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High-precision Automatic Pouring Machine with Adaptive Control Parameters

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This study contributes an advanced control system in tilting-ladle-type automatic pouring machine in casting industry. In order to reduce the preliminary experiments for tuning the pouring control system, and pour precisely the molten metal even if the pouring condition is varied, we propose the adaptive pouring control system which the control parameters are automatically tuned for pouring precisely in this study. In this proposed approach, the online model parameters identification and control parameters updating system are integrated with the pouring control system based on the mathematical model of the pouring process. The effectiveness of the proposed pouring control system is verified by the simulations with the tilting-ladle type automatic pouring machine. This paper provides valuable information to reduce casting defects caused by pouring process.

Keywords: *Automatic pouring machine, Model Based Controller Design, Environmental Adaptive Control*

1. Introduction

In recent years, an automatic pouring machine has been exploited to improve the working environment of the pouring process and to produce stable casting products. Furthermore, the automated pouring process has been required that molten metal is quickly and precisely poured into the mold. Many pouring control approaches for satisfying such requirements have been proposed in recent studies[1]. However, the conventional pouring control systems need the preliminary experiments for tuning the control parameters. These experiments take an immense amount of time and effort. Moreover in case that the pouring conditions are changed from the conditions of the preliminary experiments, it is difficult to pour precisely the molten metal by the pouring machine with the conventional control systems.

Therefore, in order to reduce the preliminary experiments for tuning the control parameters, and pour precisely the molten metal even if the pouring condition is varied, we propose the adaptive pouring control system which the control parameters are automatically tuned for pouring precisely in this study. In this proposed approach, the online model parameters identification and control parameters updating system are integrated with the pouring control system based on the mathematical model of the pouring process. These model parameters are identified automatically by minimizing the error of practical data and simulation data from the model at every pouring motion, and the control parameters according to the mathematical model of the pouring process are updated online to the controller. In this study, minimizing the error of practical data and the simulation data is performed by Gauss-Newton method for identifying the parameters in a short time. Therefore, the parameters identification and updating can be accomplished before next pouring. Even if the pouring conditions are changed, the molten metal can be poured precisely by the proposed adaptive pouring control system. The effectiveness of the proposed pouring control system is verified by the simulations with the tilting-ladle type automatic pouring machine.

2. Adaptive Pouring Control System

The proposed pouring control system is shown in Fig. 1. In order to control precisely the flow rate of outflow liquid from the ladle, the feedforward control with the inverse model of pouring process is constructed to the automatic pouring control system. The inverse models can be derived from the model of automatic pouring machine as

$$T_m \frac{d\omega(t)}{dt} + \omega(t) = K_m u(t) \quad , \quad (1)$$

$$A(\theta(t))\frac{dh(t)}{dt} = -q(t) + \left\{ h(t)\frac{\partial A(\theta(t))}{\partial \theta(t)} + \frac{\partial V_s(\theta(t))}{\partial \theta(t)} \right\}\omega(t) \quad , \quad (2)$$

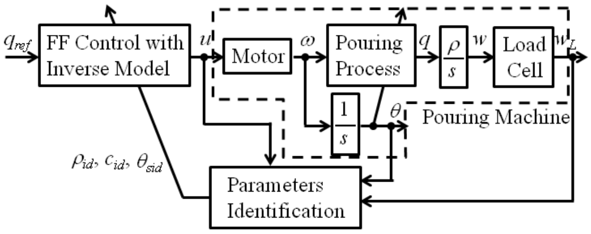

Fig. 1 Pouring Control with Adaptive Control Parameters

$$q(t) = \int_0^{h(t)} cL_f(h_b)\sqrt{2gh_b}\,dh_b\ , \tag{3}$$

$$\frac{dw(t)}{dt} = \rho q(t)\,, \tag{4}$$

$$T_L\frac{dw_L(t)}{dt} = -w_L(t) + w(t)\,, \tag{5}$$

where ω[rad/s] and θ[rad] are the tilting angular velocity and angle, respectively. T_m[s] and K_m[rad/s/V] are the time constant and gain of the motor, respectively. h[m], q[m^3/s], A[m^2] and V_s[m^3] are the liquid height on the pouring mouth, the flow rate, the area of upper surface of the liquid in the ladle, and the liquid volume under the pouring mouth, respectively. L_f[m], c, and g[m/s^2] are the width of the pouring mouth, the flow rate coefficient, and the acceleration of gravity, respectively. w[kg] and ρ[kg/m^3] are the weight and the density of outflow liquid, respectively. w_L[kg] and T_L[s] are the weight of outflow liquid detected by the load cell and the time constant of the load cell, respectively. The most parameters of model can be obtained from geometry of the ladle and specifications of the motor and the load cell. However, the flow rate coefficient c and the density ρ must be identified by the preliminary experiments. And, the tilting angle θ_s starting liquid outflow also is identified by the experiments.

In this study, the model parameters c, ρ and θ_s are identified online for reducing the preliminary experiments and adapting the pouring control system to the pouring condition as shown in Fig. 1. In the parameters identification, the cost function is minimized as

$$\begin{bmatrix} c_{id} & \rho_{id} & \theta_{sid} \end{bmatrix} = \arg\min\left\{\int (w_{L\exp}(t) - w_{Lsim}(t))^2\,dt\right\}, \tag{6}$$

where w_{Lexp} and w_{Lsim} are the weights of outflow liquid detected load cell in the experiments and simulations, respectively. Gauss-Newton approach is used for minimizing the cost function.

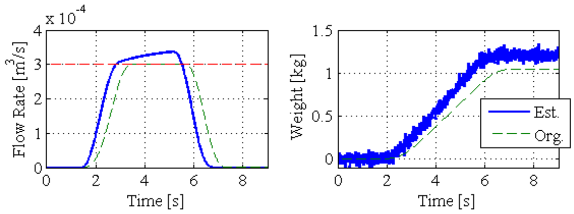

Fig. 2 Simulation results on first pouring

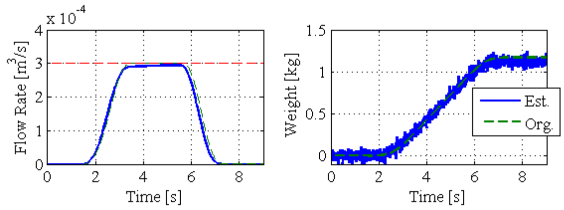

Fig. 3 Simulation results on 6th pouring

3. Simulation Results

The effective of the proposed adaptive control system is verified by the simulations with the model of the automatic pouring machine. In the simulations, the pouring conditions are given as c=0.97, ρ=1.0x10^{-3}[kg/m^3], and θ_s=33.1xπ/180[rad]. On the other hand, the control system based on the pouring model with the parameters c=0.8, ρ=0.9x10^{-3}[kg/m^3], and θ_s=32.1xπ/180[rad] is constructed in the first simulation. Fig. 2 shows the simulation results on first pouring. The left and right graphs show the flow rates and the weight of outflow liquid detected by load cell, respectively. And, the green broken lines are the simulation results with correct parameters. The blue solid lines are those with initial parameters. Since the model parameters in the control system are different to the correct model parameters, it is difficult to pour precisely. The automatic pouring process with the proposed control system is simulated repetitively. Fig. 3 shows the simulation results on 6th pouring. The arrangements of Fig. 3 are same as Fig. 2. The parameters are identified precisely by the proposed control system, even if the model parameters are varied.

4. Conclusions

The model based pouring control system with adaptive control parameters is proposed in this study. By performing repetitively, the liquid can be poured precisely.

References

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