The Method of Efficiency Definition of New Functional Task in Electric Arc Furnace Control System

O S Logunova¹, V A Oshurkov¹ and V V Pavlov²

¹ Nosov Magnitogorsk State Technical University, 38 Lenin Street, Magnitogorsk, 455000, Russia
² PJSC Magnitogorsk Iron and Steel Works, 93 Kirov Street, Magnitogorsk, 455000, Russia

E-mail: logunova66@mail.ru

Abstract. The task of the study is to create the measures and methods of efficiency definition of new functional task in electric arc furnace control system. The method of system analysis was applied. The research was carried out in the shops of Magnitogorsk Iron and Steel Works (MMK). Method of efficiency definition of new functional task module in electric arc furnace control system was developed. The capacity loading reduction of bucket quantity and materials in charging process in the electric arc furnace for any planned task was presented.

1. Introduction
Automatic control system of technological process (ACS TP) is carried out as a part of iron and steel melting facility. Automatic control system of technological process with scaled out architecture is in the priority of iron and steel melting facility in the development according to the new trend. The provision of new functional task into the control system is not complicated and expensive work for these systems [1–3]. The ACS TP functional task determining the poured bulk density properties of metal scrap fragments in melting facilities workspaces has not been researched enough yet. The problem of the study is the subject of many researches in the works of russian and foreign scientists. The authors put forward the ideas determining the intimate poured bulk density properties of metal scrap fragments of melting facilities workspaces [4,5] but with no information of the inadvertent heap in charging scrap metal. The inadvertent heap in charging scrap metal leads to increase of energy consumption, electric arc furnace effectiveness slowdown, increase the probability of breakdown electrodes. Decisions making on the number of the scoops is the task of the expert planner based on skills, method of material charging into the electric arc furnace and metal scrap net weight into the scoop. The block diagram of the decisions making on the number of the charging scoops is shown on Figure 1. The following designations are accepted on Figure 1: I₀ – information support; I₁ – information on the availability of liquid iron; I₂ – metal scrap net weight into the scoop information; I₃ – scoops identification number into sequences of the scoop; M₁ – choice the scoop from sequences of the scoop; M₂ – charging scrap metal into loading bucket and electric arc furnace; mᵢ – metal scrap net weight into the i-scoop.
The authors of the research put forward the idea to scale out the functional architecture of ACS TP steelmaking and provision of the new functional task – the intellectualization of the decisions making process on the charging scoops number with the inadvertent heap in charging scrap metal process. The authors of the research have proved the following:

– hardware and software conceptual schema was constructed of the ACS TP steelmaking with the new functional task;
– mathematical support was developed as the task of the technique of metal scrap fragments function construction of the poured bulk density in melting facilities workspace \[6,7\];
– appropriateness of results modeling experiment and simulation experiment results of the inadvertent heap in charging scrap metal was proved \[8,9\].

So the challenge is to estimate the efficiency of the new functional task of the electric arc furnace control system (ACS TP steelmaking) by the new method of efficiency definition of new functional task in electric arc furnace control system.

2. Experimental research

One of the indicators for estimate of steel cost is energy consumption and energy consumption. Duration process of heat is one of the factors affecting the electric steelmaking furnace productivity. Duration process of heat depends on scrap charge duration and additional charge duration. Energy costs determine arc under current duration. The arc under current duration reliant is dependent on the number and size of metal scrap into the scoop. Thus, time index is based on the number of scoops and/or scoops available in scrap charge and can be used for the efficiency estimate of the new functional task in the electric arc furnace control system.

In the course of the research it was gathered the empirical information from the heat report for arc under current duration and heat duration time pattern recognition. The empirical information includes: indicators of the number of heats per month where one, two or three scoops and/or a scoops were used for scrap charge; the average value of the arc under current duration; the average value of the share of time duration arc under current. The number of heats types were rated to the total heats. The average values of the indicators are shown in table 1, where \(D_1\) – the share of heats in the total quantity per month with one scoop in the scrap charge; \(D_2\) – the share of heats in the total quantity per month with two scoops in the scrap charge; \(D_3\) – the share of heats in the total quantity per month with three scoops in the scrap charge; \(T_{c}\) – heat duration time average, min; \(D_{f}\) – average value of the share of time duration arc under current.
Table 1. The average values of the indicators.

|   | $D_1$ | $D_2$ | $D_3$ | $T_c$ (min) | $D_I$ |
|---|-------|-------|-------|-------------|-------|
|   | 0.19  | 0.68  | 0.12  | 31.96       | 0.53  |

The correlation mining results data has shown the occurrence availability of dependence of average value of the share of time duration arc under current and heat duration time indicator with two scoops in the scrap charge. The statistical analysis results of correlation data mining are shown in Figures 2 and 3, where intercept – intercept term in linear regression equation; St. Err. of $b$ – standard errors $s_j$ estimates of the coefficients of the linear regression equation; $p$-level – significance level for regression equation coefficients; $b$ – the values of the coefficients of the linear regression equation; $t(31)$ - the value of the Student statistics to test the hypothesis about the zero value of the corresponding coefficients; $R$ – determination coefficient; $F$ – the value of the Fisher statistic (1 and 31 are the degree of freedom).

The statistical analysis results [10] has shown the reliable regression equations for:

- heat duration time:
  \[ T_c = 53.77 \cdot D_I + 53.03; \]  
  (1)

- share of time duration arc under current:
  \[ D_I = 0.257 \cdot D_t + 0.501. \]  
  (2)
The coefficient regression equations are significant at 5%. Therefore, it is permissible to use and determine the values of these indicators from experimental data.

3. The new method of efficiency definition of new functional task in electric arc furnace control system

The empirical equation has shown the decrease of heat duration time and decrease share of time duration arc under current with two scoops in the scrap charge. The new functional task of the electric arc furnace control system permits to make a forecast occurrence the heap of charging scrap metal and the poured bulk density of metal scrap fragments distributed in space. It becomes possible to exclude scoops in charging process with suboptimal mass and suboptimal poured bulk density of metal scrap fragments. Thus, as the performance indicators for the sophisticated control system with the new functional task of the electric arc furnace control system may be:

\[ I_1 = \frac{T_c}{T_{c0}} \cdot 100\% ; \tag{3} \]

\[ I_2 = \frac{D_{I0}}{D_{I}} \cdot 100\% , \tag{4} \]

where \( T_{c0} \) – the predicted cycle time with a reduction in the number of heats with three scoops in the charging, min; \( D_{I0} \) – the predicted fraction of the time the arc is under current in reducing the number of heats with three scoops in the charging, min.

The aggregated performance factor of the steelmaking process control systems was formulated and is based on (3) and (4):

\[ I = \alpha_1 I_1 + \alpha_2 I_2 , \tag{5} \]

where \( \alpha_1, \alpha_2 \) - weighted coefficients providing the flexibility of the process control systems when choosing priorities (\( \alpha_1, \alpha_2 = 1 \)).

Method of efficiency definition of new functional task module in electric arc furnace control system comprises:

1) using the data from the enterprise-wide information system to perform the dependencies adaptation (1) and (2) not less than 3 years;
2) using data from an enterprise-wide information system to determine the number of heats with three scoops in the scrap charge in the preceding month;
3) using dependencies adaptation (1) and (2) to determine the values of the heat duration time and share of time duration arc under current in the previous month without the new functional task module;
4) installing the new functional task module it is necessary to perform points 2 and 3;
5) to determine the performance indicator by the formula (5);
6) to perform an efficiency assessment according to new functional task module: if \( I > 1 \), where the new functional task module is efficient in other case the new functional task module is not efficient.

4. The results

The source data for the method of efficiency definition of new functional task module in electric arc furnace control system are shown in Table 2.

The results of determining the final efficiency by the formula (5) with the value of the main weight coefficient \( \alpha_1 \) with a step of 0.1 are shown in Figure 4.

5. Conclusions

1) The empirical equations were made and with the information of the number of scoops, the heat duration time and share of time duration arc under current.
2) The performance factor of the new functional task module was built with the information about the number of scoops, the heat duration time and share of time duration arc under current.
3) The new method of efficiency definition of new functional task in electric arc furnace control systems was created using the aggregated performance factor.
Table 2. The source data for the method of efficiency definition of new functional task module in electric arc furnace control system.

| The indicators | The source data | Indicators value |
|----------------|-----------------|-----------------|
| 1. The share of heats with third scoop in the scrap charge in the previous month | 0.07 | 0.1 | 0.3 | 0.4 | 0.5 |
| 2. The share of heats with third scoop in the scrap charge in the current month * | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |

Intermediate Results

| The indicators | The source data | Indicators value |
|----------------|-----------------|-----------------|
| 1. Heat duration time in the previous month, min | 56.80 | 58.41 | 69.16 | 74.54 | 79.92 |
| 2. Heat duration time in the current month, min | 58.41 | 58.41 | 58.41 | 58.41 | 58.41 |
| 3. Efficiency of the duration of the heat, $I_1$ | 0.97 | 1.00 | 1.18 | 1.28 | 1.37 |
| 4. Share of time duration arc under current in the previous month | 0.52 | 0.53 | 0.58 | 0.60 | 0.63 |
| 5. Share of time duration arc under current in the current month | 0.53 | 0.53 | 0.53 | 0.53 | 0.53 |
| 6. Efficiency of share of time duration arc under current, $I_2$ | 0.99 | 1.00 | 1.10 | 1.14 | 1.19 |

* – planned constant value of the proportion of heats with the third scoop in the current month, no more 10%.

Figure 4. The results of determining the total effectiveness of the new functional task.

4) The possibility of reducing the number of scoops in charging process with the new functional task module was presented.

References

[1] Lapshin I V 2004 Arc Furnace Automation (Moscow: Moscow State University Press) p 165
[2] Trukhov A P and Malyarov A I 2004 Foundry alloys and smelting (Moscow: Moscow State University Press) p 336
[3] Parsunkin B N, Usachev M V, Logunova O S and Koroleva V V 2019 Journal of the Minerals Metals & Materials Society (JOM) 71 pp 342–48
[4] Mordasov D M and Mordasov M M 2004 *Technical measurements of the density of bulk materials* (Tambov: TGU) p 80
[5] Li Y, Pan R and Zhu S 2019 *Archive for Rational Mechanics and Analysis* **234** pp 1281–1334
[6] Logunova O S and Oshurkov V A 2019 *Cherepovets State University Bulletin* **2** pp 32–43
[7] Oshurkov V A, Egorova L G, Lednov A V and Antipanov I D 2019 *Electrotechnical Systems and Complexes* **1** pp 59–66
[8] Logunova O S, Sibileva N S and Pavlov V V 2016 *Steel in Translation* **10** pp 733–738
[9] Logunova O S, Oshurkov V A, Sibileva N S, Gavritskov S A and Garbar E A 2019 *Steel in Translation* **4** pp 22–25
[10] Logunova O S, Romanov P U and Il'ina E A 2019 *Processing of experimental data on a computer* (Moscow: Dom «Infra-M») p 326