Open-loop Identification of the Mathematical Model of the Reheating Furnace Walking Hearth Type in Manufacturing Process

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Abstract. The Reheating Furnace Walking Hearth Type is the key of the different rolling steel process sizes. Steel in the furnace is heated to high temperature range from 950 to 1150 °C at least 30 minutes. Because of this reason, the system requires an optimal controller for control the temperature inside each zone of the furnace. If the temperature of the steel is not proper to the process, it will affect the quality of the rolling steel process such as damage in ironing broad and increase electrical energy consumption in rolling process. The factors affecting the price of wire rod are electrical power and oil fuel consumption. Consequently, the steel production manufacture select the time from 22:30 to 8:00 for steel production because it has low cost. In addition the process will stop during the day time. This paper presents the mathematical model of Reheating Furnace Walking Hearth Type using Genetic Algorithm. This method can estimate the parameters of the reheating furnace mathematical model from measured temperature in each zone of reheating process. The results of the research lead to optimal controller design for reheating furnace. The temperature responses show that the controller can reduce fuel consumption rate of the system.

Keywords: Heat transfer, Control theory, Parameter estimation, and Genetic algorithm

1. Introduction

The Reheating Furnace Walking Hearth Type, in Ratchasima Steel Products Co., Ltd (Nakhon Ratchasima Thailand), is installed in 1964. The furnace can be separated into three zones and each zone has different functions. The preheating zone (zone 1) heats the billets for moisture removing in the temperature range from 750 to 850 °C. The heating zone (zone 2) provides heat directly to the billets in the temperature range from 950 to 1150 °C and the soaking zone (zone 3) maintains the zone temperature in the range from 1000 to 1100 °C. After the billets are soft, they are sent out from the furnace. Each zone of the furnace is shown in Fig.1 In the wire rod production process, the factors affecting the price of wire rod are electrical power and oil fuel consumption. Approximately from electrical bills, the cost of electrical power is 2.25 Baht per kWatt in the time range from 22:00 to 9:00 and 3.69 Baht per kWatt from 9:00 to 22:00. the fuel is mixed between fuel oil 70% and LCB 30% and the air fuel ratio is 1:10. Therefore, the process must be planed to run in the time range C (22:30 to 8:30), stop in the time range A (8:30 to 19:30) and restart in the time range B (19:00 to 22:30). The temperature of each zone of the furnace is shown in Fig.2.

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Fig.1 Reheating furnace (WHT)

Fig.2 Temperature zones of process

The study of the reheating furnace pays attention to the thermal energy consumption and the estimation of the reheating furnace mathematical model. This is to design suitable input (on-off) burner with the desire heating curve up [1]. The system identification method can estimate the variables of multivariable system such as reheating furnace walking beam type [2]. The predictive control and system identification of the reheating furnace can predict temperature from all billets by error from predictive and target. They are input of controller and the prediction model is call ARX model [3]. The efficiency of the furnace can be improved by mathematical equation for completed combustion [4, 5]. The mathematical model of the reheating furnace is presented by sequence learning on the artificial neural network to predict the temperature in the zone of the furnace [6]. The various fuels feed conditions to the radiative slab heating affect the characteristics and thermal efficiency of a reheating furnace [7]. This paper demonstrates the open-loop system identification for parameters estimation of the mathematical model in range B by using Genetic Algorithm for control fuel consumption rate. The control method based on time and temperature response consideration for save energy in the next time

2. Mathematical Model Of Reheating Furnace Process

The mathematical model uses the theory of heat transfer with the basic assumption for avoid complexity.

- Not consider incomplete combustion
- Consider wall of furnace are insulated
- Consider only convection heat transfer and mass transfer
- Approximate temperature residue billets by theory's lump

- Preheating zone   Heating zone   Soaking zone

Fig.3 Thermal system of reheating furnace (WHT)

The overall heat transfer of the preheating zone can be written as

$$C_1 \frac{dT_1}{dt} = Q_{conv12} - Q_{loss} + Q_{flow12} - Q_{billet1} + Q_{dist1}$$

(1)

$$C_1 \frac{dT_1}{dt} = \frac{(T_2 - T_1)}{R_1} - \dot{m}_{a1}c_p(T_1 - T_0) + \dot{m}_{a1}c_p(T_2 - T_1) - \frac{a(T_1 - T_{b1})}{R_{b1}} + Q_{dist1} \tag{1.1}$$

The overall heat transfer of the heating zone is shown in Fig.3 and the system equation can be written as

$$C_2 \frac{dT_2}{dt} = -Q_{conv12} - Q_{flow12} + Q_{conv23} - Q_{billet2} + Q_{flow23} + Q_{in2} + Q_{dist2} \tag{2}$$

$$C_2 \frac{dT_2}{dt} = -\frac{(T_2 - T_1)}{R_1} - \dot{m}_{a1}c_p(T_2 - T_1) + \frac{(T_3 - T_2)}{R_2} - \frac{b(T_2 - T_{b2})}{R_{b2}} + \dot{m}_{a3}c_p(T_3 - T_2) + \dot{m}_2 LHV + Q_{dist2} \tag{2.1}$$

The overall heat transfer of the soaking zone is shown in Fig.3 and the system equation can be written as

$$C_3 \frac{dT_3}{dt} = -Q_{conv23} - Q_{flow23} - Q_{billet3} + Q_{in3} - Q_{loss} + Q_{dist3} \tag{3}$$

$$C_3 \frac{dT_3}{dt} = -\frac{(T_3 - T_2)}{R_2} - \dot{m}_{a3}c_p(T_3 - T_2) - \frac{c(T_3 - T_{b3})}{R_{b3}} + \dot{m}_3 LHV - A_k \varepsilon \sigma T_3^4 - \frac{(T_3 - T_0)}{R_k} + Q_{dist3} \tag{3.1}$$

And the residue billet system equations

$$C_b \frac{dT_{b1}}{dt} = \frac{(T_1 - T_{b1})}{R_{b1}} \tag{4}$$

$$C_b \frac{dT_{b2}}{dt} = \frac{(T_2 - T_{b2})}{R_{b2}} \tag{5}$$

$$C_b \frac{dT_{b3}}{dt} = \frac{(T_3 - T_{b3})}{R_{b3}} \tag{6}$$

And the compensate heat transfer is

$$Q_{dist} = Q_0(1 - e^{\alpha t}) + \beta m_{ax} \tag{7}$$

Where

$$\dot{m}_{ax} = 10\dot{m}_x \qquad \text{(Air/Fuel ratio = 10:1)} \tag{8}$$

From the mathematical model, we have nineteen unknown parameters but the thermal resistance depended on Nusselt number. The mass flow speed and temperature has an effect to Nusselt number. Therefore, assume the heat resistance equation is

$$R = R_0 T^{-x\dot{m}_a} \tag{9}$$

The equation (8) increases six parameters in system equations.

Specific value

LHV	:	41 MJ/kg
a, b, c (residue billet)	:	64, 29, 19 unit

3. Open-loop identification

The reheating furnace process is the open-loop control process. The mathematical model of the reheating furnace process can be estimated from experimental data. The system parameters receive from the method called Genetic Algorithm. The temperature of the reheating furnace increase according to fuel flow pass burner in heating zone and soaking zone as shown in Fig.4 and Fig.5

Fig.4 Fuel flow in heating zone

Fig.5 Fuel flow in soaking zone

The block diagram of the open-loop identification is shown in Fig.6. The method estimate system parameters from the responds by using the error between temperature of the model and the temperature data reference.

Fig.6 Open-loop identification

The logical criterion might be fitted to function of Genetic Algorithm the mean sum square error (e) for all available data, as in

$$e = \sqrt{\frac{1}{N} \sum_{i=1}^{n} \left[T^x(i) - \tilde{T}^x(i) \right]^2} \tag{10}$$

Where N is total number of data, $\tilde{T}_x$ is the temperature measurement from the mathematical model of reheating furnace in process. For parameter of Genetic toolbox are given in table 1.

Tab.1 Parameter GA Toolbox

PARAMETER TOOLBOX	
Generation	10000
Population	50,100,150,200
Selection	Tournament
Size	4
Stall Generation	inf

4. Experiment and Simulation result

In the experiment results, this method with Genetic Algorithm is used to estimate the parameters of the reheating furnace process at Ratchasima Steel Products Co.,Ltd. The response of temperature from the

experiment and simulation are shown in Fig.7, 8 and 9. The system parameters which are estimated from the Genetic Algorithm are shown in   Table 2

Tab.2 Parameter Estimation

PARAMETERS ESTIMATION					
Parameter	Result1	Result2	Result3	Result4	Average
X_{01}	0.1402	0.1425	0.1441	0.1387	0.1416
X_{02}	0.2161	0.2041	0.2216	0.2210	0.2156
X_{b1}	0.0804	0.0831	0.0856	0.0775	0.0816
X_{b2}	0.0186	0.0182	0.0156	0.0177	0.0175
X_{b3}	0.0152	0.0168	0.0104	0.0147	0.0142
X_k	0.4	0.4	0.4	0.4	0.4
R_{01}	0.0174	0.0192	0.0164	0.0167	0.0174
R_{02}	0.0551	0.0527	0.0522	0.0546	0.05365
R_{0k}	1.69	1.65	1.71	1.70	1.687
R_{0b1}	0.00529	0.0524	0.00519	0.02086	0.0209
R_{0b2}	0.00507	0.0051	0.00513	0.00516	0.00511
R_{0b3}	0.00535	0.00532	0.00529	0.00526	0.00531
C_1	52568625	52487478	52477223	52594145	52531868
C_2	32178566	32194181	32187277	32294314	32213585
C_3	30503573	30403643	30493523	30504943	30476421
C_b	610809	610809	610809	610809	610809
Q_{01}	0.02289	0.01578	0.01376	0.02387	0.01907
Q_{02}	-0.1199	-0.1241	-0.0952	-0.1107	-0.11247
Q_{03}	-0.1783	-0.2097	-0.2095	-0.1849	-0.1956
alpha1	-0.7358	-1.6131	-2.283	-1.998	-1.6574
alpha2	-0.00027	-0.00024	-0.00042	-0.00036	-0.000324
alpha3	-0.0000397	-0.00037	-0.00021	-0.00035	-0.000331
beta1	-2.5069	-0.7713	-5.2203	-1.085	-2.3958
beta2	-3.9176	-0.6732	-1.3808	-3.4329	-2.3511
beta3	-0.5652	-0.7514	-0.005	-2.5836	-0.9763

Fig.7 Temperature response of the experiment and the estimate model in preheating zone

Fig.8 Temperature response of the experiment and the estimate model in heating zone

Fig.9 Temperature response of the experiment and the estimate model in soaking zone

5. Summaries

The paper demonstrates the estimation method for approximation of reheating furnace model parameters. The open-loop identification with Genetic Algorithm is used to estimate the system parameters of the reheating furnace from process response. The simulated and measured temperature responses show the relative response of the system. The model can used to design the optimal controller for reduce fuel consumption of the reheating process.

6. References

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