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Advanced Mold Level Control System for Continuous Caster

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Abstract:

Mold level control system in No. 5 continuous caster in East Japan Steel Works (Keihin) has a problem about control response. Cause of control responsiveness deterioration is disturbances. Advanced mold level control system improved the control response.

1. Introduction

Controlling the height of the molten steel in the mold (mold level) in the process of solidifying molten steel in the continuous caster plays a critical role in securing quality, as fluctuations in the mold level cause entrainment of impurities that deteriorate billet quality. No. 5 continuous caster (hereinafter, 5CC; see **Fig. 1**) at JFE Steel East Japan Works (Keihin District) has a total of 6 strands and produces round billets, but because fluctuations of the molten steel level are large in comparison with slab casters, a high percentage of billets must be scrapped due to quality abnormalities. Since mold level fluctuations are the largest cause of scrap, at 55%, reducing mold level fluctuations is the highest priority issue for yield improvement.

As described in this report, it was possible to improve billet yield by developing and introducing a new mold level control method which is capable of suppressing mold level fluctuations.

2. Current Status and Issues of Mold Level Control

Mold level control (shown in **Fig. 2**) is a type of feedback control in which the mold level is detected by an eddy current sensor, the molten steel discharge rate from the tundish is calculated by a computer (instrumentation DCS) based on the detected level, and action commands are given to an actuator (stepping cylinder in Fig. 2).

The two main causes of mold level fluctuation at

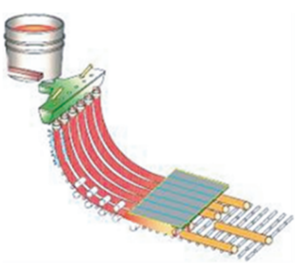

Fig. 1 No. 5 continuous caster

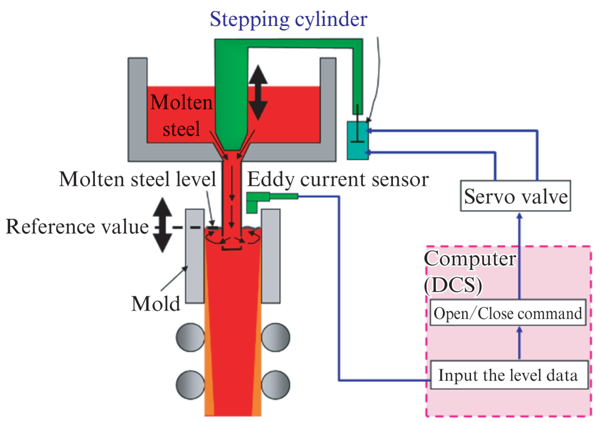

Fig. 2 Mold level control system

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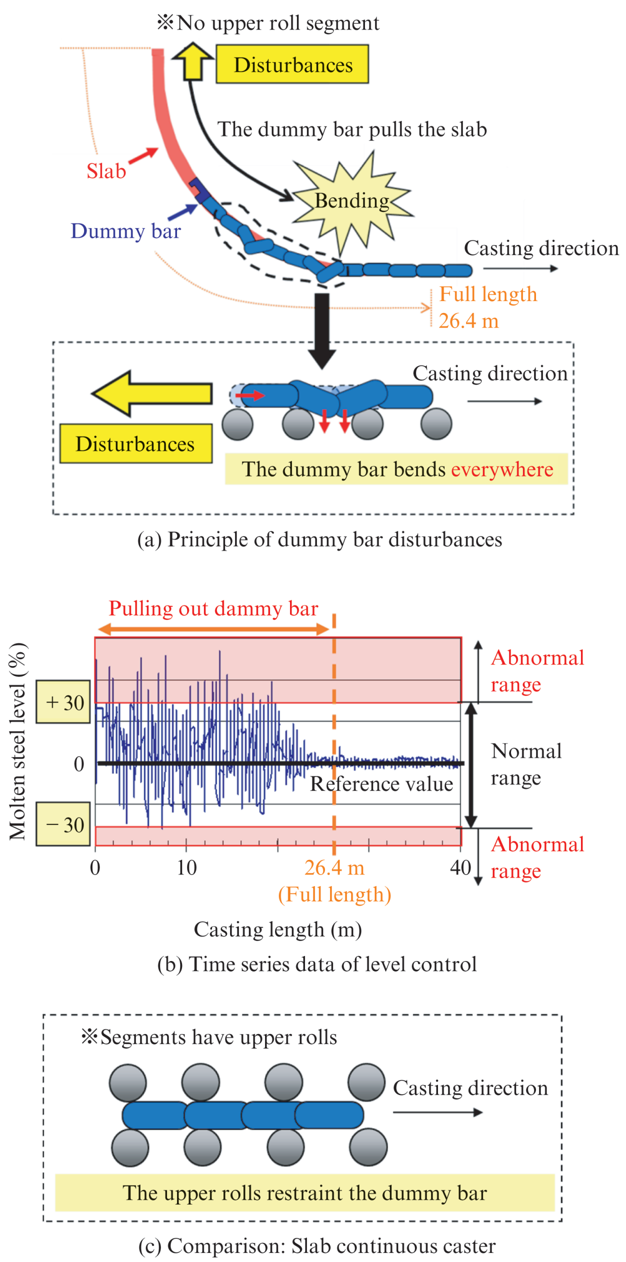


Fig. 3 Dummy bar disturbances

5CC are disturbances and system model fluctuations. The former is mainly caused by dummy bar disturbances (**Fig. 3**), which are caused by bending of the dummy bar link, and are a characteristic mold level fluctuation of 5CC.

System model fluctuations are also caused by an inherent feature of 5CC, as a stopper in the tundish is used in mold level control. Therefore, even slight wear of the refractory or warping of the stopper will cause large changes in the characteristics of the molten steel flow rate. In particular, control of control gain becomes unstable in the initial stage of casting, inducing fluctuations of the mold level. At present, control gain is adjusted manually by the operator, but because large

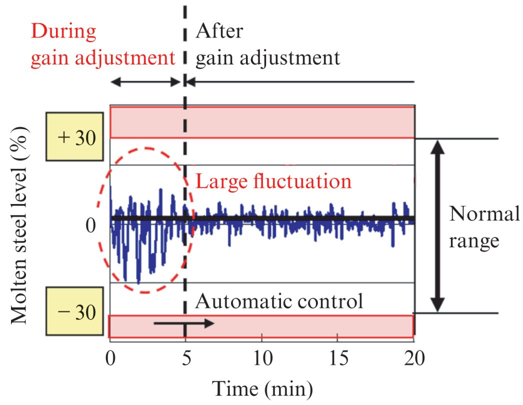


Fig. 4 Mold level data before and after gain adjustment

control gain adjustment is necessary due to large system model fluctuations, manual adjustment requires approximately 5 minutes, and mold level fluctuations cannot be suppressed during this period (**Fig. 4**). It may be noted that this kind of event does not occur at slab casters, as system model fluctuations are small because a sliding nozzle (SN) is used in control.

3. Development of Advanced Mold Level Control System

3.1 Frequency Analysis

An analysis of the frequency of dummy bar disturbances revealed that these disturbances are distributed over an extremely wide frequency band (**Fig. 5**). This occurs because dummy bar disturbances are caused by asynchronous link bending of the dummy bar at multiple points, and is consistent with physical considerations. Although there are several conventional technologies for disturbance canceling control, all of those technologies were developed to cancel disturbances in a certain local frequency band, and thus cannot cancel disturbances that occur over a wide frequency band, such as the dummy bar disturbances at 5CC. Therefore,

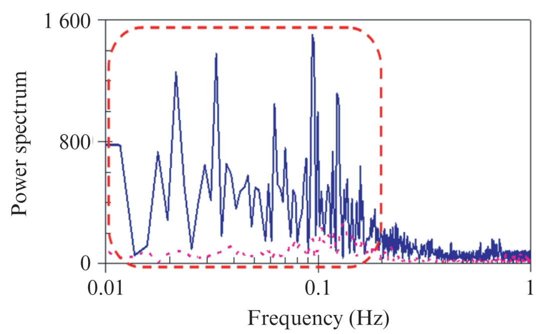
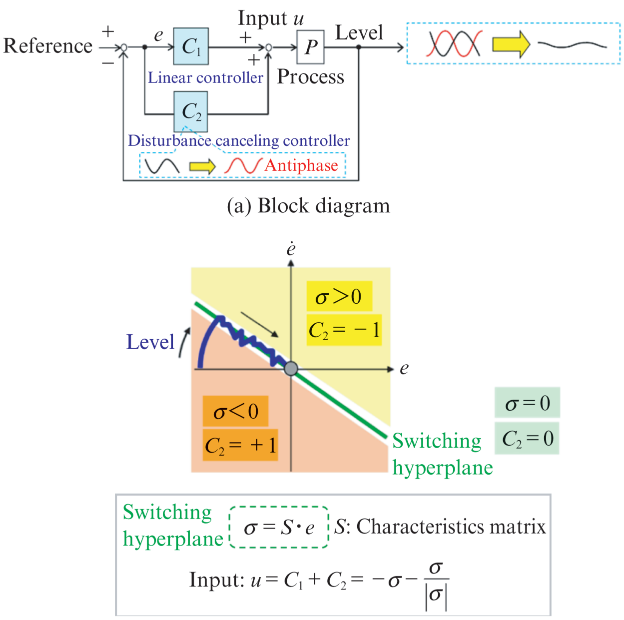


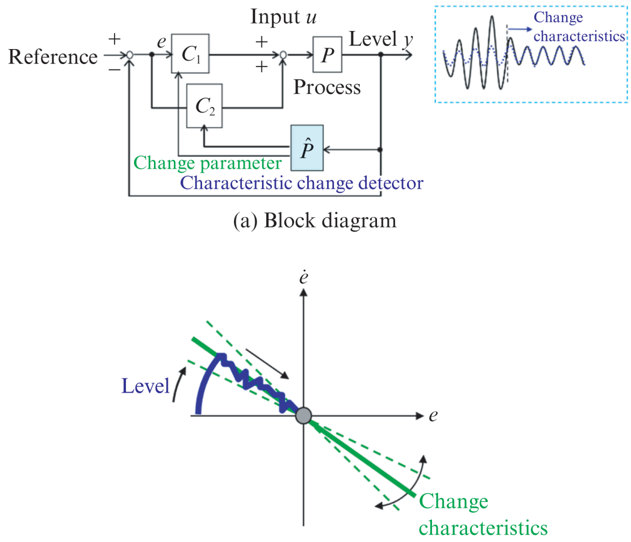
Fig. 5 Frequency analysis



(a) Block diagram

(b) Phase plane

Fig. 6 Sliding mode control



(a) Block diagram

(b) Phase plane

〈$\hat{P}$ calculation contents〉

STEP1: $e_M=y-\hat{y}$

STEP2: $S(e_M)=k\cdot e_M$

STEP3: $\sigma=S(e_M)\cdot e$

k: Constant

(c) Characteristic change detector

Fig. 7 Variable sliding mode control

a disturbance canceling control method that can cope with wide frequency band disturbances was newly developed in this research.

3.2 Control System Design

As a method for canceling dummy bar disturbances, which have a wide frequency band, sliding mode control (**Fig. 6**) was selected as the focus of this study. Sliding mode control is a type of control utilizing a linear controller and a disturbance canceling controller. The disturbance canceling controller is a control technique which detects disturbances based on error information and immediately cancels the disturbance by generating and inputting antiphase input for that disturbance to the control object. This technique also makes it possible to cancel wide-frequency disturbances such as dummy bar disturbances.

However, it is not possible to cancel system model fluctuations by sliding mode control because sliding mode control cannot return a pole that has been changed by a system model fluctuation to the desired pole. Therefore, a new technique called variable sliding mode control was developed to deal with system model changes (see **Fig. 7**[1–2]). This is a technique in which changes in the output waveform from an ideal model are captured by a newly-provided characteristic change detector, and the control characteristics are changed so as to match the output of the ideal model. This makes it possible to correct the pole assignment caused by system model fluctuation without changing the dummy bar disturbance canceling capability of the system.

4. Simulation

In verification of the response of the new control method, the ability of the simulation model to reproduce the PI control action of the existing system, which is configured with PI control, was investigated in order to verify the validity of the simulation model (**Fig. 8**). The actions during automatic control coincided with the existing response in terms of both phase and amplitude, confirming the reliability of the simulation model.

Figure 9 shows the result of a simulation of sliding model control using this simulation model. Because control to less than ±30% of the targeted mold level fluctuation rate was achieved, and it was also possible to control the stepping cylinder to within the possible action range, these results showed that reliable opera-

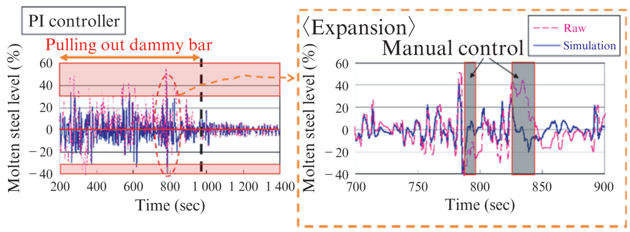


Fig. 8 Result of model identification

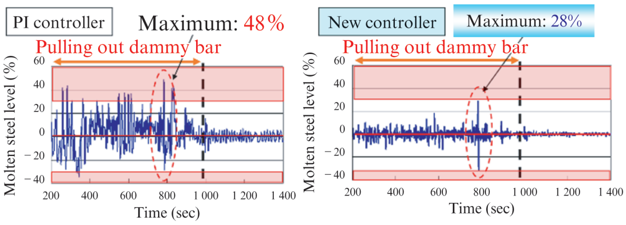


Fig. 9 Result of simulation

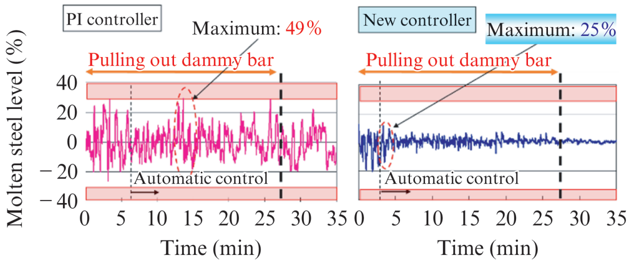


Fig. 10 Result of control response

tion and effectiveness in suppressing mold level fluctuations can also be expected with the actual continuous caster.

5. Results of Introduction at Actual Machine

Because satisfactory simulation results were obtained, variable sliding mode control was introduced at the actual CC machine. The results of introduction at the actual continuous caster are shown in **Fig. 10**. As in the simulation, control of mold level fluctuations to less than ±30% of the target fluctuation rate was achieved, and the amount of fluctuations was reduced by approximately 50%.

After introduction, the level of scrap occurrence in billet trimming at East Japan Works (Keihin) was reduced by approximately half, which was similar to the reduction level in mold level fluctuations (**Fig. 11**).

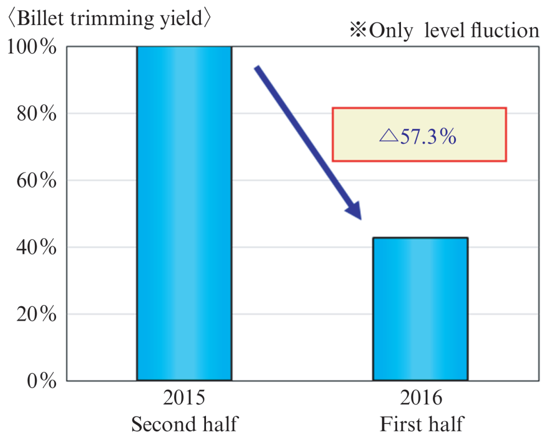


Fig. 11 Result of quality improvement

6. Conclusion

In order to reduce mold level fluctuations at No. 5 continuous caster at JFE Steel's East Japan Works (Keihin), a new technique called variable sliding mode control was developed and introduced. As a result, mold level fluctuations were reduced to less than ±30% of the target fluctuation rate, and yield was improved.

Because this technique does not require a physical model of the control target, we believe that this is a revolutionary technology which has high versatility and can be applied easily to various systems.

References

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