THE STRUCTURE OF HEATING FURNACE

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Abstract

Optimal control of reheating furnaces at metallurgical companies encounter difficulties resulting from the unevenness of the material through the furnaces because of their integration into broader technological lines. In terms of finding the optimal heating strategy, the use of the appropriate models of heating appears to be the cheapest approach. The description of these models makes up the core of the presented article.

Keywords: Heating furnace, heating models, metallurgy, optimal control of heating materials

1. INTRODUCTION

This article focuses on the possibilities of creating a simulation model explaining anomalies at heating ingots in a continuous furnace. The aim of the article is to present methods of progressive refinement of the model, which would explain the unusual behavior of ingot in the heating zone of the furnace.

To reach the shortening of the production cycle, reduction of production costs and increase in the flexibility of the company it is necessary to respond to market demand for manufactured products, to use integrated logistics and to develop and utilize new production models [1]. The same conclusion was drawn also by other authors [2].

The important place in the metallurgical production is to take care of continuous reheating furnaces of rolling mills. These aggregates from the point of view of control cannot be solved as a separate production unit, but as part of a broader technological complex. Their integration into production lines significantly affects the operation of the furnace aggregate. The power of the furnace is then given by requirements of related technologies and furnace's control system must suitably respond to these demands.

The whole problem of controlling of the furnace can be divided into two levels:

- The basic stabilization level.
- The supervisor level of control is carried out; inter alia, the selection of optimal values continuously evaluated on the basis of the temperature field of the heated material.

The core of the optimization algorithms here consists of mathematical and physical model of the processes that should replace the non-existent direct link between ongoing and self-controlled process control systems [3], [4], [5]. The reference model must be implemented largely in the environment of itself industrial control systems, which are all well equipped with features for custom classic control or control, but do not have the ability to run specialized simulation programs. However there is a solution where these models can be run on separately using computers equipped with standard operating systems.

2. CONDITIONS IMPOSED ON THE MODEL

Mathematics and physics model is understood as a set defined by its inputs, outputs, and the dynamics of this system is expressed by the transfer, both in time domain and in the domain of complex variables. This model of continuous system can be easily modelled in simulation program; integrators are simulated by inertial members of the modelled system. When modelling the system we will use the description using the input, output and state variables. Inverse Laplace transform is used to express the time behaviour of the corresponding transfer function, which is a function of time and the excitation signal.

Using discrete z-transform we obtain a discrete model of the same system where integrators are replaced by a delay element. This model can then be easily implemented in the current environment of industrial systems using basic mathematical operations.

Conditions imposed on the model are:

- sufficient prediction accuracy,
- sufficient computing speed,
- low memory requirements,
- easy implementation in an environment of industrial control systems.

It is possible to use the tools from a classical mathematical description to the artificial intelligence methods‘ usage in terms of the creating models‘ possibilities. For more details see **Figure 1**.

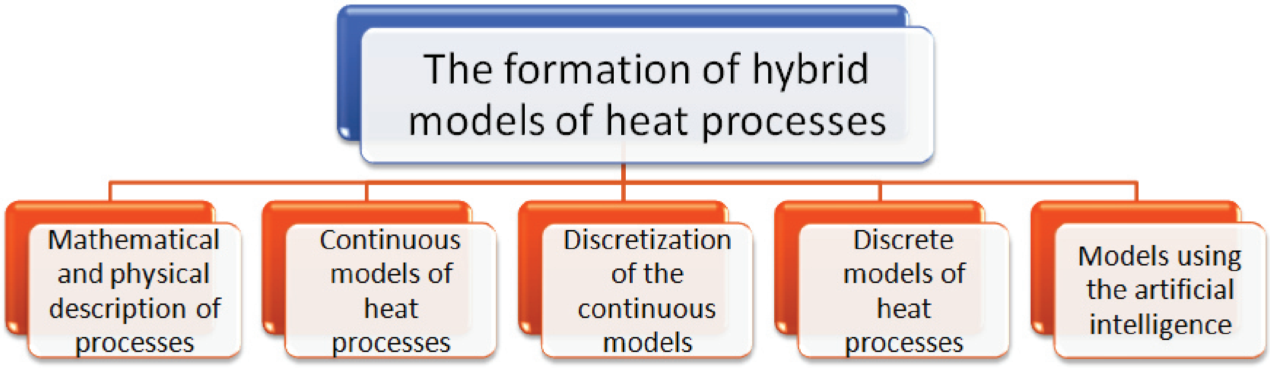

Figure 1 The overview of tools for creating hybrid models of heat processes. Source: authors.

From the viewpoint of the comparison of options for separate models (as shown in the figure) and the conditions that are put on the model it is shown that the models should exist in differential heat models which are based on the continuous models of thermal processes, whose parameters have been identified from the measurements made directly in the furnace operation.

In the chart of the ingot heating process (referring to the heating furnace zone) there was a downtime. As expected, despite the fact that the temperature has dropped slightly in the furnace environment, the measured temperature of the ingot should be still higher, therefore the temperature at thermo-couplers should increase, but measured data show an anomaly - the temperature began to go down. The simulations on the heated ingot' differential model were made (which is not part of this article and has its separate article) and there we can see that, even though the temperature field of ingot is unbalanced the difference of temperatures in the crosscut is not sufficient to ensure that the surface layers have started to cool down.

During the analysis of the furnace behavior we found out that the temperatures' drop has a correlation with the decline of the heating power of those furnace zones. This supply decrease was caused by the downtime in the following technology, where the ingots have remained longer in the same place and the model furnace level has reduced the input, to avoid overheating of the material.

The correlation between the decrease of measured temperatures and decrease of furnace wattage led us to the opinion that only the temperature measurement at thermocouples, by which the walking furnace is equipped, is not sufficient to verify the model, built only on the transfer of "the temperature of the furnace environment - the temperature of the selected place in the heated ingot".

Also, the utilization of practices and ideas published in [6] can be assumed. For preprocessing of data for the mentioned models it seems like the best way outlined in that article, which states that Winter's exponential smoothing model - this model assumes a linear trend with multiplicative seasonality estimated by exponentially weighting of all previous data values.

Other authors further recommend methods based on the multi-attribute value theory or Analytic Hierarchy Process (AHP), fuzzy programming method or genetic algorithms [7]. In the future, these methods will be used.

3. MODELS OF HEATING PROCESSES

The simplest model of the heating can be built on the modelling of heat transfer from the furnace environment to the heated material. From the heating theory point of view these models built on the transmission functions of the first and second order in general quite toughly model the behaviour of the model heated in the manufacturing furnace. Models that are built only on the fixed time constants do not quite exactly model the running of heating in the area of material's phase transformations when time constants are given by the thermal material parameters of the heated material, which at around the temperature of 600 - 900 °C intensely change and depend on the material composition of that heated steel.

For this reason it is preferable to use the model which utilizes different time constants for individual furnace zones, but, for simplicity, they are constant for each zone. In the following paragraphs we will show how gradually it is possible to improve these models to provide the authentic results as much as possible verified by direct measurements in the heating furnace. It will be a model that includes only the influence of furnace atmosphere, the second model takes into consideration also the influence of power of the furnace heating system and the last model includes also the effect of the correction on the speed movement of the material in the furnace. These models would find their application also in the analyses of the impact on the environment [8].

3.1. Model built on the temperatures in the zone of the furnace

Time constants in the single furnace zones have been identified from the heating process. In comparing the behaviour of the model and the temperatures' measurements it is evident that it does not explain the drop of the measured temperatures during the fall of the power in the furnace.

3.2. Model built on the temperatures in the zones and power in zones

This model is trying to use for the description of the non-standard behavior of the ingot temperature field also the contribution of the heat flow directly from the burnt media, as a separate heat flow. From the analysis of the function of the heating furnace, it is clear that heat energy is divided among the loss-making heat flow via furnace cover, the heat flow into the heated material and the rest passes as a not used thermal energy to the previous furnace zone. The issue of this model is (among other things) how much of heat is being transferred between the particular furnace zones, in other words, how the input power change in one zone is manifested to the temperature change in the previous zones, and therefore, how it affects the material heating in those zones. The genetic algorithms, which were searching for the coefficients expressing these heat transfers, have been used for the identification [9].

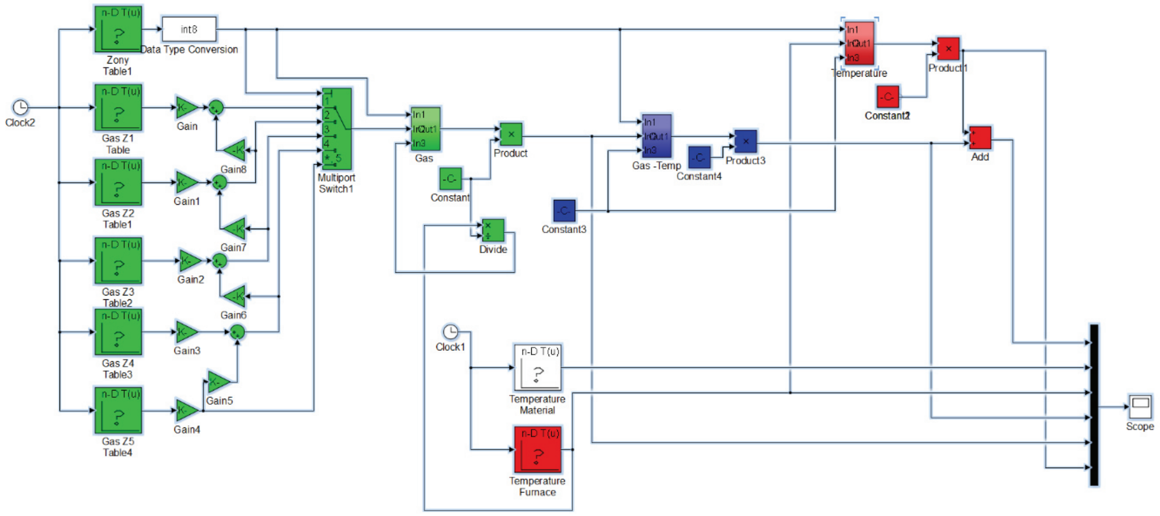

Figure 2 The structure of the simulation model. Source: authors.

Explanatory notes for **Figure 2**:

- Green painted blocks in the picture simulate the effect of input power in zones on the heated material temperature when the output of this part of the model the contribution of the heating media fictitious temperature is.
- The blue marked blocks create the part of the model simulating the dynamic behavior of system Gas temperature - Contribution to the heated material's temperature.
- The red marked blocks then model the behavior of the system Measured furnace temperature - Contribution to the heated material temperature.
- In the final sum block the entries of the gas as well as the temperature measured by the furnace thermocouples to the heated material temperature are summarized.

3.3. Model built on the temperatures in zones, power consumption in the zones and speed of material flow in the furnace

For the refinement of the previous model we checked the influence of the speed of movement of the material in the furnace on the course of the temperatures in the material. The previous model was expanded by one parameter, which corrects the temperature above ingot with regards to the speed of movement in the furnace. The following graphs (see **Figure 3** and **4**) show that the impact speed of the material in the furnace does not have a

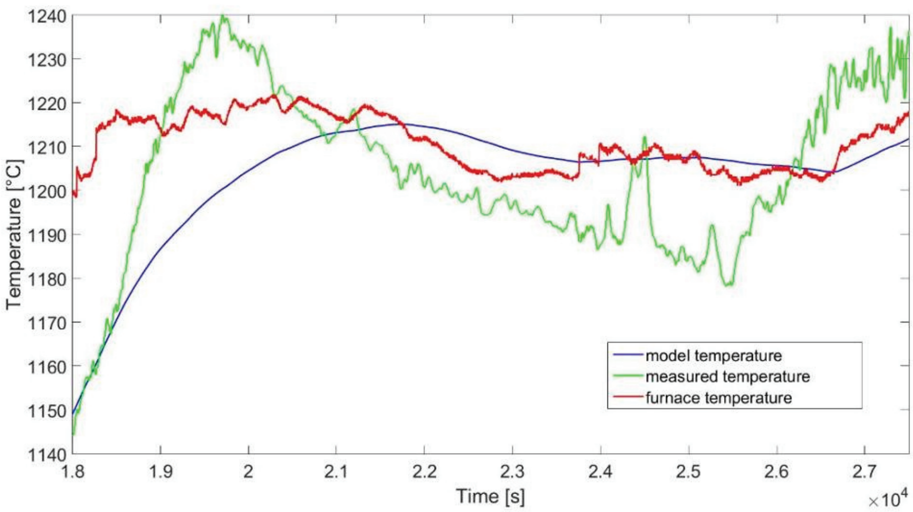

Figure 3 Comparison of the output of the model and the measured temperature in the case of decompensed course of furnace temperature

significant impact on the way of material heating. In the chart there are painted the corrected and not corrected temperatures above ingot and it is visible that the difference between these temperatures is minimal and it is possible to disregard it.

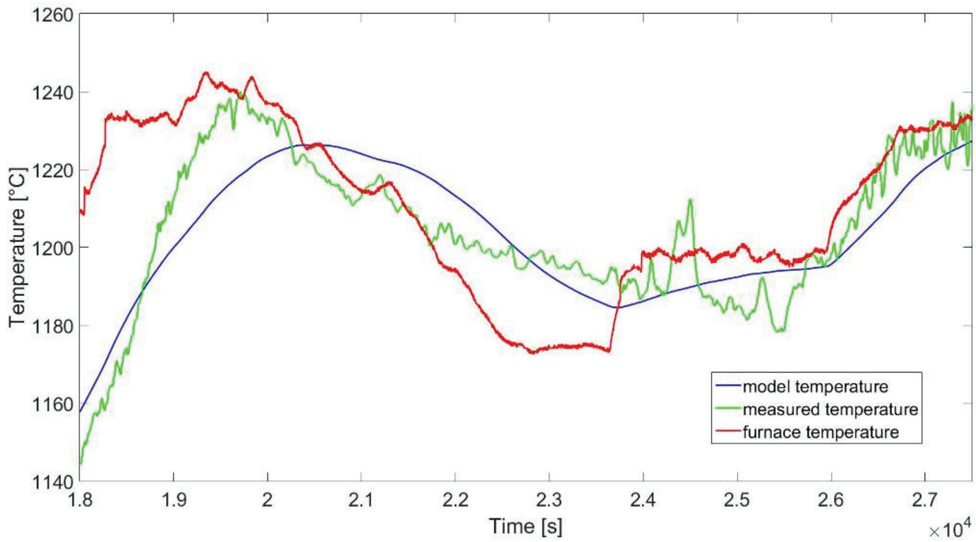

Figure 4 Comparison of the output of the model and the measured temperature in the case of compensed course of furnace temperature

4. CONCLUSION

From the analysis made above it is clear that it is possible to build the model of dynamic behavior of in the continuous furnace heated material with a sufficient accuracy on the measured temperatures of the continuous furnace' thermocouple, which serves as the reference thermocouples for the control system of the furnace, with the fact that as a next substantial input of this model the current powers, that are directly proportional to the flow of furnace heating medium, are taken.

The further advantage of the selected model is a modelling method of influencing individual furnace zones one another. From the default assumptions outlined for the application of the control model we can say that by transition from continuous to discrete time the simulation scheme, as shown in **Figure 2**, is possible to adjust to the differential models, which is a lightweight on the control system memory and computing capacity and can be directly implemented in the control systems built directly on the basis of the industrial logic controllers.

The suggested procedure of modelling is one of many that you can use for the modelling of technological processes. An example of other models based on neural networks, for example, is a Model of multilayer artificial neural network for the prediction of iron ore demand [10]. Other approaches are using Fuzzy Modelling, which can be used in the analysis of metallurgical production generally. The above models can be used within heuristic modelling [11], [12].

ACKNOWLEDGEMENTS

This article was supported by the specific university research No. SP 2016/86 and SP 2016/107.

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