IDENTIFICATION OF HEATING MATERIAL ACTUATING VARIABLES IN HEATING FURNACES WITH THE GOAL TO PREDICT AND CORRECT A HEATING METHOD

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Abstract

Optimal control of heating furnaces requires temperature-thermal mode correction with respect to actual heating conditions. Conditions are by far the most influenced by irregularities during furnace heating material withdrawal. Time flow corrections settings of required temperature values in single furnace zones is possible to optimize based on heating models prediction. Furnace temperature values play the most important role during heating simulations. However, the influence of an instant heating gas flow in nozzles within singe parts of a furnace cannot be underestimated. The article shows the way to define time trajectories of actuating variables and identification process itself, based on the identification and consequent simulation. Achieved results should be exploited for various heating ways generating, followed by optimal alternative choice.

Keywords: Optimal control, identification, simulation, heating furnaces

1. INTRODUCTION

Industrial multi-zone heating furnaces are very complex systems in terms of their modeling, because it is not easy to accurately describe all physical and chemical processes that occur in the furnace. It is even more difficult to determine the parameters of the created mathematical models. For their complexity, such models are not suitable for the heating process control in real-time systems. Simplified models are used in many cases instead. They use the temperature in each furnace zone as the input variable to calculate the temperature of the heated material at the output. The significance of these temperatures is dominant, but to ensure a proper functionality of the model, it is appropriate to influence the instantaneous flows of heating gases into the burner of individual zones. By identifying the material heating process with towed thermocouples, it was found that the influence of the instantaneous amount of heating gas on the temperature of the heated material can be quantified in single digits of percent. If we want to use these simplified and promptly working models for heating parameters prediction, we must take into account the amount of heating gas. For this reason, it is necessary to create a mathematical model of the relation between the instantaneous amount of gas in the observed zone and the desired and actual furnace temperatures. This model should be parameterized based on identification. The article deals with creation of this model [1], [2], [3], [4], [5], [6].

2. TEMPERATURE CONTROL IN INDIVIDUAL FURNACE ZONES

In practice, cascade control is usually used to control the temperature in the individual zones of the furnace (**Figure 1**), where:

$G_{TF}^{R}(p)$ Temperature controller in the selected furnace zone (transfer function)
$G_{GF}^{R}(p)$ The amount of combustion gas controller in the selected furnace zone (transfer function)
$G_{TF}^{S}(p)$ Plant of temperature control system (transfer function)
$w_{TF}(t)$ Desired variable (desired value of controlled variable) of temperature control in a furnace zone
$w_{GF}(t)$ Desired variable (desired value of controlled variable) of amount of heating gas control in a furnace zone

$u_{TF}(t)$ Actuating variable of temperature control in a furnace zone
$u_{GF}(t))$ Actuating variable of amount of heating gas control in a furnace zone
$y_{TF}(t)$ Controlled variable of temperature control in a furnace zone
$y_{GF}(t)$ Controlled variable of amount of heating gas control in a furnace zone
$e_{TF}(t)$ Control error of temperature control system
$e_{GF}(t)$ Control error of gas control system

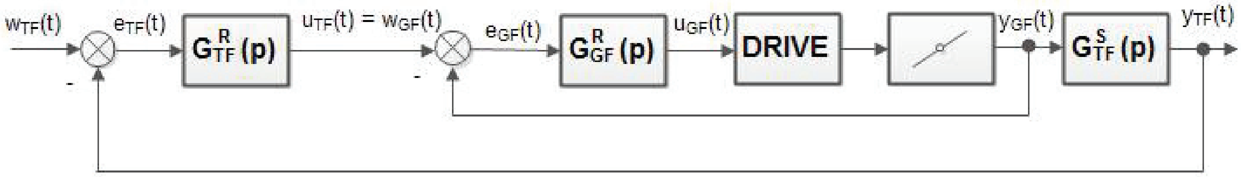


Figure 1 Block diagram of temperature control in individual furnace zones (authors)

Calculated actuating variable $u_{TF}(t)$, as temperature controller output in the observed zone, is the desired variable $w_{GF}(t)$ for the controller of heating gas flow into burners of observed heated furnace zone. We will assume that the setting of the controller of the heating gas flow into burners is optimized and we can expect a defined course of the control process that corresponds to the transfer function of the proportional first order system $G_{WG}(p)$ [7], [8]. We will expect the transfer function in the form:

$$G_{WG}(p) = \frac{1}{T_{WG}p+1} \tag{1}$$

The time constant value T_{WG} is generally unknown, therefore the time constants T_{WG} will be included within the transfer function $G_{WG}(p)$ to the complex transfer function of the controller $G_{TF}^{RC}(p)$

$$G_{TF}^{RC}(p) = G_{TF}^{R}(p) \cdot G_{WG}(p) \tag{2}$$

which will subsequently be the subject to identification.

For controller transfer function $G_{TF}^{R}(p)$ we can use, for example, the following form (PID controller with interaction)

$$G_{TF}^{R}(p) = r_0 \left(1 + T_D p + \frac{1}{T_I p}\right) \tag{3}$$

where
r_0 - setpoint P controller parameter
T_D - setpoint time constant of D controller parameter
T_I - setpoint time constant of I controller parameter

Thus, the complex transfer function of temperature controller $G_{TF}^{RC}(p)$ with subsystem of heating gas flow amount control will be in the form:

$$G_{TF}^{RC}(p) = \frac{r_0}{T_{WG}p+1} \left(1 + T_D p + \frac{1}{T_I p}\right) \tag{4}$$

For other controller types, it would be necessary to modify the complex transfer function $G_{TF}^{RC}(p)$ to correspond the actual mode of control.

3. MODEL INPUTS AND OUTPUTS

As shown in **Figure 2**, the model inputs are the setpoint temperatures of desired variable in the observed furnace zone and the actual temperature in the corresponding furnace zone. Model described by the transfer function $G_{TF}^{RC}(p)$ generates the model time course of the actuating variable $y_{GF}^{M}(t)$ (flow of the heating gas in time), from the time course of the difference between $w_{TF}(t)$ and $y_{TF}(t)$, i.e. from the control error $e_{TF}(t) = w_{TF}(t) - y_{TF}(t)$

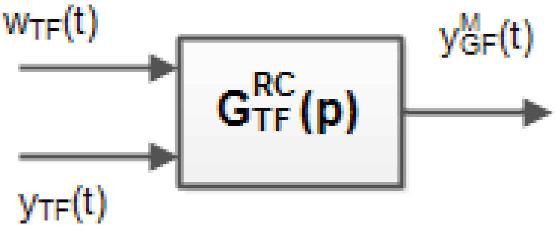


Figure 2 Model for calculation of heating gas flow (authors)

The model contains and processes as many pairs of inputs as are in the heated zone furnace, or how many of the furnace temperature controllers are. The individual controllers are typically configured to implement the PI or PID type and to generate the actuating variable (setting of the positions of the actuating members of the heating gas flows), on the respective number of outputs of for each zone.

4. OBTAINING PARAMETERS OF THE HEATING GAS FLOW CALCULATION MODEL

Using reverse Laplace transform and by modifying the expression (4) we obtain the following differential equation of integration, which is suitable after the digitization for model programing of the calculation model of the heating gases flow.

$$T_{WG}\frac{dy_{GF}(t)}{dt}+y_{GF}(t)=\frac{1}{T_I}\int_{t_0}^{t}\left(r_0\left(w_{TF}(t)-y_{TF}(t)\right)+r_0T_I\frac{d\left(w_{TF}(t)-y_{TF}(t)\right)}{dt}+r_0T_D\frac{d^2\left(w_{TF}(t)-y_{TF}(t)\right)}{dt^2}\right)dt \tag{5}$$

Figure 3 illustrates a block diagram that can be used to program algorithms to set the model parameters, so that the square of the control errors between the model actuating variable and the measured actuating variable of the actual control system is minimal.

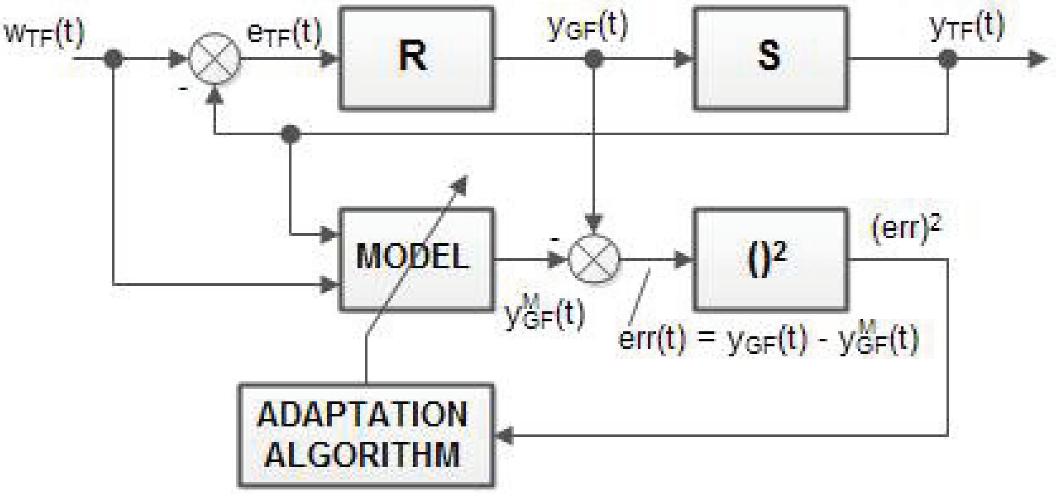
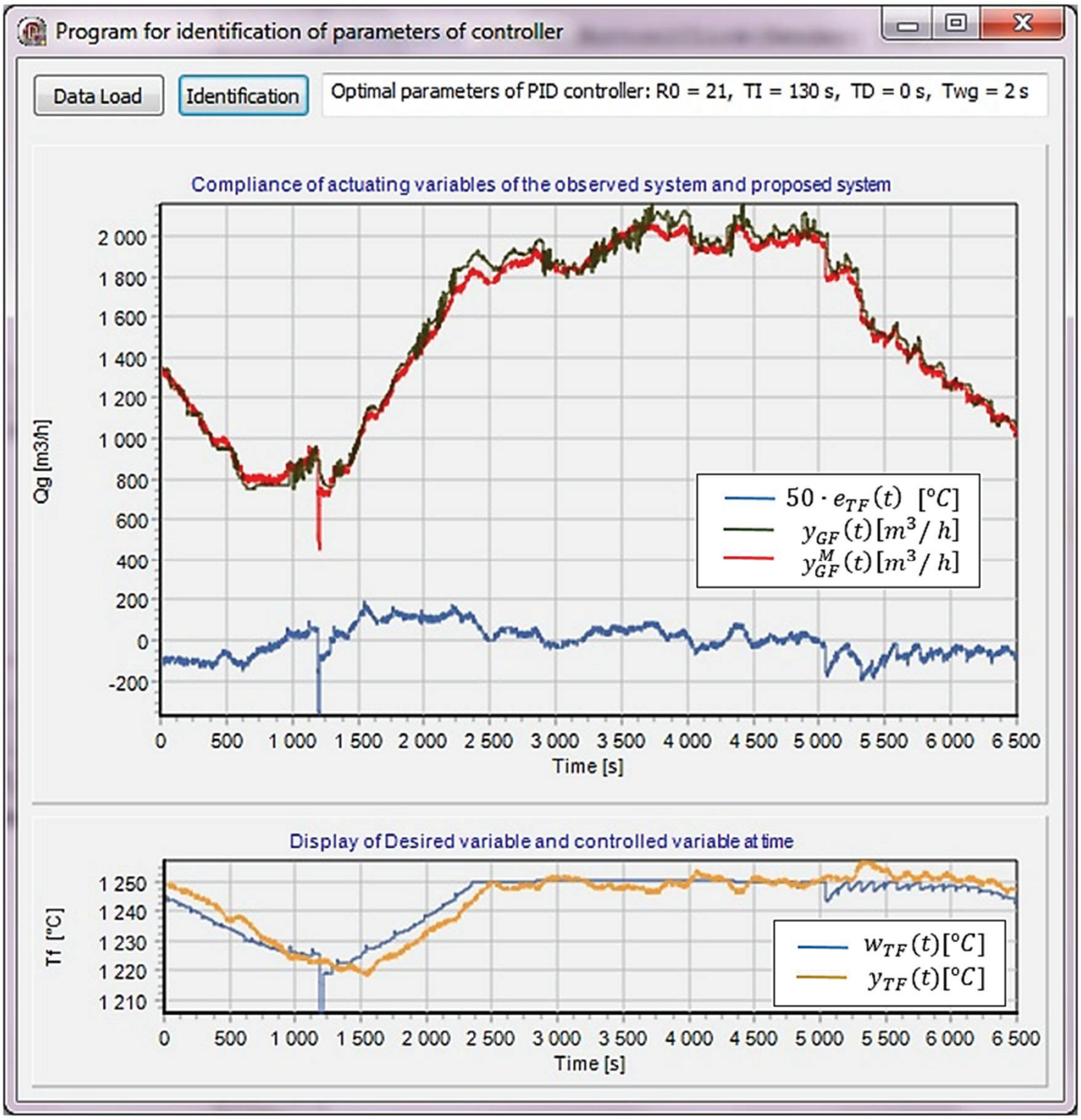


Figure 3 Block diagram of a system for obtaining heating gas flow calculation model parameters (authors)

Minimizing the error between the model and the actual process can preferably be performed using artificial intelligence or other optimization methods. The result of the optimization is to find the desired parameters T_{WG}, r_0, T_I and T_D. Knowledge of these parameters makes it possible to predict the flows of heating gases from knowledge of the expected time courses $w_{TF}(t)$ and $y_{TF}(t)$ [9], [10].



Optimal parameters of PID controller: R0 = 21, TI = 130 s, TD = 0 s, Twg = 2 s

Compliance of actuating variables of the observed system and proposed system

Display of Desired variable and controlled variable at time

Figure 4 Demonstration of the compliance of actuating variables of the observed system and proposed model

Figure 4 shows the good match between variables of observed system and proposed model.

Searched optimal parameters T_{WG}, r_0, T_I a T_D are stated in **Table 1**.

The model parameters sufficiently correspond to the observed system. The results of matches are show in **Table 1**.

Table 1 Searched optimal parameters of a controller and accuracy of the model

Parameters	Values
r_0	16
T_I	100 s
T_D	0 s
T_{WG}	2 s

Parameters	Values
ΔAME	35
ΔRME	1.5 %
Δ_{AME} - Absolute mean error	
Δ_{RME} - Relative mean error	

5. IMPLEMENTATION OF THE HEATING GAS FLOW CALCULATION MODEL INTO FURNACE MODEL

The knowledge of heating gas flow measured values (to calculate the course of the real time heating process) or values of the heating gas flow calculated by the model q_{z1}^m up to q_{zn}^m, (to calculate the expected course of the heating process), allows the use of existing simplified models based on temperature values along the length of the furnace. For calculation done by the existing model, it is only necessary to correct the measured temperatures in the individual zones t_{z1}^m up to t_{zn}^m with the ratio of influence of the measured heating gas flow values q_{z1}^m up to q_{zn}^m. We obtain the corrected temperature values in each zone of the furnace t_{z1}^{cor} up to t_{zn}^{cor}. The way of their calculation is expressed by the following relation:

$$\begin{bmatrix} t_{z1}^{cor} \\ t_{z2}^{cor} \\ \vdots \\ t_{zn}^{cor} \end{bmatrix} = w_q \begin{bmatrix} tr_{11} & tr_{12} & \cdots & tr_{1n} \\ tr_{21} & tr_{22} & \cdots & tr_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ tr_{n1} & tr_{n1} & \cdots & tr_{nn} \end{bmatrix} \begin{bmatrix} q_{z1}^m \\ q_{z2}^m \\ \vdots \\ q_{zn}^m \end{bmatrix} + w_t \begin{bmatrix} t_{z1}^m \\ t_{z2}^m \\ \vdots \\ t_{zn}^m \end{bmatrix} \tag{6}$$

Conversion matrix constants tr_{ij} can be obtained along with the values of weights w_q and w_t based on the analysis of the data obtained from test measurements of heating material with towed thermocouples. The value tr_{ij} represents the degree of influence of the heating gas flow value in j-th furnace zone q_{zj}^m on the temperature correction measured in i-th furnace zone t_{zi}^{cor}. From the direction of the flue gas flow in the furnace (from zone n to zone 1) it is obvious that values tr_{ij} for $i > j$, therefore tr_{ij} under the main diagonal, can be considered as zero.

6. CONCLUSION

These results confirm that the algorithms for implementing the model of calculation of the heating gases flow into individual zone burners, as well as algorithms for model parameter searching, can be used to predict the flow of heating gases into the individual zone burner in optimizing the furnace operation. Adaptive tuning mechanisms of the model allow us to include not only the influence of changes in the controller parameters settings, but also the influence of the actuator dynamic properties.

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