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CLOSED TYPE OG INSTRUMENTATION SYSTEM

Nobuhiro Sakanashi
Tohru Yoshida
Takeya Fukumoto
Shigeharu Kawai
Katsumi Hachiga

1 INTRODUCTION

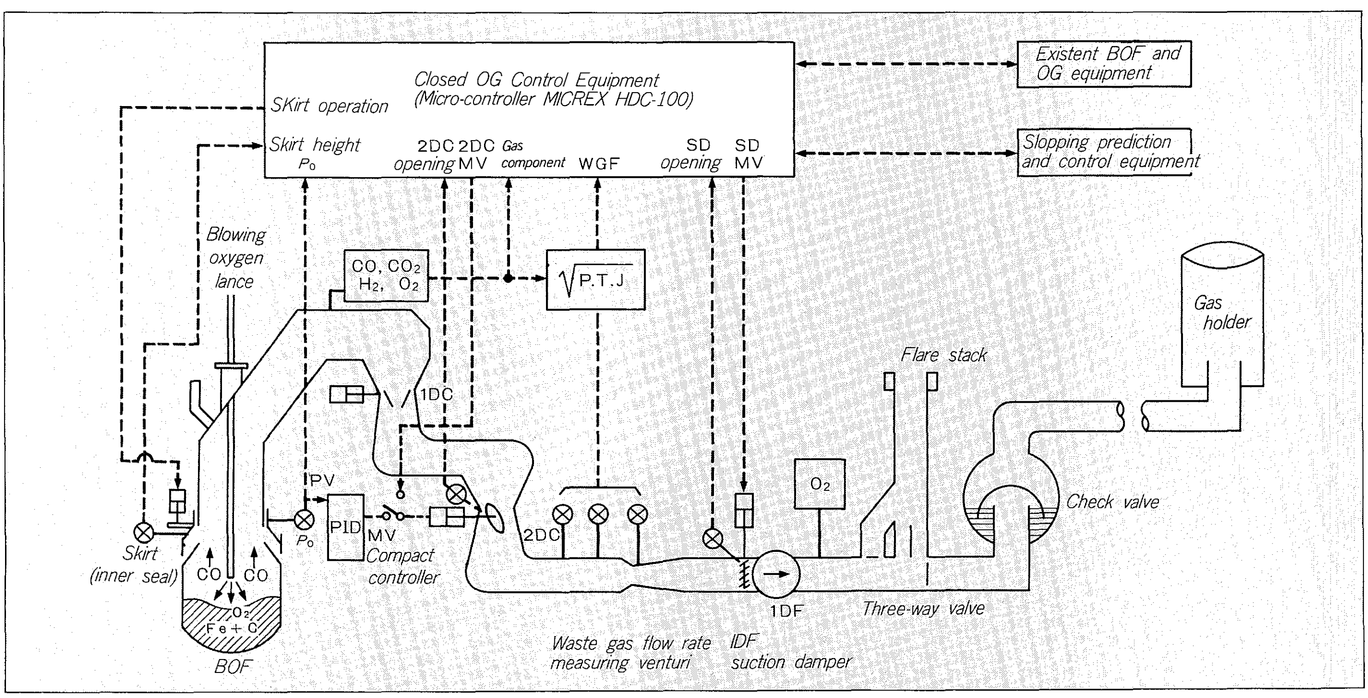
In the basic oxygen furnace method which is representative method in steelmaking, furnace waste gas whose main constituent is CO gas is produced in an enormous quantity due to decarburization reaction in the furnace at the refining process. The OG (Oxygen Furnace Gas Recovery) process are used for cooling, collecting and recovering this waste gas without combustion, and they are now widely used throughout the world for their excellent process characteristics. The amount of gas-energy recovery by OG process attains to about 12×10^{11} kcal/year for a steelmaking shop with an annual production of 6,000,000 tons, so that trying to increase the volume of waste gas recovery is now an important problem for saving energy.

Now, a Close-Type OG System for Furnace was developed and constructed through a joint research among the three companies of Nippon Steel Corp., Kawasaki Heavy Industries and Fuji Electric, and it not only contributed a great deal to increasing of waste gas recovery volume but also improved the steel yield and operation automatization. For this new development, in particular, for the instrumentation system, Fuji Electric, as a result of the joint research with Nippon Steel Corporation for nearly two years, has established a new control system that is well matched with the operation of the closed system. In the chapters that follow, characteristics of the closed type OG instrumentation system, its composition and the results of its operation are introduced.

2 OUTLINES OF OG PROCESS

Fig. 1 shows the OG process and its instrumentation flow diagram. Impurities as carbon, silicon, phosphorus, sulfur, etc. contained in the hot metal in the furnace will be oxydation-eliminated by blowing oxygen jetting out of the lance. The waste gas generated by this reaction is a high-

Fig. 1 OG process instrumentation — block diagram



temperature and dusty combustible gas, composed mainly of CO gas, and it is cooled in the hood and cooler of OG process then, cooled again and dust-eliminated by first and secondary dust collectors, then, recovered into the gas holder. The portion of waste gas in the first and last phases of refining by blowing where the concentration of CO gas is lower, will be burned and discharged. The skirt located on the upper part of the furnace is so constructed that it can go up and down and its position will be determined by the working condition.

When gas pressure near the furnace mouth, that is, hood gas pressure (hereinafter referred to as P_0) is lower than the atmospheric pressure, the atmosphere is sucked from the gap, and CO gas is combustioned, then the waste gas calories will be lowered. In case P_0 is higher than atmospheric pressure, the waste gas will blow out from the gap and the recovery gas volume will be reduced. So that, in order that gas recovery volume should be improved, it will be necessary to make the gap smaller and control well the hood gas pressure to an optimum value.

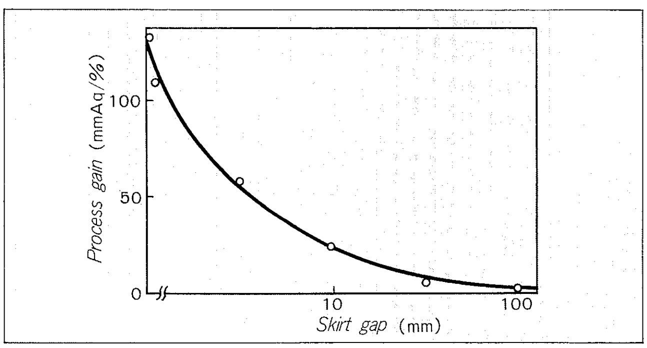
Up to now, due to constraint by BOF mouth skull owing to slopping and hood gas pressure control, operation used to be made by providing a gap of 100 to 200 mm between the furnace mouth and skirt, and that gap caused a buffer and the operation was possible also with PI control, but due to the fact that there were blowing out at the furnace mouth as well as combustion loss, there were certain limits to the increase of waste gas recovery volume. For the closed OG instrumentation system that has been developed now, the gap between the furnace mouth and the skirt was made as small as possible in order to seek for the maximum increase in the waste gas recovery volume. And by this, the process gain, once compared with that of conventional open type OG, as shown in *Fig. 2*, was made 20 to 100 times more, but this in its turn brought the following new problems:

(1) Abrupt change in process gain due to a minute change in furnace mouth gap caused by skirt height and BOF mouth skull.

(2) Change in furnace-generated gas volume, due to modification in method of charging flux as ore, lance height and blowing oxygen flow-rate, in particular short-period disturbance less than 10 seconds.

(3) Deterioration of control due to control damper response delay.

Fig. 2 Relationship between process gain and skirt gap



These can not be solved with a simple application of the optimum control theory, not to mention the conventional PI control, but it requires an introduction of adaptive control method.

3 DESIGNING OF CONTROL SYSTEM

3.1 Tranfer function approximation of OG process

The OG process is a highly non-linear process that can be expressed in terms of IDF pressure rise characteristics, gas pressure loss in the piping system, equation of state, and damper control characteristics, etc. The process is divided into the following three portions, namely: delay in the control damper, pressure transmission from the furnace mouth to control damper, and pressure transmitter filter. The relationship is approximated by transfer function and is shown in block diagram of *Fig. 3*. In that figure, K_P represents the above-mentioned process gain. The relationship of this block diagram can be expressed by the following equation (1).

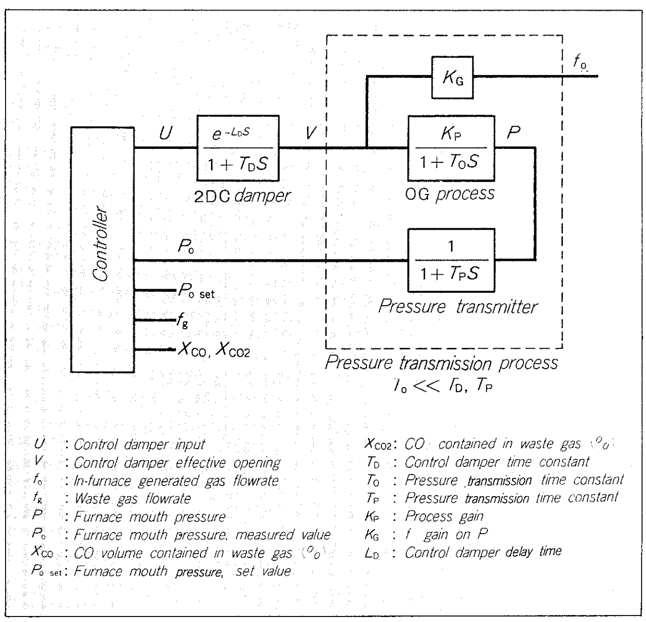
$$P_0(S) = \frac{K_P \exp(-L_D S)}{(1+T_D S)(1+T_P S)} U(S) + \frac{K_P K_G}{1+T_P S} f_0(S) \quad \ldots\ldots (1)$$

3.2 Designing of optimum control

By transforming the equation (1) into discrete equation of state, find out the control output $\Delta U(k)$ that minimizes the following equation value.

$$J_I = \sum_{i=1}^{I} \left[\{ P_0(k+i) - P_{0\,\mathrm{set}}(k+i) \}^2 + W \Delta U(k+i-1)^2 \right] \quad \ldots\ldots (2)$$

Fig. 3 Control block diagram as expressed by transfer function



whereas, W: Weight coefficient

Δ : Time difference

The value of $\Delta U(k)$ can be obtained by the optimum control theory and the following PI type optimum control formula can also be obtained.

$$\left.\begin{aligned}\Delta U(k) = {} & G_1 \quad P_0(k) - P_0 \text{ set} \quad G_2 \Delta P_0(k) \\ & + G_3 \Delta P_0(k-1) \ldots\ldots\ldots\ldots\ldots\ldots \text{①} \\ & + G_4 \Delta f_0(k) + G_5 \Delta f_0(k-1) \ldots\ldots\ldots \text{②} \\ & + G_6 \Delta U(k-1) + \ldots \\ & \quad + G_{l+6} \Delta U(k-l-1) \ldots\ldots\ldots\ldots \text{③}\end{aligned}\right\} \quad (3)$$

whereas, $G_1 \sim G_{l+6}$: Optimum feedback gain

① of the equation (3) represents the PID control term, ② is the prediction term on the change in in-furnace generated gas volume, and ③, the control delay compensating term. These elements were combined to obtain the optimum control value. By these, controllability on the change in the volume of generated gas in the ramp at the time of iron ore charging will be improved.

3.3 Designing of applicable control

With Section 3.2, the optimum control formula when K_p which is fixed was found out; however, in order to solve the problems mentioned in Chapter 2, adaption of control parameter to the non-linearity of the process and switch-over to control parameter corresponding to the disturbance pattern would be necessary. Thus, the adaptive control described in the following is introduced.

(1) $\sqrt{P_0}$ adaptive control

This exerts an adaption to the non-linearity that the process gain is proportional to $\sqrt{P_0}$, and prevents causing of unstable phenomena when a large fluctuation of P_0 occurs.

(2) Gain matching control by hunting detection

As the measures against sudden changes of the process gain due to the change in furnace mouth gap, by detecting hunting phenomena occuring when the control gain is excessive, the control gain will be weakened by $1/\alpha$ (α is about 1.5). On the contrary, when no symptom of hunting is detected for certain lapse of time, the gain will be multiplied by times.

(3) Parameter switching control

In order to improve the control characteristics in high-frequency band referred to equation (3), that is the optimum control equation, for the short-period disturbances less than 10 sec., the following P-type optimum control equation will be used.

Fig. 4 Block diagram of new control model

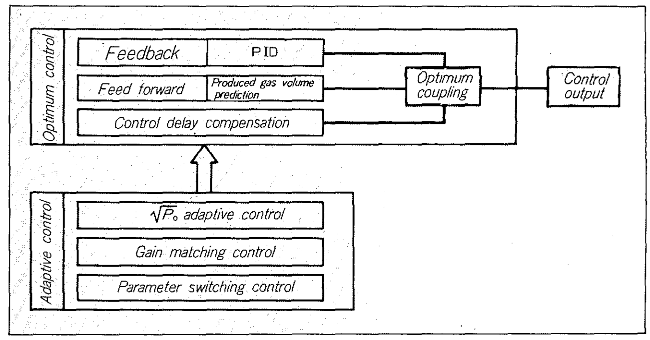
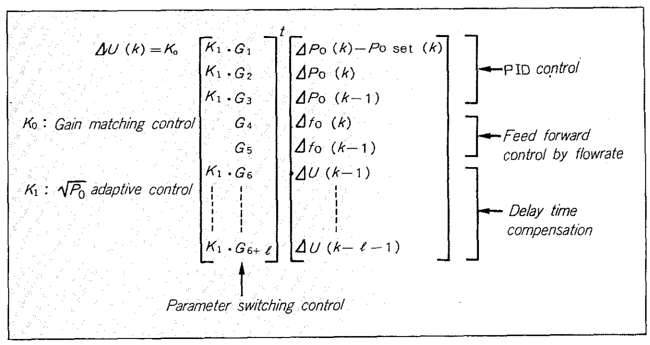


Fig. 5 Optimum control output in the new control model



$$\Delta U(k) = G_2{}' \, \Delta P_0(k) + G_3{}' \, \Delta P_0(k-1) + G_6{}' \, \Delta U(k-1) + \cdots\cdots + G'_{l+6} \Delta U(k-l-1)) \quad (4)$$

Fig. 4 shows the block diagram of the new control system thus designed and *Fig. 5* shows total control output.

4 EVALUATION OF THE NEW SYSTEM THROUGH SIMULATION

4.1 Evaluation of each control function

In order to check on the effect of individual control functions described in Chapter 3, tests have been made on (1) periodical disturbances, (2) pulse-like disturbances and (3) ramp-like disturbances that appear in the actual operation. The maximum and minimum values of P_0 ($P_{0\max}$) ($P_{0\min}$) and setting time (T_{END}) have been yet. And their results as for (a) PI control, (b) PI type optimum

Table 1 Comparison of simulation results on each control system

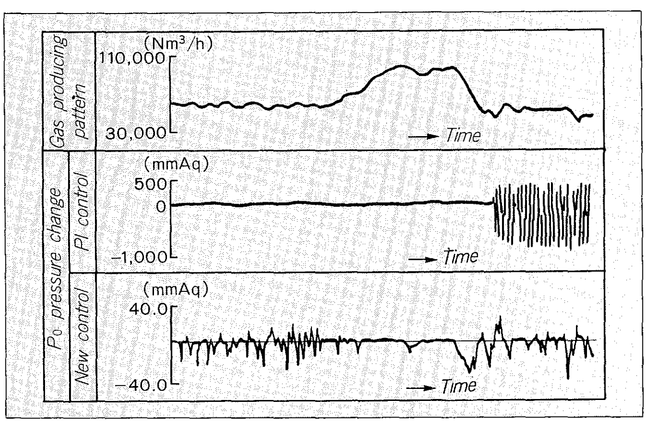
Control system \ Disturbance pattern	Ramp-like disturbance			Pulse-like disturbance			Periodic disturbance
	P_0MAX	P_0MIN	T_{END}	P_0MAX	P_0MIN	T_{END}	ΔP_0
(a) PI control	92	−92	90	150	−118	11	93
(b) PI type optimum control	35	−52	64	112	−200	20	204
(c) P + PI type optimum control	40	−56	64	91	−153	20	65
(d) New control system	40	−60	60	53	−114	14	80

control, (c) switching between P type and PI type optimum control judged by disturbance pattern, and (d) use of four control systems of the new control, are summaried and compared in *Table 1*. However, the maximum variation range (ΔP_0) only are shown for periodical disturbances. As the result, PI type optimum control has been much improved, if compared with that of PI control as for ramp-like disturbances. Further, (c) and (d) controls to which adaptive control is added to PI type optimum control, the controllability on pulse-like disturbances and periodic disturbances is remarkably improved, if compared with those of PI control. Also, controllability of (d) on ramp-like disturbances is on more or less same level as that improved in (b) above. In brief, the new control turned out to have better control on all disturbance patterns in comparison with that of PI control.

4.2 Comparison of control results on actual produced gas patterns

Fig. 6 shows the results of simulation of PI control and new control on actual gas producing pattern at the time of closed operation. The contents of the table shows that with PI control, if hunting is produced, control becomes impossible, but instead, in case of the new control, the control is still possible in the range of ± several tens of mmH_2O, that means that the closed operation is possible.

Fig. 6 Comparison of PI control system and new control system in P_0 control simulation



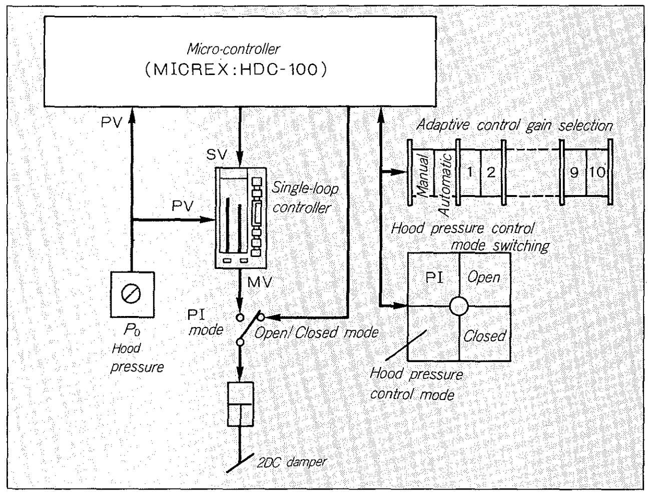
5 CONTROL SYSTEM COMPOSITION

For constructing a control system, it is a premise that the conventional operation should be possible and the conventional open operation can be switched over easily to the new closed operation.

A micro-controller will be installed for use of closed operation, and various arithmetic execution and operational sequence control for automatic operation will be carried out in order to minize the operator's burden.

Fig. 7 shows the composition of the hood gas pressure control system.

Fig. 7 Composition of furnace pressure control system



The system will have, from the point of view of operational conditions and control system, the following three hood gas pressure control modes:

(1) PI control

PI control will be carried out by a single-loop controller. The control range will be $\pm 20mmH_2O$, and it will be operated separately from the micro-controller.

(2) Open control

A new control will be carried out by a micro-controller. The control range is $\pm 20mmH_2O$.

(3) Closed control

A new control will be carried out by a micro-controller. The control range is $\pm 100mmH_2O$, and the closed operation is possible.

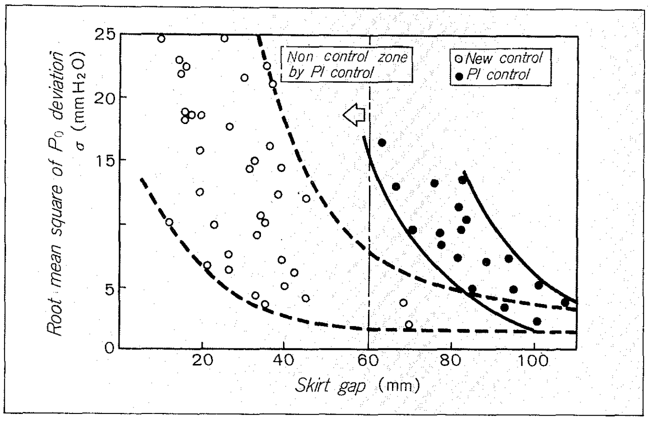
With this system, when it is judged to be impossible to continue with the closed operation due to factors as failure of micro-controller and others, the operating mode can be switched easily over to conventional open operation without need for shutting down the OG operation, and degenerate operation can be continued. Also, operational safety of the equipment is emphasized as the automatic sequence equipment, and more gradual step-by-step processing will take place depending on the operational conditions, so that the wole work factor of the system is heightened.

In the closed OG process, as mentioned before, the process gain may vary in a large scale, but in order to cope with this disadvantage, the system carries out three adaptive controlls. Among these, as for the gain adaption by hunting detection, manual and automatic modes are provided so that manual gain selection taking full advantage of operators' extended experience can also be available.

6 RESULTS OF APPLICATION IN THE ACTUAL PROCESSING

Fig. 8 shows the relationship between the skirt gap and hood pressure controllability in the actual furnace. For the new control system, its range of control is wider and also

Fig. 8 Comparison of PI control and the new control



more stable at the controllable range of the PI control. Furthermore, under the identical working conditions, hood pressure dispersion value for the new system is reduced to about 1/3 result, a large-scale improvement has been made in controllability. As seen from the description above, the new control system not only realized the closed operation system, but also it had brought about a large development forward to the hood pressure control. *Table 2* shows the results obtained from the operation of long period. Due to improvement of closed operation system and hood pressure controllability, a remarkable economic efficiency such as increase in waste gas recovery volume, improvement in steel yield and reduction in power consumption could be obtained. Also, by realization of through automatic operation, operators' intervention was drastically reduced and that opened a new perspective to automatization of blow refining technique.

Table 2 Merit of BOF closed operations

(1) Heightening of calorific value of recovered gas (High concentration Co gas) ◦ Perspective to chemical material field	Recovered volume $10Nm^3$/ton steel improved
(2) By reduction of OG combustion rate ◦ Extension of useful life due to reduction of thermal load of cooling equipment ◦ Improvement of capacity of dust collection due to enlargement of paricle diameter of the waste gas dust.	Reduced from 10% to 2%
(3) Improvement of steel yield ◦ Effect of dispersion prevention to outside of the system of the refining materials	0.4% improved
(4) Reduction of OG waste gas flow (produced gas volume + suctioned air flow) ◦ Reduction of IDF power source unit.	0.2kWh/ton steel reduced
(5) Automatization of operation	Reduction of operators' burden

7 CONCLUSION

Thanks to development of an adaptive-control added new control system on the basis of the optimum control, closed OG operation was made possible and a large economic effect could have been obtained.

As the final words, upon developing this control system and applying to actual process control, we like to express our heartfelt gratitude to all those concerned with this project, rendering us useful and indispensable instructions and guidance as well as cooperation.