Waste Melting Plant / Advanced Oxygen Cleaning Equipment

— Application of the Real Haptics sensing technology for the oxygen cleaning, and its future automatic control prospects —

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Abstract

The oxygen cleaning is occasionally done for improving the activation of the melting reaction in the furnace bottom of the Shaft-furnace type gasification which is one of the gasification and melting technologies for municipal solid waste treatment. The oxygen cleaning is performed in remote control operation by the Oxygen Cleaning Equipment. However, in the past the operators couldn't grasp the condition in the furnace for this operation, and the operation of the Oxygen Cleaning Equipment depend on operator's experience and sense.

We applied real haptics technology to the Oxygen Cleaning Equipment to this problem. Real haptics, is the technology transmitting the sense of touch to a remote place. The operators have been able to sense touchably the conditions in the furnace through the Oxygen Cleaning Equipment, and the operability for the Oxygen Cleaning Equipment has been increased.

1 Introduction

Conventional shaft-furnace type gasification and melting furnaces developed by Nippon Steel & Sumikin Engineering Co. pyrolyze and gasify waste and then burn it at high temperatures to melt and recycle ash in the waste. The configuration is simple as shown in Fig. 1 as gasification and melting is performed in one body.

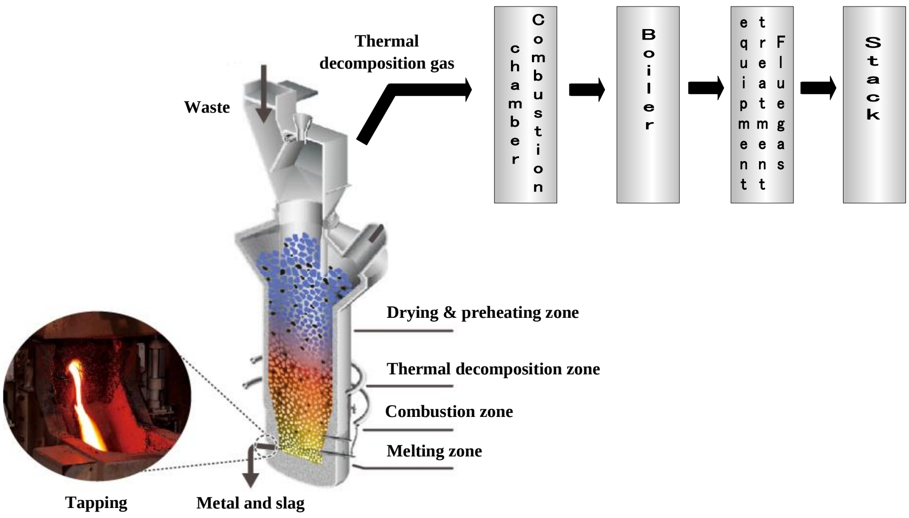


Fig. 1 Overview of Shaft-furnace type gasification and melting furnace

Waste put in the melting furnace is dried in the preheating and drying & preheating zone in the upper section. The combustibles are pyrolyzed and gasified in the thermal decomposition zone under the drying & preheating zone. The combustible residues that remain without being pyrolyzed are burned in the combustion zone in the lower section. Then, the remaining inorganic substances are melted in the melting zone in the lowermost section of the furnace at high temperatures from 1,700 to 1,800°C and turned into molten slag and metal. Molten materials are eventually discharged from the tap hole.

Nippon Steel & Sumikin Engineering has been actively working on mechanization and automation to reduce workloads during the discharge of molten materials and to improve the efficiency. As one of such activities, we applied the real haptics technology, a tactile sensing technology, to oxygen cleaning in the discharge of molten materials. This has realized a system in which an operator can understand the conditions in the furnace as tactile sensation data and that has made oxygen cleaning more efficient. Nippon Steel & Sumikin Engineering has been using this system for two years.

This report describes Nippon Steel & Sumikin Engineering's work on an Oxygen Cleaning Equipment to which the real haptics technology was applied and expansion to automatic control in the future.

2 Current Situations of Oxygen Cleaning and Their Subsequent Problems

Molten materials are temporarily accumulated in the melting zone in the lowermost section of an intermittent tapping type melting furnace and discharged out approximately once every hour. For this type, equipment for opening and closing tap holes is used in the tapping operation for discharging molten materials to the outside of the furnace, in the following order: (1) The tap hole blocked with tap hole clay is vented, (2) the molten materials are discharged, and (3) the hole is blocked with tap hole clay using the opening/closing equipment. During this tapping operation, oxygen cleaning is sometimes performed to increase the temperature at the bottom of the furnace where the temperature is low in order to accelerate the melting of inorganic substances.

In this oxygen cleaning, a pipe is put in through the tap hole to supply oxygen to coke in the lowermost section of the furnace. This operation is mainly conducted remotely and manually using an Oxygen Cleaning Equipment. However, the oxygen supply pipe gradually wears out from its end in the high-temperature lowermost section, so it is difficult to know the position of the end of the pipe. Therefore, whether oxygen is supplied to coke in an effective manner depends on the operator's experience and perception. Thus, we have been unable to start the automatization of oxygen cleaning to date.

3 Application of the Real Haptics Technology to Oxygen Cleaning

Regarding the problem with the oxygen cleaning described above, Nippon Steel & Sumikin Engineering recognized the real haptics technology as a means to allow operators to understand the operation conditions quantitatively. The real haptics technology developed by Professor Ohnishi at Keio University transmits the sense of touch to people when machines touch objects.

Haptics is a technology by which a user can receive feedback as a skin sensation through force, vibration, and movement provided to the user. It is commonly regarded as a technology that achieves virtual force sense using virtual models. However, the real haptics technology developed by Keio University has enabled long-distance transmission of information on contact with real objects and surrounding environments by implementing tactile sensation on systems. It is a completely new technology and its practical use is expected in the care, medical, and general industrial sectors.

Master-slave control is a typical example of remote control of equipment. In that control, a work device (slave) placed in a remote location operates based on the manipulation of the operating device (master). To achieve real haptics, tactile sensation needs to be transmitted interactively between the master and slave sides. Bilateral control, one type of master-slave control, is a control technology that makes such transmission possible. In bilateral control, when the master sends an operation command to the slave, the slave feeds back the reaction force of the operation from the target object or an obstacle to the master at the same time, so the master and slave are simultaneously controlled (Fig. 2). This makes it possible for the user side in a physically different place to receive the tactile sensation occurring in a remote location. In the figure, f_s is the reaction force that the slave receives from an obstacle, f_m is the reaction force that the slave transmits to the master, x_m is the information on the position of the master, and x_s is that on the position of the slave.

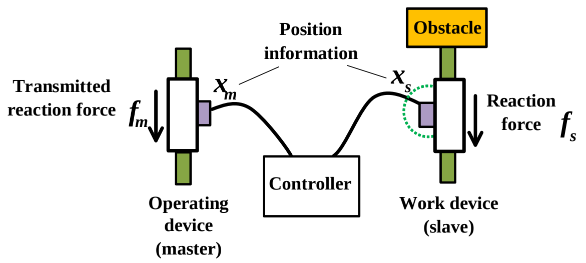


Fig. 2 Conceptual diagram of bilateral control system

To achieve real tactile sensation through the bilateral control, the positions of the master and slave and their force must be controlled at the same time. In the position control, hard motion is required to conduct fine positioning. In the force control, soft motion is required to adjust the force appropriately. As a means of satisfying these mutually contradictory requirements, Professor Ohnishi at Keio University has developed acceleration-based bilateral control (ABC method). In this control method, as shown in Fig. 3, the second derivatives of the position information values (x_m and x_s) output from the encoders installed in the master and slave systems are calculated to obtain the acceleration values (x''_m and x''_s). The position control is performed through control such that the difference between the two acceleration values becomes zero. The force control is performed through control such that the sum of the acceleration values becomes zero. This control can reproduce real tactile sensation without the problem of the position control and force control interfering with each other.

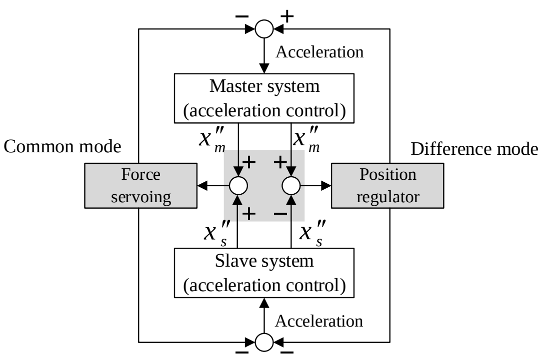


Fig. 3 Block diagram of Acceleration-based Bilateral Control

Nippon Steel & Sumikin Engineering has applied the real haptics technology using this acceleration-based bilateral control to an Oxygen Cleaning Equipment and succeeded in the practical use of a system that feeds back the conditions in the furnace to the operator as tactile sensation.

4 Oxygen Cleaning Equipment to Which the Real Haptics Technology is Applied

4.1 Configuration of the Oxygen Cleaning Equipment

Figure 4 illustrates the configuration of the Oxygen Cleaning Equipment to which the real haptics technology is applied. For the Oxygen Cleaning Equipment, when an operator manipulates the operating device lever back and forth, the pipe holder holding the oxygen supply pipe in place also moves back and forth in synchronization with the lever. Manipulating the operating device lever actuates the servo motor and the ball screw is used to move the pipe holder back and forth. This pipe holder has a microwave distance meter to measure the length of the pipe in real-time and a load cell to correct the reaction force of the oxygen supply pipe. The position information of the pipe holder is collected by the encoder installed on the servo motor in real-time.

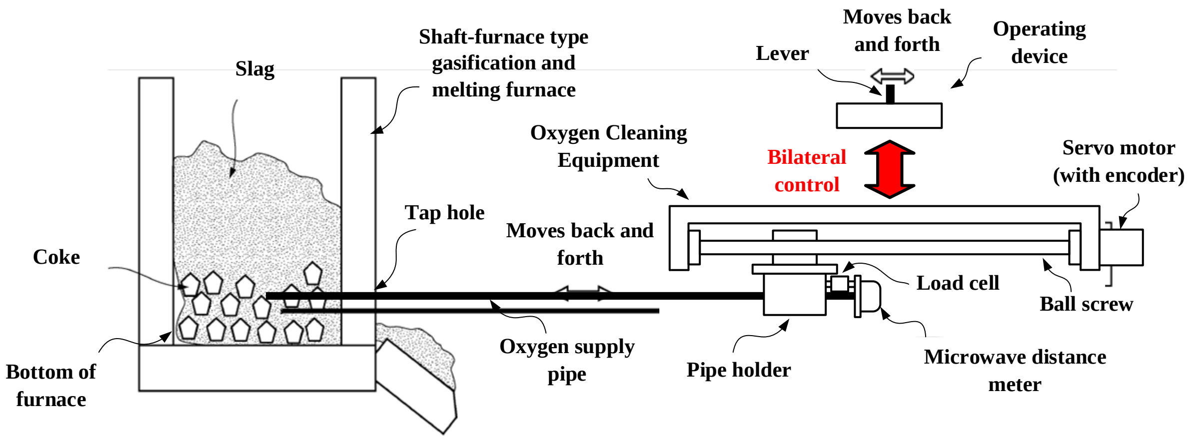
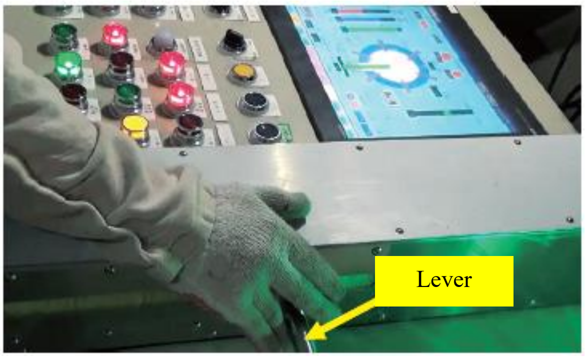


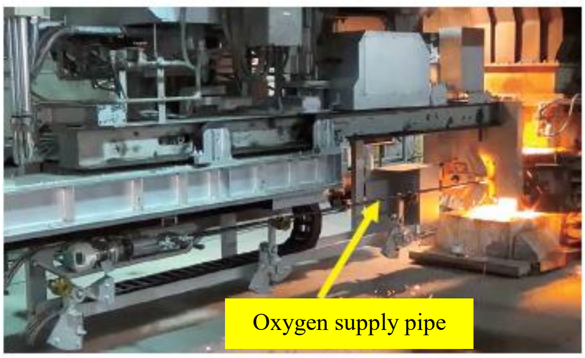
Fig. 4 Diagram of Oxygen Cleaning Equipment of Shaft-furnace type gasification and melting furnace

4.2 Operations

Figure 5 shows operation of the Oxygen Cleaning Equipment. The operator manipulates the lever of the operating device shown in (a) to operate the Oxygen Cleaning Equipment shown in (b) remotely to clean the inside of a furnace. Slag and coke coexist in the lowermost section of the furnace into which the oxygen supply pipe of the Oxygen Cleaning Equipment is placed. The reaction force received when the oxygen supply pipe moves in the furnace changes based on the condition of the mixture. Such changes in the reaction force are transmitted to the operating device as tactile sensation data, reproduced as reaction force on the operating device lever, and displayed on the monitor as numerical values. The operator can feel the reaction force that the oxygen supply pipe has received, as a “hard,” “soft,” “heavy,” or “light” touch and can see it visually as quantitative data, which allows the operator to understand the conditions in the furnace and to use such understanding to manipulate the Oxygen Cleaning Equipment. In addition, the position of the end of the pipe is calculated based on the position information of the pipe holder and the length of the oxygen supply pipe measured by the microwave distance meter. The calculated position is displayed on the monitor, which allows the operator to visually understand where the oxygen supply pipe is situated.



(a) Operating device(Master)



(b) Oxygen Cleaning Equipment(Slave)

Fig. 5 Operation scene of Oxygen Cleaning Equipment(Photo)

4.3 Improving the Bilateral Control

In bilateral control, while real tactile sensation is transmitted, control disturbance has significant impact. For the Oxygen Cleaning Equipment used this time and other larger machines, mechanical looseness of the ball screws, backlash and friction of the gears, and other similar problems become control disturbance. We faced the problem that the real reaction force at the moment when the end of the oxygen supply pipe came into contact with an obstacle was not transmitted to the operating device (Fig. 6). Therefore, a load cell (a type of force sensor) was added to make the correction that variation in load cell signals was added to the reaction force calculated from the encoder to reproduce the reaction force at the moment of collision. Figure 7 shows the example reaction force transmitted when the oxygen supply pipe collided with an obstacle where calibration by a load cell was provided and not provided. The horizontal axes in the graphs are the time. The vertical axis in the graph on the left is the value measured by the load cell and reaction force transmitted to the operating device (master). That in the graph on the right is the position of the slave. The red arrows show the timing when the pipes collided with an obstacle. When correction by a load cell was not provided, the reaction force at the time of collision gradually changed as shown in (a), so changes in the reaction force were obscure on the operating device and thereby it was impossible to recognize the collision. On the other hand, when correction by a load cell was provided, the reaction force at the time of collision suddenly changed as shown in (b), so changes in the reaction force were obvious on the operating device, making it easier to recognize the collision. As shown above, it was confirmed that for the Oxygen Cleaning Equipment and other larger machines, providing correction by a load cell (improvement) can reduce the influence of control disturbance and achieve transmission of more real tactile sensation.

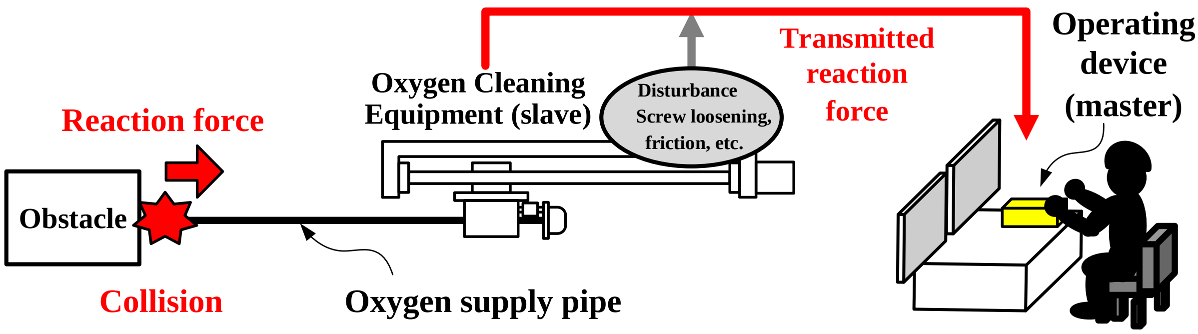


Fig. 6 Transmission of reaction force to operating device(Master)

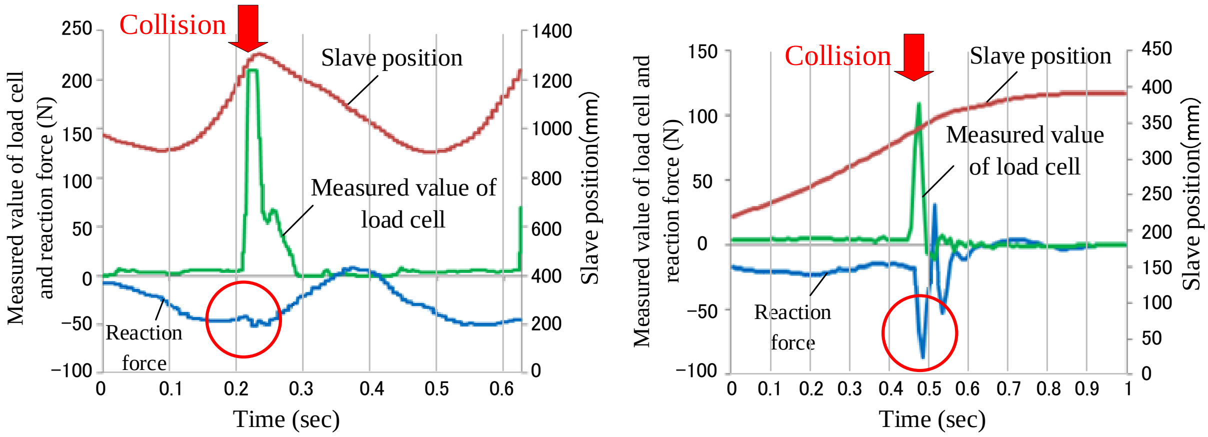


Fig. 7 Effect of calibration method by load cell

4.4 Evaluating the Operability

We asked the following questions about the operational feeling (tactile sensation) of the Oxygen Cleaning Equipment to eight operators who had actually used it for two years to evaluate the operability.

(a) Can you feel when the device comes into contact with coke in the furnace?

(b) Do you know how sticky the slag is?

As a result, all the operators replied that they could know the conditions in the furnace. The practical utility of the real haptics technology could be confirmed as real feeling of the operators.

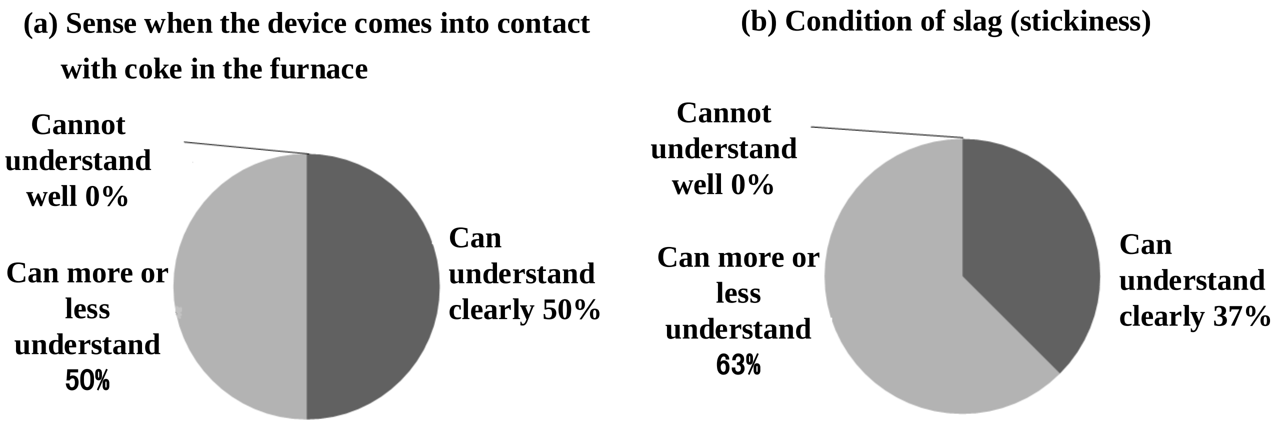


Fig. 8 Questionnaire results of operation feeling

5 Future Development

Applying the real haptics sensing technology to the Oxygen Cleaning Equipment has made it possible to quantitatively collect data on manipulation by an operator consisting of position and force. This has enabled the visualization of tacit knowledge (e.g., operator's action and know-how) to turn it into explicit knowledge as quantitative data. When an inexperienced operator manipulates the device while using such data as a good example, that can lead to handing down of the technique.

In addition, analyzing data on manipulation by operators and establishing logic from obtained manipulation patterns could lead to the automation of Oxygen Cleaning Equipment. We are working on full-automation of Oxygen Cleaning Equipment that is our next target.

The application of the real haptics technology will allow manipulation data to be quantitatively collected in the future, so further application to remote manipulation and automation of various devices in addition to Oxygen Cleaning Equipment can be expected.

6 Conclusion

Nippon Steel & Sumikin Engineering has applied the real haptics technology to the Oxygen Cleaning Equipment for our shaft-furnace type gasification and melting furnace. This report explained the actual operation performance for two years and its effectiveness.

In the history of automation of various machines, “tactile sensation” has been consigned without being implemented. The application of the real haptics technology that can achieve clear tactile sensation communications thanks to its innovative theory and high-speed ICT has made it possible for machines to have the excellent judgment and flexibility of human beings. Nippon Steel & Sumikin Engineering will work to expand the application to automate operations that are conducted through the judgement and sensibility of human beings and to allow such operations to be conducted remotely in the future. We will also work to develop the strongest system in which excellent human ability works in cooperation with the strength and reliability of machines.

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