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A Kind of Plate Laminar Cooling Strategy With High Response and Steady Precision

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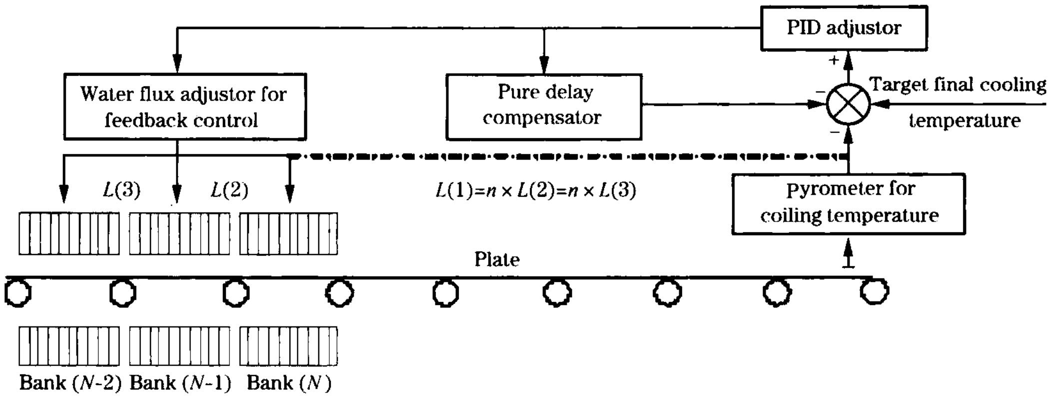
Abstract: After Smith Predictor being used to laminar cooling system, the control law for integral regulators is introduced. New notion of plate sample length is given for evading the delay time varying with the roll table speed. It is found that the integral algorithm is more controllable for system regulating process and has better steady state precision. Compared with the traditional control strategies, the new control law has faster response speed and higher steady state precision. The controller can be regulated in shorter time and the response is faster than that of routine controller and it can effectively eliminate the oscillatory instability. Owing to its easy realization and high stability, it has been applied to a plate mill. The accuracy of finish cooling temperature can be controlled within ±10 ℃.

Key words: plate; laminar cooling; Smith Predictor; time delay system

Finish cooling temperature measured by pyrometer is one of the key factors for the plate property in the laminar cooling system[1]. Depending on adjusting the water flow rate, laminar cooling system controls the finish temperature in the feedback control process. The delay time between the control point and the measure device decreases the stability of the control system. It is difficult to gain satisfied control results using regular PID controller[2-3]. A new control strategy for plate laminar cooling system is applied in this study using compensator in discrete system.

1 Application of Smith Predictor to Laminar Cooling System

Usually, for increasing measurement accuracy of the finish cooling temperature, avoiding exotic environment interference, the pyrometer is installed about 1 000 − 5 000 mm far from the exit of laminar cooling equipment, shown as Fig. 1. The temperature will be changed discontinuously by adjusting the unit of control headers and the roller velocity. So, depending on adjusting the flow rate of the fine



$L_g = L(1) = n \times L_s$, $L_s = L(2) = L(3)$

Fig. 1 Schematic diagram of cooling control system with sampling parameter L_s

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headers, laminar cooling system controls the final cooling temperature in the feedback control process.

The temperature measured with the pyrometer is different from the one measured at the exit of the last headers. The delay time in laminar cooling system is represented as Eqn. (1).

$$\tau=\frac{L_g}{v} \tag{1}$$

where, τ is delay time; v is roll table speed; L_g is distance from the adjustable headers to the pyrometer.

The control system is series connection of pure delay system and one order inertial system due to the lagging effect of switching of control valve and cooling water splashing down to plate. To improve the quality of the pure time delay control system, a Smith Predictor is introduced to the feedback control process of laminar cooling system[4-5]. Fig. 2 illustrates laminar cooling system about the controlled object with Smith Predictor.

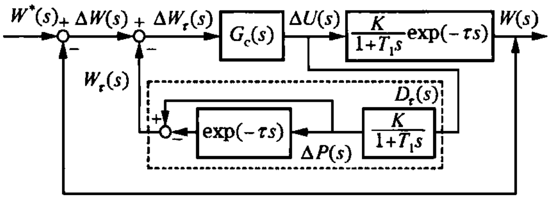

Fig. 2 Block diagram of cooling control system with Smith Prediction

As shown in Fig. 2, $G_c(s)$ is temperature controller; $D_r(s)$ is Smith Predictor; $W^*(s)$ is temperature reference; $\Delta U(s)$ is adjusting water flow value related with control algorithm and not yet calculated till now; $W(s)$ is real temperature measured by the pyrometer; $\Delta W(s)$ is difference between setting temperature and feedback temperature; $W_r(s)$ is output of lead compensation of $D_r(s)$; $\Delta W_r(s)$ is system theoretical error or input of controller $G_c(s)$.

Input of temperature controller $G_c(s)$ can be expressed as Eqn. (2):

$$\Delta W_r(s)=\Delta W(s)-W_r(s)=\Delta W(s)-\Delta P(s)+\Delta P(s)\exp(-\tau s)=\Delta W(s)-\frac{K}{1+T_1 s}\Delta U(s)+\frac{K}{1+T_1 s}\Delta U(s)\exp(-\tau s) \tag{2}$$

Discreted pure delay compensator $D_r(s)$ difference equation can be obtained as Eqn. (3):

$$\begin{cases}\Delta p(k)=a_1\Delta p(k-1)+b_1\Delta u(k)\\ w_r(k)=\Delta p(k)-\Delta p(k-l)\end{cases} \tag{3}$$

where, $a_1=\exp(-1/T_1)$; $b_1=K/T_1$; $l\approx\tau/T$, rounding, T is sampling period.

Difference equation of temperature controller $G_c(s)$ input of is:

$$\Delta w_r(k)=\Delta w(k)-w_r(k)=\Delta w(k)-[\Delta p(k)-\Delta p(k-l)]=\Delta w(k)-[a_1\Delta p(k-1)+b_1\Delta u(k)-a_1\Delta p(k-l-1)-b_1\Delta u(k-l)] \tag{4}$$

where $K=1, 2, 3, \cdots$.

From Eqn. (4), the input of laminar cooling system controller with Smith Predictor includes not only includes the process output $\Delta w(k)$ at sampling time k, but includes control laws $\Delta u(k)$ and $\Delta u(k-l)$ also.

2 Integral Laminar Cooling System

If system transfer function is not well estimated, the system stability could not be ensured[6-7]. The way to solve this problem is to choose the integral, the controller transfer function is represented $G_c(s)=\dfrac{\Delta U(s)}{\Delta W_r(s)}=\dfrac{P}{s}$; input of the controller can be expressed as Eqn. (5):

$$\frac{s\cdot\Delta U(s)}{P}=\Delta W(s)-\frac{K}{1+T_1 s}\Delta U(s)+\frac{K}{1+T_1 s}\Delta U(s)\exp(-\tau s) \tag{5}$$

Discretized Eqn. (5), control law $\Delta u(k)$ for laminar cooling system can be gotten in difference form:

$$\Delta u(k)=\frac{P}{1+b_1 P}\Delta w(k)-\frac{a_1 P}{1+b_1 P}[\Delta p(k-1)-\Delta p(k-l-1)]+\frac{1}{1+b_1 P}\Delta u(k-1)+\frac{b_1 P}{1+b_1 P}\Delta u(k-1) \tag{6}$$

During laminar cooling process, the temperature drop through every header relates to many physical parameters. Many factors should be considered such as measured deviation of temperature, system transient output response and so on. So controller magnitude P is not expected too big. Let the eliminating deviation coefficient be m, usually, the value of m is chosen from 0.8 to 1. Controller magnitude P is expressed in Eqn. (7) if system deviation wants to eliminate error in first step.

$$\frac{P}{1+b_1 P}=m\frac{1}{b_1} \tag{7}$$

After introduced Eqn. (7) into Eqn. (6), the last control law for laminar cooling integral controller with eliminating deviation coefficient m can be derived as Eqn. (8).