Analysis of the Parameters of the Ore Restoration Furnaces for Equal Power on the Shelf-Baking and Graphitized Electrodes

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Abstract: Results of calculation of the power indicators of the ore restoration arc furnaces with the set power of 10.5 MVA working on are given as on the self-baking also on the graphitized electrodes. It is established that despite high cost of the graphitized electrodes in comparison with the self-baking electrodes, power parameters much more improve. Besides, the natural power factor increases, melting time decreases and that the most important the furnace turns out compact, convenient for service, building of the graphitized electrodes is carried out for a small period, and also the number of service personnel is reduced. We propose a new design scheme of low-voltage circuit for the arc furnace according to the scheme “a triangle on the electrodes” designed in a three-bifilar version, in which more complete symmetry is gained by means of the crosspieces forming a triangle directly at the electrode arms. In the proposed scheme, the current-carrying tubes that have different polarity are located on the same arm that leads to further reduction in low-voltage circuit inductance. The application of this scheme allows for reducing reactive and active resistances of low-voltage circuits by 2.5-3 times and 15-20%, respectively, as well as for shortening the heat, reducing specific energy consumption and increasing the installation power factor.

Key words: Power indicators, ore restoration, arc furnace, self-baking, graphitized electrode, low-voltage circuit, reactive resistance, bifilar arrangement of tines.

I. Introduction

In recent years with rapid rates are developed works on creation and introduction in production of ferroalloy furnaces of low and average power. Certain success in this direction is also achieved in Georgia. In particular, we have developed and introduced the ore restoration closed electric furnace with power 10,500 kV·A for production of 75% ferrosilicium on “GTM-Group” LTD (Zestafoni, Argveta). This furnace is designed and constructed on the graphitized electrodes [1-5].

It is known that each ore thermal process of melting generally has three parameters characteristic only for this process:

- (1) Specific power consumption on product ton;
- (2) Specific electric resistance of a bathtub;
- (3) Power density in the acting bathtub volume.

These parameters are not strictly constant. They are under influence of quality of the charge, its structure and an expense which define amount of the formed slag and extent of extraction from ores of the leading elements, and also the electric mode of melting. The power of the furnace and a design of a bathtub (open or closed), a way of loading also influence these parameters but in much smaller degree [6].

2. Basic Part

For comparison of power indicators we will carry out calculations of the furnaces with the set power of 10.5 MV·A working on self-baking and graphitized electrodes. For such furnaces power 10.5 MV·A is a

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limit due to the lack of the graphitized electrodes of big diameters. Here we will note that the industry turns out the graphitized electrodes with the nominal diameter no more than 700 mm.

2.1 The Furnace on the Shelf-Baking Electrode

We will consider the operating furnace with power 10.5 MV·A for production of 75% ferrosilicium with the following electrical parameters [7]:

- useful power of the furnace: $P_{us} = 8.49$ MW;
- working current of the electrode: $I_{el} = 40$ kA;
- working tension: $U = 156$ V;
- diameter of the self-baking electrode: $d_{el} = 900$ mm;
- the internal sizes of the furnace bathtub: diameter is equal to 4,400 mm, the depth: 1,990 mm;
- the scheme of connection of the short network—a triangle on the electrodes where the current supply to electrodes is carried out through the contact cheeks, and electrodes are kept on weight by special devices.

Reactive resistance of the short network of this furnace on phases is respectively equal: for the 1st phase of 0.48 mΩ; for the 2nd phase of 0.42 mΩ; for the 3rd phase of 0.45 mΩ. Reactance of all the three phases is equal in total to 1.35 mΩ that makes 40.5% of the general reactance of the system.

For electrodes and a bathtub above-mentioned resistance on phases are equal to 0.43 mΩ for each phase that in the sum makes 1.29 mΩ, and in a percentage ratio 38.8%.

In total for the oven installation, considering besides resistance of a tyre package, flexible cables and tubes of electrode keepers, we obtain 3.33 mΩ.

2.2 The Furnace on the Graphitized Electrode

For round three electrode half-closed furnaces we choose the graphitized electrodes with a diameter of 600 mm at working current of 40 kA. Admissible value of the currents density in the electrode is equal to 15 A/cm².

Proceeding from the chosen diameter of the electrode we calculate main characteristics of the furnace.

(1) Accepting from the Ref. [8] $\eta_{el} \cdot \cos \phi = 0.78$, we find the useful power of the Furnace $P_{us} = 8,400$ kW.

(2) Diameter of the bathtub at the level of coal blocks:

$$D_B = 5.1 \cdot d_{el} = 5.1 \times 600 = 3,060 \text{ mm.}$$

(3) Diameter of the bathtub above the coal blocks:

$$d_B = 5.3 \cdot d_{el} = 5.3 \times 600 = 3,180 \text{ mm.}$$

(4) Bathtub height:

$$H_B = 2.5 \cdot d_{el} = 2.5 \times 600 = 1,500 \text{ mm.}$$

(5) Height of the coal facing:

$$H_C = 0.65 \cdot d_{el} = 0.65 \times 600 = 390 \text{ mm.}$$

Both considered furnaces work at the oven transformer main data of which are given in Table 1.

We will determine power parameters of the considered furnaces.

For the furnace on the self-baking electrodes.

(1) Specific power on the surface of the bottom [9]:

$$P_{SB} = \frac{4 \cdot P \cdot \eta_{el}}{\pi \cdot d_B^2} = \frac{4 \cdot 9300 \cdot 0.88}{3.14 \cdot 4.4^2} = 538 \text{ kW/m}^2,$$

where, $P = 9,300$ kW—the power consumed by the furnace from the network;

$\eta_{el} = 0.88$ —electrical efficiency of the furnace.

(2) Specific power in the bathtub volume:

$$P_{VB} = \frac{P_{SB}}{H_B} = \frac{538}{1.99} = 270 \text{ kW/m}^3.$$

For the furnace on the graphitized electrodes.

(1) Specific power on the bottom surface:

$$P_{SB} = \frac{4 \cdot P \cdot \eta_{el}}{\pi \cdot D_B^2} = \frac{4 \cdot 9300 \cdot 0.8}{3.14 \cdot 3.06^2} = 1,012 \text{ kW/m}^2.$$

(2) Specific power in volume of the bathtub:

$$P_{VB} = \frac{P_{SB}}{H_B} = \frac{1,012}{1.5} = 675 \text{ kW/m}^3.$$

Table 1 Ratings of the oven transformer.

Position of the indicator	Rated power (kV·A)	Side of high tension		Side of low tension	
		V	A	V	A
1	11,085		610	160	
2	10,739		590	155	
3	10,392		571	150	
4	10,046		552	145	
5	9,699		533	140	
6	9,353		514	135	
7	9,007		495	130	
8	8,660	10,500	476	125	40,000
9	8,314		457	120	
10	7,967		438	115	
11	7,621		419	110	
12	6,928		381	100	
13	6,235		343	90	
14	5,543		305	80	

From the analysis of power indicators of furnaces follows that despite of the high cost of the graphitized electrodes in comparison with the shelf-baking electrodes, power parameters are improved greatly. Besides, the natural power factor increases, melting time decreases and the most important is that the furnace becomes compact, that is convenient for service, building up of the graphitized electrodes is carried out for a small period of time and also the number of service personnel is reduced.

For the first time in practice we have carried out the original scheme of the short network with application of console electrode keepers for the graphitized electrodes.

Technical and economic indexes of the furnace installation are highly dependent on the major parameters of the furnace contour, i.e. on its active and reactive resistances [1, 2].

The reduction in the inductive reactance of low-voltage circuit, which in the large furnaces is 5-7 times higher than the active one, is of high importance, and besides, it determines $\cos\phi$.

It is known that the effective inductance of two straight-line parallel conductors of equal length with

the currents of the reverse directions is calculated by the formula:

$$L = L_{11} + L_{22} - M_{12} - M_{21} = 2(L_{11} - M)$$

where,

$$L_{11} = L_{22} \text{—self-inductances of the conductors;}$$

$M_{12} = M_{21} = M$ —mutual inductances between these conductors.

In the calculation of the factors L and M , there is usually used the following formula:

$$L(M) = 2l \left(\ln \frac{2l}{d} - 1 \right) \cdot 10^{-9} [H]$$

where, l —is a length of the conductor, d —linear dimension dependent on the cross-section shape and relative positions of the conductors.

When calculating L , d is a root mean displacement of the area from itself, but when calculating M , d is a distance between the sections of the conductors.

The aforementioned formulas show that the reduction in the reactive resistance of low-voltage circuit was achieved by the possible reduction in the length of the current-conducting wires, and by

approaching conductors with the currents of the reverse directions, in other words, by bifilar arrangement of tires or cables.

One of radical ways to reduce inductance of low-voltages circuit consists in designing the current-conducting wire according to the scheme “a triangle on the electrodes”.

On some industrial furnaces of different capacity, there has been implemented a three-bifilar scheme with the fourth arm moving simultaneously with the first one. However, this scheme has resulted in the substantial complication of furnace maintenance. In addition, the bifilar guide tubes are located on the different arms, in practice, as a rule, they are positioned at different levels, at the same time, during the period of smelting, the mutual induction effect varies frequently, as well as the value of reactive resistance.

Because of great difficulty in production and maintenance, we had to abandon this scheme. Therefore, the given paper proposes more perfect design of low-voltage circuit, the application of which allows for improving significantly furnace operating factors in all periods of smelting.

Fig. 1 illustrates a new schematic structural diagram of low-voltage circuit according to the scheme “a triangle on the electrodes” designed in a three-bifilar version, in which more complete symmetry is gained by means of the crosspieces forming a triangle directly at the electrode arms. As the crosspieces, there have been used special flexible, water-cooled cables, the length of which is determined from the distance between the electrodes and from the electrode travel. The crosspieces should facilitate the provision of the required displacement of the electrodes. The current-carrying tubes, which have different polarity and are isolated from one another, are located on the

same arm that leads to further reduction in low-voltage circuit inductance, since all of the elements of a current lead that carrying the currents of different directions are positioned right next to each other. Here, the phase currents run through the conductors of low-voltage circuit, the difference between which forms the linear currents in the electrodes.

1-Transformer; 2-Busbar package; 3-Furnace sub-station wall void; 4-Stationary shoe; 5-Flexible cables; 6, 7-Travelling shoe; 8-Bus tubes 9-Contact-type current-conducting plate with the electrode arm body; 11-Crosspieces forming a triangle at the electrode arms; 12-Electrode arms.

Fig. 1 Low-voltage circuit according to the scheme “a triangle on the electrodes” designed in a three-bifilar version.

Table 2 The basic technical data of the electric furnace transformers.

Rated power (MVA)	Primary voltage (kV)	Secondary voltage (V)	Secondary linear current (kA)	Secondary phase current (kA)	The number of secondary voltage levels
5.0	10.00	137.6 ÷ 70	21	12.1	9
11.0	10.5	160 ÷ 80	40	23.1	14

Table 3 The basic design characteristic data of the secondary current-conducting wires for the furnaces with the power capacities of 5 and 11 MV·A.

Secondary current (kA)	Bus bar bridge		Water-cooled flexible cables		Bus tubes		Graphite electrodes		
	Busbar cross-section and quantity for a pole-phase (mm)	Current density (A/mm ²)	Cross-section and quantity, for a pole-phase (mm)	Current density (A/mm ²)	Diameter (mm)	The quantity of tubes for a pole-phase	Current density (A/mm ²)	Diameter (mm)	Current density (A/mm ²)
20,000	2 (250 × 12)	1.9	1,000 × 4	2.9	80/40	1	3.0	400	15.9
40,000	4 (400 × 12)	1.22	1,000 × 8	2.89	100/60	1	4.6	600	14.1

The arrangement of the arms at different levels for the proposed scheme has no effect on mutual induction of semi-phases, since the reactive resistance total value of a secondary current lead does not change.

On one of the ferroalloy furnaces with a power capacity of 11 MV·A (Argveta plant, “GiTim Group”, Georgia), instead of a typical scheme of low-voltage circuit (a triangle on the stationary shoes), we have proposed and implemented the scheme of the aforementioned design of a secondary current, which we have pretested on a ferroalloy furnace with a power capacity of 5 MV·A [3, 10].

The above discussed furnaces are packaged complete with the electric furnace transformers, the characteristics of which are given in Table 2.

Table 3 presents the basic design characteristics of the secondary current-conducting wires for the furnaces with the power capacities of 5 and 11 MV·A.

In the scheme, the conductor sections are calculated by the maximum permitted current density. The bus bar packages were designed exclusively on a laminated form. For the flexible current-conducting wires, there have been used the copper water-cooled wires, but for the bus tubes—the water-cooled copper pipes.

3. Conclusions

(1) The comparative analysis of the ore reduction furnaces of equal power shows that despite of high cost of the graphitized electrodes in comparison with self-caking electrodes, power parameters improve greatly, the natural power factor increases, melting time decreases, the furnace becomes compact and

convenient for service, building up of the graphitized electrodes is carried out for a small period of time, and also the number of service personnel is reduced.

(2) Application of the original scheme of the short network on the console electrodes reduces both the active and reactance of the oven installation and increases power factor.

(3) The application of the proposed scheme allows for reducing the reactive resistance by 2.5-3 times, and the active resistance—by 15-20%, as well as for shortening the heat, reducing specific energy consumption and increasing the installation power factor.

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