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RESEARCH OF ARC FURNACE ELECTRICAL MODE WITH A FUZZY CONTROL MODEL

Goal. The purpose of the paper is to increase the efficiency of arc steelmaking furnace (ASF) operating modes control basing on the improvement of arc lengths control model. Method. The control model is based on the fuzzy set theory, and the structural modelling methodology is used to study the dynamics indices. Results. The structural scheme of a furnace arc lengths fuzzy control system and the electrical mode (EM) coordinate control dynamics parameters values in response to the deterministic and random arc lengths fluctuations were obtained. Scientific novelty. For the first time, a fuzzy model of an EM mismatch signal generation with operational adaptation to its current state in each phase was developed, which enabled by-phase independent control of arc lengths and improved energy efficiency. Practical value. Dynamic accuracy of EM coordinates stabilization at the setpoint level is improved, in particular the arc currents dispersion is reduced, which leads to a corresponding power loss decrease in arc furnace short network, an increase of the furnace productivity, as well as to an improvement of the electromagnetic compatibility of the arc furnace and power supply network. References 17, figures 7.

Key words: **arc steelmaking furnace, electric mode, fuzzy control, autonomy, dispersion.**

Запропоновано нечіткий закон керування електричним режимом (ЕР) дугової сталеплавильної печі (ДСП). Створено структурну Simulink-модель системи керування ЕР на основі нечіткого закону. Проведено комп'ютерні дослідження динаміки регулювання координат ЕР дугової печі ДСП-200 з використанням диференційного та нечіткого законів керування. Результати досліджень показали, що при використанні нечіткого закону зменшуються дисперсія струмів дуг і питомі витрати електроенергії та зростає продуктивність дугової печі. Бібл. 17, рис.7.

Ключові слова: **дугова сталеплавильна піч, електричний режим, нечітке регулювання, автономність, дисперсія.**

Предложен нечеткий закон управления электрическим режимом (ЭР) дуговой сталеплавильной печи (ДСП). Разработано структурную Simulink-модель системы управления ЭР на основе нечеткого закона. Проведены компьютерные исследования динамики регулирования координат ЭР дуговой печи ДСП-200 с использованием дифференциального и нечеткого законов управления. Результаты исследований показали, что при использовании нечеткого закона уменьшаются дисперсия токов дуг удельный расход электроэнергии и увеличивается производительность дуговой печи. Библ. 17 рис.7.

Ключевые слова: **дуговая сталеплавильная печь, электрический режим, нечеткое регулирование, автономность, дисперсия.**

Introduction. Technological processes of the electrometallurgical industry are characterized by the consumption of significant amounts of electricity. Its main electrotechnological units are arc steelmaking furnaces (ASFs), in which high-alloy steels and precision alloys are smelted mainly from scrap metal.

The electrical mode (EM) of the ASF is formed by a set of coordinates such as voltage, current and power of the system of three-phase arcs, and is characterized by transient random and phase-asymmetric nature of the change. The main reason for such a complex nature of the change of EM coordinates is the continuous during melting action of intense random parametric perturbations in the power supply circuit of three-phase arcs without zero conductor and fluctuations of arc lengths, the statistical characteristics of which change during melting in a wide range as well as the imperfection of automatic control systems (ACS).

One of the subsystems in the hierarchical structure of modern ACS of the EM of arc furnaces is a subsystem for adjusting the position of the electrodes. Its main task is the qualitative stabilization of the EM coordinates at the level of the set optimal values, which are operatively formed at the highest level of the hierarchy of the ACS of the EM, and the integral assessment of the quality of their operation is the variance of the EM coordinates and first of all arc currents [1-3].

Scientific problem definition and substantiation of its urgency. Qualitative stabilization of EM coordinates by a lower-level subsystem makes it possible to improve indices of energy efficiency and electromagnetic compatibility and, in addition, further enhances the effectiveness of the implementation of optimal control strategies. Therefore, the task of developing solutions to improve the quality of stabilization of EM coordinates of the ASF at the level of setpoints, and especially for powerful and superpowerful furnaces, is important and relevant, as it will comprehensively improve energy efficiency and electromagnetic compatibility of ASFs and power supply networks.

Review of literature sources. Most modern systems of automatic control (SAC) of the position of the electrodes of the ASF are electromechanical or electrohydraulic regulators of arc power, such as АРДМ-Т or АРДГ, respectively [1-5].

These SAC positions of the electrodes use mainly four models of control signal generation for electrode movement: differential and impedance models and control models by the deviation of voltage and arc current from the specified values [4, 5]. Under the control model (law) we understand the mathematical model of the formation of the EM mismatch signal, which the SAC transforms into the corresponding movements of the electrodes. Each of these models has certain advantages and disadvantages in the regulation of perturbations in different states of the EM.

The results of the study of dynamics indicators using different laws in the double-circuit structure of the ACS of the electric mode of the ASF are presented in [6, 7]. In such a structure, the laws of control of the EM are particularly pronounced. From the results obtained in [6, 7] it follows that the control laws significantly affect the indices of dynamics, energy efficiency and electromagnetic compatibility in both single- and double-circuit structures of ASF EM ACS. They show that the optimization parameters of the mismatch signal generation models are the dependence of the mismatch signal formation $U_r(U_a, I_a)$ and its coefficients, as well as the dependence of the artificial external characteristic I $I_a(U_a)$ of the double-circuit ASF EM ACS.

Most of the existing arc power regulators in single-circuit ACS operate on a differential model of EM mismatch signal formation [4, 5]:

$$U_r(U_a, I_a) = a \cdot U_a - b \cdot I_a , \qquad (1)$$

where a, b are the constant coefficients that set the constant values of arc voltage, current and power; U_a, I_a are the current values of arc voltage and current; U_r is the signal of the mismatch of the electric mode.

Using model (1), reliable arc ignition is performed in the modes of arc breaks (ABs) and short circuits (SCs), i.e. adequate implementation of extreme perturbations of the EM and close to them is performed. But under the action of small and medium deviations of arc lengths, the mismatch signal according to this model does not always adequately correspond to the real arc length – the state of the EM in this phase. The reason for this is the use of arc current in the model of differential law (1), because the phase current under the current three-phase power supply of three-phase arcs without neutral conductor is determined not only by the arc length (voltage) of this phase, but depends on arc lengths.

This shortcoming is emphasized in [8, 9]. These works indicate that the use of arc currents in electrode motion control models leads to a violation of the autonomy of the phase channels of regulating the lengths (voltages, currents, powers) of arcs.

Known regulation of the EM by the deviation of the arc voltage from the specified value (voltage model)

$$U_{r.1}(U_a) = k \cdot (U_a - U_{a.set}) , \qquad (2)$$

where $U_{r.1}(U_a)$ is the dependence of the EM mismatch signal; k is the gain of the regulator; $U_{a.set}$ is the setting of the regulator by arc voltage [4, 5].

According to this law, perfect regulation is obtained in the modes of small and medium deviations of arc lengths, but in extreme perturbations of the EM due to the displacement of the zero point of the arc voltage vector, the dynamics of electrode motion in arc ignition modes deteriorates.

Some EM regulators from Siemens and Danieli use variants of the impedance control law, according to which the arc lengths are adjusted at deviating the full phase impedance from the set value (adaptive impedance regulator) [10-12]. However, when calculating the phase impedances, phase currents are also used, which, for the reasons indicated above, does not make it possible to fully obtain the phase-by-phase autonomy of the arc length regulation process.

In [12, 13], an improved hydraulic drive of the mechanism of movement of the electrodes (MME) with a servovalve with a nonlinear control characteristic and an adaptive nonlinear model of phase impedance stabilization is considered. In [8, 11, 14] the regulation according to the nonlinear model of the admittance is considered. These papers emphasize that such models are easier to set up and have improved dynamic characteristics compared to other EM regulators. But these models in the vicinity of the point of a given EM are sensitive to the action of perturbations of other phases, which a priori negatively affects the dynamic accuracy of stabilization of the coordinates of the EM.

The analysis of other modern technical solutions for EM SAC shows that the improvement of the model of mismatch signal U_r formation in the function of which the signals U_c^{la} of electrode motion control are formed, is an effective factor and an important and urgent task in improving ASF energy efficiency indices.

The goal of this work is to increase the efficiency of control of the operation modes of the arc steelmaking furnace on the basis of improving the model of regulation of arc lengths.

Substantiation of the research direction. The process of EM control and control of ASF coordinates in the conditions of transient random perturbations actions takes place in the conditions of incomplete information about change of parameters of elements and coordinates of electric circuit of three-phase arcs of the ASF, because it is impossible to realize exact operative on-line operational control. Therefore, given the complexity of processes in the power circuit and their mathematical description, the presence of uncertainties in control, it is appropriate for control tasks for ASF EM to use intelligent methods, including the use of fuzzy control models, because indicated features and nature of processes in the ASF correspond to the peculiarities of application and functioning of fuzzy control models [15].

The main results of the investigations. From the above it follows that the main attention of the study should be paid to improving the systems of SAC of arc lengths.

Figure 1 shows a block diagram of an electromechanical power regulator of arc powers type АРДМ-Т, on the basis of which the proposed system of fuzzy adaptive control of the lengths of the arcs of the ASF is based.

The three-phase system of arcs of a ASF (AF) is fed from a secondary winding of the furnace transformer FT with phase voltage U_{2pf}. The electric mode in the given SAC of the АТДМ-Т regulator is regulated by the differential law, and the mismatch signal $U_r(U_a, I_a)$ of the EM is formed in the BC comparison block according to model (1). The current values of the arc voltage U_a and the arc current I_a are generated at the outputs of the sensors of arc voltage VS and arc current CS, respectively. At the output of the CSFB control signal generating block as a function of the mismatch signal U_r, taking into account the insensitivity zone, SAC gain for raising and lowering the electrodes, restrictions on the maximum speed of raising and lowering the electrodes, the electrode movement control signal U_c^{la} is formed. The electric drive of the EM, which in the АРДМ-Т-12 controller is represented by a reversible system «thyristor converter – DC motor» (ED TC-M), and the mechanism of movement of the electrode (MME) type «gear-rail» transform the control signal U_c^{la} into the corresponding movements of the electrode $\pm\Delta l_a$ in the direction of elimination of disturbances.

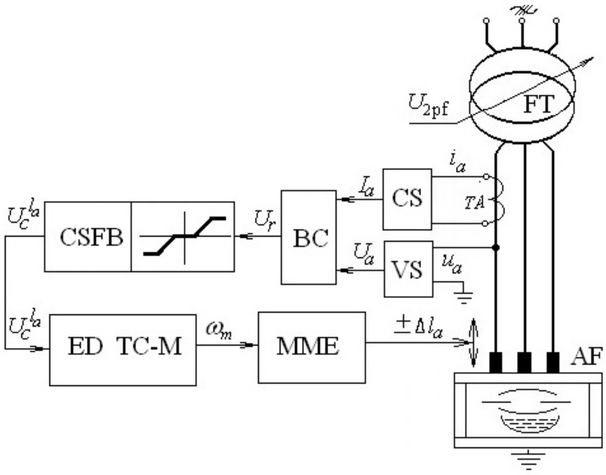

Fig. 1. Functional block diagram of the SAC of arc lengths of the ASF

Figure 2 shows the natural external characteristic $I_a(U_a)$ and the dependence of the arc power $P_a(U_a)$ of the arc steelmaking furnace ДСП-200. This figure also shows the points of the steady state mode of the furnace $A(U_{a.set},\ I_{a.set})$ and of the set power of the arcs $B(U_{a.set},\ P_{a.set})$, where $U_{a.set}$ = 198.3 V; $I_{a.set}$ = 43.97 A; $P_{a.set}$ = 8.72 MW are the settings for arc voltage, current and power, respectively.

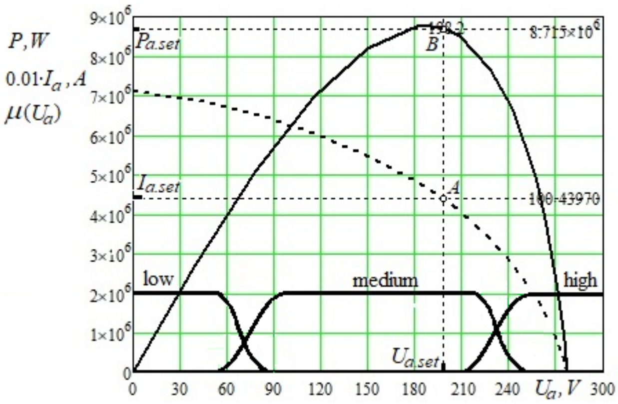

Fig. 2. External characteristic $I_a(U_a)$ and power characteristic $P_a(U_a)$ of arcs of the arc furnace ДСП-200 and membership function $\mu(U_a)$ of the linguistic variable «arc voltage»

The main task of ASF EM SAC is to reduce the dispersion of EM coordinates during melting, i.e. to maximize the operating time of the furnace in the modes around the operating point A of the furnace, then the values of all energy efficiency indices will approach the maximum, and the variance of EM coordinates is minimized.

To do this, instead of model (1), in the BC comparison block it is proposed to use a control model adaptive to the change of EM states, which combines a model of a modified differential law based on the principles of fuzzy logic

$$U_{r.2}(U_a, I_a) = a \cdot U_a - b \cdot (I_a - I_{a.set}) \tag{3}$$

and the voltage law (2).

With such a solution in the on-line mode active in each phase, the law of control $U_r(U_a,\ I_a)$ is established which corresponds to the current state of the EM in this phase. EM states in phases are identified by the phase arc voltage, because the voltage at the arc column unambiguously and linearly depends on its length $U_a = \alpha + \beta \cdot l_a$, where α, β are the anode-cathode voltage drops at the arc column; l_a is the length of the arc. Operational control of the arc voltage U_a is proposed to be performed by a device that operates on the basis of neural network identification technologies [16]. The above correspondence of voltages on arcs to states of EM (lengths of arcs) is described by shown in Fig. 3 membership functions $\mu(U_a)$. It is proposed to change the control laws (calculation models $U_r(U_a,\ I_a)$) in phases according to the fuzzy Takagi-Sugeno model.

During the control process, three EM states are identified: the mode of operational short circuit and close to it (these are short arcs), rational modes (medium arcs) as modes around the operating point of furnace A, and the mode of arc break and close to it (long arcs) .

The range of low voltages (these are short arcs) in the model of the fuzzy output system Takagi-Sugeno is described by the term *low* (this is the state of short circuit or close modes), medium – *medium*, and long – *high* (these are states of AB or close) to him) (Fig. 2). The terms of the linguistically variable U_a are presented by membership functions of type *gauss2mf*.

In the states of the EM in the vicinity of the operating point A, the mismatch signal is calculated according to the voltage law (2), because it allows to implement autonomous (phase-independent) regulation of arc lengths. This increases the dynamic accuracy of the stabilization of the EM coordinates at the level of the settings.

In the states of the EM arising under the influence of extreme perturbations – SC, AB or close to them, active for the formation of the mismatch signal $U_r(U_a,\ I_a)$ an improved differential law (3) is established, which, in contrast to the voltage one (2), better implements arc ignition processes.

Figure 3 shows the developed block diagram of the BC comparison block (Fig. 1), which implements in each phase of regulation a fuzzy adaptive to the state of the EM model the formation of the mismatch signal

$$\begin{aligned} U_r(U_a, I_a) &= (1 - k(U_a)) \cdot U_{r.1}(U_a) + \\ &+ k(U_a) \cdot U_{r.2}(U_a, I_a). \end{aligned} \tag{4}$$

The presented block diagram illustrates the implementation of the proposed fuzzy adaptive to the states of the EM model (4) for calculating the mismatch signal $U_r(U_a,\ I_a)$ of the EM. As a function of this signal in the CSFB block (Fig. 1) the electrode motion control signal U_c^{la} is formed.

Fuzzy adaptation of the control process is realized by the fuzzy inference system FIS, which operates on the basis of the Takagi-Sugeno model (Fig. 3).

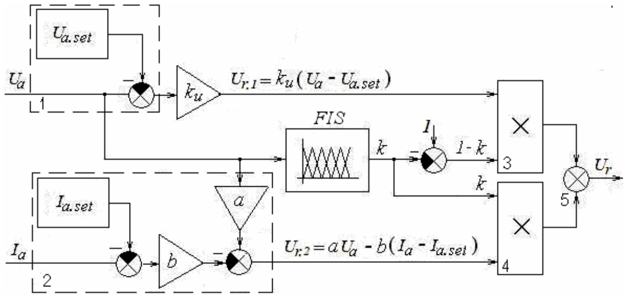

Fig. 3. Block diagram of the BC with adaptive to changing the states of the EM fuzzy model of the formation of the mismatch signal

The input linguistic variable for FIS is the current value of the arc voltage U_a. For its operative processing in the FIS block the following base of rules of fuzzy products is implemented:

$$\begin{aligned}&1.\ \text{if } U_a \in low \quad \text{then} \quad k=1 \quad [1]\ ;\\&2.\ \text{if } U_a \in medium \quad \text{then} \quad k=0 \quad [1]\ ;\\&3.\ \text{if } U_a \in high \quad \text{then} \quad k=1 \quad [1]\ .\end{aligned} \qquad (5)$$

The above algorithmic and parametric degrees of freedom of the FIS fuzzy inference system correspond to shown in Fig. 4 dependence $k(U_a)$.

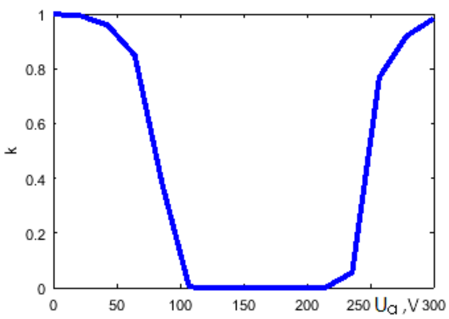

Fig. 4. Dependence $k(U_a)$ of fuzzy inference system FIS

In the process of implementation of EM disturbances in block 1 (Fig. 3), a mismatch signal is continuously formed according to the voltage deviation law $U_{r.1}(U_a)$ (2) and according to the modified differential law $U_{r.2}(U_a, I_a)$ (3) in block 2. These mismatch signals in blocks 3 and 4 are multiplied by $1-k$ and k, respectively, and then in the adder 5 in accordance with model (4) $U_r(U_a, I_a)$ is calculated. From the proposed fuzzy control model (4) it follows that at point A of the given mode the mismatch signal $U_r(U_{a.set}, I_{a.set}) = 0$.

In the modes of action of extreme perturbations, the control of electrode motion is performed according to the differential law ($k \cong 1$), according to which the control of electrode movements effective for reliable ignition of arcs is realized.

In the modes close to the given ЕЬ ($k \cong 0$) – around the point $A(U_{a.set}, I_{a.set})$ the control of the motion of the electrodes is realized according to the law of deviation of the arc voltage (2). This results in autonomous phase-by-phase control of the electrode movement.

The study of the efficiency of the developed fuzzy adaptive to EM states model of arc length control is performed on the three-phase in the instantaneous coordinates the Simulink model of SAC of the position of the electrodes of the arc furnace ДСП-200 [6, 17]. This model is accepted as the basic one. It studied the dynamics of EM SAC with power regulator АРДМ-Т-12 used on this furnace. Subsequently, in the comparison block of this Simulink model the fuzzy law (4) of formation of the mismatch signal is realized (Fig. 3). On such Simulink model the dynamics of regulation of coordinates of EM is investigated with use of the proposed fuzzy model of regulation of lengths of arcs.

For adequate reproduction in Simulink models of states and dynamics of regulation of EM coordinates in different technological stages of melting, they provide the possibility of realization of models of dynamic volt-ampere characteristics (DVAC) of arcs $u_a(i_a)$ and models of generating random processes of disturbances $f_{la}(t)$ by the lengths of the arcs.

For this purpose in Simulink models the possibility of realization of three models of DVAC is provided: linear $u_a(t) = R_a(t)\cdot i_a(t)$, nonlinear based on the arctangent function

$$u_a(t) = 2\cdot E_{am}\cdot \arctan(k\cdot i_a(t))/\pi\ ,$$

and nonlinear based on the Cassie differential equation

$$\theta_a \cdot \frac{dg_a(t)}{dt} = \left(\frac{u_a(t)}{E_{am}}\right)^2 \cdot g_a(t),$$

where $g_a(t)$, $R_a(t)$ are the instantaneous arc conductivity and resistance; E_{am} is the counter-EMF of the arc; $u_a(t)$, $i_a(t)$ are the instantaneous arc voltage and current, θ_a is the arc time constant, which characterizes its thermal inertia.

In Simulink models of EM SAC 3 generators of independent random processes with variable parameters of their stochastic characteristics are realized. In the process of computer research, random processes are generated that differed in frequency spectrum and amplitude characteristics, and which correspond to the processes of perturbations acting at the technological stages of melting wells in the charge, collapse of the charge and oxidation of the melt in the arc furnace ДСП-200.

Computer studies of the dynamics of arc length control are performed when implementing in the Simulink model of EM SAC of the differential law (1) of the mismatch signal formation used in the regulator АРДМ-Т-12 arc furnace ДСП-200, and using the proposed fuzzy law $U_r(U_a, I_a)$ (4). In order to correctly compare the dynamics of both laws, the studies are performed under the action of the same realizations of deterministic and random perturbations that correspond to the studied stage of melting.

Based on the results of comparative analysis of the dynamics indices of regulation of EM coordinates using both laws of regulation of arc lengths, conclusions are drawn about the effectiveness of the proposed fuzzy model (4) in comparison with the differential one (1).

Figure 5 shows the time dependencies of the voltages and currents of the arcs of the furnace ДСП-200 obtained on Simulink models during the implementation of the sequence of deterministic perturbations, namely, the symmetric three-phase operational short circuit $t \in$ 0.5-1.75 s; single-phase short circuit in phase C $t \in$ 1.75-2.8 s and close to the arc break in phases A and B $t \in$ 2.8-4 s, by differential (1) and fuzzy (4) control models.

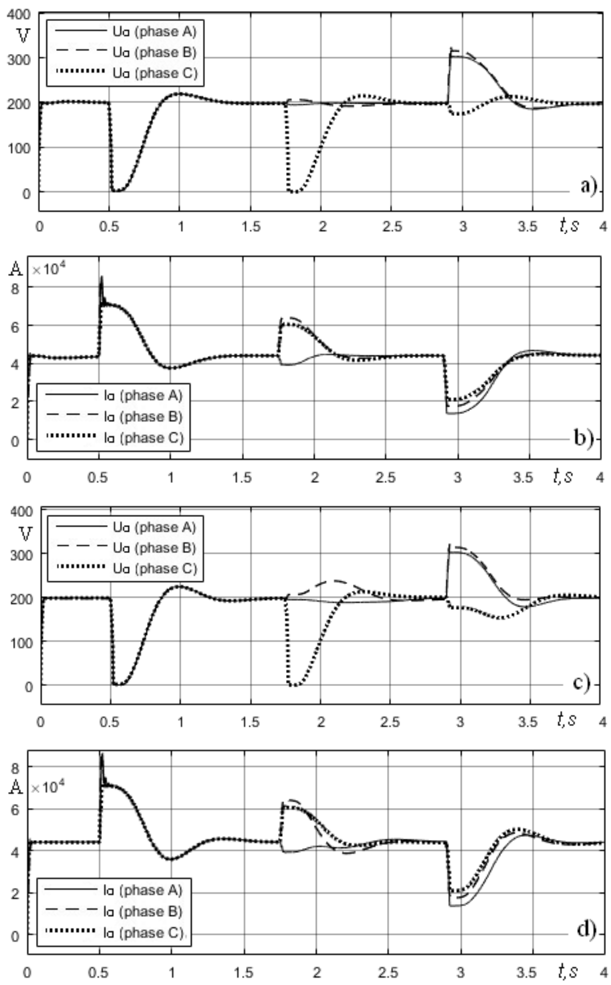

Fig. 5. Time dependencies of voltages and currents of arcs of furnace ДСП-200 in the regulation of deterministic perturbations: *a*, *b* – fuzzy model (4), *c*, *d* – differential model (1)

Three-phase symmetrical operational SC is implemented by both models $U_r(U_a, I_a)$ equally, because in this mode there are no interactions of phase loads. Analysis of the obtained processes $U_{aj}(t)$ ($j = A,B,C$) at implementation of asymmetric deterministic perturbations shows that in fuzzy model (4) the arc length is regulated only in those phases where arc length deviations have occurred. The movements of the electrodes in the phases where there is no perturbation are minimal. They occur only in the first moments of extreme perturbations, when the differential law (1) is used to ignite the arcs. In the differential model (1) of regulation (АРДМ-Т-12 regulator) the movements of the electrodes in certain states of the EM are wrong, they do not always correspond to the phase states of the EM.

These conclusions are also confirmed by the analysis of time dependencies of phase signals of mismatch $U_{rj}(t)$ and speeds $\omega_j(t)$ of motors of movement of electrodes at implementation of the same determined perturbations which are shown in Fig. 6.

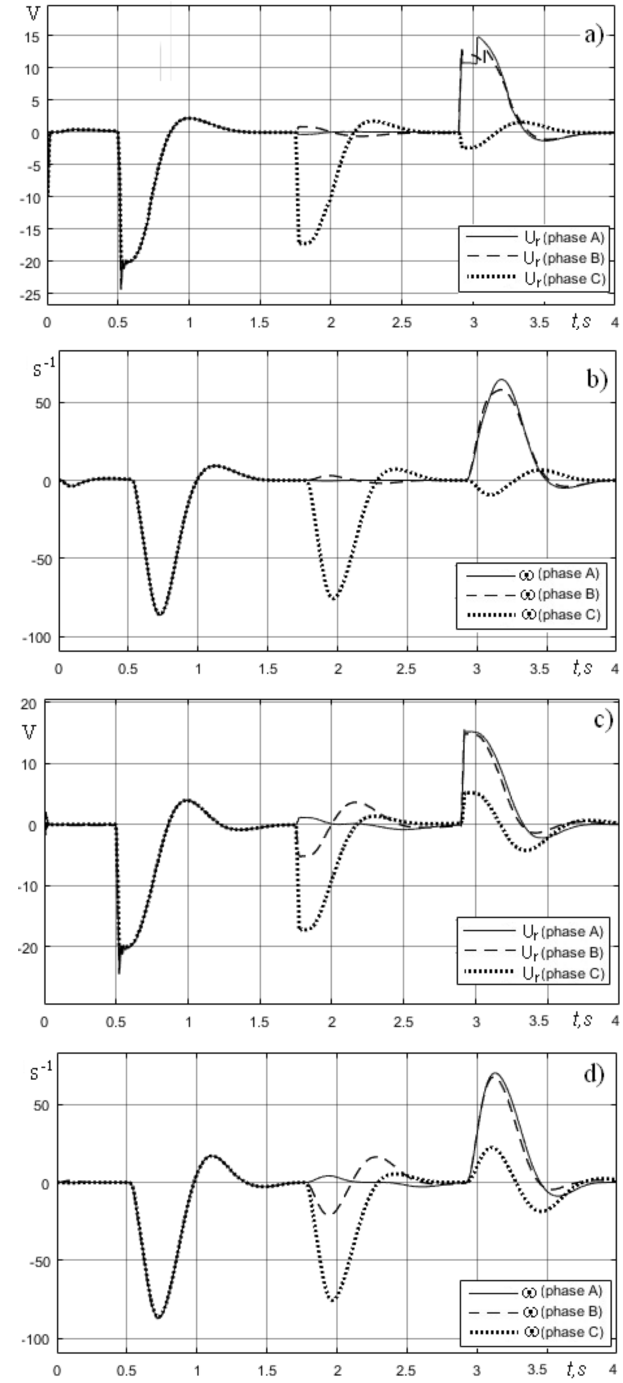

Fig. 6. Time dependencies of mismatch signals $U_{rj}(t)$ and speeds $\omega_j(t)$ of MME motors of electrodes with fuzzy (4) (*a*, *b*) and differential (1) (*c*, *d*) models of arc length control

Shown in Fig. 5, 6 dynamic processes of regulation of deterministic perturbations in such a «pure» form in the melting interval are rare. Therefore, their research and analysis are conducted only as testing to confirm the correct operation of the designed system of fuzzy derivation of FIS in the structure of the EM SAC. For completeness of their analysis, we note that the regulation time of the investigated deterministic perturbations when using the fuzzy model (4) of the BC comparison block is

10-20 % less than using the differential one (1). The phase-average integral quadratic estimation of the quality $I_{sq} = \int_0^4 (\bar{I}_a - I_a(t))^2 dt$ of regulation of these perturbations in the interval $t \in [0, 4]$ s improved by 8.6 %. The value of this estimate is proportional to the reduction of power losses in a short network of the ASF.

The obtained values show the increase of the control speed, the improvement of the dynamic accuracy of the stabilization of the EM coordinates and the improvement of the energy efficiency of the ASF in the regulation of deterministic perturbations by the fuzzy model (4) of the BP.

However, it is possible to obtain an integrated estimation of the efficiency of the proposed fuzzy model of arc length regulation only on the examples of phase-asymmetric random perturbations regulation by arc lengths, which are the main perturbations in the melting process in the ASF.

For this purpose, computer simulations of the modes of control of random perturbations at stationary intervals T_c = 180-240 s and their changes for different technological stages of melting using both control models are performed. Figure 7 shows obtained on Simulink models the fragments $t \in$ 0-30 s of these processes of regulation of EM coordinates using the developed fuzzy model (4) (Fig. 7,*b*, Fig. 7,*c*) and according to the differential law (1) (АРДМ-Т-12 regulator) (Fig. 7,*d*, Fig. 7,*e*) of the ДСП-200 furnace. The perturbation processes $f_{aj}(t)$ (Fig. 7,*a*) corresponded to the stage of charge collapse.

This figure shows the processes of change of voltages $U_{aA}(t)$ and currents $I_{aA}(t)$ of phase A arcs. Analysis of the processes $I_{a.j}(t)$ obtained in these computer experiments shows that the dispersion of arc currents using a fuzzy (4) control model amounted to: D_{I_A} = 168.3 kA^2; D_{I_B} = 159.3 kA^2, D_{I_C} = 181.2 KA^2, and by the differential model D_{I_A} = 236.3 kA^2; D_{I_B} = 235.1 kA^2, D_{I_C} = 219.9 kA^2. The average phase dispersion of arc currents for these control models is: $D_{I.fuz}$ = 169.6 kA^2, $D_{I..dif}$ = 203.3 kA^2, respectively, and the average phase reduction of the dispersion of arc currents ΔD_I = 33.7 kA^2 or 4.5 % of the maximum possible dispersion of arc currents.

Studies of the dynamics of arc current regulation at other technological stages of melting, i.e. under the action of random perturbations with other amplitude and frequency characteristics, show that the dispersion of arc currents using the proposed fuzzy control model decreased by 3-7.5 %.

According to the known results of researches, at the obtained estimation of decrease in dispersion of currents of arcs by 3-7.5 %, arc furnace productivity increases by 4-5 %, and specific electricity consumption decreases by 3-4 %. For the superpowerful ДСП-200 furnace it gives essential improvement of indicators of electrotechnological efficiency.

In the future it is planned to investigate the influence on the dynamics indices of other algorithmic and parametric degrees of freedom of the FIS fuzzy derivation system model on the dynamics of EM coordinate control and on the energy efficiency indices of the arc furnace.

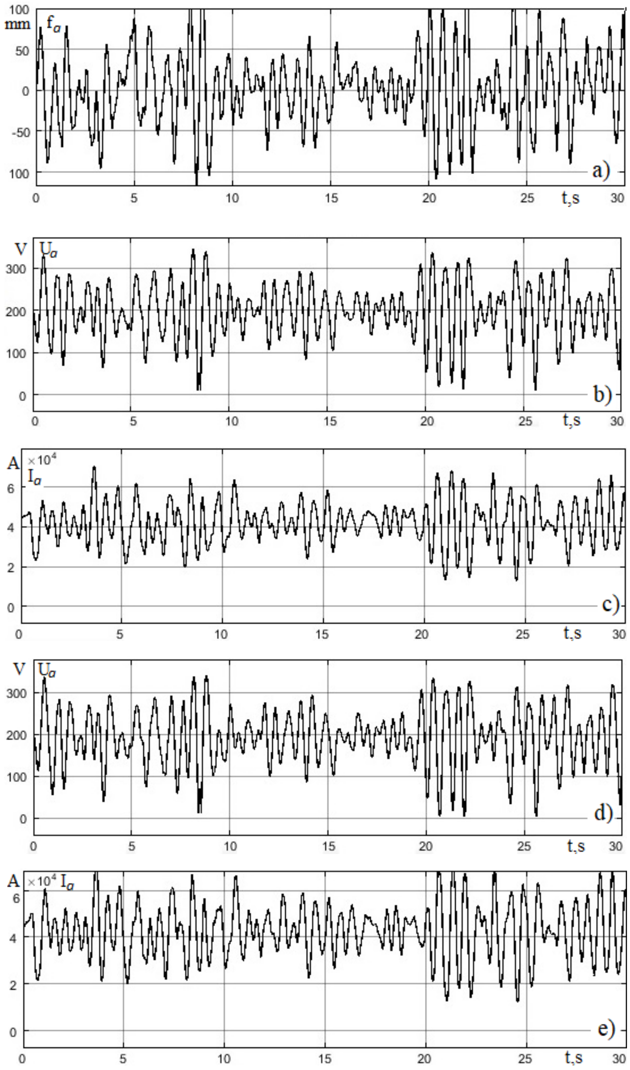

Fig. 7. Time dependencies of perturbations $f_{a,A}(t)$ (*a*), voltages $U_{a,A}(t)$, $I_{a,A}(t)$ of arcs when using fuzzy (4) (*b*, *c*) and differential (1) (*d*, *e*) models of arc length adjustment

Conclusions.

1. The proposed fuzzy model of EM mismatch signal generation with operative adaptation to its current state in each phase in comparison with known control models allows to implement phase-by-phase autonomous regulation of arc lengths and increase control efficiency of the ASF operation modes.
2. The possibility of realization of phase-by-phase autonomous implementation of deterministic and random EM perturbations in the range of average arc lengths using the proposed fuzzy model is confirmed, which allows to reduce in average by phases at different melting stages to decrease the dispersion of the ASF arc currents by 3-7.5 % and on this basis to increase the productivity of the ASF by 4-5 %, as well as to reduce the specific consumption of electricity by 3-4 %.

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