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Optimized Design of Casting Operation Control System Using Fuzzy Control

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ABSTRACT

Casting is one of the most sensitive stages of metal producing. In this stage, molding operation is performed after primary metal production treatments and it needs very high precision. In this paper, a controller system which manages metal casting, is designed and simulated. This method makes casting industries such as copper, steel and aluminum factories, independent of imported technologies. Due to practical issues in Iran, PID controller is chosen. The designed system is based on the control of liquid weight in casting mold. For used dynamic model, proposed hybrid controller consists of a feed-forward controller and a feedback controller. These controllers are used to control on weight of melt metal that comes out from casting spoon. PID controller parameters are optimized by using of online Fuzzy control. Simulation results show quality improvement on cast mold. Also, weight tolerance and casting time are reduced.

KEYWORDS: Automatic Casting System, optimal design of casting, Optimal PID.

1. INTRODUCTION

Casting factories are Contaminated and risky places for workers, especially on melt movements. For sake of safety and improving the efficiency of producing, automation is unavoidable. One of the most important factors in casting procedure is melt amount controlling that is placed on casting mold. Copper melt level controlling in spoon and mold, is led to casting process controlling. quality of controlling, straightly has influences on products quality. Past works on liquid level controlling, categorized in two ways that is illustrated in below.

1.1. Liquid level controlling without using PID

In 1998, Sang Teu Lian. et al. [1] used a Fuzzy-Neural Network controller based on Radial Basis Function (RBF) that was combined with Genetic Algorithm (GA), to control liquid level automatically. Also Ming Chen et al. designed a Sliding-Mode controller for inspecting and tracking surface level in 2007 [2]. In 2008, Kaveh Hooshmandi and Mohsen Montazeri from Shahid Abbaspur University used Model Predictive Control (MPC) for controlling level of drum water and boiler in power plant of Gilan [3]. Zhin Lee Feng et al .in Jian Chin University performed Bang-Bang controller based on Fuzzy decision for liquid tanks [4]. Also in 2010, Lee Guy et al. used Fuzzy controller to manage liquid level [5].

1.2. Liquid level controlling using PID

In 2008, Zhin Lee Feng et al. [6], in Jinan Shandug University of China, used Fuzzy controller and Fuzzy PID controller for liquid level controlling. In 2009, Mohammad Abid Ali et al. [7], in International University of Tanga Malaysia, designed a PID controller that adjusted in online mode with GA. In 2010, Zheou Ming Zeu [8] from Howayan Institute, perform a liquid level controller based on Improved polynomial selection algorithm (IPSA) method and RBF Neural Network. Also Zheou et al. [9] in Nanchang University of China implemented a liquid level controller based on Fuzzy PID controlling. In same year, Yu Hu Gen from Electrical University of Shang Hi made a PID controller using PLC for liquid level controlling. In 2011, Bijay Kumar and Rashtan Dayman [11], India University of Science and Technology, used Artificial Intelligence techniques to design PID controller. Lee Yong from Buto University of Science and Technology of China used a hybrid model of PID and Fuzzy controller for liquid level controller. Due to presented matters, designed system in this paper is based on liquid weight controlling in casting mold.

Casting spoon are used in this system is a kind of tilting. By using Mathematical model of parts, this process is modeled. Then, a control system including combination of feed-forward control and feed-back control for liquid weight control (molten metal) is designed. In order to optimize the liquid outlet weight of casting spoon, online PID controller using Fuzzy control is set.

2. MATERIALS AND METHODS

Figure 1 shows an automatic casting system that is used in this paper. The machine is rotated in θ direction by using an AC servo motor. Rotation axis centroid of spoon is near to center of gravity of spoon. So, spoon nozzle rotates Circular path [12].

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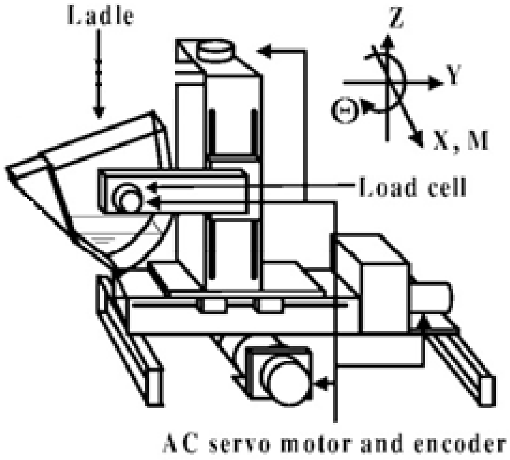

Fig. 1. Automatic casting system

2.1 Casting control system modeling

In this sector three models are considered. First model is between servo motor input voltage and angular velocity (G0M). Second model is between angular velocity of spoon and outlet liquid flow (GF). Third model is between coefficient of liquid flow rate integral and spoon outlet weight (GL). These models are named servo motor, flow rate and weight models, respectively.

2.1.1. Servo motor model

Relationship between angular velocity of spoon and input voltage of servo motor is shown in below[12].

$$\frac{d\,\omega(t)}{dt} = -\frac{1}{T_{0m}}\omega(t) + \frac{K_{0m}}{T_{0m}}u(t) \qquad (1)$$

ω(t)[rad/s] is angular velocity of spoon, u(t)[v] is input voltage of servo motor in θ direction, K_{0m}[rad/(sv)] is servo motor gain and T_{0m}[s] is time constant of servo motor.

2.1.2. Flow rate model

In this system a fan type spoon is used for casting. Area of liquid is constant when spoon get reverse. So casting flow rate will be constant when spoon turns with constant angular velocity. Flow rate model is considered as first order transfer function [12], Where: K_f [m3/rad] is gain and T_f [s] is time constant.

$$\frac{dq(t)}{dt} = -\frac{1}{T_f}q(t) + \frac{K_f}{T_f}\omega(t) \qquad (2)$$

2.1.3. Load cell model

For finding output weight of casting spoon, outcome flow rate integral is multiplied in melt density D(t). Load cell dynamic model is shown below [12], Where: W_L(t) is output liquid weight that measured with load cell and T_L is load cell constant time.

$$\frac{dw_L(t)}{dt} = \frac{1}{T_L}w_L(t) + \frac{1}{T_L}D(t) \qquad (3)$$

2.2. Liquid weight feed-forward controlling

Feed-forward controlling is led to high precision if it is used properly. For reducing time latency and having a steady controlling, feed-forward controller with predetermined pattern is necessary. Flow rate of casting pattern is assumed ideal.

2.2.1. Input

If copper temperature be lower than normal temperature at first, casting rate could be chosen higher than normal rate. In higher rates, precision of mold weight and quality of casting is reduced. Higher rates should be chosen temporary, such as primary casting molds until temperature of casting spoon gets to operational temperature. Usually rapid pouring and also casting rate of 1,2,4 stages are descending. Casting rate of stage 3 is lowest between all [13].

Rate selecting procedure has these features: rapid pouring rate is almost one volt higher than stage1, also stage one's rate is about 2 or 3 volt more than stage two, stage two's rate is 0.5 volt higher than stage four. At last stage three's rate is lower than stage two's rate about 2 volt. Return rate is chosen between 1 to 10 intervals [13]. Figure 2 shows a feed-forward input that is designed using illustrated rules.

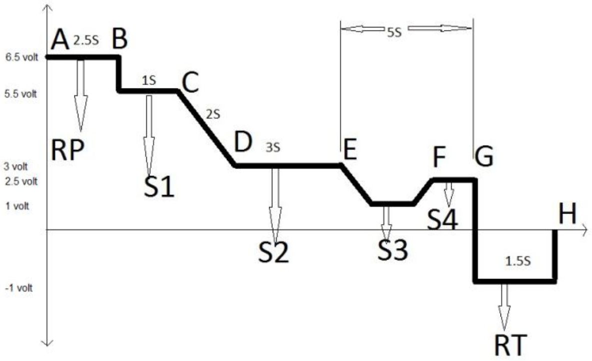

Fig. 2. Casting rate configuration plot

2.2.2. Simulation of feed-forward controller

In this section, casting procedure is simulated using feed-forward input and system's dynamic equations. Input is fed to system in voltage form where it has a feed-forward controller inside itself. Using this feature is led to controlling final value of output mold. Final value of output mold is assumed 345 kg that is equal with copper anode mold weight in Sarcheshmeh copper casting factory. Figure 3 shows result of simulation of feed-forward controlling.

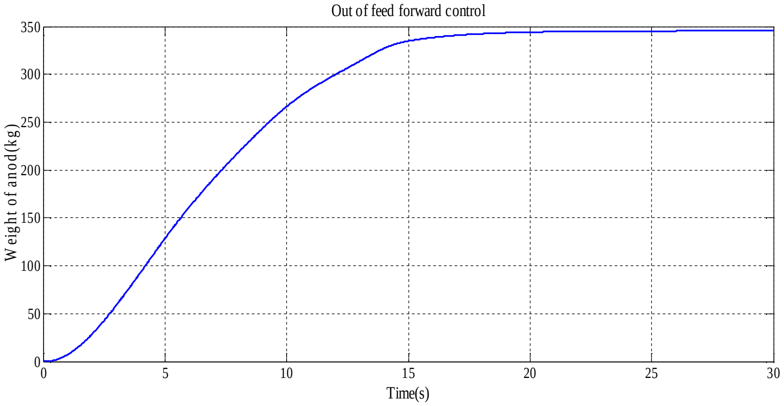

Fig. 3. Output mold weight in presence of feed-forward controlling

2.3. Liquid weight feedback controlling

If feed-forward controller implanted in appropriate place and it has not any conflict on casting process, then liquid weight is set at acceptable point. So when a disturbance is happened in casting process, feed-forward controlling cannot set the liquid weight properly. In this situation a feedback from liquid weight, reduces error. PID controller is used to remove system disturbance. Usually disturbance is happened at specific time and after a specific threshold. In addition to disturbance, a white noise is mixed to input to simulate electrical distortion. This noise is removed using mentioned controller.

2.3.1. PID controller designing

First of all, transfer function is calculated from dynamic model and is shown as G(s) in equation 4.

$$G(s) = \frac{254}{(S+166.7)(S+10)(S+0.415)} = \frac{254}{S^3 + 177S^2 + 1740S + 692} \qquad (4)$$

PID controller's transfer function is show below.

$$G(c) = K_p + \frac{K_i}{S} + K_d S \qquad (5)$$

In controller designing, it's important that overshoot and steady state error be zero. System is working in two states: 1) non-controller region, 2) PID-controller region. Non-controller region consists feed-forward signal transition from an idependent source that passes through original transfer function. Output is controled by a switch. Whenever output value be higher than defined threshold, PID controller works. PID controller try to reduce overshoot and steady state error in least time. Controller block diagram is shown in figure 4. Proposed design is based on root locus method, and the effect of poles that creates undershoot and overshoot in the system, can be controlled by proper design of zero. Using this method is led to cotrolling both of poles dominant and system will has a proper settling time. Two remained poles are so far in compared with dominant poles, so their effect on overshoot is ignorable.

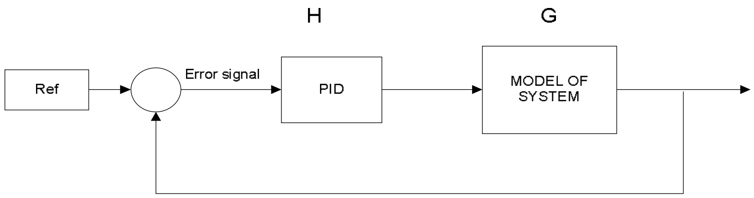

Fig. 4. controller designing block diagram

2.3.2. Feedback controller simulation

Based on illustrated model, a hybrid controller system that consists feed-forward and feedback controllers is designed to control the weight of output melt. PID controller coefficients are assumed K_p=0.9, K_i=0.001 and K_d=3.78. Simulation results show that steady state error is 3.67*10-3 and system settling time affected by S=-10. Also output response hasn't any overshoot and due to proper zeros designing, system safe margin is good enough. Figure 5 shows the effect of white noise with power 0.1 db as feed-forward input. Also disturbance effect is shown using a step source with amplitude 10 in [5 to 8] intervals of time. The designed controller is used for noise and disturbance eliminating. Simulation results are shown in figures 5-7. First figure shows output without using feedback controller and in presence of noise. Second figure shows output without feedback in presence of disturbance and third one shows output using designed system in presence of noise and disturbance simultaneously.

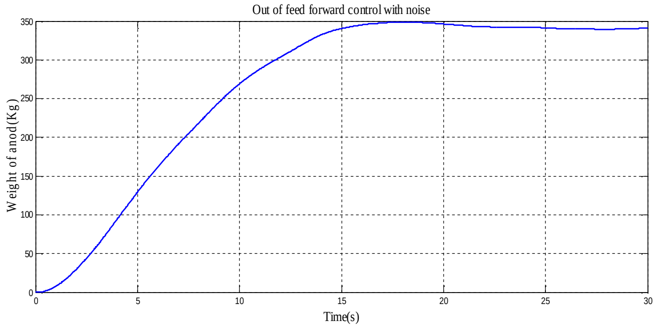

Fig. 5. Output mold weight in presence of feedback controlling with noise

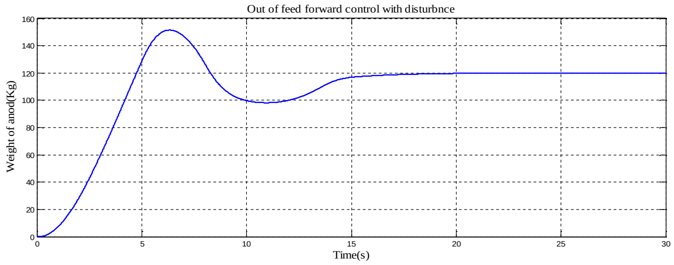

Fig. 6. Output mold weight in presence of feedback controlling with disturbance

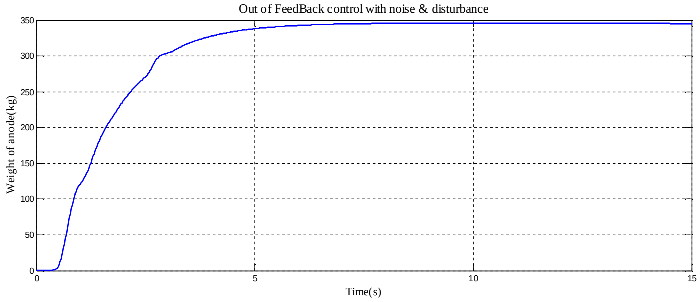

Fig. 7. Output mold weight in presence of feedback controlling with noise and disturbance

2.4. Proposed method for optimized liquid's weight controlling

Regard to Introduction section, Fuzzy PID controller that is used for liquid level controlling has reasonable and accurate results. Also Fuzzy systems have capability to create Fuzzy models, using comparative techniques. In this section, Fuzzy PID management on copper anode's weight is illustrated.

2.4.1. Fuzzy system implementation

Fuzzy system's input is the error signal. Due to subtracting between input and the constant value 345 (desired Anode's weight set point), error signal is a positive value.

Input membership functions are named Small Positive (SP), Medium Positive (MP) and Big Positive (BP). Also this naming method is repeated to output triple signals that are the PID controller signals. Table 1 shows Fuzzy rules are used to design the system and Convergence figure of output anode's weight are shown in figure 8 respectively.

Table. 1. fuzzy rules

Output Input	K_p	K_i	K_d
SP	BP	BP	BP
MP	MP	MP	MP
BP	SP	SP	SP

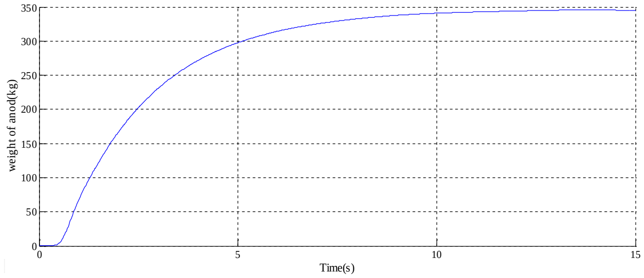

Fig. 8. output anode copper's weight in Fuzzy system

3.Conclusion

In this paper, a method proposed for adjusting melt's weight in mold and eliminating weight tolerances of casting spoon in presence of noise and disturbance. Based on mathematical model of casting process, a hybrid approach including feedback and feed-forward controller simulated. Then PID controller's parameters optimized using Fuzzy control.

Proposed controller system evaluated with simulating and results showed a good safety margin. Also system showed proper performance against noise and disturbance. Because of system stability, mold quality gets better. Also weight tolerance and casting time are other consequences of proposed method.

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