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Information modelling system for diagnostics of different types of blast-furnace smelting deviations from normal conditions

N A Spirin, O P Onorin, A S Istomin, V V Lavrov and I A Gurin

Ural Federal University n.a. the first President of Russia B.N. Yeltsin, 51 Lenina ave, Ekaterinburg, 620075, Russia

E-mail: n.a.spirin@urfu.ru

Abstract. A logic basis for assessment of normal progress of blast-furnace smelting and identification of different types of deviations from normal smelting conditions were developed, including peripheral gas stream, central (axial) gas stream, hot and cold run, tight furnace operation, upper and lower suspension of burden in the blast furnace. Both the complex of controlled characteristics and design parameters of the model-based decision support system (URFU-MMK model of blast-furnace process) are used for assessment. The main complex design parameters for diagnostics of blast-furnace smelting progress characterize heat, blast, gas dynamic and slag conditions, blast-furnace smelting rate in terms of quantity. Identification of Blast-Furnace Smelting Deviation Type software was developed in accordance with modern principles of application program development (functionality, expandability, database integration, user-friendly interface, security, data estimation). It is efficient to use the developed software in computer decision support systems for blast-furnace smelting control in real-time mode.

1. Introduction

High technical and economic performance of the blast furnace can be achieved only in a stable process of blast-furnace smelting without significant deviations from normal conditions of blast furnace operation.

Characteristics of normal operation of each furnace are, as a rule, well known and described in appropriate process instructions of the blast furnace plant. These instructions also describe possible deviations from normal conditions, characteristics of these deviations and measures to be taken to recover the normal conditions of blast-furnace smelting.

In conditions of quick-changing world and overall automation the problem of blast-furnace smelting diagnostics and control system implementation has not been solved yet.

Application of the automated information logic system for assessment of blast-furnace smelting progress and identification of deviations from normal conditions can be a solution to the problem of blast-furnace smelting state diagnostics. The logic basis for identification of deviations from normal conditions of blast-furnace smelting is described in papers [1-8].

2. Probability estimate of normal smelting operation

The calculation method is as follows. A set of characteristics is considered for two periods of furnace operation, i.e. base period and estimated period. The base period represents a set of assigned (reference) values characterizing the optimum conditions of furnace operation. The estimated period is a set of parameters for the last period between iron and slag tappings.

At normal operating conditions the deviation for the module of *i*-th characteristic ΔX_i describing furnace operation in the base $X_i^{Б}$ (assigned values) and estimated periods $X_i^{П}$ shall not exceed the allowable value $\Delta X_i^{доп}$, which is a model setting.

$$\Delta X_i = \left| X_i^{Б} - X_i^{П} \right| \leq \Delta X_i^{доп}. \quad (1)$$

If the condition (1) is fulfilled ("True"), the *i*-th identifier of P_i characteristic is assigned the value "1", otherwise ("False") – the value "0". All the characteristics herewith are being ranked. Each of them is assigned the value of its rank R_i varying in the range from 0 to 1, which is determined by the expert assessment method.

Probability of normal blast furnace operation ($B_н$) is calculated by the following proportion:

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

where α_i is a weight coefficient of *i*-th characteristic identifier varying in the range from 0 to 1; *n* is a number of characteristics.

The number of controlled characteristics used in the model for identification of normal conditions of blast furnace operation is 12.

Unlike well-known works of other authors, this study integrates sets of controlled characteristics and design parameters of blast-furnace smelting. The mathematical and program software uses additionally a set of nine main design parameters used in the model of blast-furnace process (URFU-MMK model of blast-furnace process) [9-16] and adapted with respect to conditions of Magnitogorsk Iron and Steel Works (MMK). Thus, the number of characteristics reaches 21.

The main complex design parameters for diagnostics of blast-furnace smelting operation refer to the following conditions:

- heat conditions – generalized parameters describing the thermal state: in the upper (thermal state index in the furnace stack) and lower (thermal state index in the bottom) parts of the blast furnace;
- gas dynamic conditions – degree of gas utilization for burden balancing in the upper and lower parts of the furnace, in particular ring areas, etc. Prediction and calculation of critical gas dynamic parameters of blast-furnace smelting;
- slag conditions – viscosity and viscosity polytherms of final slag: slag viscosity at the designed temperature, slag viscosity gradient within the range from 2.5 to 0.7 Pa*s, Pa*s/ °C, slag viscosity gradient within the range from 1400 to 1500°C, Pa*s/°C;
- smelting rate (volume of melted burden per time unit, m3/min).

3. Diagnostics of different types of blast-furnace smelting deviations from normal conditions

In case of deviations from normal furnace operation, the main types of deviations are analysed.

1. Loss of gas stream stability (peripheral, central and channel gas streams).
2. Disturbance of heat conditions of blast-furnace smelting (hot and cold run, furnace cooling and heating).

3. Failure of smooth burden descent in the furnace (upper and lower suspension of burden, tight operation).

To identify the type of smelting deviation from normal conditions of blast-furnace operation, we found it reasonable to compare parameters of two periods. The first period is the base period whose smelting parameter values $X_i^Б$ are a model setting and describe the normal operating conditions. The second period for identification of deviations from normal conditions of blast furnace operation is the estimated period where data are collected during the last period between tappings.

If there is a deviation from normal conditions of blast-furnace smelting, the difference between the values of ***i***-th characteristic ΔX_i describing furnace operation in the base $X_i^Б$ and estimated $X_i^П$ periods exceeds the allowable value $\Delta X_i^{доп}$.

$$\Delta X_i = \left(X_i^Б - X_i^П\right) \geq \Delta X_i^{доп} . \tag{3}$$

Identification probability of deviations from normal conditions, value $B_н^{отк}$ is calculated by the proportion similar to equation (2).

Diagnostics of deviations from normal conditions of blast-furnace smelting, number of controlled and design (by model) parameters for assessment of these conditions are given in table 1.

Table 1. Number of controlled and design (by model) parameters for assessment of deviations from normal conditions of blast-furnace smelting.

Type of deviation from normal conditions	Number of controlled parameters	Number of complex design parameters	Total
Loss of gas stream stability:			
– peripheral gas stream;	9	3	12
– central gas stream;	8	2	10
Disturbance of heat conditions of blast-furnace smelting:			
– hot run of smelting;	8	4	12
– cold run of smelting;	7	5	12
Failure of smooth burden descent in the furnace:			
– upper suspension of burden;	6	3	9
– lower suspension of burden;	3	3	6
– tight furnace operation;	6	6	12
Total:	47	26	73

4. Software implementation and example use of information logic system

Following development of the information logic system, it is logical to implement this system as a computer software enabling technical personnel to get on-line data about blast-furnace smelting operation and react appropriately in case of any deviations.

Software implementation is made with the use of functional modelling, .NET technology in C# language in Microsoft Visual Studio 2015. Due to convenience and huge functionality, this set of tools has recently become a de facto standard for development of desktop applications [17-19].

Table 2 shows a fragment of one variant for assessment of normal operation of Blast Furnace No.10 of MMK.

The probability value of normal progress of blast-furnace smelting equal to 0.63 implies normal conditions of smelting at the blast furnace in question.

The modelling results given in table 3 show that probability of deviations of any type from normal conditions does not exceed threshold limit values taken equal to 0.9.

Table 2. Probability calculation of normal progress of blast-furnace smelting.

No.	Characteristic, unit of measurement	Base period	Estimated period	Parameter deviation	Allowable deviation	Rank of characteristic, R_i	α_i	P_i
P_1	Blast low rate, m3/min	3422	4019	597	603	0.9	0.06	1
P_2	Blast temperature, °C	1147	1154	7	50	0.5	0.03	1
P_3	Total pressure drop, kPa	131	140	9	5	0.7	0.04	0
P_4	Lower pressure drop, kPa	92	98	6	3.5	0.8	0.05	0
P_5	Upper pressure drop, kPa	39	42	3	1.5	0.7	0.04	0
P_6	Circumferential distortion of gas temperature, °C	193	332	139	100	0.6	0.04	0
P_7	Non-uniform distribution of top gas temperature in gas pipes, °C	95	95	0	100	0.8	0.05	1
P_8	Deviation of averaged top gas temperature, °C	184	161	-23	100	0.8	0.05	1
P_9	Si content in hot metal, %	0.72	0.948	0.228	0.1	0.9	0.06	0
P_{10}	CO_2 content in top gas, %	20.26	19.21	-1.05	1	0.8	0.05	0
P_{11}	Hot metal temperature, °C	1416	1475	59	50	0.8	0.05	0
P_{12}	Slag basicity (CaO+MgO)/SiO_2, ratio	1.221	1.214	-0.007	0.05	0.9	0.06	1
P_{13}	Thermal state index at the bottom, ratio	1	1.1	0.1	0.05	0.9	0.06	0
P_{14}	Thermal state index at the furnace top, ratio	0.7	0.7	0	0.05	0.6	0.04	1
P_{15}	Degree of gas utilization for burden balancing, ratio	0.55	0.58	0.03	0.1	0.9	0.06	1
P_{16}	Degree of gas utilization for burden balancing in the upper part of the furnace, ratio	0.3	0.3	0	0.05	0.9	0.06	1
P_{17}	Degree of gas utilization for burden balancing in the lower part of the furnace, ratio	0.65	0.7	0.05	0.1	0.9	0.06	1
P_{18}	Viscosity of final slag at temperature 1500 °C, Pa*s	0.35	0.3	0.05	(0.05)	0.7	0.04	1
P_{19}	Slag viscosity gradient within the range (2.5-0.7 Pa*s), Pa*s/°C	0.0175	0.0185	0.001	0.005	0.7	0.04	1
P_{20}	Slag viscosity gradient within the range from 1400°C to1500°C, Pa*s/°C	0.005	0.0055	0.0005	0.001	0.8	0.05	1
P_{21}	Volume of melted burden per time unit, m3/min	6.5	6.75	0.25	0.5	0.8	0.05	1
	Probability of normal furnace operation, ratio							0.63

Table 3. Calculation results of blast-furnace smelting deviation probability in the estimated period.

No.	Deviation type	Deviation probability, ratio
1	Peripheral stream	0.169
2	Axial stream	0.208
3	Hot run	0.191
4	Cold run	0.172
5	Tight operation	0.265
6	Upper suspension of burden	0.097
7	Lower suspension of burden	0.000

5. Conclusion

The mathematical model of state diagnostics and blast-furnace smelting prediction was improved due to development of the logic model block using a set of controlled and design parameters.

A software was developed which enables to asses progress of blast-furnace smelting in real-time mode as well as types of deviations from normal conditions when necessary.

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