Conference Paper

Logical-mathematical Evaluation Model of Blast-furnace Melting Operation

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Abstract

The logical-mathematical evaluation model of blast-furnace melting operation is represented. The model provides an opportunity to evaluate the normal operation mode of blast furnace and further deviations from this mode such as overdeveloped gas flows (peripheral and central), violation of thermal melting conditions (hot and cold course of melt), violation of smooth descent of burned materials in the furnace (tight furnace operation, higher and lower suspension of burden). The functional capabilities of developed software are represented.

Keywords: blast-furnace production, information logical system, software development, blast-furnace melting operation diagnostics

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1. Introduction

To improve the technologies of iron smelting and solve the tasks of control of such complex and power-intensive process units as blast furnaces it is necessary to use the intelligent control systems [1–10]. The contemporary process of iron smelting in the blast furnace is subject to the influences of numerous and variable controlled and uncontrolled factors which cause the violations of blast-furnace melting operation. One of the methods to diagnose and control the blast-furnace melting operation consists in using the expert systems that include either determined knowledge about the process or formalized practical knowledge of blast furnacemen. The state analysis of question regarding the real practical use of mathematical models of blast furnace management on a real-time basis provides an opportunity to state that these methods and corresponding software are not practically developed today thus determining the actuality of this article [8–10].

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2. Detection of the Normal Operation Mode of Blast Furnace

The deviation of ΔX_i feature characterizing the furnace operation during the base X_i^B (set values) and project period X_i^P in *i* modulus shouldn't exceed the accepted ΔX_i^{acc} value that is a model setting.

$$\Delta X_i = \left|X_i^B - X_i^P\right| \leq \Delta X_i^{acc} \quad (1)$$

If condition (1) is met («True»), the value '1' will be assigned to *i*'s identifier of P_i indication. In other way ('False'), it will be equal to 0. Therein, all indications are ranked. Each of indications is assigned with the value of its R_i rank that is changed from 0 to 1 and determined by means of the expert evaluation.

The probability of normal operation of blast furnace (P_n) is calculated according to the following correlation:

$$P_n = \sum_{i=1}^{n} \left(P_i \times \frac{R_i}{\sum_{i=1}^{n} R_i}\right) = \sum_{i=1}^{n} \left(P_i \times \alpha_i\right), \quad (2)$$

where α_i – weighting factor of *i*'s indication identifier changing in the range of 0 to 1; *n* – number of indications.

To identify the normal operation mode of blast furnace, the values of X_i^B indicators are used for model setting and corrected for operating conditions of the certain blast furnace. There are 15 controlled indications used in the model to identify the normal operation mode of blast furnace. Unlike the known works of other authors, this research integrates the complex of controlled indications and designed parameters of blast-furnace melting operation. The mathematical support and software additionally use the complex of 9 main estimate indicators applied in the model of blast furnace melting operation and adapted from MMK perspective. Thus, the number of indicators is equal to 24.

The main complex design parameters for diagnostics of blast-furnace melting operation embrace the following ones [11–13]:

1. **Temperature condition** – generalized parameters characterizing the thermal state of upper (index of the shaft thermal state etc.) and lower part of the blast furnace (theoretical flame temperature; bottom thermal state index, that is, a specific enthalpy of melting products including the iron melting heat except of slag formation heat (heat input for physical heating of melting products and recovery of oxides of hard-to-recover elements in the iron according to the reactions of direct iron recovery etc.)

2. **Gas-dynamic mode** – degree of compensation of burden material by means of gas in the upper and lower parts of furnace as well as in the separate annular areas etc. The forecasting and evaluation of gas-dynamic parameters of the blast-furnace melting operation.
3. **Slag mode** – viscosity and viscosity polytherms of final slag; slag melting temperature; slag viscosity at given temperature; gradients of slag viscosity, basicity of slag; melting temperature, melting temperature range of iron-ore materials and thickness of zone of IOM viscoplastic state.
4. **Melting intensity** – volume of melt burden per unit time, m^3/min. The main complex parameters (some of specified design parameters) were used for further diagnostics of blast-furnace melting operation.

The configuration and location of zone of viscoplastic state of iron-ore materials (melting temperature and temperature range of iron-ore materials melting; height and thickness of zone of IOM viscoplastic state in the different vertical elements of blast furnace) are additionally identified apart from the modes evaluation.

The algorithm scheme for identification of deviations from the normal operation mode of blast furnace is presented in Figure 1.

3. Detection of Deviations from the Normal Operation Mode of Blast Furnace

The diagnostics of the following deviations from the normal operation mode of blast furnace is specified:

1. Violation of gas flow stability (peripheral and central gas flows).
2. Violation of thermal melting condition (hot and cold course of melt).
3. Violation of smooth descent of burned materials in the furnace (suspension of burden (upper and lower), tight furnace operation).

In addition, the same methodology as for evaluation of normal operation mode of blast furnace is used. To find out the type of melting deviation from the normal operation mode it was considered expedient to compare two periods. One of such periods is a base one for which the values of melting parameters are a model setting that characterizes its normal operation mode. The second (project period) is chosen to identify the types of deviations from the normal operation mode of blast furnace. The data are collected during this period within 2 hours.

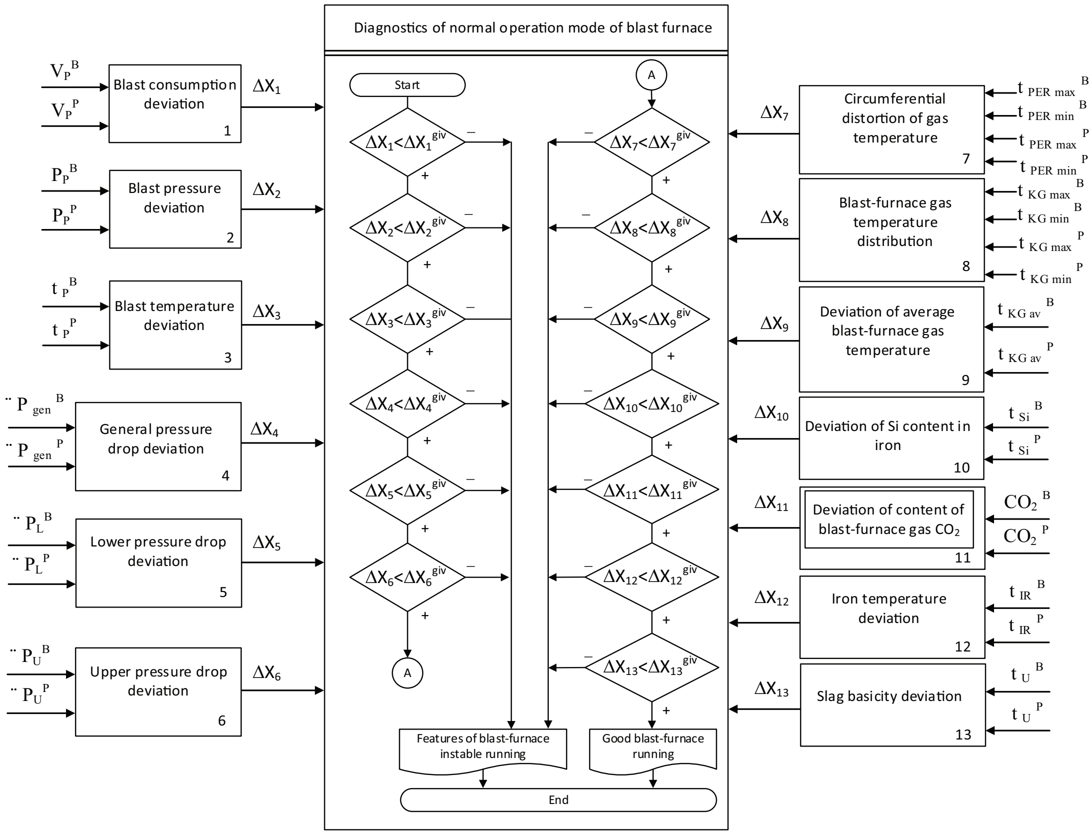

Figure 1: Fragment of algorithm identifying the deviations from the normal operation mode of blast-furnace melting.

The diagnostics of normal operation mode of blast-furnace and types of deviations from the normal operation mode of blast-furnace, the number of controlled and design (due to model) parameters for evaluation of these modes are represented in Table 1. Thus, 111 parameters including 40 complex design values are used to evaluate the blast-furnace melting operation.

4. Functional Modeling

The formation of functional model was the first stage of program product development. It was developed by means of AllFusion Process Modeler (BPwin) program according to IDEF0 (Integrated computer aided manufacturing DEFinition) standard. The use of IDEF0 technique provided an opportunity to create the functional structure of program complex, find out its activities and connections between those activities, administrative actions and mechanism to execute every function that finally allowed the prevention of possible errors in early stages of design.

Table 1: Number of controlled and design (due to model) parameters for evaluation of normal operation mode and types of deviations from the normal operation mode of blast-furnace.

Type of deviation from the normal operation mode	Number of controlled parameters	Number of complex design parameters	Total
Normal blast furnace operation mode	15	9	24
Violation of gas flow stability:			
– peripheral gas flow;	9	5	14
– central gas flow.	8	5	13
Violation of thermal melting condition:			
– hot course of melt,	8	4	12
– cold course of melt.	8	4	12
Violation of smooth descent of burned materials in the furnace:			
– upper suspension of burden;	8	4	12
– lower suspension of burden;	7	4	11
– tight furnace operation	8	5	13
Total:	71	40	111

The general number of decomposed blocks of functional model comprises 90 blocks. The fragment of 1st level chart of functional model for subsystem that predicts the occurrence of deviations in the course of blast furnace melting shown in Figure 2 embraces the following functions:

1. *'Data collection and preprocessing' (A1*) ensures the automatic filling of system with the data from CAPCS and enterprise information system (EIS).

2. *'Detection of features of normal blast furnace operation' (A2*) ensures the revaluation and analysis of parameters deviation features.

3. *'Detection of features of deviation from the normal blast furnace operation' (A3*) ensures the revaluation and analysis of such deviations as peripheral gas flow; central gas flow; hot course of melt; cold course of melt; tight furnace operation; upper suspension of burden; lower suspension of burden; number of feeds.

4. *'Development of recommendations on the maintenance technologies of blast furnace melting operation»' (A4*). The recommendations on the melt process correction are developed based on found deviations.

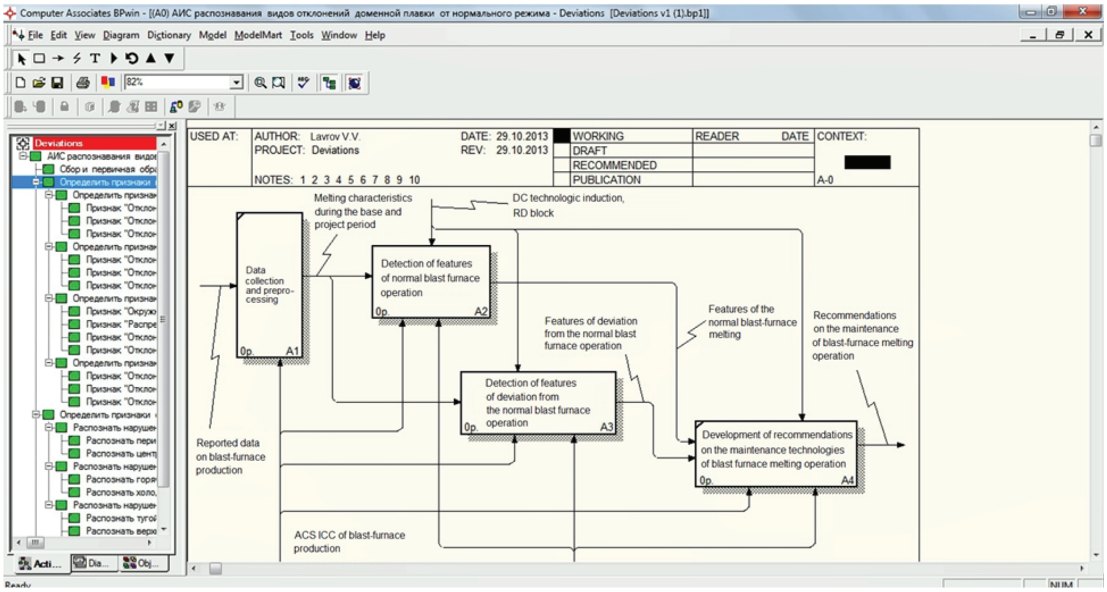

Figure 2: The first level of functional model of information system that identifies the types of blast-furnace melting deviations.

The results of functional modeling permitted to further proceed to the next stages of system development, that is, creating the software architecture and implementation.

Figure 3 shows the architecture of information system software in which the basic components of its implementation are pointed out.

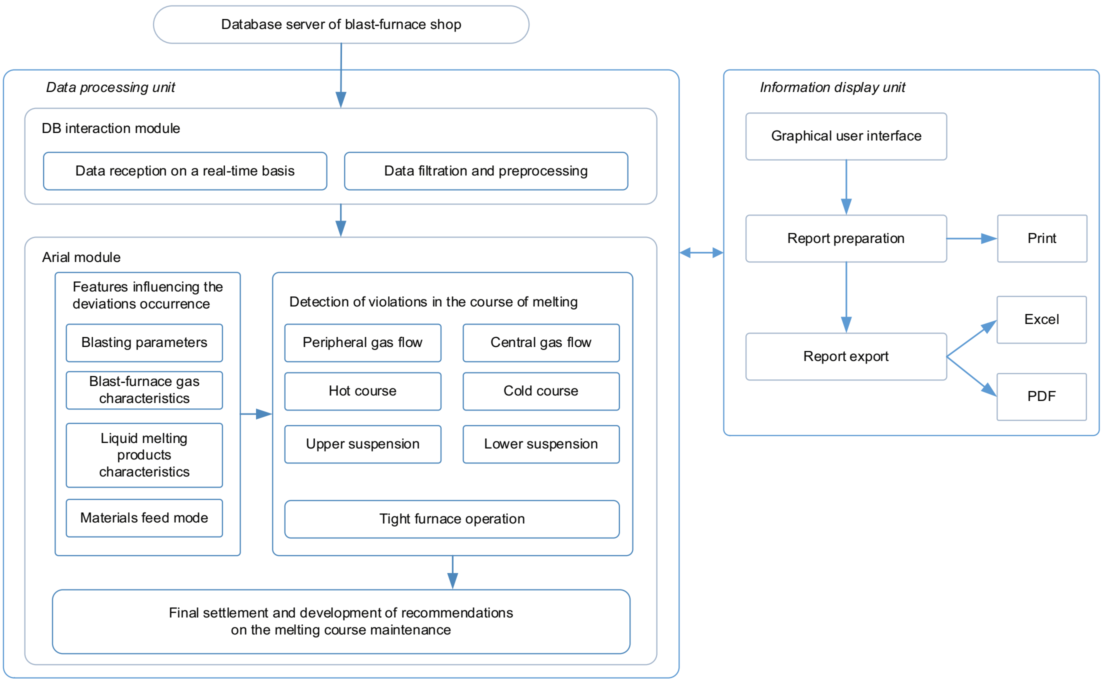

Figure 3: Software architecture.

The 'Identification of deviation type of blast-furnace melting operation' software in the form of web application is developed in accordance with the modern principles

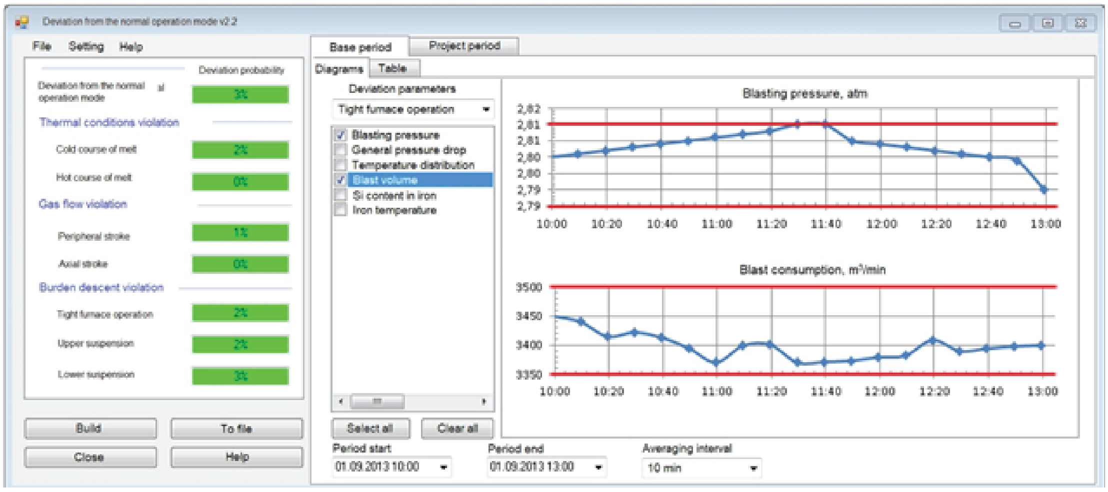

Figure 4: Fragment of software screen identifying the type of deviation of blast furnace melting from the normal operation mode.

of development of application programs (functionality, expandability, integration with databases, user-friendly interface, safety, information estimation)..NET technology is the basis for program implementation thus giving the additional freedom to choose the platform and programming language. The program product is written in C# language with the use of Microsoft Visual Studio 2015 programming environment.

The program module is a part of system that optimizes the technological process of blast furnace melting being included into the composition of automated information system of analysis and forecasting of manufacturing situations of 'MMK' PJSC blast-furnace shop and intended for the engineering and technology personnel.

Figure 4, as an example, shows the home screen of program where the blast furnace working state is represented. Three types of violations are considered in the course of analysis: thermal conditions violation, gas flow violation and burden descent violation. The state of every deviation is specified. Moreover, there is a possibility to provide the detail information on the deviation. The form represented in Figure 4 as diagram shows the information about parameters influencing the probability of occurrence of the certain deviation.

5. Summary

1. The logical-mathematical model and program product for evaluation of the blast-furnace melting operation that provides the user with an opportunity to promptly evaluate the melting course are developed.

2. The use of computer information logical system allows the operating personnel to perform the diagnostics of blast-furnace operation on a real-time basis as well as solve the operational tasks relating to the controlling of blast-furnace melting technology.

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