METALLURGY AND THE USE OF FUZZY CONTROL

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Abstract

Fuzzy logic controllers serve the same function as the more conventional controllers, but they manage complex control problems through heuristics and mathematical models provided by fuzzy logic, rather than via mathematical models provided by differential equations. This is particularly useful for controlling systems whose mathematical models are nonlinear or for which standard mathematical models are simply not available, such as in metallurgy. The aim of this article is to design fuzzy controller for use in metallurgy and compare him with conventional PID controller.

Keywords: Fuzzy, PID

1. INTRODUCTION

A heating of materials is a common technological process. Especially in the field of metallurgy reheating and cooling processes are very often and important parts of manufacturing metals. In heating segment it is true, that even a small percentage of a reduction of an energy consumption can lead to very interesting economic benefits. Also the quality of the final products after the metal working is to a considerable extend influenced by the heating quality in heating furnaces that forms the important part of industrial hot forming technologies. The paper deals with the identification system in MATLAB, setting up and comparing the classic PID and fuzzy controller. The aim of this article is to design fuzzy controller for use in metallurgy.

2. PI-TYPE CONTROLLER

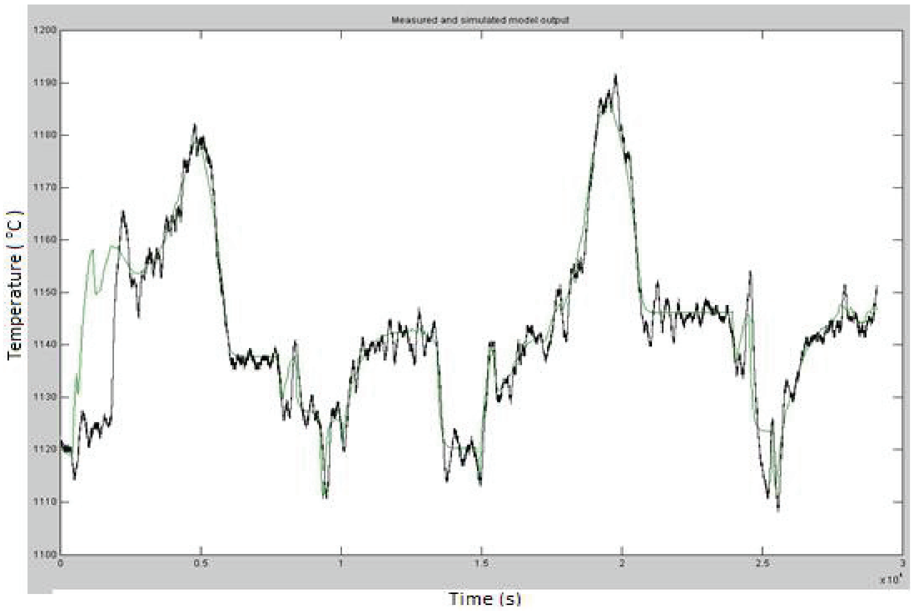

Figure 1 Measured and simulated temperature distribution

For this article was used data file with the measured temperature, depending on the amount of supplied fuel gas in the furnace. Temperature values were identified using System identification tool in Matlab. The output of identification is transmission of system *G (s)* (see equation 1):

$$G\ (s) = \frac{0.99932}{223.62s + 1} \tag{1}$$

Figure 1 shows the measured temperature from data file (black line) and simulated values from the detected transmission (green line). The control circuit of classic PID controller created in Simulink is shown in **Figure 2**, detected transmission from equation 1 is used as a transfer function.

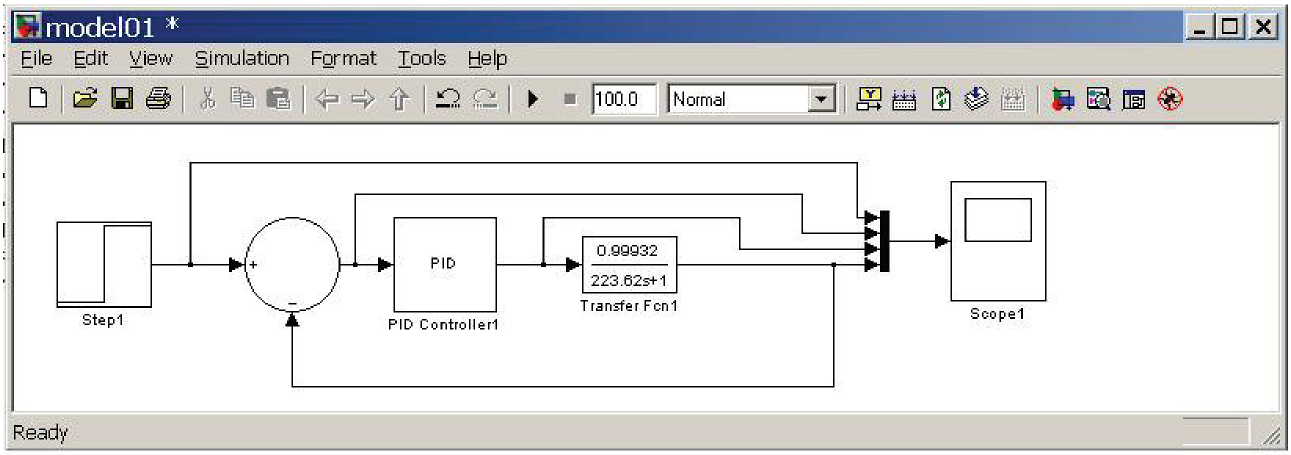

Figure 2 Control circuit of classic PID controller created in Simulink

Using the desired model method (inverse dynamics method), which allows adjustment of digital and analog controllers with and without time delay the suitable type of controller and its adjustable parameters was chosen. Based on the transmission of controlled system was analog PI controller chosen for its regulation [1].

Calculation of controller parameter r_0 (see equation 2) [1].

$$r_0 = \frac{2T_I}{K(2T_W)} = \frac{2 \cdot 223.62}{0.99932 \cdot (2 \cdot 10)} \cong 22.38 \tag{2}$$

Where:

T_W - time constant of the closed loop system (s)

K - gain (-)

T_I - integration time constant (s)

r_0 - proportional constant (-)

Calculation of the integral component I (see equation 3) [1].

$$I = \frac{1}{T_I} r_0 = \frac{1}{223.62}\ 22.38 \cong 0.1 \tag{3}$$

Figure 3 shows the step response of control process with classic PI controller, controlled variable *y (t)* and tracking error *e (k)*.

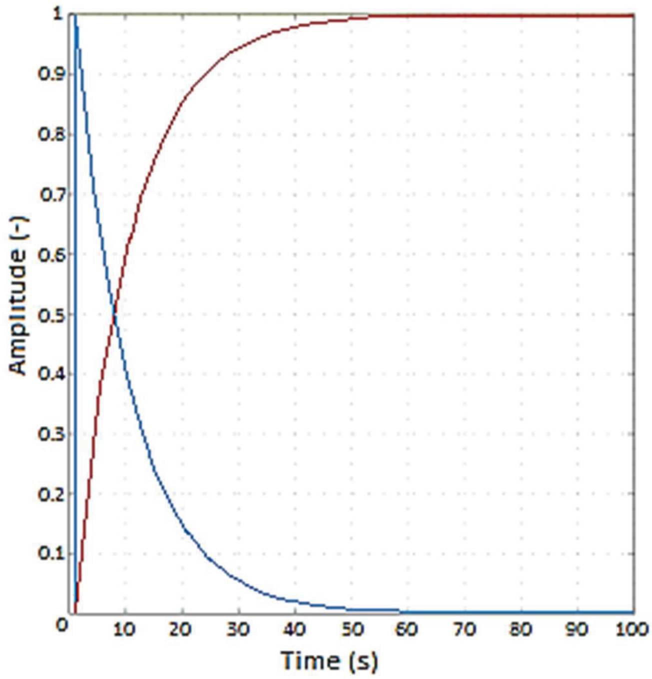

Figure 3 Step response - controlled variable *y (t)* and tracking error *e (k)*

3. MAMDANI FUZZY PI-TYPE CONTROLLER

Controller output operates with derivative of control signal $\Delta u\ (k)$ it is shown in equation 4 and **Figure 4**- it is block diagram of fuzzy PI controller [2], [3].

$$\Delta u\ (k) = K \cdot (\Delta e\ (k) + \frac{1}{T_I} \cdot e\ (k)) \tag{4}$$

Where:

K - gain (-)

Ti - integration time constant (s)

e (k) - tracking error (-)

Total action intervention *u (k)* shown in equation 5 is realized out of fuzzy model in adder, block diagram of fuzzy PI controller (see **Figure 4**) [2], [3]. In **Figure 4** (*F*) stands for fuzzification, (*D*) for deffuzification and (*IM)* is interference mechanism.

$$u\ (k) = u\ (k-1) + \Delta u\ (k) \tag{5}$$

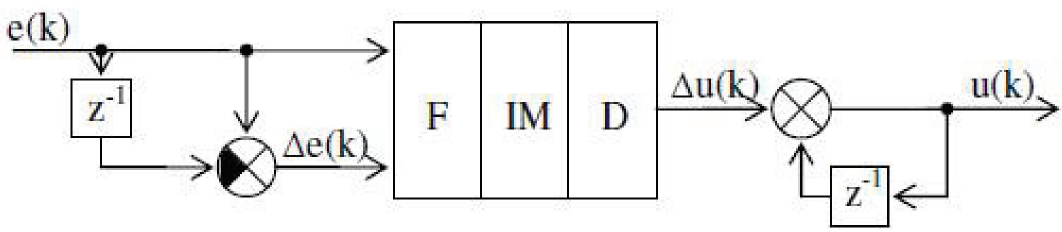

Figure 4 Block diagram of fuzzy PI controller

We modify the equation 4 by adding a variable *M*, to set the universe range for tracking error e (k) and its derivation Δ*e (k).* We also adjust integration time constant T_I. We get the equation 6.

$$\Delta u\ (k) = K \cdot \frac{M}{T_I} \cdot \left(\frac{T_I}{M} \cdot \Delta e\ (k) + \frac{1}{M} \cdot e\ (k) \right) \tag{6}$$

For equation 4 is valid equation 7, which is in a different form.

$$\Delta u\ (k) = \frac{u\ (k) - u\ (k-1)}{T} \tag{7}$$

Where:

T - sampling period (s)

We use fuzzification (*F*) and deffuzification (*D)* to equation 6 and deduce the equation 8 using equation 7 for action intervention *u (k)* [4]*.*

$$u\ (k) = K \cdot \frac{M \cdot T}{T_I} \cdot \boldsymbol{D} \left\{ \boldsymbol{F} \left\{ \frac{T_I}{M} \cdot \Delta e\ (k) + \frac{1}{M} \cdot e\ (k) \right\} \right\} + u\ (k-1) \tag{8}$$

Figure 5 is a diagram of fuzzy PI controller simulated in simulink, which represents equation 8.

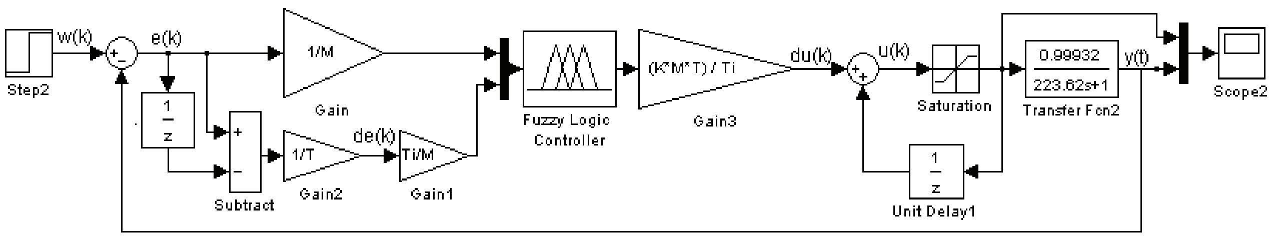

Figure 5 Control circuit with fuzzy PI controller, simulated in Simulink software

Recommended template for fuzzy PI controllers was rewritten to 49 rules in rules editor. **Figure 6** shows a template for PI and PD controllers [5].

Template		e						
		NB	NM	NS	Z	PS	PM	PB
Δe	NB	NB	NB	NB	NB	NM	NS	Z
	NM	NB	NB	NB	NM	NS	Z	PS
	NS	NB	NB	NM	NS	Z	PS	PM
	Z	NB	NM	NS	Z	PS	PM	PB
	PS	NM	NS	Z	PS	PM	PB	PB
	PM	NS	Z	PS	PM	PB	PB	PB
	PB	Z	PS	PM	PB	PB	PB	PB

Figure 6 Template for PI and PD controllers

As a defuzzification method was chosen centroids (Center of Gravity - CoG). For the simulation these parameters were set: M = 50; K = 80; Ti = 0.1; T = 0.2; limit for the action intervention +22, 0 [6].

Figure 7 shows the step response of control process with fuzzy PI controller, controlled variable *y (t)* and tracking error *e (k)*.

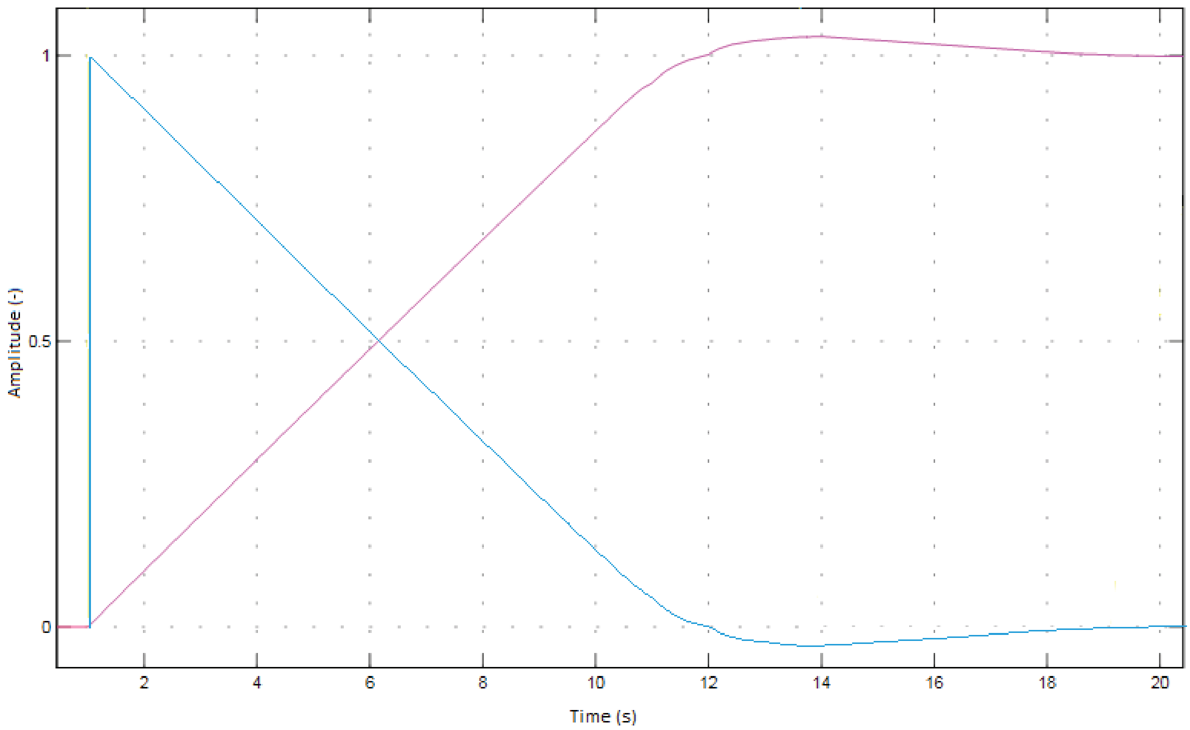

Figure 7 Step response - controlled variable *y (t)* and tracking error *e (k)*

4. MAMDANI FUZZY PID-TYPE CONTROLLER

Fuzzy PID controller is created as a sum of PI and PD controller. **Figure 8** shows control circuit with fuzzy PID controller in Simulink [2]. Triangular fuzzy number (TFN) shape of fuzzy sets was used as membership functions for PI and PD controllers.

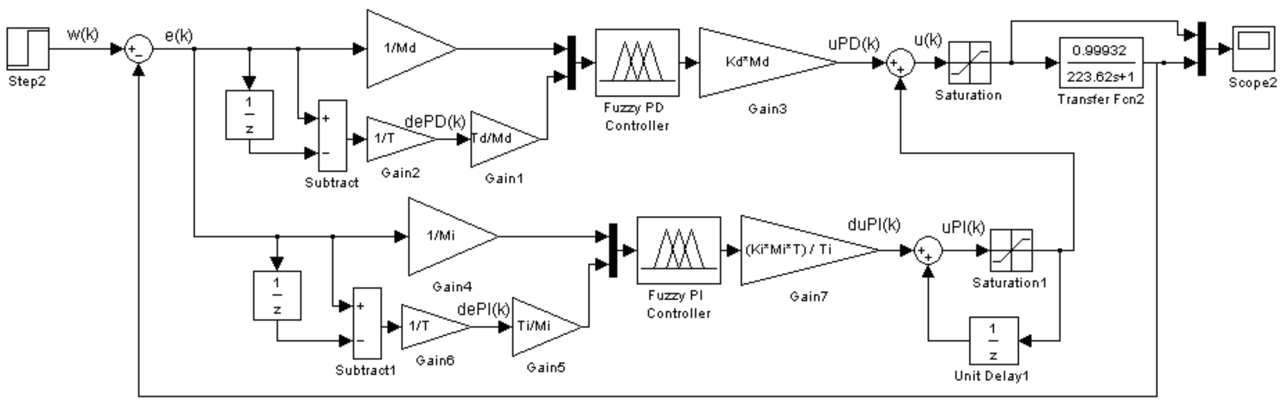

Figure 8 Control circuit with fuzzy PID controller, simulated in Simulink software

5. CONCLUSION

When using a fuzzy controller, it was reached significantly faster period of control in compare with classic PI controller. Fuzzy PI controller needs more action interventions, this would adversely affect the service life of switching elements in practice, but time of regulation was in this example more than half faster. With fuzzy PID controller time of regulation remained the same and the number of action interventions is lower compared with fuzzy PI. Here are the various uses of fuzzy control in metallurgy, isn't hard to design fuzzy controller, more complicated is to set the parameters to tune regulation. We achieved better result of regulation with basic settings of parameters with fuzzy controller than with classic PI controller.

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