Improving the heat insulation efficiency of the blast furnace tuyere

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Abstract. A proposed method to increase the service life of the heat-insulating insert in the air passage of the blast furnace tuyere suggested gluing heat-resistant siliceous fabric onto its outer surface, and to reduce heat loss and increase the tuyere resistance to burnout, fixing a ceramic disk to the end of the tuyere’s nose. The necessity of measures to increase the service life of a heat-insulating insert in the tuyere was justified by simulating its stress state in Ansys. The use of heat-resistant siliceous fabric on the entire outer surface of the insert allowed a more than twofold increase in the insert’s service life compared to the option when the fabric was glued to the insert part from the flange to the gas pipe. Using simulation of the tuyere’s thermal state in a DEFORM–2D environment and industrial experiments, the possibility of reducing heat loss and protecting the tuyere from burnout by thermal insulation of the end of its nose using a ceramic disk is shown.

1. Introduction

The development and improvement of metallurgical production requires a number of technical, process and organizational problems to be solved [1-22].

Tuyeres are one of the most important structural elements of a blast furnace that determine the efficiency of its operation: failure of tuyeres entails the need to stop the furnace to replace them. Downtime of the furnace due to tuyere replacement leads to a significant reduction in smelting of cast iron and an increase in coke consumption. In addition, tuyeres account for 30% of all heat losses in the furnace [23]. Therefore, the issues of increasing the heat resistance of tuyeres and reducing heat loss through their surface are relevant. Under normal operating conditions of the blast furnace, the nose, outer and inner cups of the tuyere provide for 18, 36, and 46% of heat loss, respectively [24], and according to [25] - up to 60%.

Currently, these problems are solved in various ways: by applying thermal spray coatings to the working surface of the tuyere [26], which are also successfully used to improve the metal quality further [27, 28], by lining with refractories from the side of the air passage [29, 30], by using heat-insulating materials with low thermal conductivity on the outer surface of the tuyeres [31] and etc.

One of the methods to provide thermal insulation for air passages is the use of a refractory insert [32, 33]. In addition to reducing heat loss, it contributes to the additional heating of natural gas, which positively affects the coke to natural gas substitution factor [34]. However, the temperature stresses
arising in it can lead to its premature destruction during operation. As for heat loss through the tuyere’s outer surface, it is most important to isolate the outer surface of the nose [31]. The outer cup is covered with a skull, which, however, periodically falls off the surface of the tuyere.

The research is aimed to develop measures to increase the service life of the heat insulating insert in the air passage, as well as to increase the resistance to burnout and reduce heat loss of the blast furnace through the surface of the tuyere.

A proposed method to increase the service life of the insert suggested gluing heat-resistant siliceous fabric onto its outer surface, and to reduce heat loss and increase the tuyere’s resistance to burnout, fixing a ceramic disk to the end of the tuyere’s nose.

2. Gluing heat-resistant siliceous fabric onto the insert’s outer surface

A thermal state simulation of the insert was made earlier using modern software, in particular, Ansys; and using the Static Structural module, stress simulation was conducted for the insert in a stationary state [35–37]. The insert’s thickness was taken equal to 10 and 13 mm, and the air gap between the insert and the inner cup was 0; 1 and 2 mm (Figure 1).

Calculations showed that the air gap has a major effect on the stresses in the insert. The maximum stresses are concentrated in the insert area around the gas nozzle, their values not exceeding the tensile strength of the insert’s material under compression (σ в = 111.7–117.0 MPa). Actual stresses in the insert will be lower than calculated due to their relaxation [38]. Therefore, the temperature stresses themselves cannot cause the insert failure. A periodic change in these stresses, including their direction due to heat changes caused by the furnace shutdown to replace damaged tuyeres, can shorten the life of the insert.

![Figure 1. Stresses on the surfaces of the insert in a stationary state: 1 – h_{вст.} = 10 mm, h_{воз.} = 0 mm; 2 – 10 mm and 1 mm; 3 – 10 mm and 2 mm; 4 – 13 mm and 1 mm (start from the top left image clockwise)](image-url)
It was assumed that the heat-resistant siliceous fabric glued to the outer surface of the insert would keep it from breaking for some time after cracking occurred while maintaining its performance.

An experiment was conducted at a facility of Severstal, PJSC. There, heat-resistant siliceous fabric was glued both to the entire outer surface of the insert and to its upper part to increase its durability, since the destruction of the insert during the tuyere operation started in its upper part due to the presence of holes for supplying natural gas there.

The operation of the tuyeres at the furnace DP-5 showed that gluing the fabric to the entire length of the insert increases the time of the insert operation before its destruction over than twofold, if compared to cases the fabric was glued to the insert from the flange to the gas supply hole. When tuyeres were installed to the furnace DP-4, while the fabric was glued on the entire surface of the insert, the insert remained operable till the end of the tuyere’s service life, as heat losses through the tuyere during 287 days of operation did not change amounting to 120–130 Mcal/h.

3. Attaching a ceramic disk to the tuyere’s nose ends.

Since 18% of all tuyere heat loss passes through its nose [24], experiments were conducted on the thermal insulation of this part of the tuyere. In addition, heat insulation can protect the tuyere from burnout attributable to its nose [39].

Initially, the dynamics of heating the blast furnace tuyere’s nose was simulated using a DEFORM-2D finite element analysis computing environment [40]. The effect of the thickness of the insulation installed on the nose end inside the annular protrusion on its temperature field was studied. The simulation results showed that the temperature of the copper protrusion, which protects the heat insulation during the tuyere transportation and installation in the furnace, does not exceed the permissible temperature for copper. Heat insulation of the tuyere’s nose end reduces the temperature of its heating, which ensures a reduction in heat loss with water used for the tuyere cooling. An increase in the thickness of heat insulation from 10 to 20 mm has a negligible effect on the temperature of the nose end covered by it, and therefore, when choosing the thickness of the heat insulation, one must proceed from its strength characteristics and cooling conditions of the nose. Possible destruction of heat insulation will not lead to the tuyere failure.

As an example, Figure 2 shows the temperature field of the nose with heat insulation.

![Figure 2. The temperature field of the tuyere nose with heat insulation: protrusion height = 15 mm, heat insulation thickness = 10 mm; heat insulation properties: thermal conductivity factor - 3 W/(m•K); specific heat - 780 J/(kg•K); blackness - 0.46](image-url)
3 tuyeres with a ceramic disk at the nose end were manufactured at a facility of Severstal, PJSC. According to the data on heat losses through the tuyeres, the disk performed heat-insulating functions on the tuyere for at least 2.5 months. Remains of a ring protecting the heat insulation were found on a spent tuyere, which is consistent with its temperature field. Moreover, none of the tuyeres failed because of burnout.

4. Conclusion
1. The necessity of measures to increase the service life of a heat-insulating insert in the tuyere was justified by simulating its stress state in Ansys. The use of heat-resistant siliceous fabric on the entire outer surface of the insert allowed a more than twofold increase in the insert’s service life compared to the option with the fabric was glued to the insert part from the flange to the gas pipe.
2. Using simulation of the tuyere’s thermal state in a DEFORM–2D environment and industrial experiments, the possibility of reducing heat loss and protecting the tuyere from burnout by thermal insulation of the end of its nose using a ceramic disk is shown.

References
[1] Radyuk, A.G., Gorbatyuk, S.M., Gerasimova, A.A. Use of electric-arc metallization to recondition the working surfaces of the narrow walls of thick-walled slab molds (2011) Metallurgist, 55 (5-6), pp. 419-423 DOI: 10.1007/s11015-011-9446-y
[2] Bardovskiy, A.D., Gorbatyuk, S.M., Keropyan, A.M., Bibikov, P.Y. Assessing Parameters of the Accelerator Disk of a Centrifugal Mill Taking into Account Features of Particle Motion on the Disk Surface (2018) Journal of Friction and Wear, 39 (4), pp. 326-329 DOI: 10.3103/S1068366618040037
[3] Karelin, I.N., Sedykh, V.D., Sedykh, L.V. Modernization of a sharply bending elbow in a steel pipeline (2013) Chemical and Petroleum Engineering, 49 (5-6), pp. 351-354. DOI: 10.1007/s10556-013-9754-0
[4] Keropyan, A., Gorbatyuk, S., Gerasimova, A. Tribotechnical Aspects of Wheel-Rail System Interaction (2017) Procedia Engineering, 206, pp. 564-569. DOI: 10.1016/j.proeng.2017.10.517
[5] Zakharov, A.N., Gorbatyuk, S.M., Borisevich, V.G. Modernizing a press for making refractories (2008) Metallurgist, 52 (7-8), pp. 420-423. DOI: 10.1007/s11015-008-9072-5
[6] Gorbatyuk, S.M., Pavlov, S.M., Shapoval, A.N., Gorbatyuk, S.M. Experience in application of screw rolling mill for deforming the billets of refractory metals (1998) Metallurg, 5, pp. 32-35.
[7] Gerasimova, A., Gorbatyuk, S., Devyatiarova, V. Application of gas-thermal coatings on low-alloyed steel surfaces (2018) Solid State Phenomena, 284 SSP, pp. 1284-1290. DOI: 10.4028/www.scientific.net/SSP.284.1284
[8] Bast, J., Gorbatyuk,S.M., Kryukov, I.Yu. Horizontal hcc-12000 unit for the continuous casting of semifinished products (2011) Metallurgist, 55 (1-2), pp. 116-118. DOI: 10.1007/s11015-011-9399-1
[9] Gorbatyuk, S.M., Kochanov, A.V. Method and equipment for mechanically strengthening the surface of rolling-mill rolls (2012) Metallurgist, 56 (3-4), pp. 279-283. DOI: 10.1007/s11015-012-9571-2
[10] Gorbatyuk, S.M., Morozova, I.G., Naumova, M.G. Reindustrialization principles in the heat treatment of die steels (2017) Steel in Translation, 47 (5), pp. 308-312. DOI: 10.3103/S0967091217050047
[11] Gorbatyuk, S.M., Osadchii, V.A., Tuktarov, E.Z. Calculation of the geometric parameters of rotary rolling by using the utomated design system autodesk inventor (2011) Metallurgist, 55 (7-8), pp. 543-546. DOI: 10.1007/s11015-011-9465-8
[12] Gorbatyuk, S.M., Pavlov, V.M., Shapoval, A.N., Gorbatyuk, M.S. Experimental use of rotary rolling mills to deform compacts of refractory metals (1998) Metallurgist, 42 (5-6), pp. 178-183. DOI: 10.1007/BF02766359

[13] Keropyan, A.M. Features of interaction of traction wheels of an electric locomotive and a diesel locomotive in the conditions of open mountain works (2016) Journal of Friction and Wear, 37 (1), pp. 78-82. DOI: 10.3103/S1068366616010074

[14] Gerasimova, A.A., Keropyan, A.M., Girya, A.M. Study of the Wheel–Rail System of Open-Pit Metallomotives in Traction Mode (2018) Journal of Machinery Manufacture and Reliability, 47 (1), pp. 35-38. DOI: 10.1007/S1052618818010065

[15] Gorbatyuk, S.M., Sedykh, L.V. Improving the durability of rolling-mill rolls (2010) Metallurgist, 54 (5-6), pp. 299-301. Цитировано 7 раз. DOI: 10.1007/s11015-010-9297-y

[16] Gorbatyuk, S.M., Osadchii, V.A., Tuktarov, E.Z. Calculation of the geometric parameters of rotary rolling by using the automated design system Autodesk Inventor (2011) Metallurgist, 55 (7-8), pp. 543-546. DOI: 10.1007/s11015-011-9465-8

[17] Gorbatyuk, S.M., Pashkov, A.N., Zarapin, A.Y., Bardovskii, A.D. Development of Hot-Pressing Technology for Production of Aluminum-Matrix Composite Materials (2019) Metallurgist, 62 (11-12), pp. 1261-1266. DOI: 10.1007/s11015-019-00784-01

[18] Gorbatyuk, S.M., Morozova, I.G., Naumova, M.G Color Mark Formation on a Metal Surface by a Highly Concentrated Energy Source (2016) Metallurgist, 60 (5-6), pp. 646-650.

[19] Gorbatyuk, S., Kondratenko, V., Sedykh, L. Tool stability analysis for deep hole drilling (2018) MATEC Web of Conferences, 224, article No. 01035. Cited 7 times. DOI: 10.1051/matecconf/201822401035

[20] Gorbatyuk, S., Kondratenko, V., Sedykh, L. Investigation of the Deep Hole Drill Stability When Using a Steady Rest (2019) Materials Today: Proceedings, 11, pp. 258-264. Cited 2 times. DOI: 10.1016/j.matpr.2018.12.140

[21] Gorbatyuk, S., Kondratenko, V., Sedykh, L. Influence of critical speed when working shafts with symmetrically located monolithic weighting on the accuracy of work surfaces (2019) Materials Today: Proceedings, 19, pp. 2361-2364. DOI: 10.1016/j.matpr.2019.07.695

[22] Gorbatyuk, S., Kondratenko, V., Sedykh, L. Influence of critical speed when working shafts with asymmetrically located monolithic weighting on the accuracy of work surfaces (2019) Materials Today: Proceedings, 19, pp. 2117-2120. DOI: 10.1016/j.matpr.2019.07.222

[23] Borodulin, A. V. Scientific bases of rational use of energy resources in blast furnace production (1994) Abstract of dissertation of Grand PhD in Engineering sciences, p. 46.

[24] Borodulin, A. V., Vasil’ev, A. P., Gluschenko, E. L., et al. On the informativeness of heat losses in the working space of blast furnaces (2002) Materials of the 2nd international scientific and practical conference “Automated furnace units and energy-saving technologies in metallurgy”, pp. 424-426.

[25] Bondarenko, A. A., Gorbik, A. S., Dyshelevich, G. G. Study of heat stress of various sections of tuyeres (1983) Stal’, 7, pp. 11-12

[26] Radyuk, A.G., Titlyanov, A.E. Blast-Furnace lances with a gas-Thermal aluminum coating (2011) Steel in Translation, 41 (10), pp. 819-822. DOI: 10.3103/S0967091211100172

[27] Radyuk, A.G., Gerasimova, A.A. Development of a Method for Calculating the Thickness of Thermal-Spray Aluminum Coating Used to Protect Low-Alloy Steel During Heating for Rolling (2018) Metallurgist, 62 (1-2), pp. 176-180. DOI: 10.1007/s11015-018-0641-y

[28] Gerasimova, A.A., Radyuk, A.G., Zarapin, A.Y. The calculation of the thickness of thermal spray coating for protection of low alloyed steel when heated under rolling (2018) Materials Science Forum, 945 MSF, pp. 729-734. DOI: 10.4028/www.scientific.net/MSF.945.729

[29] Radyuk, A.G., Titlyanov, A.E., Tarasov, Y.S., Sidorova, T.Y. Decreasing the Heat Losses at the Air Tuyeres in Blast Furnaces (2019) Steel in Translation, 49 (4), pp. 257-260. DOI: 10.3103/S0967091219040119
[30] Radyuk, A.G., Titlyanov, A.E., Sidorova, T.Y. Effect of slurry coating on the resistance of thermal insulation insert in blast furnace air tuyere (2020) Metallurgist, 63 (11-12), pp. 1153–1159. DOI: 10.1007/s11015-020-00935-8

[31] Vinogradov, E.N., Radyuk, A.G., Volkov, E.A., Terebov, A.L., Sidorova, T.Y. Reducing Heat Losses Through Blast Furnace Tuyeres (2019) Steel in Translation, 49 (11), pp. 778-782. DOI: 10.3103/S0967091219110160

[32] Radyuk, A.G., Gorbatyuk, S.M., Tarasov, Y.S., Titlyanov, A.E., Aleksakhin, A.V. Improvements to Mixing of Natural Gas and Hot-Air Blast in the Air Tuyeres of Blast Furnaces with Thermal Insulation of the Blast Duct (2019) Metallurgist, 63 (5-6), pp. 433-440. DOI: 10.1007/s11015-019-00843-6

[33] Gorbatyuk, S.M., Tarasov, Y.S., Levitskii, I.A., Radyuk, A.G., Titlyanov, A.E. Effect of a ceramic insert with swirler on gas dynamics and heat exchange in a blast furnace tuyere (2019) Izvestiya Ferrous Metallurgy, 62 (5), pp. 337-344. DOI: 10.17073/0368-0797-2019-5-337-344

[34] Feschenko, S. A., Pleshkov, V. I., Lizunov, B. N., Lapshin, A. A., Soveiko, K. N., Loginov V. N., Vasil’ev, L. E. Increasing the efficiency of blast furnace melting with natural gas injection due to its heating (2007) Metallurgist, No.11, pp. 44-48.

[35] Radyuk, A.G., Titlyanov, A.E., Sidorova, T.Y. Thermal state of air tuyeres in blast furnaces (2016) Steel in Translation, 46 (9), pp. 624-628. DOI: 10.3103/S0967091216090084

[36] Levitskii, I.A., Radyuk, A.G., Titlyanov, A.E., Sidorova, T.Y. Influence of the method of natural gas supplying on gas dynamics and heat transfer in air tuyere of blast furnace (2018) Izvestiya Ferrous Metallurgy, 61 (5), pp. 357-363. DOI: 10.17073/0368-0797-2018-5-357-363

[37] Tarasov, Y.S., Skripalenko, M.M., Radyuk, A.G., Titlyanov, A.E. Computer Simulation of Thermal and Stress-Strain State of Blast Furnace Tuyeres (2019) Metallurgist, 62 (11-12), pp. 1083-1091. DOI: 10.1007/s11015-019-00760-8

[38] Aksel’rod, L.M., Zabolotskij, A.V. Mathematical modeling of metallurgical equipment’s liner destruction caused by thermal shock (2010) Coll. of scientific articles “Modern science”, 2 (4), pp. 165-169.

[39] Radyuk, A.G., Titlyanov, A.E., Skripalenko, M.M. Modeling of the Temperature Field of Blast Furnace Tuyeres Using Deform-2D Software (2017) Metallurgist, 60 (9-10), pp. 1011-1015. DOI: 10.1007/s11015-017-0400-5

[40] Radyuk, A.G., Titlyanov, A.E., Skripalenko, M.M., Stoishich, S.S. Modeling of the Temperature Field of Air Tuyeres in the Blast Furnaces with Thermal Insulation of the Nose Portion (2018) Metallurgist, 62 (3-4), pp. 310-313. DOI: 10.1007/s11015-018-0661-7