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Modeling of Power Control of Arc Steel Melting Furnace with Fuzzy Correction of Regulation Signal

***Abstract**. A system for arc steel melting furnace arcs power control with fuzzy corrector is proposed. Digital model of the system was created and numerical simulation under influence of deterministic and random disturbances of arc lengths were conducted. Results of simulations are shown, which prove improvements of dynamic and static indices of arc power regulation.*

***Streszczenie.** Praca przedstawia system sterowania mocą łuku w łukowym piecu do wytopu stali. Zaproponowano model cyfrowy układu. Badania numeryczne przedstawione w pracy analizują wpływ zakłóceń deterministycznych i losowych na długość łuku. Wyniki tych badań posłużyły do poprawy statycznych i dynamicznych wskaźników jakości łuku (**Modelowanie układu sterowania mocą pieca łukowego stali z rozmytą korekcją sygnału regulacyjnego**).*

Keywords: arc steel furnace, fuzzy corrector, controller, control
Słowa kluczowe: piec łukowy, korektor rozmyty, sterowanie piecem

Introduction

Arc steel furnaces (ASF) as control object belong to the class of complex systems. The processes of electric mode (EM) coordinates (lengths, voltages, currents and powers of arcs) changes in arc steelmaking furnaces (ASF) are dynamic, non-stationary and random. Three-phase electric circuit of arcs supply is nonlinear. Parameters of arc gaps and elements of ASF power circuit (PC) vary in wide limits during melting process. Electric load in phases are interrelated. These factors negatively affect the dynamic and static indices of arcs power regulation, which leads to significant dispersion of EM coordinates during melting. Mentioned factors degrade electro-effectiveness, electromagnetic compatibility and ecology friendliness [1].

The main requirement that is set to automatic control systems (ACS) of melting regimes in arc furnaces, is the qualitative stabilization of EM coordinates at the level of a priori synthesied for each melting stage values, in particular optimal values by selected criterion. Existing ACSs do not meet the requirements complex in full. In particular, precision of arcs lengths adjustment in existing electromechanical systems of automatic arcs lengths regulation (ARS) (arc power regulators) is low, which makes it impossible to get high energy efficiency, energy conservation, electromagnetic compatibility and ecology indices [1].

Taking into account the complexity of the existing ARS, dynamics, nonlinearity and interphase asymmetry, regimes interdependency, nonstationarity of coordinate disturbances processes and parametric instability, it is impossible to obtain accurate mathematical models of three-phase PC and arc gaps. Lack of the same precise mathematical models does not allow to implement qualitative stabilization of EM coordinates at set values basing on classic control theory methods.

To address the outlined above problem of qualitative EM coordinates stabilization in this paper we propose to use approaches based on the methods of modern control theory, namely to implement adaptive optimal EM coordinates stabilization on the basis of fuzzy control theory methods [2]. From the review of literature and analysis of a number of practical implementations, the specified approach is effective provided the absence of mathematical description, nonlinearity, interphase non-symmetry and interrelativity of regimes, influence of stochastic parametric and coordinate disturbances, uncertainty, that corresponds to the ASF mode features.

Investigation problem posing

For the solution of the above task of comprehensive improvement of electro-efficiency, electromagnetic compatibility and ecology indices it is appropriate to utilize the prompt signal correction based on the use of fuzzy controller (FLC). Using fuzzy controller makes it possible to implement an integrated control process adaptation to the different parametric and coordinate disturbances. To estimate the effectiveness of this approach it is necessary to create a numerical model of EM coordinates control system with fuzzy correction and perform dynamic and static regulation studies under the influence of deterministic and random arc length disturbances. We also need to investigate the sensitivity of the system to the changes of ASF electric circuit parameters.

Research results

The optimum solution for a system of ASF electrodes position adjustment is implementation of aperiodic (or close to aperiodic) law of the electrodes movement during working out deterministic disturbances in arc lengths with the highest possible speed that is determined by mechanical strength of electrodes movement kinematic scheme elements. This corresponds to aperiodic voltages, currents and arc powers control processes. This will have positive impact on the integral index of control quality – reduce the dispersion of EM coordinates during melting [3].

It is appropriate to implement the above strategy of optimal EM coordinates control using the fuzzy correction of electrodes movement control signal U_d , preserving current differential control law of control signal forming or its modified version [1].

Proposed for this approach structure of electromechanical electrodes movement control system with fuzzy dynamic electrodes movement control signal correction is shown in Fig. 1.

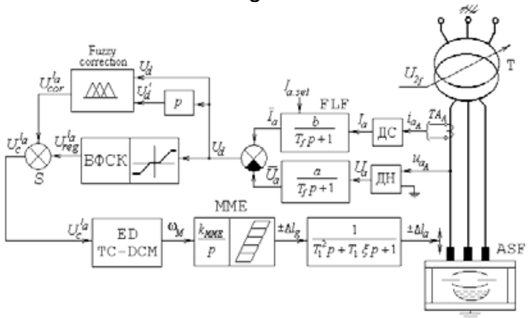

Fig.1. Functional diagram of the ASF electric mode control system with fuzzy compensator.

The key factors determining the efficiency of fuzzy correction is grounding for the task of ASF electric mode quality coordinates stabilization procedures of phasing, dephasing, and model of fuzzy output. In the proposed control system structure they are implemented in fuzzy compensator (controller).

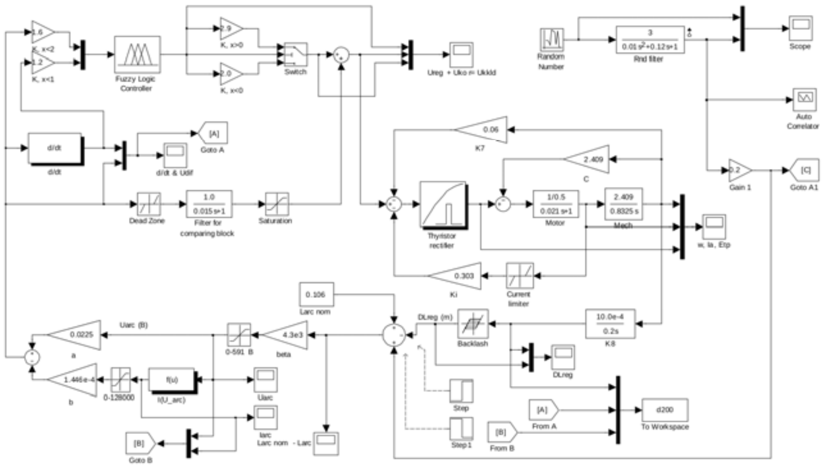

Fig.2. Structure diagram of Simulink-model of ASF DSP-200 EM control system with ARDM-T-12 regulator based on „thyristor converter – DC motor" structure with fuzzy corrector

For efficient forming of adjusting signal it is proposed to use fuzzy Takagi-Sugeno controller with constant output, which is included in parallel to the control signal forming block (CSFB) into existing arc power regulator of ARDM-T-12 type with "thyristor converter - DC motor" electric drive (fig.1).

Input signals of the fuzzy controller are regime deviation signal, which is calculated by the differential control law [1, 3] and the derivative of this signal.Input signals of the fuzzy controller are regime deviation signal, which is calculated by the differential control law [1, 3] and the derivative of this signal.

Output signal of Takagi-Sugeno fuzzy controller is formed by the following model of fuzzy rules

$$\text{IF } U_{r_\kappa} \in A_{1\kappa} \text{ and } U'_{r_\kappa} \in A_{2\kappa} \text{ THEN } U^{I_a}_{cor_\kappa} \in B_\kappa ,$$

where B_κ are output values for the corresponding ranges of fuzzy controller input signal values.

The sum of signals $U^{I_a}_{reg}$ (main arc power controller signal) and $U^{I_a}_{cor}$ (output signal of fuzzy corrector), is input signal of the thyristor converter TC of electrodes movement mechanism electric drive ED: $U^{I_a}_{c} = U^{I_a}_{reg} + U^{I_a}_{cor}$, where $U^{I_a}_{reg}$ is the main control signal component, which is formed by CSFB in function of differential deviation signal:

$$U_d = a\overline{U}_a - b(\overline{I}_a - I_{a.set}),$$

where $\overline{U}_a$, $\overline{I}_a$ - averaged by supply voltage period signals of corresponding phase voltage and current, which are formed on outputs of voltage and current channels low-pass filters; a, b - constant scale coefficients, which set steady-state electric mode point; $I_{a.set}$ - differential arc power regulator current setting (electrodes positioning control system).

To describe each input linguistic variable seven terms with uneven subranges decomposition scale are used: inner membership functions are triangular, and membership functions for extreme subranges are trapezoidal (Fig. 3). Estimates of the membership functions parameters and output signal for each range are calculated by the analysis of responses (processes of arc lengths changes) of ARDM-T power regulator for different by sign unit arc length disturbances. These responses were obtained on the created digital Simulink-model of ARDM-T-12 power regulator for DSP-200 arc furnace in Matlab version R2007b (Fig.2).

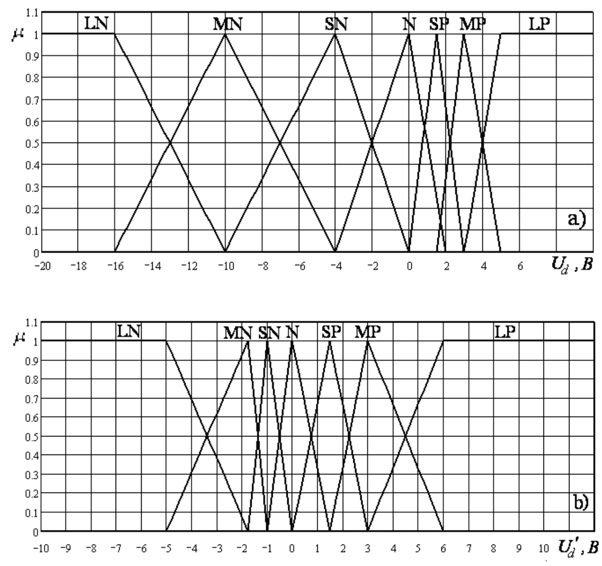

Fig.3. Error membership functions U_d a) and their increments U'_d b)

Obtained from the processing of control system responses to deterministic disturbances fuzzy controller membership functions parameters are further refined during mathematical experiments on a digital model using the developed methodology. Their calculated optimal values meat the criterion of minimum dispersion of voltages, currents and arcs powers during working-out stationary random arc length disturbances for various technological stages of melting. The resulting membership functions of control error and its increments are shown in fig. 3.

Study of the efficiency of control signal fuzzy correction for moving the electrode was made on a digital Simulink-model of DSP-200 furnace arc power control system. To do this, a study of the EM coordinates change dynamics under the influence of deterministic and random disturbances of arc length have been performed and the estimation of control system with fuzzy correction sensitivity to parametric disturbances obtained.

Fig.4. shows obtained on a digital model time dependences of arc voltage and current changes when working out short circuit mode without fuzzy correction (arcs power regulator of ARDM-T type), and fig.5 - time dependences of the same coordinates for short circuit mode, but using fuzzy correction.

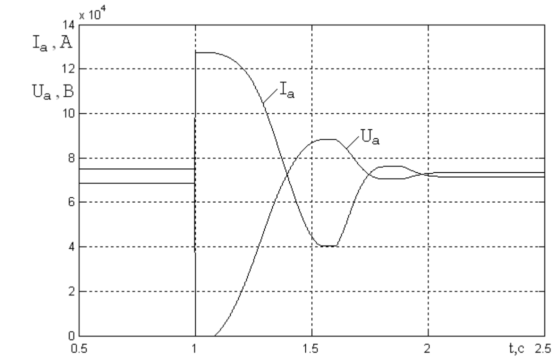

Fig.4. $I_a(t)$ and $U_a(t)$ dependences when working out short circuit mode with typical ARDM-T-12 arcs power regulator

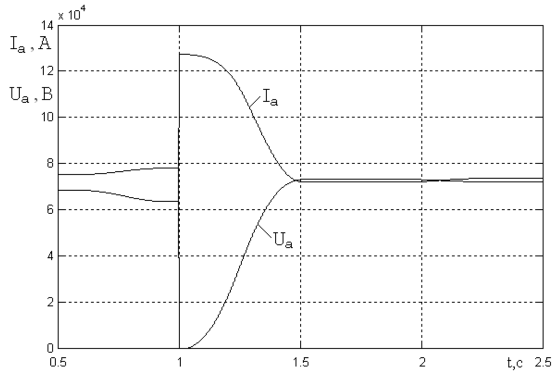

Fig.5. $I_a(t)$ and $U_a(t)$ dependences when working out short circuit mode using ARDM-T-12 regulator with fuzzy correction

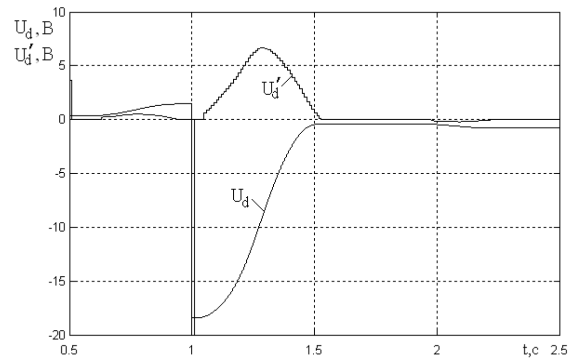

Fig.6. Dependences $U_d(t)$ and $U'_d(t)$ $U_c(t)$ when working out short circuit mode using ARDM-T-12 with fuzzy correction

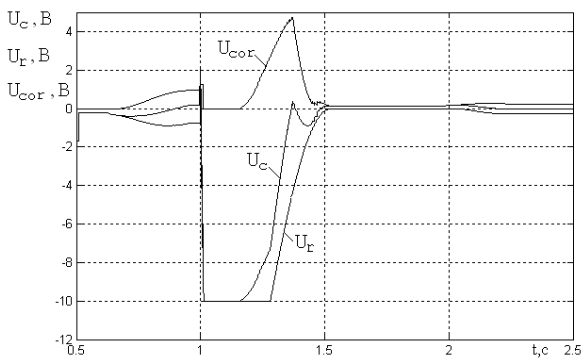

Fig.7. Dependences $U_r(t)$, $U_{cor}(t)$ when working out short circuit mode using ARDM-T-12

Fig. 6 shows time dependences of control signal error $U_d(t)$ and its derivative $U'_d(t)$ (inputs signals of fuzzy corrector), and the fig. 7 – time dependences of input signals $U_{reg}^{I_a}$, $U_{cor}^{I_a}$ and output signal of adder S: $U_c^{I_a} = U_{reg}^{I_a} + U_{cor}^{I_a}$.

The analysis of working out arc lengths deterministic disturbances when using proposed control system with fuzzy correction shows the implementation of the desired aperiodic arc voltage and current control process and approximately twice as fast adjustment of EM coordinates under other equal conditions.

By changing the scale factors of fuzzy corrector input and output signals optimum belonging functions parameters were reached for minimizing the dispersion of EM coordinates.

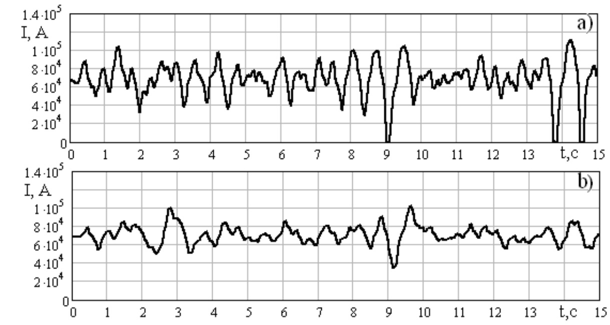

Fig.8. Time dependences of arc currents under ARDM-T-12 regulator functioning (a) and control system with fuzzy correction (b) respectively

Their comparison shows a reduction of the arc current dispersion when using fuzzy correction of electrode movement signal from $3.46{\cdot}10^8$ A^2 to $8.63{\cdot}10^7$ A^2, i.e. approximately 4 times.

Analysis of EM coordinates dependencies for various technological stages of melting (for different frequency parameters of arc length random disturbances) showed that the reduction of EM coordinates dispersion coefficient within 3-5 times. The research results also showed the reduction of sensitivity of control system using fuzzy correction dynamics indices to the ASF control system parameters.

In fig.8 fragments of obtained time dependences of arc currents when using arcs power regulator ARDM-T-12 are shown: (a) - without fuzzy correction, and (b) - using fuzzy correction.

Conclusions

Using the proposed model of electrodes movement control signal synthesis based on fuzzy controller makes it possible to increase ASF EM coordinates dynamic stabilization precision, and, as a result, increase the indices of electro-technological efficiency and electromagnetic compatibility of electric arc furnace and power supply regimes. The method of fuzzy controller parametric synthesis using a digital model of control object makes it possible to get optimum settings of fuzzy corrector by the selected criteria, such as the criterion of minimum arc length, currents, voltages or power dispersion.

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