DEVELOPMENT OF A COMPENSATORY CONTROL SYSTEM TO REDUCE HYSTERESIS OF STEEL LEVEL CONTROL EQUIPMENT IN CONTINUOUS CASTING MOLD

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Abstract. In the continuous casting process, mold level fluctuation is the major cause of the surface and sub-surface defects. In the No.3 bloom continuous caster at Kobe Works, we ensured that the major cause of mold level fluctuation was mechanical hysteresis which existed in the driving system of mold level control. Moreover, we found out that it was possible to greatly improve the stability of mold level by estimating this mechanical hysteresis and compensating it on-line. As a result of applying a new level control system based on this method, we got accurate control over good stability.

Keywords. Continuous casting; Level control; Hysteresis compensation; On-line estimation

INTRODUCTION

Recently in the continuous casting process, the requirement for the production of high quality blooms has become a major issue. In such a situation, mold level fluctuation is thought to be a big cause of surface and sub-surface defects.

Suggested methods which control mold level in good stability include the following: reduction of control the cycle, making the response of driving system high-speed, automatic tune-up of control gain, etc.

In the No.3 continuous caster, after we tested the effect of reducing the control cycle and made the response of driving system high-speed, we found that these are effective for mold level control. But making the response of driving system high-speed needs plenty of costs and time for reconstruction. And it is impossible to greatly improve the stability of mold level by only making the response of driving system high-speed. If optimum control gain is unknown, automatic tune-up is effective, but when optimum gain is fixed, it can't greatly improve,

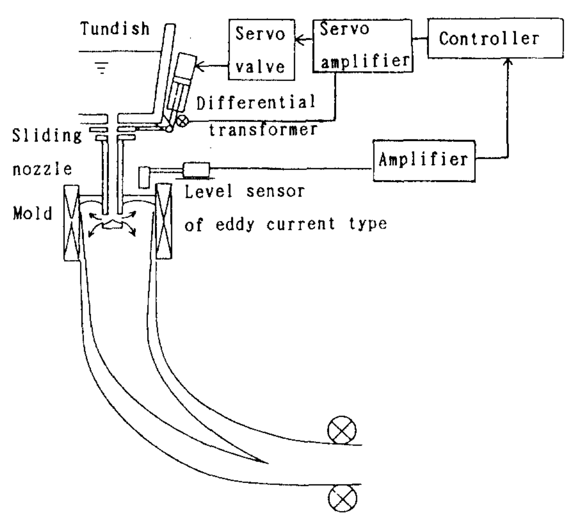


Fig.1 Mold level control system

because the gain in the control system isn't as flexible.

From above, as the result of looking at the former control system (Fig.1) again, we found out that the lag of response caused by mechanical hysteresis between the hydraulic cylinder and the sliding plate resulted in the main cause of negative change in mold level control. The quantity of hysteresis varies at each tundish and it fluctuates according to the amount of thermal instability during casting even in the same tundish. So there were limitations on reducing mold level fluctuation by compensating the hysteresis off-line. So, to overcome this problem, we developed control logic which could estimate this hysteresis and then compensate it. In February, 1991, we began to employ this control system, and today, we have accurate control.

This paper shows a basic theory about this control system and hysteresis compensation.

THE SPECIFICATION OF THIS SYSTEM AND NO.3 CC

The general features are as follows.

(1)No.3 cc equipment specification

① type …… vertical bending type

② bloom size …… 300 × 430 mm^2, 2 stands

③ radius of curvature …… 10 m

④ EMS …… M + F EMS

⑤ caption …… 32.3 m

⑥ capacity …… 50,000 tons/month

(2)characteristics of mold level control system

① reduction of lag in controller by high-speed control cycle 100 msec

② elimination of the influence of a ripple on the molten steel in mold

③ on-line mechanic[illegible]ry control system

④ reduction of mold level fluctuation caused by change of casting speed by using casting speed forward.

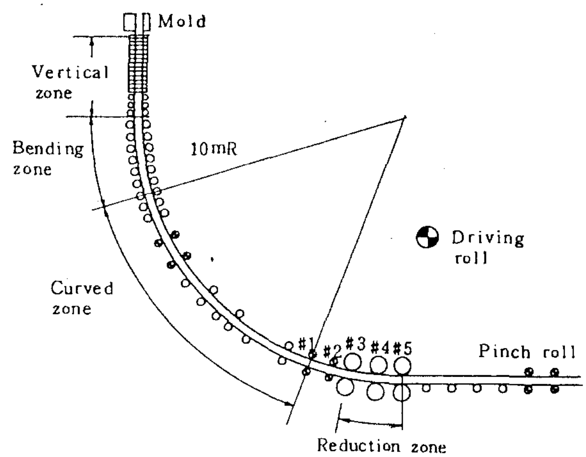


Fig.2 The roll profile of No.3CC

HYSTERESIS COMPENSATORY CONTROL

The influence of hysteresis

The parts where the mechanical hysteresis exists are shown in Fig.4.

We simulated the influence of hysteresis value on control. The block diagram of control system is shown in Fig.3 and the examples of simulation are shown in Fig.5. The relationship between the hysteresis value and mold level fluctuation is shown in Fig.7.

Fig.7 shows that the quality of hysteresis has a strong relationship to mold level fluctuation and if the compensation which halves the quantity of hysteresis is made, it is possible to halve mold level fluctuation.

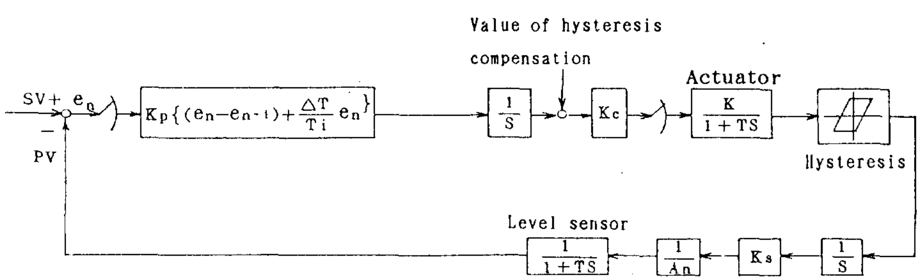
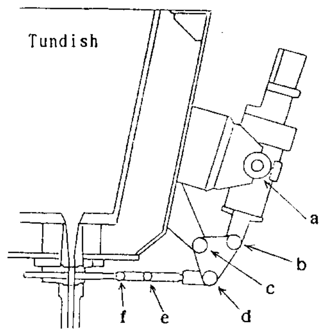


Fig.3 Block diagram of control system



a ～ f : Points of the hysteresis factor

Fig.4 Parts the hysteresis exists

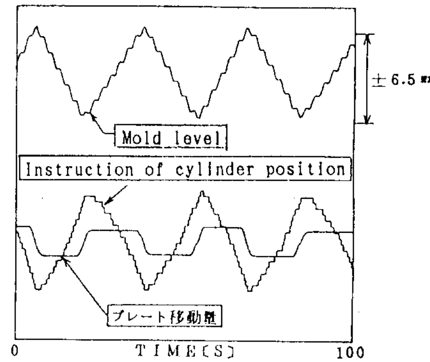


Fig.5 Simulation analysis of level control with actual hysteresis 5.0 mm

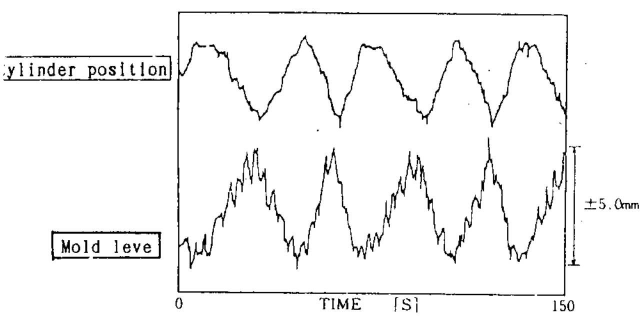


Fig.6 Typical example of level control

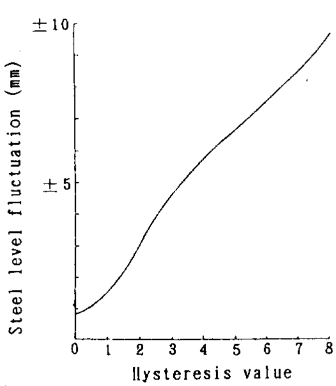


Fig.7 Influence of hysteresis on level fluctuation(Simulation analysis)

Hysteresis estimation

The simulation with actual hysteresis 5.0mm and compensation 4.6mm is shown in Fig.8, which shows that compared with non-compensation (Fig.6), mold level fluctuation is reduced about 25%, and hysteresis compensation is very effective.

The relationship between the manipulated variable, the quantity of hysteresis and PI output in the case of low compensation for actual hysteresis is shown in Fig.9.

The control flow including this logic is shown in Fig.10. As shown in Fig.9, the actual hysteresis in the driving system is calculated and estimated from the pattern of the manipulated variables, and it is auto-tuned to optimum control variable (hysteresis compensation) from the results of control. The hysteresis compensation is added to PI output when the direction of slide value changes and it improves the lag by hysteresis in the driving system.

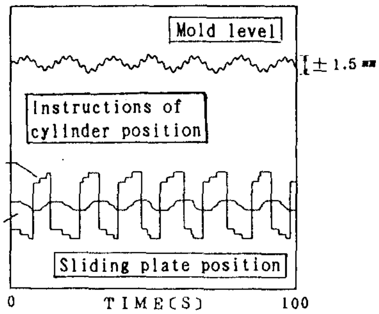
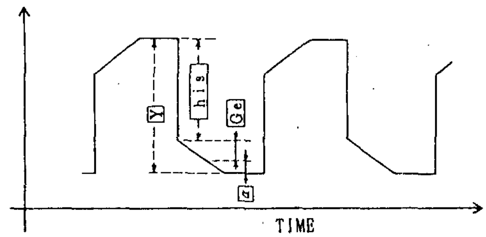


Fig.8 Simulation analysis of level control with actual hysteresis 5.0mm and hysteresis compensation 4.6mm



Y = his + Ge + α
Y: Instruction of cylinder position
his: The latest hysteresis
Ge: Deficiency of a doposit
α: PI operation value

Fig.9 Hysteresis compensation logic

THE RESULT OF APPLICATION

A new control system consisted of hysteresis compensatory logic is shown in Fig.11. The result of application of a new system shown in Fig.12 indicates that level fluctuation is reduced fast. The influence of varied quantity of actual hysteresis caused by changing tundish and thermal fluctuation is eliminated, so we have accurate control over good stability.

CONCLUSION

In order to improve mold level control by using the sliding plate, we developed a new control system which compensated mechanical hysteresis on-line, and could make mold level fluctuation 50% of the former system. As a result of development of the control system, we could use the former servo driving system continuously, and have as accurate control as high-speed stopper control system. In the future, we will extend the application of a new system for similar equipments.

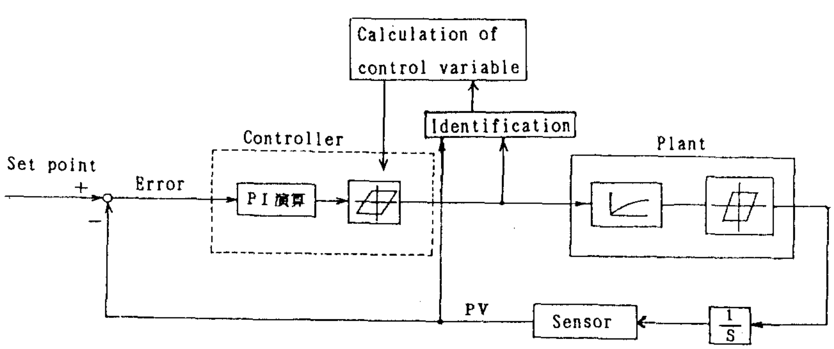


Fig.10 Control flow

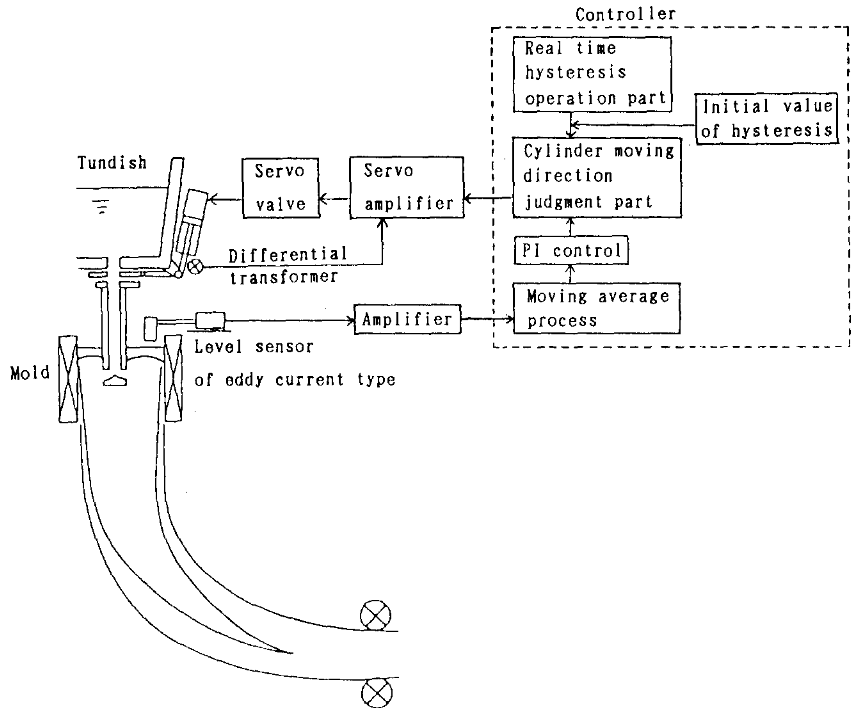


Fig.11 Hysteresis compensatory mold level control system

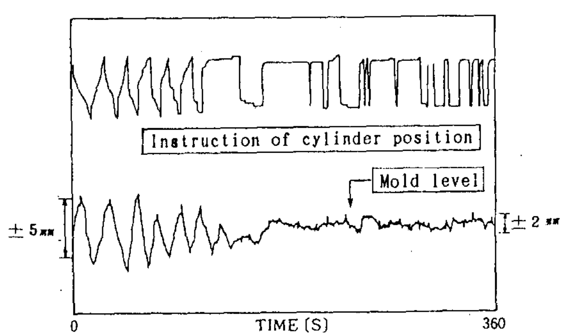


Fig.12 Effect of level control by hysteresis compensatory system