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Control of mold level in continuous casting based on a disturbance observer

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ABSTRACT

Regulating molten steel level in continuous casting is difficult because it suffers from various disturbances, among which the bulging disturbance is the most prominent. Moreover, as the casting speed increases in continuous casting, the phase lag due to the system delay increases. To eliminate the bulging disturbance in the presence of system delay, we propose an adaptive sine estimator based disturbance observer and a phase lead adaptive fuzzy controller. We tested the proposed method using a 1:1 scale hardware simulator and confirmed that the method successfully decreased the bulging disturbance effect from the molten steel level.

1. Introduction

Control of molten steel level in continuous casting is important because it determines the surface quality of the slab. However, regulating molten steel level is difficult, because it suffers from various disturbances, including variations in casting speed and tundish weight, clogging and unclogging of the nozzle, and bulging disturbances [10]. Among these, the bulging disturbance is the most severe [11]. It is created when the supporting rollers push the liquid steel upward periodically. The bulging disturbance is almost sinusoidal in shape and degrades the quality of the molten steel level. Therefore, we focus on removing the bulging disturbance effect from the molten steel level.

Various control strategies have been proposed, including a disturbance observer to remove disturbances [1], a master-slave PID controller in which a slave PID control loop is used inside a master PID control loop to reduce sensitivity to disturbance [2], a model-based controller for stable regulation of mold and tundish level [3], a neural network model for stopper control to reduce the casting speed variation [4], a fuzzy logic controller to remove disturbances [5], a notch filter, PID and a fuzzy logic controller to remove disturbances [6], an $H\infty$ controller to balance disturbance rejection and robust stabilization [7], a notch filter and an $H\infty$ controller to reduce the amplitude of surface waves [8], and an iterative learning controller to reduce the bulging disturbance [17].

In these papers, however, the molten steel level dynamics are described with only an integrator and a first-order transfer function, whereas in reality the dynamics are more complicated mainly due to time delay in the molten steel level system. In the past, the casting speed and the bulging frequency were relatively low, so the effect of system delays, which consist mainly of actuator delays and sensor delays, were not so serious. However, as the demand for a high-speed casting process increases, the bulging frequency increases and the phase lag due to system delays also increases. For example, given the command $sin(\omega t)$, the mold response will be $A_m \cdot sin(\omega(t+t_d)+\theta) = A_m \cdot sin(\omega t + \omega t_d + \theta)$, where A_m is mold response amplitude, and ωt_d is the phase lag due to system delay t_d. So, whenever the casting speed increases, ω increases, and the phase lag ωt_d increases even though the system delay t_d is fixed. For this reason, the system delay has become a crucial obstacle to stabilizing the molten steel level. An adaptive fuzzy estimator has been proposed to remove the bulging disturbance taking the system delay into account [9], but its performance degrades significantly when applied to a molten steel level system with a time-varying bulging disturbance. In this paper, we propose an adaptive sine estimator based disturbance observer, which is used to eliminate the time-varying bulging disturbance in the presence of system delay. In addition, we supplement this observer with a phase lead adaptive fuzzy controller to reject the remaining disturbance.

This paper is organized as follows. In Section 2, the system modeling is derived. In Section 3, the proposed controller is presented.

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