MONITORING OF ELECTRICAL, THERMAL AND TECHNOLOGICAL PROCESSES IN ORE-THERMAL ELECTRIC FURNACE FOR THE PRODUCTION OF HIGH-CARBON FERROCHROME

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ABSTRACT

The article is devoted to improving the technical and economic indicators (TEI) of ore-thermal furnaces operation.

The reserves for improvement TEP depending on the degree of development of the technological process are available on any electric furnace. To search for these reserves requires holding furnace on special studies or work-related furnace for a given program for some time (active experiment, the preferred option), or without interfering with the normal course of its operation (passive experiment).

The main ways to increase TEP operation of the electric furnace:
- monitoring the state of the elements of its construction;
- reduction of the heat losses (based on heat balance);
- providing input into the bath furnace maximum useful power;
- ensuring the stability of the process parameters;
- determination of rational parameters of power furnace operation
on the basis of a comprehensive analysis of the array data;
- improvement of the automated control system of an electric furnace.

The technique of long-term comprehensive experimental studies of electrical, thermal and technological processes for operating electric furnace for the production of carbon ferrochrome at the application of various types of charge materials is considered. The description used measurement systems, methods of processing, storage and presentation of the information received. Recommendations for improving the energy efficiency of the furnace are provided. The issues related to the creation and the use of systems to make operational decisions and management of electro-technological process of production of ferroalloys are analyzed.

The complexity of maintaining a rational mode of operation of the electric furnace is also related to the fact that the process in it is a complex multifactorial system that fails to fully give way to prior analytical calculations, so the task requires experimental solution due to the need for additional instrumentation of the furnace.

The implementation of the provisions set forth is also contributed by specifically developed for this purpose POLINOM program. This program set in ACS furnace allows tracking additional relationships between parameters and facilitating maintenance of electro-technological process either in the form of advice to the operator or automatically.

The algorithms used in the ACS on the basis of the work carried out in electric furnaces in the smelting of high-carbon ferrochrome can be used in the smelting of other types of ferroalloys with minor adjustments

INTRODUCTION

In conditions of a severe competition between producers of ferroalloys for markets the most important indicator of economic stability of the company is the reduction of production costs. The main directions of solving these tasks may be considered the acquisition of charge materials at lower prices, search for new raw materials, adaptation to the conditions of this technological process, and the improvement of technical and economic indicators by increasing productivity and reducing energy consumption [1].

It should be noted that the acquisition of cheap raw materials (mainly reducing agent) can lead to the opposite result, i.e. to the decrease in TEI, if the input raw materials are used arbitrarily without technological communication with the other components of the charge. In this case, it is necessary to adapt new raw materials to a specific process by finding rational power modes of operation of the electric furnace in the new conditions, i.e. with the analytical adjustment of the relationship of input and output parameters.

At Tikhvin Ferroalloy Plant (LLC″TFP″) after the start of the first electric РКО-16,5ФХ-М and commissioning of the whole production line for the production of carbon ferrochrome the problem of improving the technical and economic indicators of production became urgent, since this path can be considered the most effective and the one that leads to significant economic effect. The analysis of the situation led to the identification of the following ways to improve technical and economic indicators:

- increasingthe capacity of the furnace (within the designed capacity of furnace transformers) to the economically justified level;
- definition of electric rational modes;
- search for possible ways to reduce electrical and thermal losses;
- increasing the reliability of the lining of the bath, structural elements and electrical equipment of the kiln;
- ensuring process stability.

The above provisions have determined the direction and procedure of the studies on РКО-16,5ФХ-М electric furnace.

MAIN SPECIFICATIONS OF THE ELECTRIC FURNACE

″TFP″ ferroalloy furnace РКО-16,5ФХ-М is designed for the production of carbon ferrochrome and is equipped with three single-phase transformers of ЭОЦНР-12500/10 type of the total installed capacity of 22.5 MW.

The electric furnace has a cylindrical bath with three self-baking electrodes. The lining of the furnace, the bottom and walls of the melting space, is made of magnesite bricks. The lower part of the hearth is lined with chamotte bricks.

Electric furnace bath is covered with low umbrella with three openings to service the mouth. The umbrella which is not water-cooled is gunited from inside with the refractory mass. Through the openings in the cover of the umbrella there are three self-baking electrodes.

The power supply to the electrodes consists of a contact node, the system of current-carrying pipes with slip rings and the carrier beam. The contact assembly includes 8 copper contact cheeks and thrust ring with hydraulic clamping of the contact cheeks.

Vertical movement of each electrode is carried out by the electric motor which is by a system of pulleys and ropes through the yoke linked with the suspended casing which the current carrying facility is attached to. The electrode is equipped with a pneumatic bypass device and contact cheeks of current carrying facility.

Short network of the electric furnace provides a current supply from low-voltage lead wire of a furnace transformer to the movable shoe s of current carrying facility. The short network packs are made of copper bars with section of 12x400 mm and connected to lead wires of furnace transformers by compensators of copper strips which remove dynamic loads from lead wires. Flexible part of a short network is made of МГЭ-1000 cables [2].

Main specifications of the electric furnace are shown in Table 1.

Table 1: The main specifications of the electric furnace.

№	Name of the parameter	Measurement unit	Value
1	Nominal power of the furnace	kVA	16500
2	Installed power of the furnace transformers	kVA	22500
3	Limits of the secondary voltage	V	137÷204
4	Maximum current in the electrode	A	60000
5	Diameter of the electrode	mm	1200
6	The diameter of the distance between electrodes	mm	3200-3400
7	Diameter of the casing of an electric furnace	mm	10000
8	Dimensions of the melting area - bath diameter - bath depth	 mm mm	 6900 3000
9	Number of taholes	pcs	1
10	Water consumption for furnace cooling	$м^3$/h	220

EVALUATION OF THE MAIN PARAMETERS OF THE ELECTRIC FURNACE ON THE FURNACE-ANALOGUES

Technological requirements that must be considered when choosing rational modes of operation, and evaluation of compliance of the basic parameters of the furnace (electric and geometric) of its power can be obtained on the basis of furnaces-analogues with high technical and economic indicators. Calculation of the furnace parameters is performed in accordance with the theory which is based on the criterion of electric similarity

$$ES = \frac{U_п \times d_э}{\rho \times I_э}$$

where $U_п$- is a useful phase voltage, V;

d_e - electrode diameter, cm;

ρ – specific electric resistance of the reaction zone, Ohm/cm;

$I_э$ - the current in the electrode, A.

Based on the criteria of ES accounting for the fact that furnaces with the same technology have almost the same value of ρ, the following ratio if obtained

$$U_п = C \times j_э^{0,33} \times P_п^{0,33}$$

where C - the coefficient of similarity;

j_e - the current density in the electrode, A/cm2 ;

$P_п$ - useful power on the electrode, kW.

Below is the calculation result for the electric furnace РКО-16,5ФХ-М on the power of 22.5 MVA which is carried out for two counterparts [3]. The calculation results are shown in Table 2.

Design parameters of the electric furnace РКО-16,5ФХ-М on the power of 22.5 MVA

Table 2

Parameters	*The calculation is similar to the -1*	*The calculation is similar to - 2*	Average result
$S_{ном}$, kVA	*22500*	*22500*	*22500*
$P_{акт}$, kW	*17300*	*18700*	*18000*
U_2, V	*190*	*209*	*200*
$I_э$, kA	*68.5*	*62.3*	*65.0*
Cos φ	*0.77*	*0.83*	*0.80*
$d_{эл}$, mm	*1200*	*1400*	*1300*
$d_р$, mm	*3400*	*3900*	*3650*
$d_в$, mm	*7500*	*8400*	*8000*
$h_в$, mm	*2700*	*3400*	*3000*

From the data in Table 2 we can conclude that the geometric parameters of the furnace РКО-16,5 ФХ-М in its current version (d_{el}=1200 mm and d_p=3200 - 3400 mm) do not allow it to supply power more than 17- 17,5 MW, as the specific power $P_{удп}$ in the bath of the Jyf becomes unacceptably large (load on the furnace bottom up to 550 kW/m^2 at 390 - 425 kW/m^2 for analogue furnaces).

To check the correctness of the drawn for the existing furnace РКО-16,5ФХ-М comprehensive studies were carried out that required the installation of recording and measuring devices and the subsequent processing of the obtained data arrays about the operation of the furnace.

A comprehensive target setting required a phased work: the first stage was conducted in 2008, the second in 2011 being continued till present.

At the first phase hardware support of the experiment was identified and installed, and the maximum allowable powers of the furnace under the design and rational modes for the same type of raw material were worked out that was used during the experiment. Thermal conditions of the technological process and electrical parameters of the furnace control in automatic mode with minimization of the staff involved in melting to reduce the impact of the human factor were investigated.

As the primary furnace contol option in ACS mode the current limitation mode was selected, as it reduces losses from accidents on the electrodes. The practice of our operation of the electric furnace it is normal when the furnace operates in the ACS control mode for all three electrodes of 60 to 80% of the total time of its operation.

In the second phase of operation rational electric modes were identified in connection with the changes in the ore base in terms of chemical and particle size, as well as the use as a reductant some other types of carbon materials.

Further continuation of operation allowed at this stage to make the assumption that on the basis of the available hardware complex and the obtained data it is possible to create a model of furnace control which provides not only usual functions of the ACS, but the forecast of the possibilities to use different types of raw materials which are cheaper or were not previously used. Possible options of this forecast is from the point of view of technical and economic indicators - positive, negative or neutral – can be converted into financial result for decision-making about the use of new material. This will allow reducing the duration of the experiment not only as planned, but also taking into account the overlapping of other associated factors that are specific for the ore-smelting furnace, and to make the right decision in a shorter time.

ALGORITHM OF ENGINEERING CALCULATION OF ELECTRIC PARAMETERS USED WHEN PROCESSING EXPERIMENTAL DATA

For continuous registration and recording of controlled electrical parameters of the measuring system based on the four panel programmable analyzers CVM-NRG96 by CIRCUTOR (Spain) is developed. The analyzer is designed to measure basic electrical parameters of three-phase industrial electric furnaces with symmetrical or asymmetrical load. The analyzer simultaneously registers the following parameters:

- voltage - linear and phase (for each phase);
- current;
- active and reactive power (for three phase);
- full power (for three phases);
- power factor (for each phase);
- pickup of active and reactive power (for three phases) and other parameters required for the analysis.

There is a possibility to connect analyzer with a personal computer.

The program of processing of experimental data obtained during operation is developed on the basis of engineering algorithms and provides the necessary calculations, plotting of various graphs and dependencies, presenting of the experimental and calculated data in a readable form. The source for the processing is the file created in the course of the experiment using a measuring part of the program. The information unit is a daily archive file for random access. Selected and opened file is analyzed primarily for the purpose of elimination of distorted and unreliable data. According to the analysis. a new file is created being the basis for all calculations.

The data processing program includes two parts: calculation (to perform the necessary calculations and averaging) and graphic (charting). The graphic part of the program, in turn, has two components: building of dependencies of the furnace operation performance and graphing functions of time.

Building of dependencies is carried out automatically, and the program determines the averaging interval (interval criterion is the constant level of voltage). Having built a dependence for one interval, the program at the user's instruction can build for the next interval, etc. until the end of the day.

ELECTRIC CHARACTERISTICS OF THE ELECTRIC FURNACE

The experimental data array obtained from the furnace based on the installed equipment, and processed using algorithms allowed us to obtain the electrical characteristics of the furnace which give the opportunity to define rational mode of the furnace operation. There is further opportunity to quickly adjust the progress of the technological mode in this way directly during the operation of the furnace.

To determine the dependence of the inductive resistance of the heater circuit on the current data in a wide range of current change with hourly averaging of parameters were processed. As a result, using a parabolic correlation, the following dependence is obtained

$X_{пк} = 1{,}643 - 1{,}237\cdot 10^{-2} I_э + 1{,}701 \cdot 10^{-5} I_э^2$, mOhm

This dependence is set in the program of calculation of electrical characteristics of the furnace. Value $R_{тп}$ is left constant, since the active resistance of the current carrying facility is slightly dependent on the current and is in the area of operating modes only part (10 - 15%) of the active resistance of the entire furnace.

The electrical characteristics for voltage steps 1 through 17 are calculated. In Fig.1, for the purpose of illustration the full set of electrical characteristics of the furnace for the 1st stage of voltage. From the electrical characteristics for all voltage steps the dependences of active power on the current in the electrode $P_a = f(I_э)$ are taken and combined on one graph (Fig. 2). The result is a line of maximum powers for all voltage steps.

But when allowable currents of furnace transformers by voltage steps are taken into consideration, the maxima of active power can be achieved only on the steps starting with the 6th and below. At higher levels the current limit of the transformers do not allow to reach the maximum points (see the line where the limitations are taken into consideration). Zone of operating modes is to the left of this line, i.e. in the zone of lower currents.

As noted above, electric characteristics of furnaces reflect the electrical side of the process, i.e. show for each atep of the voltage what the maximum active power can be achieved at the data of electrical parameters of the furnace circuit.

But from the point of view of process technology the maximum power is not necessarily rational (it might be excessive), so the operating mode can only be determined either by practice (this requires a long period of operation with a gradual withdrawal at an acceptable mode), or by calculation on the basis of analogue furnaces.

RESEARCH OF THERMAL MODES OF THE ELECTRIC FURNACE

Research of thermal modes is required for the following reasons:

- serch for the opportunities to reduce heat losses;
- confirmation and further justification for limiting power;

- monitoring of the furnace condition and the lining durability [4].

Study of the thermal modes of the electric furnace was conducted in several areas:

- continuous monitoring of temperatures inside magnesite masonry
- the vertical part of the lining at the level of the ends of the electrodes in the areas
- opposite and between the electrodes using duplex thermocouples
- HA type with automatic recording their readings;
- periodic measurements of the temperature distribution on the casing surface
- electric furnaces with TESTO 880 thermal imager;
- periodic measurements of the velocity and temperature of cooling air
- the furnace bottom for each of the 12 cooling channels
- thermal anemometer of TESTO-420-2 type;
- periodic measurements of cooling water consumption and its temperature
- heat-stressed structural elements of the electric furnace.

Calculation results on the input and consumption of heat, supplemented with data of averaged statistics for furnaces which are close in terms of power and designed for smelting ferrochrome allowed for an approximate heat balance of the furnace РКО-16,5ФХ-М.

Table 3: The heat balance of the electric furnace

No.	Input items	Power, kW			№	Consumption items	Power, kW		
		14100	16200	18300			14100	16200	18300
1	Electricity	13100 75%	14700 75%	16800 75%	1	Useful heat (target reactions)	12300 70%	13700 70%	15700 70%
2	Physical heat of the charge	530 3%	590 3%	670 3%	2	The heat of alloy being tapped	1050 6%	1180 6%	1350 6%
3	Heat of exothermic reactions	1580 9%	1760 9%	2020 9%	3	The heat of out-going slag	350 2%	390 2%	450 2%
4	The combustion gases at the top	2290 13%	2550 13%	2910 13%	4	The heat with gases	820 4.7%	940 4.8%	1060 4.7%
					5	Losses through side lining	520 3.0%	540 2.8%	550 2.5%
					6	Losses through the furnace hearth furnace	120 0.7%	145 0.7%	160 0.7%
					7	Losses with water cooling	760 4.3%	1810 9.2%	1730 7.7%
					8	The thermal conductivity through electrodes	180 1%	200 1%	220 1%
					9	Unaccounted losses	1400 8.3%	695 3.5%	1180 5.4%
	Total	17500 100%	19600 100%	22400 100%		Total	17500 100%	19600 100%	22400 100%

Analysis of Table 3 shows that in the comsumption of the heat balance the item that contains the possibility of reducing the power loss is water cooling [5].

ELECTROTECHNOLOGICAL MODES OF THE FURNACE

For the entire period of operation 3.238.915 kg of chrome ore is processed with an average content of Cr_2O_3 - 46,96%, SiO_2 - 8.59%, S - 0,046%, quartzite - 112002 kg, coke - 724747 kg. The moisture content in the ore 2.43%, in coke - 17,53%. The charge loaded in a furnace contained an average of 48.1% of fines sized 10mm or less, and on some days up to 67.6% of fines of this size. Obtained ferrochrome amounts to 1133.97 tonnes with an average content of Cr – 69.63%, C - 8.41%, Si - 0.27%, and S – 0.038%.

The basis of the studies on the electric furnace was an active experiment in the power range from 13 to 17 MW with different size composition of chrome ore (the ratio of lump and fines from 30/70% to 70/30%). Table 4 lists the preset modes of furnace operation, thus the active experiment was started with a large-size of ore (70/30 % ratio). An average active power preset for each mode was maintained with an accuracy of ± 1 MW.

Table 4: Preset modes of active experiment for the Furnace No. 1 TFP

Mode No..	The beginning and the end of the mode	Lump/fine ratio, %		Active power P_a, MW		
		70/30	50/50	13	15	17
	May 14-15	Charge loading with 70/30% ore size				
1	May 16-17	+		+		
2	May 18-19	+			+	
3	May 20-21	+				+
4	May 23-24		+			+
5	May 25-26		+		+	
6	May 27-28		+	+		

Voltage steps at each given power was chosen in the experiment, in accordance with the status of the furnace for the period and had to provide this capacity.

During the active experiment, the ratio of the charge components (quartzite share, excess/deficiency of a reducing agent, etc.) should remain unchanged.

Each mode was maintained for 2 days, between modes with different lump/fines ratios was a transitional period with a duration of 1 day, the total duration of the active experiment was 16 days.

Preset modes were held as precisely as possible [6]. As a result, the following averages of rational modes of the furnace operation were obtained (Table 5)

Table 5

Ore breakup	30/70 with anthracite	30/70 without anthracite	50/50	70/30
Electrical parameters:				
Active power, MW	13.40	12.72	15.70	15.67
Reactive power, MBAR	7.36	7.33	9.14	10.1
Current per phase, kA	47.2	47.5	56.15	57.76
The voltage per phase, V	104.6	108.9	109.0	111.6
X of the bath, mOhm	0.687	0.657	0.59	0.61
R of the bath, mOhm	1.81	1.79	1.57	1.58
Cos φ	0.862	0.857	0.86	0.85
Voltage steps	4-6	3-5	3-4	2-3
Technological parameters:				
Pickup of active electric energy, kWh	25244	25520	26050	26503
Pickup of reactive electric energy, kBARh	14740	16200	16604	16604
The amount of charge per melting, kg:				
Ore	18517	16904	17315	17881
Quartzite	605	603	435	435
Coke	3634	3904	3184	3545
Anthracite	1040	0	1222	1123
Metallurgical concentrate	2793	2083	2609	2686
Technical and economic indicators:				
Obtained FeCr (per melting), phys. t	7.48	8.60	8.64	9.02
Performance, phys. t/h	4.00	4.32	5.22	5.30
Specific consumption of electric. energy, MWh/t	3.4	2.9	3.01	2.91

Analysis of the electrical parameters of the furnace РКО-16,5ФХ-М allows drawing the following conclusions:

- inductive resistance of the heater circuit on chrome ore sized 30/70% is $X_{пк}$= 1.10 mOhm, for the ore sized 70/30% - $X_{пк}$= 1.05 mOhm, active resistance of the current carrying facility - $R_{тп}$ = 0.14 mOhm at the current in the electrode $I_э$= 54 kA. When calculating the electrical characteristics of the furnace

the dependence of the inductive reactance from the current $X_{пк}$ = f ($I_э$) is taken into account,

the gradient change is ΔX = 0,005 mOhm/kA;

- electrical characteristics are calculated for the voltage steps of furnace transformer – the 1st (204 V), 3rd (192.5 V), 5th (182 V), 7th (172.5 V) and 9th (164 V) at a ratio lump/fines 30/70 and 70/30%;

- characteristics show (Fig.1) that the maxima of active and useful powers do not match:

with increasing current the maximum of useful power comes earlier. This should be considered in the analysis and calculation of electric modes of the furnace, therefore, on the basis of the obtained characteristics, the dependencies are grouped by sizes of the ore and the voltage steps. One can see what maximum power can be achieved on the relevant the voltage steps in data electrical parameters heater circuit and in which the currents the electrode is achieved;

- if these maximum powers are imposed restrictions on the currents associated with the allowable currents furnace transformers, on the top voltage steps magnitude of achievable powers are reduced, and the area of operation modes is shifted towards the decreasing current;

- based on the allowable load on the bottom $P_{удп.доп.}$ = 450 kW/m^2, the active power the furnace should be limited to the value of $P_а$ = 16,8 МВт.

- comparison of the results of measuring active resistance of the bath when the furnace operates using the ore of the Kempirsai deposit and Albanian-Turkish ore shows the reducing resistance of the bath on average by 15%. In this regard, electric modes of voltage and current are changed as well. Analysis of the data obtained shows that with the increasing power the amount of carbon ferrochrome slightly increases, silicon content reacts more noticeably and sulfur content reduces. This composition of the charge affects the resistance of the bath and, ultimately, the increase in specific energy consumption. Because of increased fines content during the furnace operation at an average power of 18 MW, there was a sharp increase in the fly of dust into the system of flue gases cleaning [7]. Increasing the sample of quartzite in the charge by on average 50% does not provide noticeable effect in the resistance of the bath.

When the furnace operates at an average power of 18 MW due to frequent exits to open arc and, as a consequence, emissions with increased fine dust fly the loss from a water-cooled furnace structural elements creased sharply. The allocation of a temporary period of each melting is of practical interest for further analysis. Analysis of the electrical parameters by meltings gives the opportunity to evaluate and, further, to adjust the power mode, demonstrating the reason for high unit cost of electricity.

CONDITIONS OF INCREASE IN CAPACITY OF THE ELECTRIC FURNACE UP TO 19 MW

Active power $P_а$ = 19 MW can be obtained at the 1st voltage step of furnace transformers (204V) when the current in the electrodes $I_э$ = 64 kA, which corresponds to the current of the secondary windings of the transformers at this step of 37 kA (permissible current in the windings at this step is 36.75 kA).

The specific power density at the bottom when $P_а$ = 19 MW

$$P_{удп} = \frac{Pa}{0{,}785 d_в^{\,2}} = \frac{19000}{0{,}785 \times 6{,}9^2} = 510 \text{ kW/m}^2 \qquad (P_{удп.доп.} = 450 \text{ kW/м}^2)$$

If we proceed from the allowable load on the furnace hearth, the diameter of the furnace bath РКО-16,5 ФХ-М should be increased from 6900 to 7500 mm, then

$$P_{удп} = \frac{Pa}{0{,}785 d_в^{\,2}} = \frac{19000}{0{,}785 \times 7{,}5^2} = 430 \text{ kW/m}^2 < 450 \text{ kW/m}^2$$

The increase in bath diameter can be performed by decreasing the lateral thickness of the side lining at the level of the bottom by 300 mm aside without changing the diameter of the furnace casing, but with the possible adjustment of materials and layers of the lining (if required, by the results of the calculation).

RATIONAL ELECTROTECHNOLOGICAL OPERATING MODES OF THE FURNACE

The choice of rational energy modes of ferrochrome smelting in the electric furnace РКО-16,5-ФХ-М at the 1st stage requires the formation of data array (in tabular form). Technological parameters, as well as main output technical and economic indicators are subject to manual input.

Rational mode is designed for electric furnaces РКО-16,5ФХ-М TFP after putting them in a normal operation over the range of operating power values. The goal is to achieve the best technical and economic indicators of production at each furnace individually in terms of a specific technology.

The basis of suggestion is a specially designed computer program for processing of experimental data array obtained from the existing furnace and characterizing its work. The data consist of input and output parameters and parameters of the electric furnace condition in periods of stable operation. Data collection is expected to be implemented using storage measuring devices.

To implement the program, experimental data array is required to be generated in a text editor following the given form.

The input values
1. Power of electric furnace, kW
2. Operating voltage, V.
3. The current in the electrode, kA.
4. Volume of loaded charge by its components, t/h.
5. Content of the leading element in the charge.
6. Excess of reducing agent %.
7. Size of the charge, mm.
8. Moisture content in the charge, %.
9. Charge input mode.
10. Melt tapping mode.
Output values
1. Furnace capacity, tons/day.
2. Specific energy consumption, kWh/t.
3. Recover of the main element, %.

All the necessary calculations for the quantities can be obtained from the subsystem of data collection, archiving and the formation of technological reports with the addition of information from recording devices aditionally installed on the furnace.

Special requirements to the file of experimental data:
- the possibility of changing the set of input and output values;
- the possibility to change the periodicity and frequency of values measurement within a specified period;
- the possibility of averaging the values within a specified period;
- the file should be generated automatically based on specified conditions;
- the output of the data array in the form of the specified table in a file on the diskette.

Characteristics of the charge (components, their ratio, chemical composition, granulometric composition, moisture), as well as the mode of its loading and all changes can be periodically entered into the system manually according to the results of control established by the plant, but a continuous automatic input of these parameters into a table of experimental data should be provided.

The quality of the experimental data array (reliability and the degree of their relationship) is estimated by the correlation coefficient. In this case ranking of the input values according to their importance and influence on the output values is also possible.

The sources of experimental data table generation:
- readings of the measuring devices;
- manual data input;
- data on the downtime of the furnace (to be excluded from the experimental data array of unrepresentative periods).

At the initial stage of introduction and development of optimization of electric furnaces operation modes manual entry of the data array in the program on the basis of the table in any form is possible.

After entering of the experimental data file in the program and its processing obtained mathematical dependences of the output values on input values are investigated for the extremum with the help of OPTIM program and the combination of input parameters, at which the best output performance of the electric furnace is achieved, are given [8]. The results of data array processing for the shift may be given in the mode of the recommendation to the following shift.

At subsequent stages of work it is appropriate to conduct active experiment with a pre-designed program of trial melts.

MINIMIZATION OF THERMAL LOSSES AT ELECTRIC FURNACE DOWNTIME

Due to possible interruptions in the electric furnace operation (in terms of technology, under the constraints of power consumption, repair, and also for the reasons underlying state of the market - difficulties in the marketing of products, the transfer of the electric furnace to another production), the furnace have to be off for a certain periods. Such downtime can be "held" in different ways: with a complete disconnection of the electric furnace (in this case the heat accumulated by lining is completely lost) or at idle running power (in this case the electricity to maintain heat accumulated by lining is consumed). The question of choosing the option of downtime is solved by the prior (to stop of the furnace) parallel calculation of both options with a gradual increase in the duration of downtime and comparison of the energy loss in each case. Depending on the planned duration of the outage (for calculation, it is desirable to know it in advance) the option of furnace downtime with minimal loss of energy is selected.

The options of electrical modes during the periods of power limitation from the power system, taking into account different rates for electricity in the daytime and at night can be calculated.

ADJUSTMENT OF TECHNOLOGICAL MODES OF OPERATION DUE TO THE TECHNOLOGICAL CHANGES

In the operation of furnaces various possible violations of technological progress associated mainly with changes in the chemical composition of the mixture components and their ratio in preparation for smelting are possible. As a result, physical properties of the melt and, consequently, the resistance of the furnace bath, change. If these properties of the melt are known before and after burdening change, namely:

- specific electric resistance, Ohm-m;
- density, t/m^3;
- specific heat capacity, W-h/kg-°C;
- specific heat of melting, W-h/kg;
- process temperature, °C

or at least part of this information, the calculation can be adjusted by electric melting conditions. Using a similar calculation we can determine the electric furnace operation during the transition to the production of other alloy.

DIRECTIONS FOR IMPROVING TEI OF ELECTRIC FURNACES

On the basis of materials obtained during the execution of the present work the following areas for further work can be projected:

- adjustment of rational modes of operation of the electric furnace in the course of technological changes associated with changes in the composition of raw materials, ACS means;
- minimization of heat losses during the furnace downtime;
- increasing the reliability of structural elements.

CONCLUSION

1. After start-up of an electric furnace and commissioning of the whole production line for the production of carbon ferrochrome the problem of improving technical and economic indicators of production becomes urgent, since the improvement of these indicators even by 5-10% leads to a significant economic effect.

2. For working voltage steps the electric characteristics of the electric furnace are calculated. The line of maximum power by voltage steps constructed on the basis of these characteristics reflects the possibility of the furnace circuit (active and reactive resistances), but does not take into account the allowable values of current for the furnace transformer for voltage steps.

3. Taking into account the allowable values of current for the furnace transformer we obtain a line of maximum power achievable in an electric furnace without taking into account the technological aspects of the process.

4. To account for technology, calculations were made on the basis of analogue furnace – a well and steadily operating furnace for the production of ferrochrome (electric ОКБ-539 of the Serov Ferroalloy Plant). In addition, the data obtained on the furnace РКО-16,5ФХ-М on stages of its development were taken into account. Based on the calculation results, we can conclude that the maximum power for the furnace in its current version is 17 and 17.5 MW. Thus the power density at the bottom does not exceed the allowable value of 450 kW/m^2. The power of 20.5 MW achieved with the furnace can be only momentary and is not allowed for permanent operation, as the load on the furnace bottom reaches 550 kW/m^2.

5. The electrical characteristics testify to the fact that the maxima of active and useful power occur at different values of the current (maximum net power occurs earlier, i.e. at a lower current value). Electric mode should be supported to the maximum useful power.

6. Additional measuring means in the electric furnace include a control thermocouple in the side lining of the baths, TESTO 880 IRSoft thermal imager and CVM-NRG96electroanalyzer.

7. The inductive resistance of the heater circuit is introduced into the algorithm for calculating the electrical characteristics not like a constant value, as is customary, but a variable obtained continuously in the process of conversion of readings of CVM-NRG96electroanalyzer. The active resistance of the current supply facility is taken to be constant (0.14 mOhm).

8. The possibility of investigation with the help of TESTO 880 IRSoft thermal imager the entire housing of the furnace and diagnosis on this basis of the total volume of the lining is shown.

9. The plots of temperature distribution along the circumference of the furnace for three zones, and, at the height of the casing for areas across the electrodes and for areas between the electrodes common to all round three-electrode

furnaces, are common in nature, and therefore represent the interest of the ratio of these temperatures in the form of coefficients, which can be used for other similar furnaces.

10. The proposed method allows automatic monitoring of the condition of lining with checking compliance with the conditions $t < t_{доп}$ in each layer of the lining and $t < t_{кр}$on the inner surface of the lining. In the case of non-compliance of these conditions there should be a signal indicating a dangerous place and the temperature deviation from the norm. This requires the development and implementation of communication “exit from the thermal imager in the selected reference points of the temperature field of the casing - entrance to the algorithm of calculation of the temperature of chains along radial directions of the total volume of the lining” to diagnose its condition.

11. The search for the relationship of the magnitude and distribution of heat losses with the air through the bottom cooling channels with a ratio of the power at the electrodes and erosion of the bottom under each electrode (in conjunction with the control thermocouple readings under the electrodes) is the subject of further more detailed studies with further introduction into ACS of the electric furnace of the monitoring method of the bottom condition and the progress of the entire process.

12. Concerning the water cooling system, we can conclude that the largest proportion of losses in the water cooling system is in the contact cheeks (60-65%), and increasing the power of the electric furnace from 14.4 or 14.8 MW to 17.2 - 18.8 MW, i.e. by 23%, was accompanied by an increase in loss in the water cooling system from 660 - 850 kW to 1730 - 1810 kW, which is 2.3 times more that perhaps speaks of redundancy of power 18 - 19 MW to the furnace (this is primarily confirmed by the analysis of the electrical characteristics of the furnace).

13. The loss of heat with the furnace gases (gas mixture which results in combustion of gases in the top of the furnace due to the oxygen of the air) amounted to a range of 820 kW at RA = 14.1 MW up to 1060 kW at P_a= 18.3 MW.

14. Approximate heat balance of the РКО-16,5-ФХ-М furnace shows that water cooling in the main item which has the possibility of reducing.

15. Further continuation of this work allowed at this stage to make the assumption that on the basis of the available hardware and the obtained data it is possible to create a model of furnace control which provides not only the usual functions of the ACS, but also the forecast of the possibilities of using other raw materials which are cheaper or not previously used, if the characteristics of these raw materials are investigated. Possible options of such a forecast - positive, negative or neutral - can be converted into financial result to make right decisions about the use of new material in a shorter period.

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