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Blast Furnace Shaft Thermal State Monitoring System

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Abstract—A system is proposed for thermal monitoring over the height and circumference of the shaft in a blast furnace operated by Metinvest Holding, LLC. The reasons for the development of the system are outlined; the requirements on information presentation are noted; and experience with the system in blast-furnace management is described.

Keywords: blast furnace, smelting, furnace lining, thermocouples, monitoring system, charging conditions, batch, air tuyeres, slag coating, gas fluxes, gas temperature, pulverized-coal injection

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Automation is essential to the further development of blast-furnace operation. In recent years, blast furnaces have been equipped with improved automatic systems and systems for parameter stabilization. Many operational parameters are monitored and automatically controlled in current furnaces. As a rule, however, the monitoring systems and data-display systems employed in blast-furnace automation do not permit the operator to make effective and timely use of the information in furnace management. For example, in most cases, the information from thermocouples and other sensors is displayed as time plots of the readings. That prevents detailed assessment of the parameter variation for the furnace as a whole or assessment of the state of individual regions over the circumference or height of the furnace—for example, when thermocouples are installed in the furnace lining. Hence, for effective use, the information provided by the monitoring system should be as complete as possible. For example, the data should be preliminarily analyzed to eliminate unreliable values from malfunctioning sensors and also to eliminate atypical circumstances such as furnace downtime. (The furnace operator may specify which circumstances fall within that category.) The information must also be presented as the average for any specified time interval and for any specified combination of sensors over the height and circumference of the furnace shaft.

In the present work, we outline our experience in developing a system for thermal monitoring over the height and circumference of the furnace shaft in a blast furnace operated by Metinvest Holding, LLC. This furnace is equipped with a nonconical charging system and up-to-date monitoring instruments, including thermocouples in the furnace lining [1, 2]. Those thermocouples are installed at a depth of 100 mm; the design thickness of the lining is 300 mm. Thermocouples are positioned at six levels within the shaft and also at the bosh and bosh extension and below the tuyeres. Eight thermocouples are distributed around the circumference, at the level of the bosh and bosh extension and at the three lower levels of the shaft. At the two higher levels, there are six thermocouples around the circumference; and at the highest level four are used (Fig. 1) [1, 2].

Two different refractories are used at different heights of the furnace shaft.

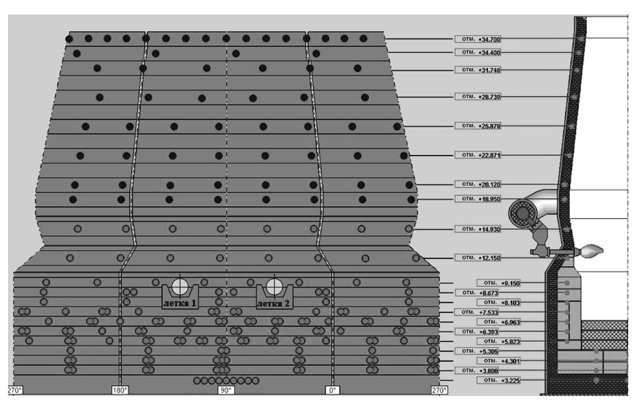

Fig. 1. Distribution of thermocouples over the height and circumference of the blast furnace.

(1) A refractory with high silicon-carbide content for the zone from the bottom of the bosh to the middle of the shaft. This ensures durability of the material in contact with the hot metal and the slag. In addition, the excellent heat conduction of the refractory tends to decrease the temperature of the hot refractory surface, with the subsequent formation of a protective slag coating, while maintaining high strength.

(2) A refractory with high content of fireclay-based alumina for the middle and upper sections of the shaft. This ensures high resistance to chemical action and abrasive wear in the reducing atmosphere.

The development of a system for thermal monitoring over the height and circumference of the furnace is prompted by the need for effective utilization of the information from the thermocouples in order to manage blast-furnace operation. Visualization of the information as trend lines in real time is not adequate to that purpose. The intended functions of the thermal monitoring system include the following.

(1) Assessment of the remaining lining thickness on the basis of the variation in the mean monthly temperature.

(2) Determination of the coating formed in the lower part of the furnace.

(3) Monitoring of the distribution of the peripheral gas flow over the height and circumference of the furnace, so as to assess the effectiveness of the charging conditions and select the geometric parameters of the air tuyeres and also the positions of the closed tuyeres.

The first step in the process was to investigate the influence of various factors on the temperature of the shaft lining over five years of blast-furnace operation. In this period, the furnace was repaired twice, with shotcreting of the shaft [2]. The limiting temperatures corresponding to partial or complete lining wear were determined. Likewise, the limiting temperatures in the lower part of the furnace corresponding to a stable coating were established. At a mean monthly lining temperature of 400°C in the middle and upper sections of the shaft, considerable wear was observed. Then the lining destruction slowed. With increase in mean monthly temperature to 450°C, as shown by two runs, the lining in the middle and upper sections of the shaft completely disintegrated.

With a mean monthly temperature of 300°C at the bottom of the shaft and in the bosh and bosh extension, an unstable coating formed in the lower part of the furnace. That entailed correction of the batch composition and the conditions in which it was formulated. Lining temperatures above 300°C in the lower part of the furnace indicated complete lack of a protective coating. Mean monthly lining temperatures above 350°C in the lower part of the furnace were not observed over a period of five years. If recorded, such readings could have indicated disintegration of the lining [2].

In addition, the temperature distribution of the peripheral gas flow over the furnace height was studied with practically no lining. These measurements were made two years after shotcreting of the furnace shaft and also for particular blast conditions: the use of wet blast in gas-free batch; the use of a blast containing natural gas; and pulverized-coal injection. The temperature distributions observed for the gas flow permitted the identification of the position where the zone of viscoplastic states begins [3]. Thus, the results obtained in this preliminary research permitted the development of algorithms for the proposed thermal monitoring system.

The purpose of the thermal monitoring system is to support decision making in blast-furnace operation on the basis of information regarding the distribution of the lining temperature in the shaft, bosh and bosh extension, and upper hearth. In particular, it must aid in the selection of the air-tuyere diameter and the number and configuration of closed tuyeres; in correcting the azimuthal batch distribution; and in monitoring the position where the zone of viscoplastic states begins. Since pulverized-coal injection is accompanied by intense lining wear, it is particularly important to monitor the state of the lining and to take timely decisions regarding the required correction of the charging conditions or the blast parameters [4]. If regulation of the pulverized-coal injection among individual tuyeres is possible, the thermal monitoring system permits adjustments in response to changes in lining temperatures over the furnace circumference.

The system permits display of the information as follows. The thermocouple data at nine levels from the tuyere band to the upper level of the shaft are assigned to sectors corresponding to standard positions of the charging trough: 30°–90°, 90°–150°, 150°–210°, 210°–270°, 270°–330°, 330°–0°–30°. The choice of 60° sectors permits successive control of the azimuthal batch distribution. Where necessary, the sectors may be linked to furnace equipment: the air tuyeres, hot-metal tap holes, inclined bridges, and blast supply points.

The lining temperatures over the six sectors may be displayed on the basis of mean hourly, daily, or monthly data, as a scan over the furnace or dynamically (Fig. 2). A single level or several averaged levels of the thermocouples may be selected (shown by the symbol ☑ in the display). In each sector, the mean temperature is denoted by means of colors ranging from blue (the lowest temperatures) to red (the highest). In addition, the temperature over the height of the furnace may be displayed (on the right side of Fig. 2), in terms of averages over the furnace, over each sector, or over several averaged sectors. (Once again, the selected sectors are shown by the symbol ☑ in the display).

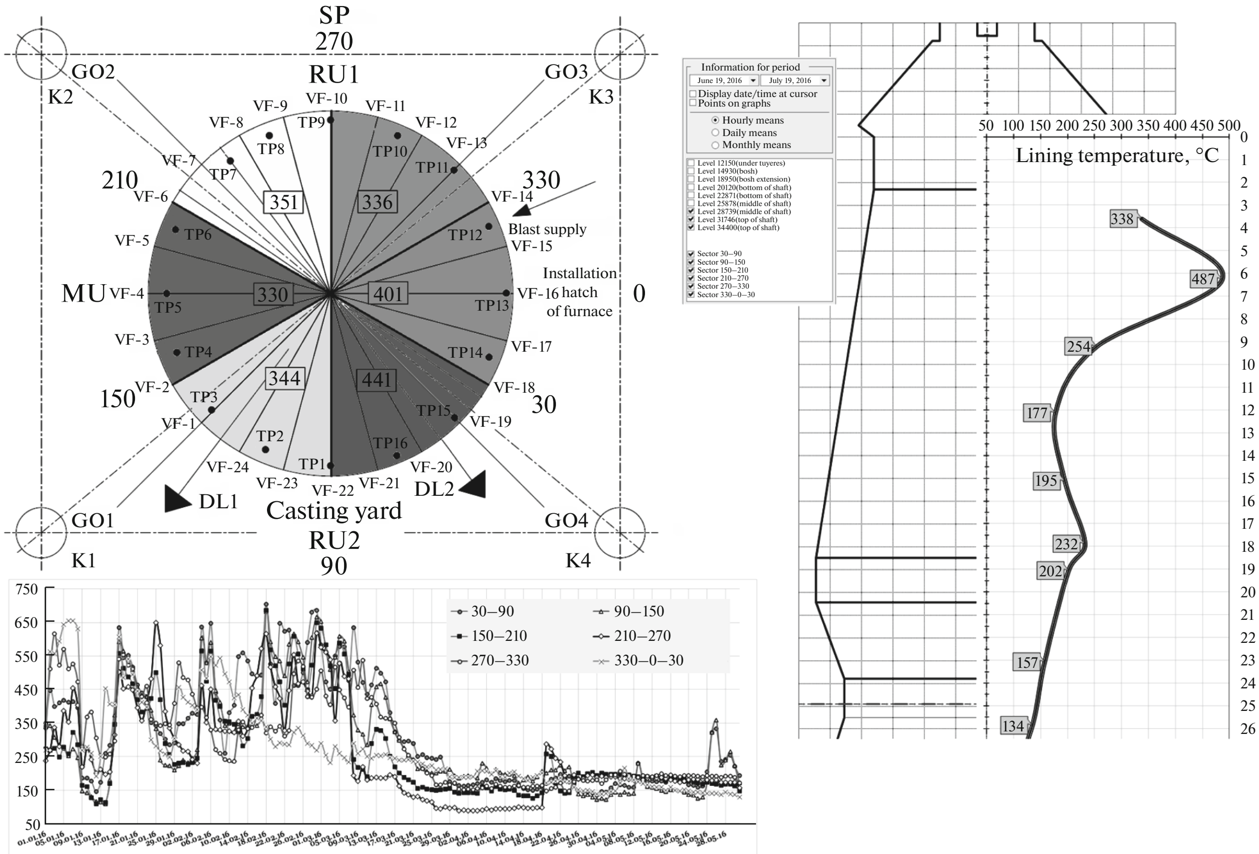

Fig. 2. Screen shot of the system for thermal monitoring over the height and circumference of the furnace.

As an example, consider the use of the thermal monitoring system in regulating the distribution of the lining temperature over the circumference of the blast furnace. In Fig. 3, we show fragments of video images for two operating periods: before (August 19–30, 2016) and after (August 31–September 9, 2016) the change in position of the closed air tuyeres. The latter configuration is associated with high lining temperatures in the 330°–0°–30° sector over the whole furnace height. To assess the influence of the closed tuyeres on the lining temperature, we use a coefficient characterizing the number of open tuyeres in the sector. If this coefficient is 1.0, all the tuyeres in the sector are open; if it is 0.0, they are all closed. In the given operating periods, the coefficient declines from 0.67 to 0.52 in the 30°–90° sector; and rises from 0.70 to 0.80 in the 330°–0°–30° sector. In the other sectors, the coefficient remains unchanged: 0.62 in the 90°–150° sector, 0.60 in the 150°–210° sector; and 0.80 in the 210°–270° and 270°–330° sectors.

As a result of the change in position of the closed air tuyeres, the azimuthal nonuniformity of the lining temperatures is reduced, and their mean values fall. For example, the mean lining temperatures at the bottom of the shaft and in the bosh and bosh extension decline by 33°C: from 264 to 231°C. Likewise, the lining temperatures in the middle and upper sections of the shaft fall by 88°C: from 476 to 388°C. This is due to redistribution of the gas flow from the periphery to the center, in view of the increased height of the tuyeres in the furnace's working space. In addition, the redistribution of the gas flow in the second period decreases the coke consumption by 1.7%, with practically no change in the consumption of pulverized coal and coke nuts, in the blast temperature, or in the characteristics of the iron ore and coke.

CONCLUSIONS

A system for thermal monitoring over the height and circumference of the furnace has been developed. This system supports decision making in the course of blast-furnace operation on the basis of data regarding the lining temperature in the shaft, bosh, and bosh extension.

The information provided by the monitoring system assists in the selection of the air-tuyere diameter and the number and configuration of closed tuyeres; in correcting the azimuthal batch distribution; and in monitoring the position where the zone of viscoplastic states begins.

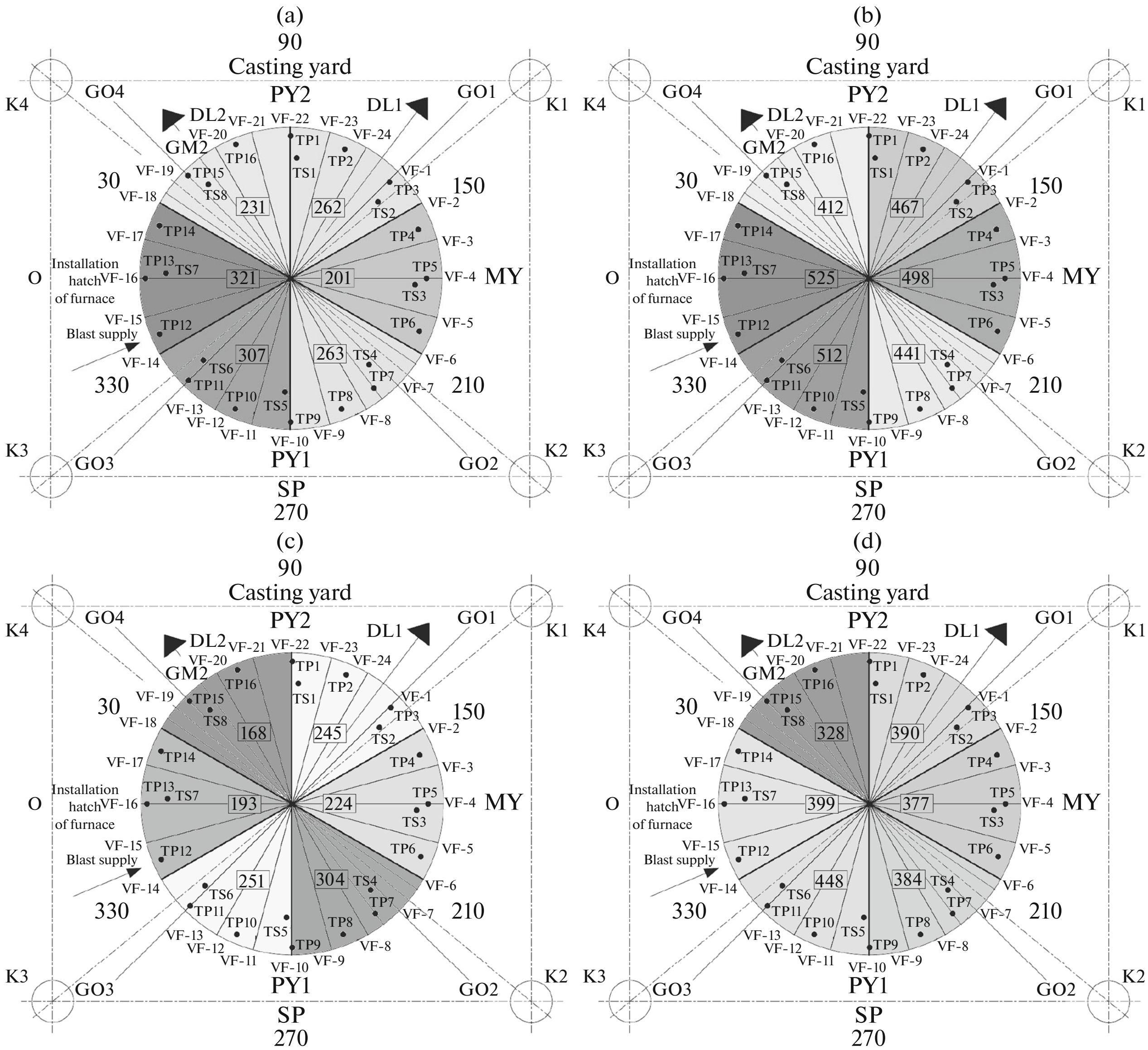

Fig. 3. Fragments of the images from the system for thermal monitoring over the height and circumference of the furnace before (a, b) and after (c, d) change in position of the closed air tuyeres: Temperature distribution of the lining of the bottom of the shaft and in the bosh and bosh extension (a, c) and in the middle and upper sections of the shaft (b, d) for the periods August 19–30, 2016 (a, b) and August 31–September 9, 2016 (c, d).

Since pulverized-coal injection is accompanied by intense lining wear, it is particularly important to monitor the state of the lining and take timely decisions regarding the required correction of the charging conditions or the blast parameters. The proposed system meets that need.

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