I. ŠPIČKA, M. HEGER, O. ZIMNÝ, Z. JANČÍKOVÁ, T. TYKVA

ISSN 0543-5846
METABK 55(4) 719-722 (2016)
UDC – UDK 669.04:681.5.015.23:048.34:004.896:669=111

OPTIMIZING THE MODEL OF HEATING THE MATERIAL IN THE REHEATING FURNACE IN METALLURGY

Received – Prispjelo: 2015-11-06
Accepted – Prihvaćeno: 2016-04-20
Preliminary Note – Prethodno priopćenje

The optimal operation of reheating furnaces in the metallurgical industry is subject to regularities in the work of the furnace. In practice, however, one cannot avoid downtime to some extent, which causes the deterioration of economic indicators in the furnace. The article demonstrates how to use simulation models for reducing the negative impact of downtime by correcting the temperature in individual zones of the furnace. Corrections are calculated on the basis of predictions of initial heating curves of the processed material and subsequent optimization while using the elements of artificial intelligence.

Key words: metallurgy, reheating furnace, model of heating, optimization, artificial intelligence

INTRODUCTION

Reheating furnaces in metallurgy are among units with very high energy consumption and high material flows. Any partial improvement in the control of heating leads to significant financial savings. The regularity of the run of reheating furnaces depends upon the regularity of the heated material withdrawal followed by the technology. The article deals with the method of creating such models by using the elements of artificial intelligence [1, 2].

TYPES OF MODELS

Models can be viewed from several perspectives. In principle, the creation of models may be based on the analytical description of the regularities that occur in the real object, or mathematical relationships can be created on the basis of the analysis of the results of the observed experiment object [3]. These processes are referred to as identification. Heating models in reheating furnaces acquired by means of analytical identification can accurately describe any ongoing physical processes [4, 5]. Models obtained by experimental identification are mathematically simpler. Less physical correspondence is offset by a more accurate determination of the model parameters based on actual measured values in a specific object [3].

DESRTIPTION OF MODELS

To optimize the heating correction of temperatures in zones of the furnace it is useful to apply models based on experimental identification. A typical heating process of materials in the reheating furnace is accompanied by data collection, which is superordinate to the control and visualization system. Thus, there are real-time data available on the temperatures in individual zones of the furnace , the quantity of fuel gas and combustion air fed into the burners of individual heated zones of the furnace, information on the charge material and thus its shifts during the stay in the furnace. The structure of the model is shown in Figure 1.

In the first part, based on the charge material and shifts in the furnace, a calculation of the time trajectory of the movement of the heated material along the length of the furnace is made.

In the second part, based on the measured temperatures in zones of the furnace a calculation of the temperature field along the length of the furnace is made and a specific time trajectory of furnace temperatures in

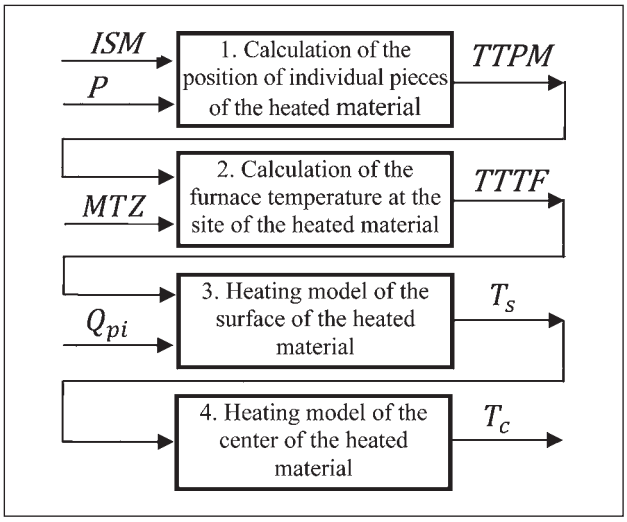

Figure 1 The structure of the model

I. Špička, M. Heger, O. Zimný, Z. Jančíková, T. Tykva,
VŠB – Technical University of Ostrava, Czech Republic
Faculty of Metallurgy and Materials Engineering

places designated by the time trajectory of the movement of the heated material is assigned.

The third part presents a surface heating model of the heated material, which, based on the knowledge of the furnace temperature at the site of a specific piece of the heated material (*TTTF*) and the quantity of fuel gas fed to the burners of the furnace, determines the surface temperature (T_S) in a defined position of the heated material.

The fourth part contains an internal heat transfer model and determines the temperature of the centre of the heated material. This part of the model is adequately addressed in previous articles [1, 2] and therefore it will not be listed here in detail.

IDENTIFICATION OF THE HEATED MATERIAL

In order to calculate the surface temperature of the heated material, it is necessary to know the temperature of the furnace in the place where the currently observed piece of the heated material is. In practice, the data on the temperatures measured in the different zones of the furnace using thermocouples is available, which are part of the control circuits of the temperatures in the furnace. Denser measurement network provides more accurate information on the temperatures in the furnace. The furnace temperature at the site where the monitored piece of the heated material is, is obtained with sufficient accuracy by a linear approximation of the measured temperatures of the two neighbouring sites.

Generally models that operate in real time, calculate the surface temperatures of the heated material, possibly its inner layers only from the furnace temperature.

This type of model has been selected for the method of identifying heating in the furnace, which would lead to obtaining a simplified dynamic model. Identification was carried out in Matlab - Simulink. The dynamic model was described by general transition using Laplace's transform. The furnace temperatures at the site of the monitored piece of the heated material were the input of the model, and then the outlet was the temperature of the heated surface material (Figure. 2).

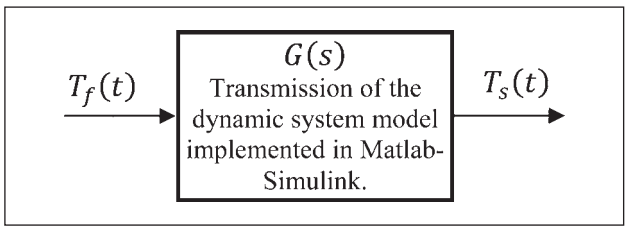

Figure 2 The structure of the dynamic heating model

Custom identification was carried out by the successive refinement of parameters of the dynamic model using genetic algorithms based on multiple simulations. The optimality criterion was the sum of the square of deviations between the time course of the surface temperature of the observed piece of the heated material obtained by the simulation (model) and the time course of the measured surface temperatures of the heated material using towed thermocouples.

Waste gas properties at any point in the furnace are influenced by many parameters. The dominant role plays an instantaneous quantity of fuel gas fed to the individual burners of the furnace. The counterflow method of spreading waste gases in the furnace determines the distribution method of the impact of the amount of gas in the corresponding zone and the following zones.

The model uses the following sets of equations (1-5) to determine the effective amount of gas in individual zones:

$$Q_{Ef}^5 = k_5 \cdot Q_M^5 \tag{1}$$

$$Q_{Ef}^4 = k_4 \cdot Q_M^4 + k_{45} \cdot Q_{Ef}^5 \tag{2}$$

$$Q_{Ef}^3 = k_3 \cdot Q_M^3 + k_{34} \cdot Q_{Ef}^4 \tag{3}$$

$$Q_{Ef}^2 = k_2 \cdot Q_M^2 + k_{23} \cdot Q_{Ef}^3 \tag{4}$$

$$Q_{Ef}^1 = k_1 \cdot Q_M^1 + k_{12} \cdot Q_{Ef}^2 \tag{5}$$

where (Q_{Ef}^i) is the effective amount of gas in the zone *i*, k_i, – the contribution of the amount of gas fed into the zone *i* for the zone *i*, Q_M^i – the amount of gas fed to the zone *i*, $ik_{i,i+1}$ – the contribution of the effective amount of gas fed into the zone *i* + 1 for the zone .

To use a model based on the knowledge of temperatures, it is preferable to calculate the so-called "additive contribution representing the temperatures of the quantity of fuel gas", which would be the second input of the heating model. Laplace's equation describing the calculation of the contribution (6) is determined by the general relationship:

$$T_Q^X(s) = G_Q^i(s) \cdot Q_{Ef}^X(s) \tag{6}$$

where $T_Q^X(s)$ is the additive contribution representing the temperatures of the quantity of fuel gas at the site of the monitored piece of the heated material, $G_Q^i(s)$ – the general transition of the proportional system of the 1st order for the appropriate zone *i*, $Q_{Ef}^X(s)$ – the effective amount of gas in the zone.

We assume the transition of $G_Q^i(s)$ (7) in the form:

$$G_Q^i(s) = \frac{k_Q}{\tau_Q^i \cdot s + 1} \tag{7}$$

where k_Q is the amplification, and τ_Q^i – is the time constant.

Now it is possible to calculate the time course of the surface temperature of the heated material during heating in the furnace. For the calculation it is possible to apply a general form (8), which is expressed by Laplace's image of the equation:

$$T_s(s) = G_{Tf}^i(s) \cdot T_f^X(s) + G_{TQ}^i(s) \cdot T_Q^X(s) \tag{8}$$

where $T_s(s)$ is Laplace's image of the surface temperature of the heated material, $T_f^X(s)$ Laplace's image of the surface temperature of the heated material. Transitions of $G_{Tf}^i(s)$ and $G_{TQ}^i(s)$ may also be more complex, here transitions are used describing the proportional systems of

the first order. We are dealing here with the following transitions (9,10):

$$Q_{TQ}^{i}(s) = \frac{k_{TQ}}{\tau_{TQ}^{i} \cdot s + 1} \tag{9}$$

$$Q_{Tf}^{i}(s) = \frac{k_{TF}}{\tau_{TF}^{i} \cdot s + 1} \tag{10}$$

where k_{TF} is the amplification of the transition from the furnace temperature to the surface of the heated material, τ_{TF}^{i} – the time constant of the transition from the furnace temperature to the surface of the heated material, k_{TQ} – the amplification of the transition from the additive contribution representing the temperatures of the quantity of fuel gas to the surface of the heated material, τ_{TQ}^{i} – the time constant of the transition from the additive contribution representing the temperatures from the quantity of fuel gas to the surface of the heated material.

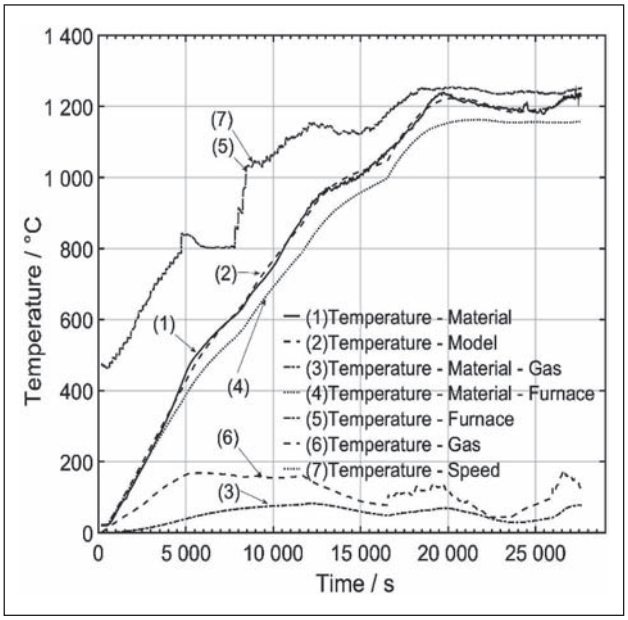

Figure 3 Time course of the measured and calculated values.

All the constants, based on multiple simulations, were optimized so as to minimize the purpose functional (11) in the form of:

$$J(t) = \int_{t0}^{t1} (T_s^m(t) - T_S^S(t))^2 \, dt \tag{11}$$

Using the method of genetic algorithms sequentially population values of the constants of the model were generated. Research results are clearly seen in Figure 3.

These results were achieved with the following parameters used in the method of the genetic algorithms.

Table 1 **GA parameters**

	Population size	Selection	Elite count	Crossover fraction	Fraction
Parameters	200	Stochastic uniform	10	16	0,2
	Interval	Initial penalty	Penalty factor	Generations	
Parameters	20	10	100	2 800	

RESULTS OF THE SIMULATION

In Table 2 final optimal constants of the model are presented.

Table 2 **Optimal constants of the model**

Amplification					
	3,996		0,931		0,561
	0,362		0,295		0,219
	0,102		0,773		0,368
	0,102		0,192		0,571
	-370,0				
Time constants					
	4 847		3 791		4 059
	3 372		3 318		1 000
	1 086		10,25		1 000
	1 088		1 500		1 378
	1 499		10,21		815

CONCLUSION

Currently it is not necessary to use complex numerical models. However, it is possible to use models that use simple but fast working models, which are required during the real time optimization of the control of reheating furnaces [6]. It has been found that models based only on the knowledge of furnace temperatures are very likely to be used with sufficient accuracy during a regular operation of the furnace. If in the work of the furnace there are substantial irregularities (downtime), so-conceived models exhibit higher errors in this non-uniformity. The accuracy of the model will increase, if it accepts the influence of the dynamics of the furnace atmosphere, which may be taken into account by calculating and applying it to the input of a so-called "additive contribution representing the temperatures of the amount of fuel gas. Although the calculation of the custom optimization lasted on an average PC dozens of hours, the model that has already been optimized can work easily in real time and can be implemented in the existing technology of the control system of the reheating furnace. Control algorithms can then be used by models in the rapid predictions of the temperatures of the heated material in a set of the simulated control and on its basis one can select the best control option.

Acknowledgements

The work was created in the Projects No. SP 2016/107 and SP 2016/86

REFERENCES

[1] R. Garzinova, P. Svec, R. Frischer, Operative control with structured data processes in steel operations environment, In Conference proceedings of 23rd International Conferen-

ce on Metallurgy and Materials Conference METAL 2014. Ostrava: TANGER, 2012, pp. 1647-1653.

[2] J. David, R. Frischer, M. Stranavova, Usage of rfid wireless identification technology to support decission making in steel works, In Conference proceedings of 21th International Metallurgical and Materials Conference METAL 2012. Ostrava: TANGER, 2012, pp. 1734-1738.

[3] M. Stráňavová, M. Heger, I. Špička, J. Franz, O. Zimný, Increasing the profitability of the operation of rating furnaces using models and data mining systems, In Conference proceedings of 21th International Metallurgical and Materials Conference METAL 2012. Ostrava: TANGER, 2012, pp. 1229-1234.

[4] S Kluska-Nawarecka, E Nawarecki, B Śnieżyński, D Wilk-Kołodziejczyk, The recommendation system knowledge representation and reasoning procedures under uncertainty for metal casting, Metalurgija 54 (2015) 1, 263-266.

[5] D Wilk-Kołodziejczyk, G Rojek, K Regulski, S Kluska-Nawarecka, M Adrian, Mathematical formalisms to represent knowledge concerning the production process of austempered ductile iron, Metalurgija 55 (2016) 1, 3-6.

[6] L. Socha, J. Bazan, K. Gryc, J. Moravka, P. Styrnal, V. Pilka, Z. Piegza, Optimisation of the slag mode in the ladle during the steel processing of secondary metallurgy, Materiali in tehnologije 47 (2013) 5, 673-678.

Note: The responsible translator for English language is Eva Tenzin, Czech Republic