxiliaries. A retry function is also necessary so the automatic devices continue operating as permitted by the cycle time and that manual intervention occurs when the specified number of trials is exceeded. To minimize this manual intervention rate, meticulous maintenance was performed on the coke ovens and their auxiliaries, and the work time extension arising from manual intervention was accurately evaluated.

2.2 Mechanization of coke oven tasks

The unmanned operation of the coke ovens is impossible simply when technology is established for the coke oven machines to run unattended. It becomes feasible only when the mechanization and automation of ancillary coke oven tasks are accomplished.

In developing automation technology, current coke oven tasks were analyzed, and necessary techniques to be developed for the unmanned operation of all coke oven machines and for the reduction of maintenance tasks for environmental control were identified. The results are shown in **Table 1**. The important and essential items shown in **Table 1** were implemented in the automatic operation system of the Oita No. 3 and No. 4 coke oven batteries.

3. Description of Automation Technology Implemented

3.1 Application of Automation Technology

In the automatic operation system of the Oita No. 3 and No. 4 coke oven batteries, the first of its kind at Nippon Steel, the pushers, charging cars, and coke guide cars were designed for unmanned operation (the coke dry quench (CDQ) locomotives were already unmanned), and a monitor was assigned in the master control room. In addition, a preliminary ascension pipe opening car towed by the charging car was introduced to automate the ascension pipe and to reduce the labor required for oven-top work.

In the automatic operation system of the Oita No. 3 and No. 4 coke oven batteries, the operators of the two pushers were eliminated, and a monitor was assigned in the central control room[1,2]. The automatic operation system of the Yawata No. 5 coke-oven battery is compared with that of the Oita No. 3 and No. 4 coke oven batteries in terms of investment efficiency as follows.

(1)Similar to the Oita system, it supervised the operation of the coke oven machines from the central control room (Oita System).

(2)The pusher was manned, but the other coke oven machines were operated unattended. The pusher had a system monitoring function, and the pusher operator additionally supervised control of the system[3,4] (Yawata System). The automatic operation system of Nippon Steel Chemical's Kimitsu No. 4 and No. 5 coke oven batteries was of the same composition as the Yawata system (see **Fig. 2**).

3.2 Automatic Operation System and Its Configuration

The overall configuration of the automatic operation system is shown in **Fig. 3**[5-7]. A traveling programmable logic controller (PLC) is mounted on each coke oven machine. The central master controller issues operational instructions for one pushing cycle to each coke oven machine, grasps the macrooperating status of each coke oven machine, and performs interlock control between the coke oven machines. The PLC receives operational instructions from the central master controller and automatically operates its coke oven machine for one pushing cycle. This combination of central control and on-machine distributed control is advantageous in that should the central master controller fail, the operator can intervene to ensure the automatic operation of the coke oven machines is at the same level as before. The Yawata and Kimitsu

Table 1 Issues with development of techniques for mechanizing coke oven tasks and reducing manpower required for coke oven tasks, and items of development for their implementation

No.	Task	Automatic device	Technical content and point	Implementation
1	Monitoring of charging hole lid for gas leakage	Gas leak sensor	Detection of hydrogen gas	×
2	Prevention of gas leakage from charging hole lid	New lid lifter	Linear contact between lid and well	○
3	Confirmation of ascension pipe operation	Mechanical check device	Check outdoors under high temperature	○
4	Confirmation of oven door installation	Mechanical check device	Check outdoors under high-dust concentration	○
5	Ignition of ascension pipe	Ignitor	Check outdoors under strong wind	○
6	Decarbonization of vertical section of ascension pipe	Combustion decarbonizer	Check of decarbonization by air scarfing	○
7	Monitoring of oven	Oven profile measuring device	Check under high temperature	×
8	Decarbonization of oven	Combustion decarbonizer	Optimum air circulation	○
9	Cleaning of charging well	Scraper-type cleaner	Check of cleaning	×

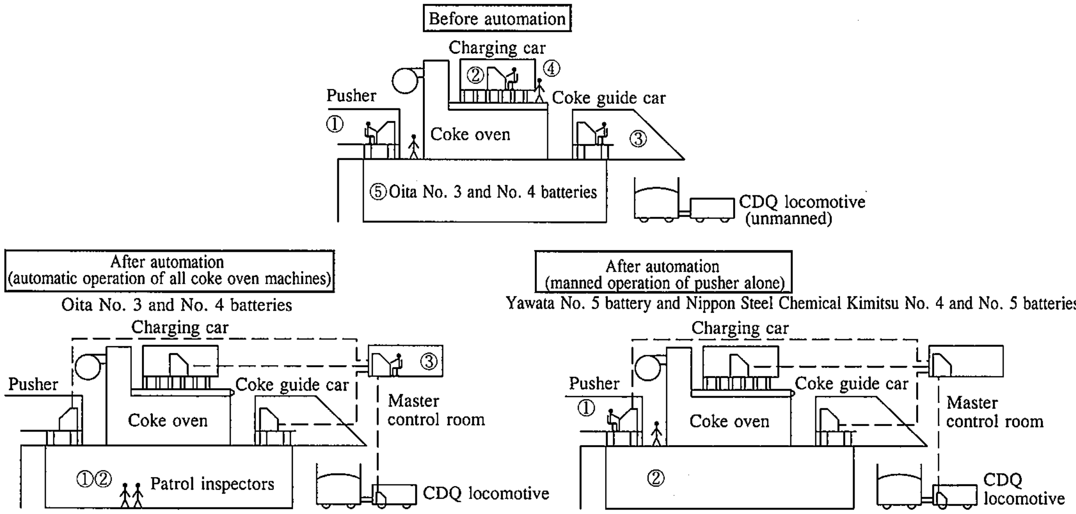


Fig. 2 Details of personnel rationalization

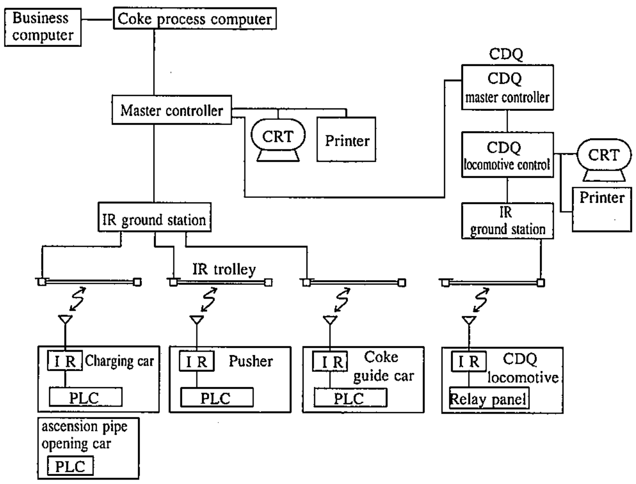


Fig. 3 Configuration of automatic operation system

systems have pushers equipped with a coke oven machine operating status display function that allows the pusher operator to monitor the entire system. Signals are transmitted by the inductive radio (IR) method.

3.3 Constant-position stop control system of coke oven machines

The constant-position stop control system of the coke oven machines appears in **Fig. 4**, and the oven center sensor is schematically illustrated in **Fig. 5**. The control flow is as follows:

(1) The PLC of each coke oven machine receives the information on the number of the oven to be worked on and the task to be performed at the oven from the ground master controller. It also calculates the distance to the target position, and starts the coke oven machine running toward the target position.

(2) The absolute coder detects the present position of the coke oven machine, and the PLC calculates the remaining distance to the target position and controls the variable-voltage variable-frequency inverter (VVVF) motor of the coke oven machine.

(3)When the coke oven machine approaches the target position and the target oven enters the oven center sensor's field of view, the travel control of the coke oven machine is switched from the absolute coder to the oven center sensor.

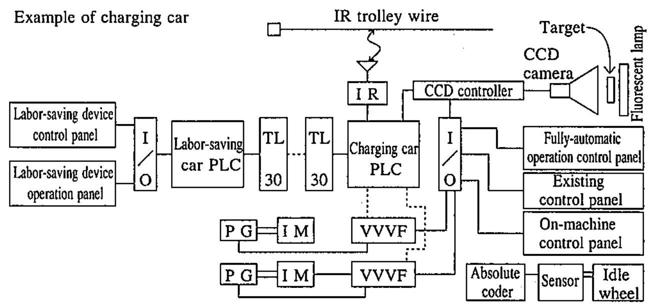
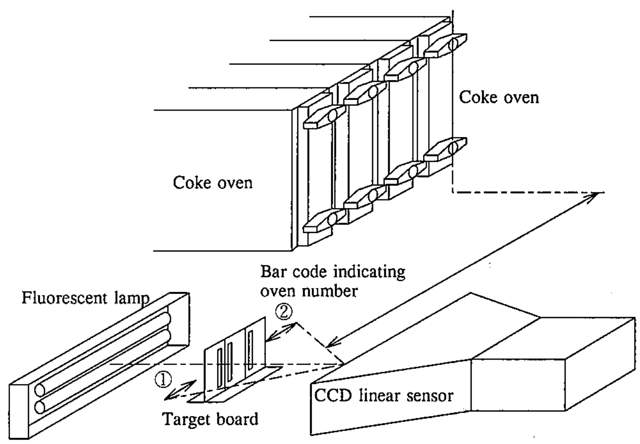


Fig. 4 Constant-position stop control system



Oven center is detected when slits ① and ② fall within limits on image

Fig. 5 Schematic illustration of oven center sensor

(4)The PLC calculates the deviation between the center position of the target board and the center position of the oven center sensor's field of view, and controls the VVVF motor so that the deviation falls within ±10 mm.

(5) The oven center sensor checks the oven number data encoded by the slits opened in the target board and completes the constant-position control of the coke oven machine.

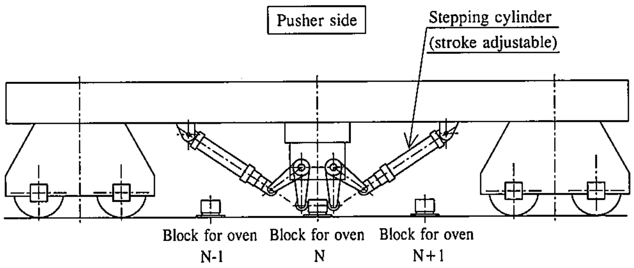


Fig. 6 Schematic illustration of pusher APS

A higher stopping accuracy of ±5 mm is required of the pusher so that its ram head does not damage the oven walls. Since the pusher is also heavy, the automatic positioning stopper (APS) shown in **Fig. 6** is used in combination with the VVVF motor.

The constant-position stop control system raised the single-try stop rate efficiency, or the condition of a coke oven machine being brought to stop at the target position within the specified limits by a single stopping operation, and improved the control method for better the stopping accuracy. The details are described in Section 3.5.3.

3.4 Reduction in number of oven-top operators[3,4,7]

Nippon Steel decided to promote an overall labor-saving campaign by mechanizing the previously mentioned coke oven tasks as well as by operating all coke oven machines unmanned.

3.4.1 Coking chamber decarbonizer (see **Fig. 7**)

This device burns and removes the carbon buildup on the coking chamber walls by spraying high-pressure air. Developed and implemented at Nippon Steel, it is an effective automatic decarbonizer. To improve the capability of the device to decarbonize the charging hole areas, a short lance was added to decarbonize the No. 5 charging hole alone, and charging hole air outlet nozzles were added to the No. 2 to No. 4 charging hole lances. This modification helped to eliminate the manual labor formerly required to decarbonize the charging hole areas.

3.4.2 Preliminary ascension pipe opening car

The preliminary ascension pipe opening car is equipped with devices for opening and closing the top cover of the ascension pipe, switching the dry main damper, and automatically igniting the gas generated when the ascension pipe is opened. Experimental results show that the ignitor actuates despite rain and strong wind as long as a spark source is available. Two ignitors are installed to prevent ignitor failure. **Fig. 8** schematically shows the preliminary ascension pipe cap opening car. Carrying a complete set of automatic devices, the car is towed by the charging car. In the implementation stage, variations in the installation accuracy (position and inclination) of individual ascension pipes were corrected, and a mechanism tolerant of such variations was developed. In the automatic operation system of the Yawata No. 5 coke oven battery, the preliminary ascension pipe opening car is installed at the tenth oven ahead of the oven actually being charged so that the ascension pipe of the tenth oven is opened at the same time when the other oven is being charged. This automated mechanism helped to shorten the cycle time of the charging car.

3.4.3 Ascension pipe base decarbonizer

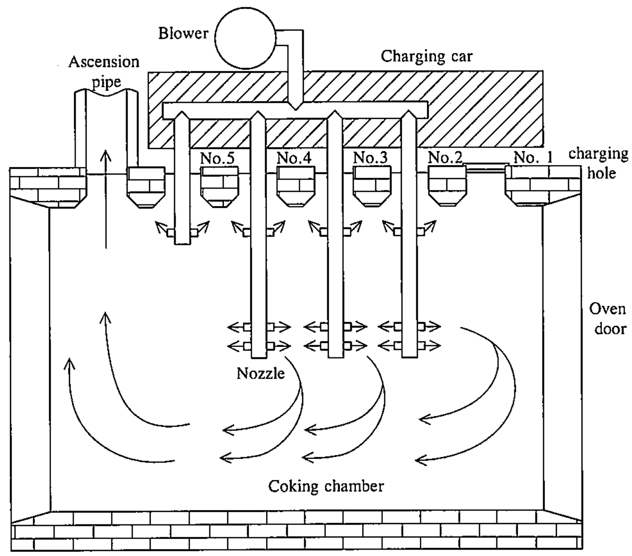


Fig. 7 Schematic illustration of coking chamber decarbonizer

The carbon buildup at the base of the ascension pipe increases the pushing load and decreases the cross-sectional area of the ascension pipe base, raising the pressure in the coking chamber and inducing gas leakage. Formerly, an air scarfing device was inserted into the ascension pipe base by the pusher and fired to remove the carbon buildup at the base of the ascension pipe. Since the air scarfing device was low in decarbonization efficiency, however, this carbon buildup had to be periodically removed manually. In the automatic operation system, the discharge nozzles of the air scarfing device were modified into Laval nozzles with a supersonic discharge speed. The Laval nozzles entrap surrounding air caused by the ejector effect and increase the amount of air introduced into the base of the ascension pipe. As a result, decarbonization efficiency was substantially improved in comparison with the conventional method. (see **Fig. 9**)

3.4.4 Prevention of gas leakage from charging hole lids

According to charging hole gas leakage investigation results, after an oven was charged, mortar was applied to the charging holes of the oven to keep them gas tight. While the next oven was being charged, the oven-top cleaner caused deterioration of the

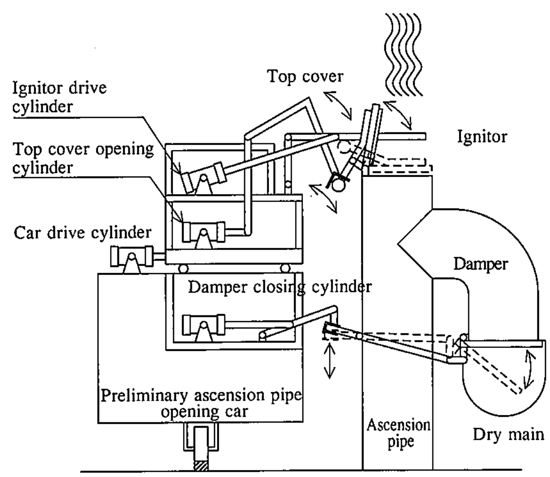


Fig. 8 Schematic illustration of preliminary ascension pipe cap opening car (Japanese patent provisional publication No. Hei 7-82563)

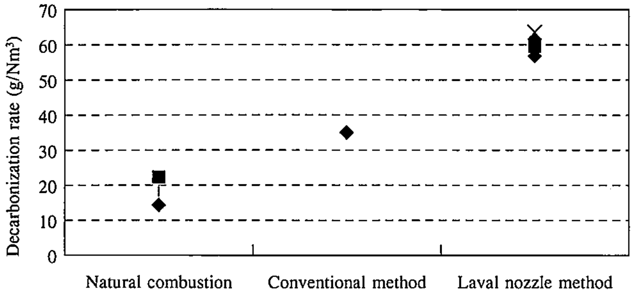


Fig. 9 Relationship between decarbonizing method and rate

mortar's seal tightness. A resealing device was added to apply another mortar seal to each charging hole after the cleaning of the oven top. This addition helped obviate the labor of one operator previously assigned to the charging hole lid sealing task.

3.5 Response to high push rate

The Yawata No. 5 coke oven battery for which the second automatic operation system was implemented pushed 140 ovens per day due to this production balance, as compared with the push rate of 110 ovens per day at the Oita No. 3 and No. 4 coke oven batteries. The following measures were taken to shorten the cycle time per oven at the Yawata No. 5 coke oven battery.

3.5.1 Introduction of preliminary ascension pipe opening car

One additional task to be performed by the charging car in the automatic operation system was the opening of the ascension pipe caps. When the charging car opens the ascension pipe cap, it must charge the oven, change from the high-pressure to the low-pressure ammonia liquor ejector in the fifth preceding oven already charged, decarbonize the fifth succeeding oven already pushed, and open the ascension pipe cap of the tenth succeeding oven to be pushed next. The resultant increase in the travel distance of the charging car considerably extends the cycle time. A preliminary ascension pipe cap opening car was introduced to open the ascension pipe cap of the tenth succeeding oven to be pushed next while the charging car is charging an oven. The cycle time was thereby maintained.

The preliminary ascension pipe cap opening car is drawn by the charging car. This measure shortened the cycle time by 105 min per day, reduced the ascension pipe cap opening time, and increased the recovery of COG by about 1%.

3.5.2 Development of coke-oven cycle time simulator[8)]

The cycle time of each coke oven battery was previously calculated by hand. Since the ovens were pushed by the synchronized operation of the pusher, charging car, coke guide car, and CDQ locomotive, the setup of simulation examples had to be restricted, and the simulation of various operating patterns encountered with actual ovens was limited. When automating the operation of the Yawata No. 5 coke oven battery, a coke oven cycle time simulator was developed to faithfully simulate the sequential motion of interlocked coke oven machines on a personal computer. When the simulation calculation results were compared with the results of actual operation, the computational error of the simulator was found to be a mere 1%. The cycle time simulator allowed the cycle time of a coke oven battery under various operating patterns to be accurately calculated and was used to study the effect of the manual intervention rate on the pushing time and to investigate the measures for shortening the cycle time, among other things. An example of operating pattern improvement achieved by the simulator is shown in **Fig. 10**.

3.5.3 Measures for improving single-try stop rate of coke oven machines

The following measures were taken to improve the single-try stop rate of the coke oven machines and to prevent the cycle time from increasing as a result of automation.

The absence of a constant-speed region during high-speed travel and the action of deceleration during acceleration were found to be responsible for large errors in the stop position of the coke oven machines as far as the constant-position stop control system is concerned. Based on this finding, a travel control system was developed and introduced that decreases the maximum travel speed with decreasing travel distance and provides a constant-speed region over a sufficient distance. A control method of adjusting the stop position of the machines for each oven was also employed.

The vertical level, distortion and joint mismatch of the charging car and coke guide car rails were adjusted to prevent the single-try stop rate of the machines from deteriorating due to oven body variations.

The above measures helped the charging car to achieve a single-try stop rate of 100% at the Yawata No. 5 coke oven battery, as shown in **Fig. 11**. The other coke oven machines accomplished single-try stop rates of nearly 100%.

3.6 Safety measures

The automatic operation of the coke oven machines requires greater safety measures than implemented before with automatic operation. The following measures were implemented to meet this purpose.

Among the software and hardware safety measures implemented concerning the travel of the coke oven machines are those for controlling deceleration at a specified point, checking the travel speed, monitoring overrun, setting travel limits, and preventing reverse travel. In the automatic operation system of the Oita No. 3 and No. 4 coke oven batteries, the coke oven machines for the two batteries run on the same track. Microwave-type collision

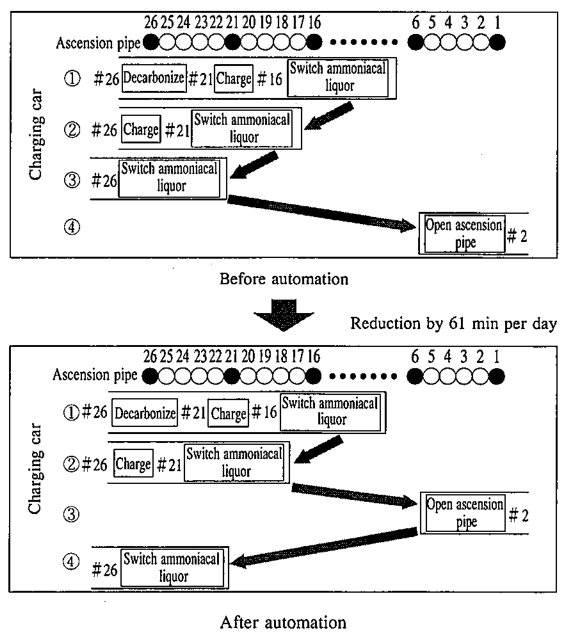


Fig. 10 Improvement in charging car operating pattern

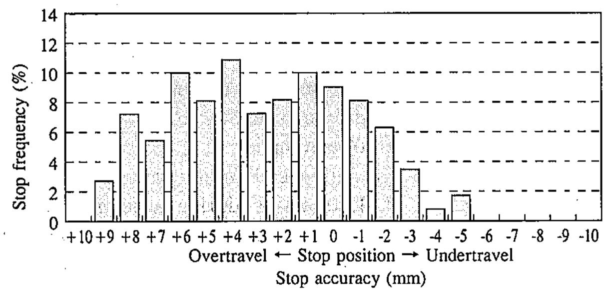


Fig. 11 Stop accuracy of charging car at Yawata No. 5 coke oven battery

avoidance devices are installed on each of the charging cars, coke guide cars, and pushers.

In addition, the following measures are provided to ensure safety during the charging and pushing of the coke ovens:

(1)ITV for monitoring oven openings

(2)Sensor for checking engagement of door latch bar with latch hook

(3)ITV for monitoring areas around coke oven machines

Each pusher stops at the target position with an accuracy of ±5 mm and is fitted with the automatic positioning stopper (APS) as described above. The thermal distortion of the pusher ram head sometimes causes its misalignment with the center of oven door during removal and replacement. To prevent the ram head touching the oven walls, the operator checks on the ITV that there is some clearance between the ram head and the door frame at the pusher-side oven opening, and backs up the APS. Before automatic operations, the pusher and coke guide car operators checked that the oven doors were properly latched in place after they were removed. In the automatic operation system, the door lifter is provided with two projecting levers. The levers detect any level difference between the latch bar and hook to see that the door is properly latched in place. **Fig. 12** shows the sensor for checking the engagement of the door latch bar with the latch hook.

The Oita No. 3 and No. 4 coke oven batteries are each equipped with ground-fixed ITV cameras for monitoring the entire oven-top regions, pusher machines, and coke guide cars.

3.7 Performance of automatic operation systems

The stop accuracy of each coke oven machine has met the target value. The automatic operation rate has been stable at 88 to 93% for the automatic operation control system of the Oita No. 3 and No. 4 coke oven batteries (all coke oven machines fully automated), and at 94 to 97% for the automatic operation system of the Yawata No. 5 coke oven battery (the pusher alone manually operated). This is described in **Fig. 13**. Most of the causes for manual intervention in the coke oven machines lie not in the automatic operation systems, but in the coke oven machines. Meticulous maintenance of the door machine and other devices is a key to the stable operation of the automatic operation systems of the coke oven batteries.

3.8 Benefits of automatic operation systems

Table 2 shows the coke oven machine operator reductions achieved by the automatic operation systems. Their number is lowered by 32 and 9 at the Oita and Yawata batteries, respectively. As an incidental benefit, the installation of the preliminary ascension pipe cap opening car has shortened the COG release time and increased the recovery of COG.

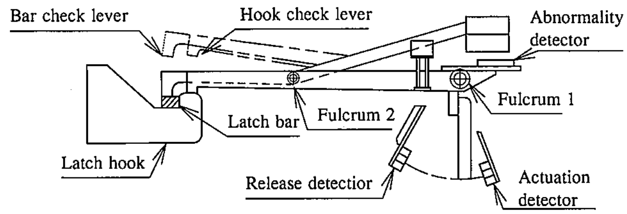


Fig. 12 Sensor for checking engagement of oven door latch bar with latch hook

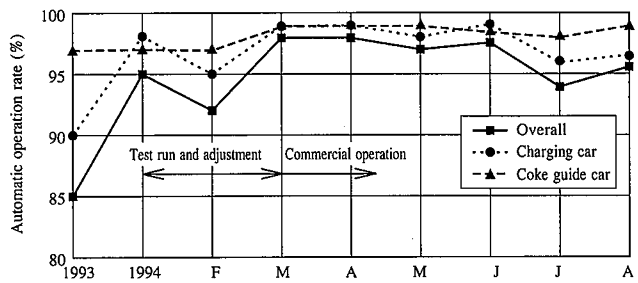


Fig. 13 Automatic operation rate of Yawata No. 5 coke oven battery

Table 2 Labor-saving benefits of automatic operation systems of Oita and Yawata coke oven batteries

	Oita		Yawata	
	Oven work	Ascension pipe work	Oven work	Ascension pipe work
Before automation	5×4×2 =40	14	4×4=16	3
After automation	3×4+2 =14	8	2×4=8	2
Number of operators reduced	▲26	▲6	▲8	▲1
	▲32		▲9	

4. Conclusions

Problems with the automatic operation of coke oven machines and new techniques as solutions to these problems have been described. The automatic operation system of the Oita No. 3 and No. 4 coke oven batteries accomplished the unmanned operation of all coke oven machines, sharply improving the productivity of coke oven operators and greatly contributing to the creation of a comfortable working environment. The engineering expertise accumulated with the Oita system was utilized to build the second, reliable automatic operation system for the Yawata No. 5 coke oven battery. In addition, a cycle time simulator was developed and applied to achieve a high push rate of 140 ovens per day. Another automatic operation system was then introduced for the No. 4 and No. 5 coke oven batteries at Nippon Steel Chemical's Kimitsu Works. An automatic operation system is under construction for the No. 4 coke oven battery at Nippon Steel's Yawata Works.

There still remain the following problems with the automatic operation of the coke oven batteries:

(1)Suppression of oven body variations and intensified maintenance of coke oven machines and auxiliary devices to ensure stable operations of the automatic operation systems for aging coke ovens

(2)Improvement in coke oven equipment and operating practice at automatically operated coke oven batteries to meet increasingly stringent gas emission and other environmental regulations

The authors will continue their work to solve these problems and to promote the automation of coke oven batteries within and without Nippon Steel.

References

1) Itoh, S. et al.: 2nd ICMC. London, 1992
2) Ogata, Y. et al.: 53th AIME. Chicago, 1994
3) Matsunaga, M. et al.: 54th IME. Nashville, 1995
4) Sakaida, M. et al.: 94th Special Meeting of Coke Committee, Joint Research Society, ISIJ, 1994, p.49
5) Watanabe, I. et al.: CAMP-ISIJ. 4, 1117 (1991)
6) Watanabe, I. et al.: CAMP-ISIJ. 5, 1125 (1992)
7) Watanabe, I. et al.: CAMP-ISIJ. 6, 60 (1993)
8) Sakaida, M. et al.: CAMP-ISIJ. 7, 971 (1994)