Information technologies and automatic control in ferrous metallurgy / **Информационные технологии и автоматизация в черной металлургии**

UDC 669.162.263
DOI 10.17073/0368-0797-2025-4-402-410

Original article
Оригинальная статья

Information modeling system for assessing instability of blast furnace functioning

N. A. Spirin, **I. A. Gurin, V. V. Lavrov**

Ural Federal University named after the first President of Russia B.N. Yeltsin (28 Mira Str., Yekaterinburg 620002, Russian Federation)

n.a.spirin@urfu.ru

Abstract. The article discusses the development of an information modeling system for assessing the instability of a blast furnace. The presented approach is based on the application of mathematical models and methods for analyzing the parameters of the blast furnace process, which makes it possible to assess the impact of technological and organizational factors on the furnace stability. The developed system is designed for automated collection, processing and analysis of data in real time, as well as forecasting technological deviations. The methodology is based on the use of integral stability indicators, including the technical and economic characteristics of smelting, the properties of raw materials, the parameters of blast, gas dynamic, thermal and slag modes. To determine the integral indicators, a set of controlled and calculated features is used, ranked according to the degree of significance. The main modules of the system include functional blocks for data collection, calculations, analysis and visualization. The system architecture is implemented on the basis of a client-server approach, which provides the possibility of integration with existing metallurgical production management systems. The practical implementation of the system makes it possible to improve the performance of blast furnace smelting, reduce fluctuations in the parameters of the technological process and improve the quality of the resulting cast iron. The above calculation examples confirm effectiveness of the developed tool. The presented results may be useful for the specialists in the field of blast furnace production automation, as well as for the researchers involved in analysis and forecasting of instability of technological processes.

Keywords: blast furnace, modeling, instability, information system, metallurgy, mathematical model

For citation: Spirin N.A., Gurin I.A., Lavrov V.V. Information modeling system for assessing instability of blast furnace functioning. *Izvestiya. Ferrous Metallurgy*. 2025;68(4):402–410. https://doi.org/10.17073/0368-0797-2025-4-402-410

Информационно-моделирующая система оценки нестабильности функционирования доменной печи

Н. А. Спирин, **И. А. Гурин, В. В. Лавров**

Уральский федеральный университет имени первого Президента России Б. Н. Ельцина (Россия, 620002, Екатеринбург, ул. Мира, 28)

n.a.spirin@urfu.ru

Аннотация. В статье рассматривается разработка информационно-моделирующей системы оценки нестабильности функционирования доменной печи. Представленный подход базируется на применении математических моделей и методов анализа параметров доменного процесса, что позволяет оценивать влияние технологических и организационных факторов на стабильность работы печи. Разработанная система предназначена для автоматизированного сбора, обработки и анализа данных в реальном времени, а также прогнозирования технологических отклонений. В основе методики лежит использование интегральных показателей стабильности, включая технико-экономические характеристики плавки, свойства сырья, параметры дутьевого, газодинамического, теплового и шлакового режимов. Для расчета интегральных показателей применяется совокупность контролируемых и расчетных признаков, ранжированных по степени значимости. Основные модули системы включают функциональные блоки сбора данных, расчетов, анализа и визуализации. Архитектура системы реализована на основе клиент-серверного подхода, что обеспечивает возможность интеграции с существующими системами управления металлургическим производством. Практическая реализация системы позволяет улучшить показатели производительности доменной плавки, снизить колебания параметров технологического процесса и повысить качество получаемого чугуна. Приведенные примеры расчетов подтверждают эффективность разработанного инструмента. Представленные результаты могут быть полезны для специалистов в области автоматизации доменного производства, а также для исследователей, занимающихся анализом и прогнозированием нестабильности технологических процессов.

Ключевые слова: доменная печь, моделирование, нестабильность, информационная система, металлургия, математическая модель

Для цитирования: Спирин Н.А., Гурин И.А., Лавров В.В. Информационно-моделирующая система оценки нестабильности функционирования доменной печи. *Известия вузов. Черная металлургия*. 2025;68(4):402–410. *https://doi.org/10.17073/0368-0797-2025-4-402-410*

Introduction

The development of information and control systems for blast furnaces aims to create an efficient management framework that ensures stable production while minimizing costs. These systems must account for technological requirements and the specific features of the equipment. To support the advancement of an automated system for analyzing the operating parameters of individual furnaces and the blast furnace shop as a whole, an information modeling system is being developed to assess process instability in blast furnace operations [1].

Fluctuations in charge composition [2 – 4] and smelting parameters [5 – 7] can significantly impact furnace performance. These variations affect the composition and temperature of the hot metal and lead to pressure losses in the burden's gas column. As a result, key parameters may exceed the limits defined by hot metal quality requirements and the need to maintain steady furnace operation under varying counterflow conditions [8; 9]. Several factors directly influence the furnace's thermal state and the resulting temperature and composition of the hot metal. These include the iron content in the charge, moisture and ash content of the coke, blast air temperature and humidity, natural gas consumption, the ratio of iron-bearing materials to coke, and their distribution at the furnace top [10 – 12]. Variations in these parameters lead to fluctuations in the furnace's thermal balance, causing deviations in the average silicon content and temperature of the hot metal. Instability in the smelting process, especially when using iron ore feedstock with variable chemical composition, can significantly degrade the quality of the molten blast furnace products. For example, reference data [5] show that reducing fluctuations in sinter basicity (CaO/SiO_2) by ±(0.075 – 0.100) units can increase blast furnace productivity by 1.5 % and lower specific coke consumption by 0.8 %.

The total potential benefit of reducing variability in blast furnace parameters is estimated at a 5 – 6 % reduction in coke consumption and a 9 – 10 % increase in productivity. Moreover, a 0.1 % reduction in the standard deviation of iron content in the burden results in a 0.28 % decrease in coke consumption and a 0.29 % increase in productivity [2]. Organizational factors that affect the process include furnace downtime, idle running, regularities in burden charging, and tapping schedules. The impact of some of these factors remains poorly studied and is proposed to be evaluated using empirical data [13 – 15]. These include the mechanical and physicochemical properties of raw materials and coke, as well as gas distribution within the furnace. Assessing their influence requires further research and development of mathematical process models.

Existing systems often lack the precision or flexibility to fully account for all factors affecting operational stability. This highlights the need for advanced information-based modeling systems capable of handling multiple variables and providing real-time analysis of blast furnace instability.

Algorithmic support of the information modeling system

To assess the smelting process stability, the following key integral indicators (B_1) have been developed:

1. Technical, economic, and technological performance indicators of smelting (B_1).

2. Indicators of raw material properties (iron ore materials, coke, fluxes) (B_2).

3. Indicators of blast and gas dynamic modes (B_3).

4. Indicators of the thermal mode (B_4).

5. Indicators of the slag mode (B_5).

6. An integral indicator of blast furnace operating stability based on B_3, B_4, B_5, characterizing the blast, gas-dynamic, thermal, and slag modes (B_{BF}).

7. Final stability indicator of raw material properties and overall blast furnace operation (B_{final}).

The types and number of features used in the assessment depend on the specific integral indicator being calculated.

In addition to controlled (measured) parameters, the stability assessment incorporates a set of calculated parameters that describe the blast conditions, gas dynamics, thermal and slag modes, and the technological parameters of blast furnace smelting, as detailed in [16 – 18].

The approximate number of features used for evaluating each integral indicator is provided in the Table.

For a given time interval of blast furnace operation, the root mean square (RMS) deviations ΔX_i of both controlled and calculated features are used as input data for computing each integral indicator (B_1).

Under stable operating conditions, the RMS deviation ΔX_i of the i-th feature – used to characterize furnace stability during the specified period – must not exceed a predefined threshold value ΔX_i^{pre}, which is a model setting:

Number of features used to calculate the stability indicators of the furnace operation

Количество признаков, используемых для расчета показателей стабильности работы печи

Designation	Indicator	Number of features		
		Controlled	Calculated	Total
B_1	Technical, economic, and technological performance indicators	6	6	12
B_2	Raw material properties (iron ore materials, coke, fluxes)	16	0	16
Blast furnace stability indicators				
B_3	Blast and gas dynamic modes	9	10	19
B_4	Thermal mode	4	7	11
B_5	Slag mode	6	4	10
Total features		41	27	68

$$\Delta X_i \le \Delta X_i^{\text{pre}}. \qquad (1)$$

If condition (1) is satisfied ("True"), the *i*-th feature identifier P_i is assigned a value of 1; otherwise ("False"), it is assigned a value of 0. All features are then ranked. Each feature is assigned a normalized rank value R_i, ranging from 0 to 1, determined using an expert evaluation method.

The stability of blast furnace operation for each of the integral indicators B_j is calculated using the following relationship:

$$B_j = \left(\sum_{i=1}^{n} P_i \frac{R_i}{\sum_{i=1}^{n} R_i} \right) \cdot 100\ \%, \qquad (2)$$

where n is the number of features associated with the given integral indicator B_j.

If the resulting value of B_j exceeds 80 % (according to normative and reference data), the furnace operation is considered stable with respect to that indicator.

If B_j falls within the range of 60 – 80 %, the furnace operation is assessed as unstable with respect to that indicator.

If B_j is below 60 %, the blast furnace is considered to have operated in an unstable mode for the corresponding integral indicator.

To determine the overall stability criteria for furnace operation and process conditions, the following integral indicators are calculated:

– the integral indicator of blast furnace operating stability B_{BF}, based on B_3, B_4, B_5, characterizing the blast, gas-dynamic, thermal, and slag modes:

$$B_{\text{BF}} = \left(\sum_{i=3}^{5} B_i \frac{R_i}{\sum_{i=3}^{5} R_i} \right) \cdot 100\ \%, \qquad (3)$$

– the final stability indicator of furnace operation:

$$B_{\text{final}} = \frac{B_1 R_1 + B_2 R_2 + B_{\text{BF}} R_{\text{BF}}}{R_1 + R_2 + R_{\text{BF}}}.$$

Key system requirements

Key system requirements are as follows:

– automated data collection: the system must automatically collect real-time data on blast furnace operating parameters;

– real-time visualization: the system must present analysis results in the form of graphs, tables, and charts that are easy for operating personnel to interpret;

– seamless integration: the system should integrate smoothly with the plant's existing process control systems.

Functional modeling of the information modeling system

The design of the information modeling system is based on functional modeling methodology and the IDEF0 graphical notation for structured analysis and design. The IDEF0 method is founded on the SADT (*Structural Analysis and Design Technique*) [19 – 21]. The model, developed using the Ramus Educational software package [21], consists of more than 50 blocks across four levels of decomposition. These blocks define the system's key functions, the relationships among functional units, the control inputs, and the execution mechanisms for each function.

Architecture of the information modeling system

The architecture of the developed information modeling system for assessing blast furnace operation instability is shown in Fig. 1. The system is divided into small, independent blocks – modules – each implementing a functionally complete segment of the program. This modular approach allows the functionality of individual components to be updated without requiring changes to the entire system, enhancing its reliability and scalability. The modules are implemented using mathematical libraries and classes [22].

The information modeling system includes the following modules:

– input module for entering the permissible values of the RMS deviations and the feature ranks (ΔX_i^{pre}, R_i);

– computation module for calculating the arithmetic means and RMS deviations of parameters characterizing the technical, economic, and technological indicators of smelting; the properties of raw materials (iron ore materials, coke, and fluxes); as well as the blast, gas-dynamic, thermal, and slag modes;

– module for calculating stability scores of blast furnace operation for each integral indicator B_j, the overall stability indicator B_{BF}, and the final stability indicator B_{final};

– analysis and output module for processing and presenting the results.

The output from the calculation modules is analyzed and presented in both numerical and graphical formats. The system also provides the option to generate and export reports in Microsoft Excel format.

Software implementation of the Information modeling system

The software implementation of the information modeling system is based on a client–server architecture, designed to to enable seamless integration with existing enterprise software and facilitate data exchange via an API (*Application Programming Interface*) [23]. The client–server model follows a classic three-tier architecture consisting of the presentation layer, application layer, and data layer.

The presentation layer is implemented using high-level web technologies: JavaScript, HTML5, and CSS (*Cascading Style Sheets*). The visual design is built using the Bootstrap *framework*, and the user interface is developed with the UmiJS and React libraries. Graph plotting is handled by Ant Design Charts. This layer is supported by the users' computing resources – specifically, their web browsers.

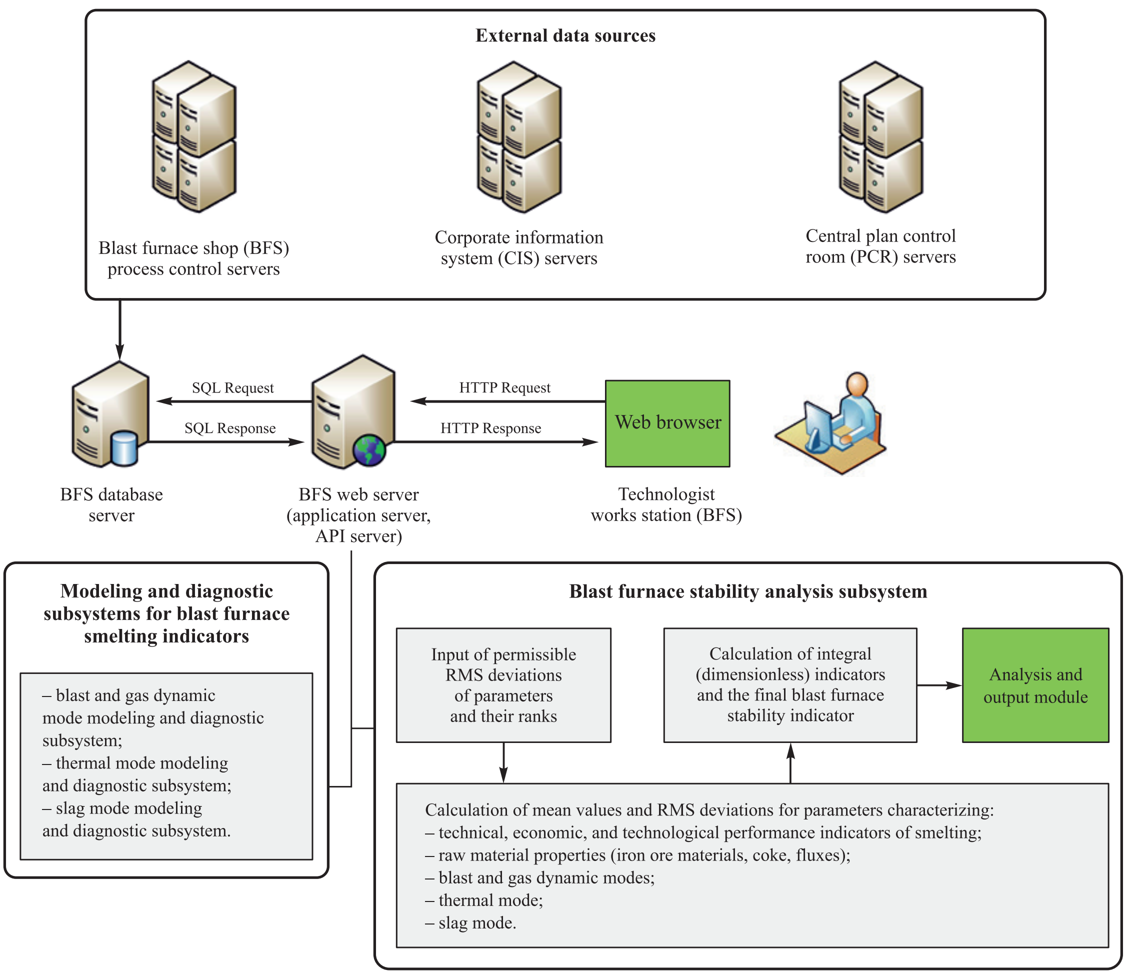

Fig. 1. Architecture of the information modeling system for assessing the instability of a blast furnace

Рис. 1. Архитектура информационно-моделирующей системы оценки нестабильности функционирования доменной печи

The application layer is developed in C# using the ASP.NET Core MVC framework and the .NET 8 platform [24]. ASP.NET Core handles user requests through a middleware pipeline, which includes the following components.

Error handling middleware, which enables the system to signal software-related issues when exceptions occur, and to continue functioning properly, including correctly displaying web pages in cases such as database connection failures, calculation algorithm errors, and other similar situations.

Authentication middleware, which integrates the standard ASP.NET Identity mechanism for authentication and authorization into the information system and manages user accounts.

Session middleware, which processes temporary user data during system usage.

Web API middleware, which incorporates the routing system, dependency injection, model binding, and data validation.

The data layer consists of a database and software components for managing read/write access. The system uses PostgreSQL as the database management system. Communication between the application and the database is handled via Entity Framework Core, which uses ORM (*Object-Relational Mapping*) technology. ORM allows developers to work with data as objects or classes in object-oriented programming languages and to build virtual database schemas. Input of initial blast furnace operation data for a given time period can be carried out either through the API and integration with the blast furnace process control systems (PCS) or manually.

Description of the information modeling system software functions

The developed software module provides the following capabilities:

1. Selection of operating periods via a calendar interface, with the option to set the data averaging interval (hour, shift, day, week, or hot metal tapping period).

2. Selection of one or more blast furnaces to be included in the analysis.

3. Calculation of average values and RMS deviations for a set of operational indicators.

4. Presentation of analysis results in an intuitive format, including tables and histograms; individual blast furnaces can be assigned distinct colors for baseline and comparison periods.

5. Notification of out-of-range values, with customizable alerts configured for all or selected blast furnaces.

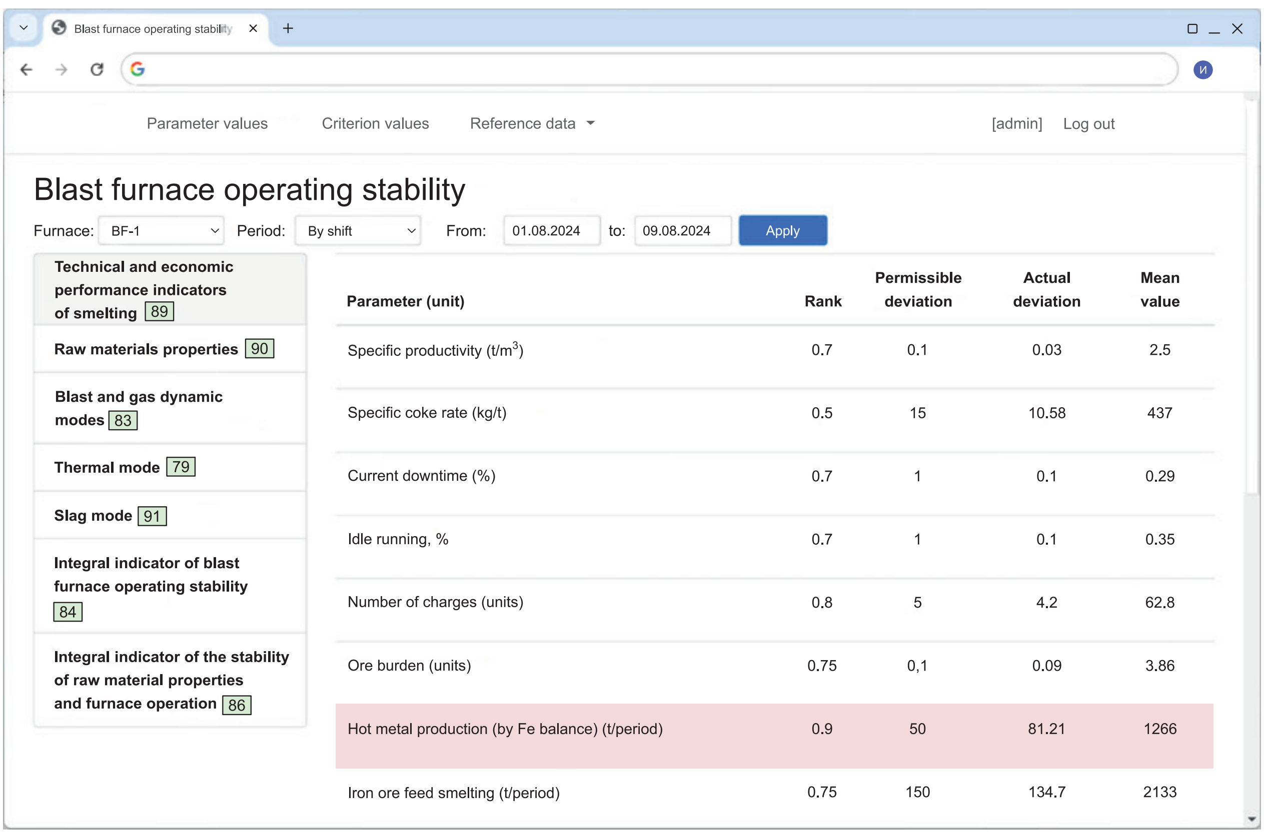

Fig. 2. Fragment of a web page for assessing the instability of technical, economic and technological indicators of a blast furnace

Рис. 2. Фрагмент веб-страницы оценки нестабильности технико-экономических и технологических показателей доменной печи

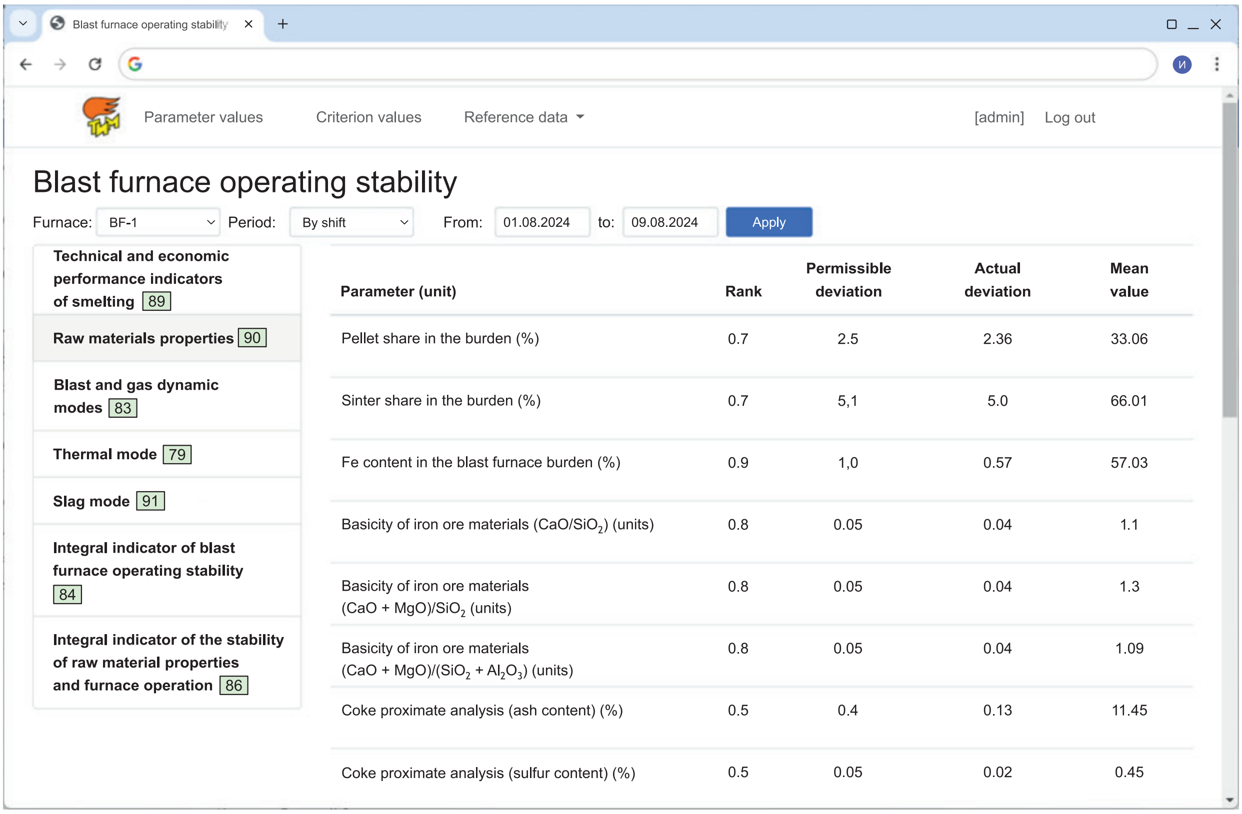

Fig. 3. Fragment of a web page for assessing the instability of raw material properties (iron ore materials, coke, fluxes)

Рис. 3. Фрагмент веб-страницы оценки нестабильности свойств сырья (железорудных материалов, кокса, флюсов)

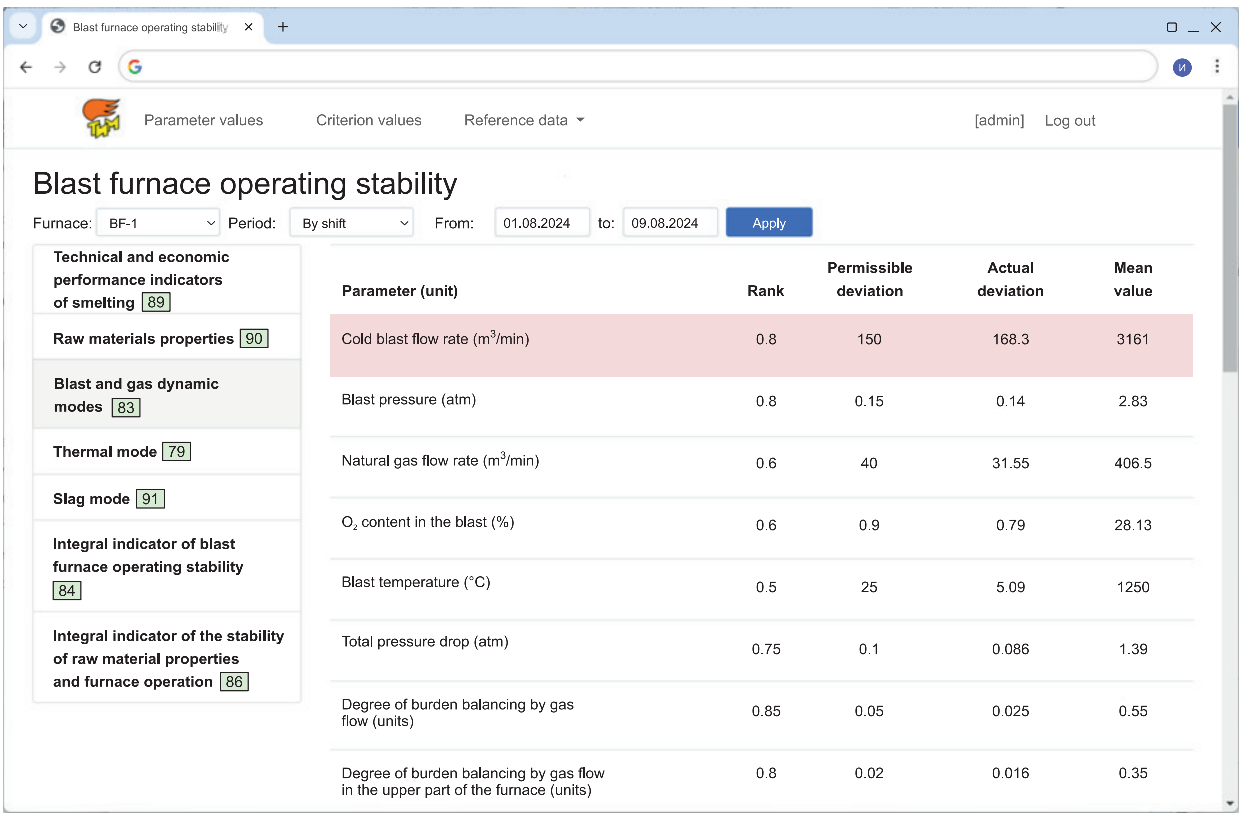

Fig. 4. Fragment of a web page for assessing the instability of indicators of blast and gas dynamic modes of a blast furnace

Рис. 4. Фрагмент веб-страницы оценки нестабильности показателей дутьевого и газодинамического режимов доменной печи

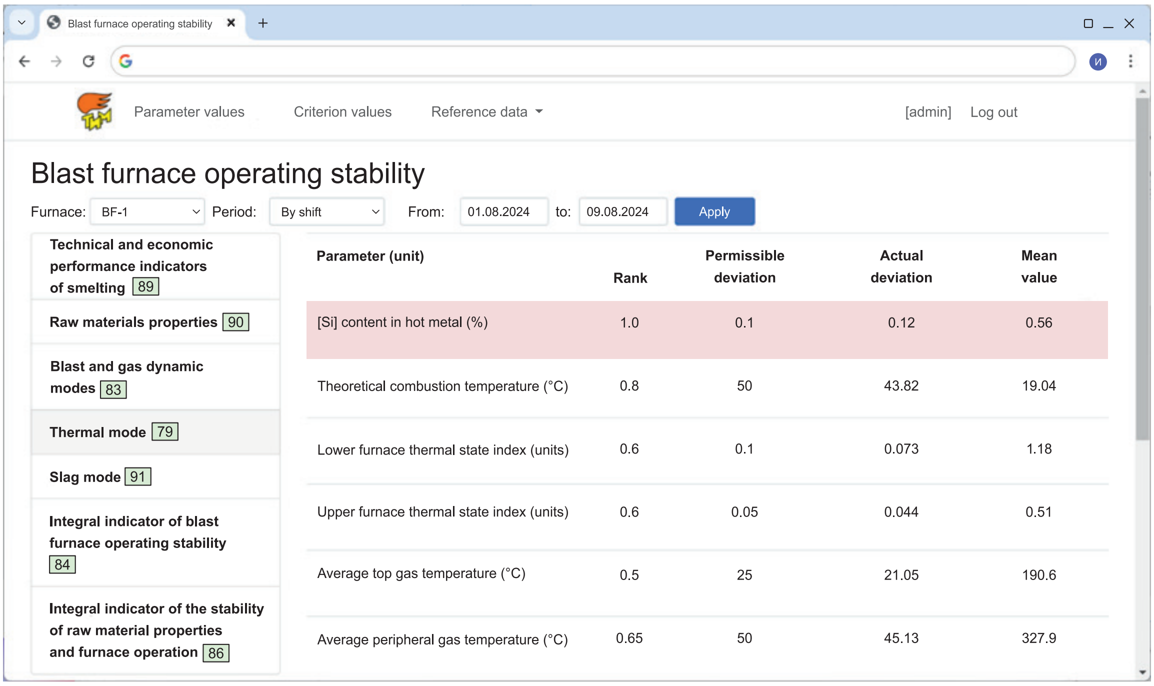

Fig. 5. Fragment of a web page for assessing the instability of thermal mode indicators

Рис. 5. Фрагмент веб-страницы оценки нестабильности показателей теплового режима

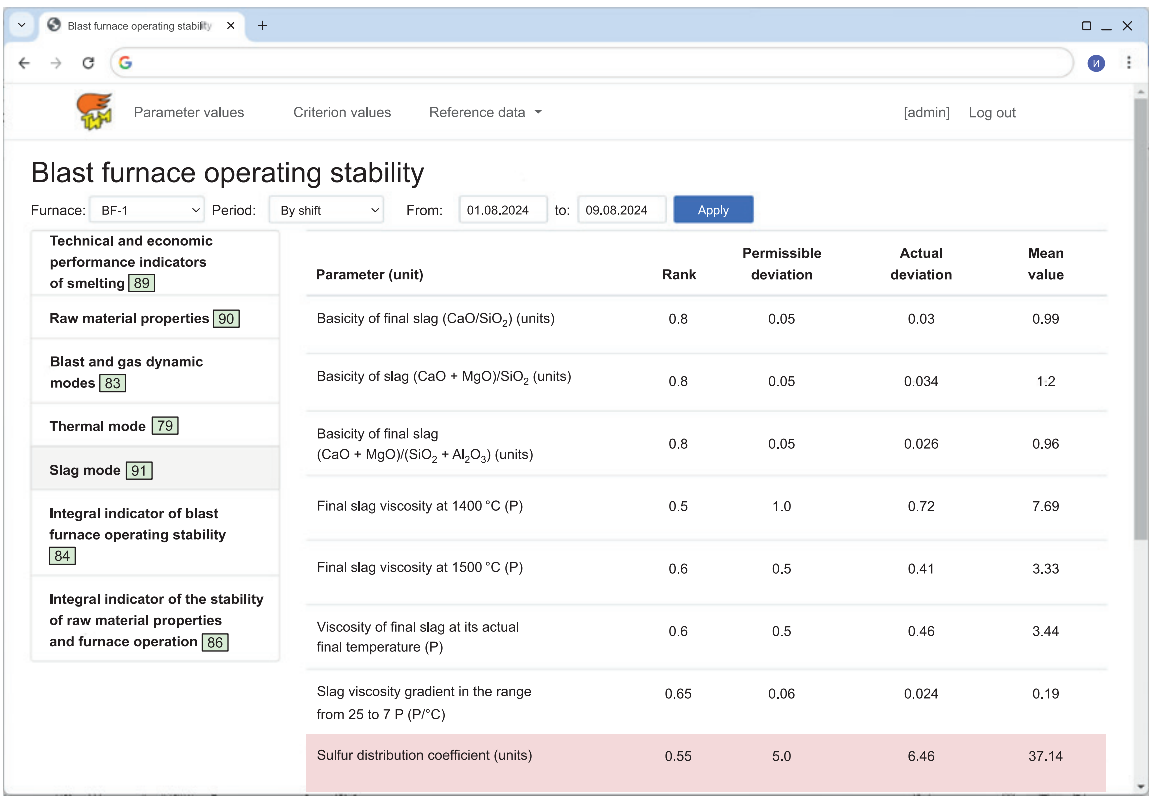

Fig. 6. Fragment of a web page for assessing the instability of slag mode indicators

Рис. 6. Фрагмент веб-страницы оценки нестабильности показателей шлакового режима

Figs. 2 – 6 show fragments of the system's web interface illustrating the modeling results of blast furnace instability assessment.

For the analyzed period, the modeling results indicated stable operation with respect to technical, economic, and technological indicators, raw material properties, blast and gas dynamic modes, and the slag mode. However, instability was observed in the thermal mode. The values of the integral indicators exceeded 80 %, indicating overall stable operation of the blast furnace.

Conclusions

Using modern information technologies, an information modeling system has been developed for evaluating the instability of blast furnace operation. The system supports automated data collection and processing, and calculates a set of parameters that characterize the technical, economic, and technological performance of the smelting process, raw material properties, and the thermal, blast, and gas dynamic modes, as well as the processing of molten blast furnace products.

References / Список литературы

1. Spirin N.A., Lavrov V.V., Gurin I.A., Zubakov S.V. Evaluation of blast furnace instability. In: *Automation Systems (in Education, Science and Production) AS'2024. Proceedings of the All-Rus. Sci. and Pract. Conf. (with Int. Participation).* Novokuznetsk: SibSIU; 2024:167–171. (In Russ.).

   Спирин Н.А., Лавров В.В., Гурин И.А., Зубаков С.В. Оценка нестабильности функционирования доменной печи. В кн.: *Системы автоматизации (в образовании, науке и производстве) AS'2024. Труды Всероссийской научно-практической конференции (с международным участием).* Новокузнецк: ИЦ СибГИУ; 2024:167–171.
2. Tovarovskii I.G. Blast-Furnace Smelting. Dnepropetrovsk: Porogi; 2009:768. (In Russ.).

   Товаровский И.Г. Доменная плавка. Днепропетровск: Пороги; 2009:768.
3. Tovarovsky I.G., Merkulov A.E. Analytical study of blast-furnace smelting processes and modes at various iron contents in the charge. *Ferrous Metallurgy. Bulletin of Scientific, Technical and Economic Information*. 2010;(4(1324)): 19–27. (In Russ.).

   Товаровский И.Г., Меркулов А.Е. Аналитическое исследование процессов и режимов доменной плавки при различных содержаниях железа в шихте. *Черная металлургия. Бюллетень научно-технической и экономической информации*. 2010;(4(1324)):19–27.
4. Gerdes M., Chenault R., Kurunov I., Lingardi O., Ricketts D. Modern Blast Furnace Process. Moscow: Metallurgizdat; 2016:280. (In Russ.).

   Современный доменный процесс / М. Геердес, Р. Ченьо, И. Курунов, О. Лингарди, Д. Риккетс. Москва: Металлургиздат; 2016:280.
5. Ostroukhov M.Ya., Shparber L.Ya. Guide of Blast Furnace Master. Moscow: Metallurgiya; 1977:304. (In Russ.).

   Остроухов М.Я., Шпарбер Л.Я. Справочник мастера-доменщика. Москва: Металлургия; 1977:304.
6. Bolshakov V.I., Semenov Y.S., Ivancha N.G., Vishnyakov V.I., Shumelchik E.I., Podkorytov A.L., Semion I.Y., Kuznetsov A.M., Zubenko A.V. Study of the flow of burden materials and their distribution on the furnace top of a modern blast furnace. *Metallurgical and Mining Industry*. 2012;4(3):158–165.
7. Bol'shakov V.I. The Technology of High-Efficiency Energy-Saving Blast Furnace Smelting. Kyiv: Naukova dumka; 2007:411. (In Russ.).

   Большаков В.И. Технология высокоэффективной энергосберегающей доменной плавки. Киев: Наукова думка; 2007:411.
8. Bol'shakov V.I., Murav'eva I.G., Semenov Yu.S. Forecasting the thermal condition of blast furnace hearth. *Stal'*. 2009;(5):7–9. (In Russ.).

   Большаков В.И., Муравьева И.Г., Семенов Ю.С. Прогнозирование теплового состояния горна доменной печи. *Сталь*. 2009;(5):7–9.
9. Babarykin N.N. Theory and Technology of Blast Furnace Process. Magnitogorsk: MSTU; 2009:257. (In Russ.).

   Бабарыкин Н.Н. Теория и технология доменного процесса. Магнитогорск: МГТУ; 2009;257.
10. Fojtik D., Tuma J., Faruzel P. Computer modelling of burden distribution in the blast furnace equipped by a bell-less top charging system. *Ironmaking & Steelmaking*. 2021;48(10):1226–1238.
    https://doi.org/10.1080/03019233.2021.1952829
11. Cameron I., Sukhram M., Lefebvre K., Davenport W. Blast Furnace Ironmaking: Analysis, Control and Optimization. 1st ed. Elsevier Science; 2019:828.
    https://doi.org/10.1016/C2017-0-00007-1
12. Gordon Y., Izumskiy N., Matveienko G., Chaika O., Lebid V., Vyshinskya O. Diagnostics, optimization and mathematical models of coke-sinter-hot metal production process. In: *AISTech 2019 – Proceedings of the Iron & Steel Technology Conference*. 2019;2019:479–484.
    https://doi.org/10.33313/377/050
13. Agrawal A., Agarwal M.K., Kothari A.K., Mallick S. A mathematical model to control thermal stability of blast furnace using proactive thermal indicator. *Ironmaking & Steelmaking*. 2019;46(2):133–140.
    https://doi.org/10.1080/03019233.2017.1353765
14. Ueda S., Natsui S., Nogami H., Yagi J., Ariyama T. Recent progress and future perspective on mathematical modeling of blast furnace. *ISIJ International*. 2010;50(7):914–923.
    https://doi.org/10.2355/isijinternational.50.914
15. Taylor A.G. The application of principal component analysis for predicting blast furnace stability. *IFAC Proceedings Volumes*. 1998;31(23):223–226.
    https://doi.org/10.1016/S1474-6670(17)35884-6
16. Pavlov A.V., Onorin O.P., Spirin N.A., Lavrov V.V., Gurin I.A. Some Issues of Technology, Management and Diagnostics of Blast Furnace Smelting. Yekaterinburg: AMK "Den' RA"; 2023:282. (In Russ.).

    Некоторые вопросы технологии, управления и диагностики доменной плавки: монография / А.В. Павлов, О.П. Онорин, Н.А. Спирин, В.В. Лавров, И.А. Гурин. Екатеринбург: АМК «День РА»; 2023:282.
17. Spirin N.A., Lavrov V.V., Rybolovlev V.Yu., Krasnobaev A.V., Onorin O.P., Kosachenko I.E. Model Decision Support Systems in the Automated Process Control System of Blast Furnace. Yekaterinburg: UrFU; 2011:462. (In Russ.).

    Модельные системы поддержки принятия решений в АСУ ТП доменной плавки: монография / Н.А. Спирин, В.В. Лавров, В.Ю. Рыболовлев, А.В. Краснобаев, О.П. Онорин, И.Е. Косаченко. Екатеринбург: УрФУ; 2011:462.

18. Spirin N.A., Lavrov V.V., Rybolovlev V.Yu., Gileva L.Yu., Krasnobaev A.V., Shvydkii V.S., Onorin O.P., Shchipanov K.A., Burykin A.A. Mathematical Modeling of Metallurgical Processes in Automated Process Control. Yekaterinburg: UrFU; 2014:558. (In Russ.).

Математическое моделирование металлургических процессов в АСУ ТП / Н.А. Спирин, В.В. Лавров, В.Ю. Рыболовлев, Л.Ю. Гилева, А.В, Краснобаев, В.С. Швыдкий, О.П. Онорин, К.А. Щипанов, А.А. Бурыкин; под ред. Н.А. Спирина. Екатеринбург: УрФУ; 2014:558.

19. Methodology of functional modeling IDEF0. State standard of Russia. Moscow: IPK "Izdatel'stvo standartov"; 2000:75.

Методология функционального моделирования IDEF0. Госстандарт России. Москва: ИПК «Издательство стандартов»; 2000:75.

20. Waissi G.R., Demir M., Humble J.E., Lev B. Automation of strategy using IDEF0 – A proof of concept. *Operations Research Perspectives*. 2015;2:106–113. https://doi.org/10.1016/j.orp.2015.05.001

21. Popov A.I. Free Tools for Designing Information Systems. Moscow: IPK "Izdatel'stvo standartov"; 2014;78. (In Russ.).

Попов А.И. Свободные инструменты проектирования информационных систем. Москва: ИПК «Издательство стандартов»; 2014:78.

22. Gurin I.A., Lavrov V.V., Spirin N.A., Nikitin A.G. Web-technologies for construction of automated information-modeling systems of technological processes in metallurgy. *Izvestiya. Ferrous Metallurgy*. 2017;60(7):573–579. (In Russ.). https://doi.org/10.17073/0368-0797-2017-7-573-579

Гурин И.А., Лавров В.В., Спирин Н.А., Никитин А.Г. Веб-технологии построения автоматизированных информационно-моделирующих систем технологических процессов в металлургии. *Известия вузов. Черная металлургия*. 2017;60(7):573–579. https://doi.org/10.17073/0368-0797-2017-7-573-579

23. Peralta J.H. Microservice APIs in Python: Using Python, Flask, Fastapi, Openapi and More. Manning Publications; 2023:425.

Перальта Х. Микросервисы и API. Санкт-Петербург: Питер; 2024:464.

24. Price M.J. C# 10 and .NET 6 – Modern Cross-Platform Development. 6th Ed. Packt Publishing; 2021:826.

Прайс М. C# 10 и .NET 6. Современная кросс-платформенная разработка, 6-е изд.: пер. с англ. Санкт-Петербург: Питер; 2023:848.

Information about the Authors

***Nikolai A. Spirin**, Dr. Sci. (Eng.), Prof., Head of the Chair "Thermal Physics and Informatics in Metallurgy"*, Ural Federal University named after the First President of Russia B.N. Yeltsin
ORCID: 0000-0001-6582-3428
E-mail: n.a.spirin@urfu.ru

***Ivan A. Gurin**, Cand. Sci. (Eng.), Assist. Prof. of the Chair "Thermal Physics and Informatics in Metallurgy"*, Ural Federal University named after the First President of Russia B.N. Yeltsin
ORCID: 0000-0002-4989-7029
E-mail: ivan.gurin@urfu.ru

***Vladislav V. Lavrov**, Dr. Sci. (Eng.), Prof. of the Chair "Thermal Physics and Informatics in Metallurgy"*, Ural Federal University named after the First President of Russia B.N. Yeltsin
ORCID: 0000-0002-6953-5519
E-mail: v.v.lavrov@urfu.ru

Сведения об авторах

***Николай Александрович Спирин**, д.т.н., профессор, заведующий кафедрой теплофизики и информатики в металлургии*, Уральский федеральный университет имени первого Президента России Б.Н. Ельцина
ORCID: 0000-0001-6582-3428
E-mail: n.a.spirin@urfu.ru

***Иван Александрович Гурин**, к.т.н., доцент кафедры теплофизики и информатики в металлургии*, Уральский федеральный университет имени первого Президента России Б.Н. Ельцина
ORCID: 0000-0002-4989-7029
E-mail: ivan.gurin@urfu.ru

***Владислав Васильевич Лавров**, д.т.н., профессор кафедры теплофизики и информатики в металлургии*, Уральский федеральный университет имени первого Президента России Б.Н. Ельцина
ORCID: 0000-0002-6953-5519
E-mail: v.v.lavrov@urfu.ru

Contribution of the Authors

N. A. Spirin – creating the article idea, justifying the topic relevance, conceptualization, preparing a detailed plan and draft version of the article, preparing examples of practical implementation of modern information systems in industry, selecting references, final editing, preparing a conclusion.
I. A. Gurin – development of the sections content related to the development and software implementation of modern information systems in metallurgy, preparing abstracts and keywords, translation of the article materials into English.
V. V. Lavrov – development of the main sections content, selection and verification of references, preparing of the article materials for publication.

Вклад авторов

Н. А. Спирин – идея статьи, обоснование актуальности темы, подготовка концепции, развернутого плана и чернового варианта статьи, подготовка примеров практической реализации современных информационных систем в промышленности, подбор библиографических ссылок, окончательная правка, подготовка заключения.
И. А. Гурин – проработка содержания разделов, связанных с разработкой и программной реализацией современных информационных систем в металлургии; подготовка аннотации и ключевых слов, перевод на английский язык материалов статьи.
В. В. Лавров – проработка содержания основных разделов, подбор и проверка библиографических ссылок, подготовка материалов статьи к публикации.

Received 22.02.2025
Revised 21.03.2025
Accepted 24.03.2025

Поступила в редакцию 22.02.2025
После доработки 21.03.2025
Принята к публикации 24.03.2025