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SIMULATION OF THE MELTING PROCESS IN AN ELECTRIC ARC FURNACE

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ABSTRACT

In this paper, a process model was presented taking into account the change in length of the electric arc during melting caused by the continuously changing of the geometry and state of the environment of the inter-electrode gap. A mathematical model of an electric steel-smelting furnace was proposed. A simulation study was conducted to identify the characteristic features for the process of burning an electric arc.

1. INTRODUCTION

Steel is one of the most important products of the ferrous metallurgy, used as the main material in the construction of both large objects (railways, bridges, structures), and small ones (machines, instruments, etc.). Steel smelting is considered as a complex and time-consuming process.

The steel production in arc steel-smelting furnaces is done based on the burning of electric arcs, causing high-power electrical discharges to have a low voltage with relatively large amperage. While burning arcs in chipboard, a continuous change occurs in their shape, size and consequently, all the parameters related to the operating mode of the furnace would change. Managing such an object is very complex. The complexity is aggravated by the nonlinear characteristic of the arc and continuously changing the state of the arc gap.

To build a model used in the control system, numerous studies have been conducted in this regard [1-3], and the basic principles of its construction have been formed. The basis is concerned with a calculation method upon which the equivalent circuit of an electrical circuit in the installation is considered with corresponding active and inductive resistance. The model is updated by calculating the electrical circuit parameters on the secondary side of a low voltage transformer and using the data presented in the literature [4–8].

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2. MODEL BUILDING

The impedance of the system in accordance with the replacement circuit consists of transformer losses, (this parameter is often neglected in modeling because it is insignificant) resistance of the short network, (which may consist of several sections of the circuit) and dynamic resistance of the arc.

Today, the software market offers a wide variety of full-featured professional systems for modeling and analyzing various electrical power systems. However, due to the versatility, and ability to use functional and simulation approaches, MATLAB® Simulink® has gained the greatest popularity among the researchers engaged in mathematical modeling.

Arc furnaces, as melting units, are directly dependent on the parameters of the electric arc, namely, the power determining the thermal mode of the installation. At the same time, the melting process itself includes several different stages, requiring different values of the input power or the corresponding electrical modes. At present, there are several possible control paths, namely, a change in the voltage supplied to the furnace, and a change in the inter-electrode space, as well as the arc length. These parameters are rendered as the input effects on the control object.

Therefore, a block diagram for a mathematical model of an electric steel-smelting furnace was proposed in the MATLAB® Simulink® package (Figure 1).

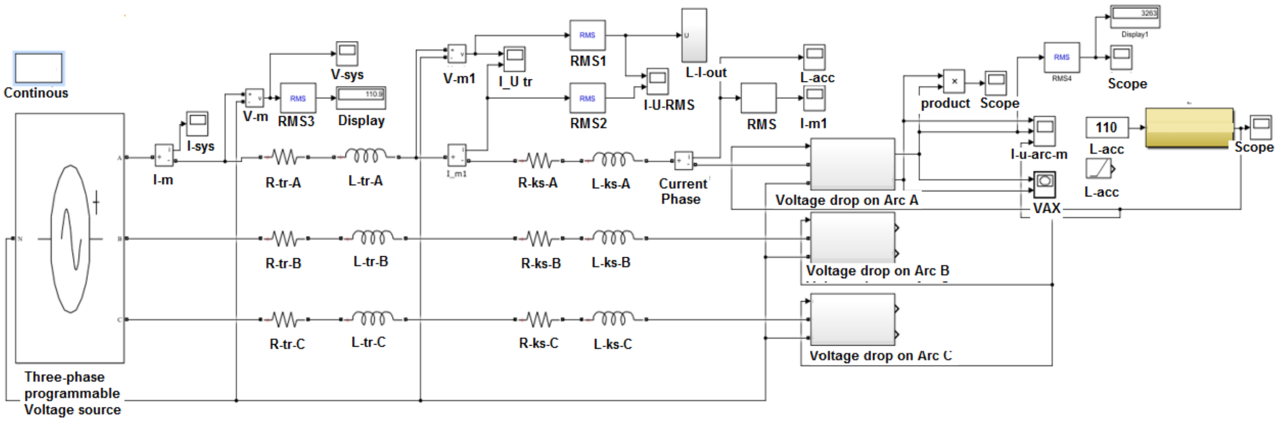

Figure 1: Mathematical model of the arc furnace in the MATLAB Simulink® Package.

The model included an alternating voltage source, active resistance and inductance of a transformer on the low voltage side and a short circuit, introduced as a model of an AC electric arc. The purpose of the simulation is identifying the control actions with the greatest effect on the state of the system, and the characteristics dependent on the input and output of the coordinates, and also formulating the recommendations for managing the process.

3. SIMULATION RESULTS

Dynamic characteristics are related to the relationship between changes in input and output values in a dynamic mode (in time). To analyze the control object, a dynamic current-voltage characteristic (VAC) was constructed for sinusoidal curves of the current values, oscillograms of the current and voltage, and dynamic characteristics for non-sinusoidal curves of RMS current values of the current. To do this, the action of one of the inputs was changed by 20%, while maintaining the value of the others unchanged. The results are presented in Figures 2 and 3. The current-voltage characteristic and oscillograms of the current values were considered for different stages of the melting.

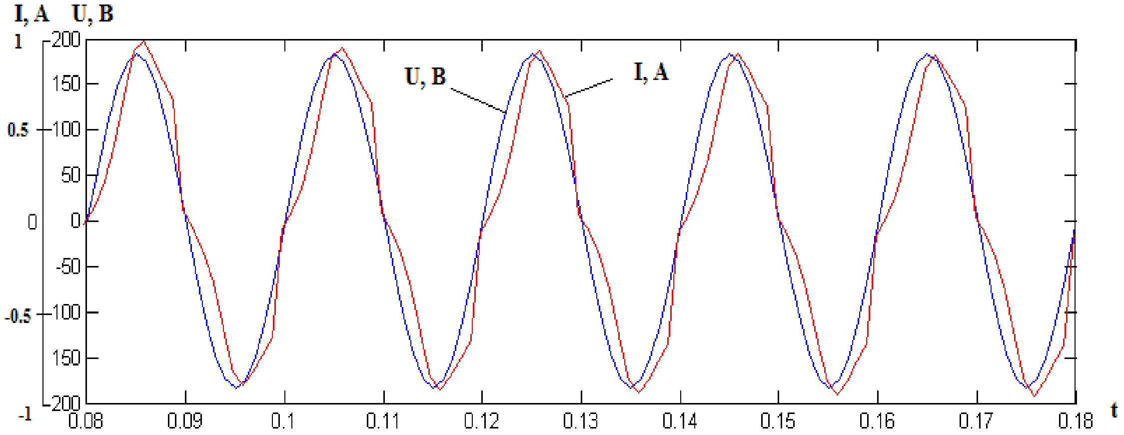

Figure 2: Waveforms of the current and voltage of the arc.

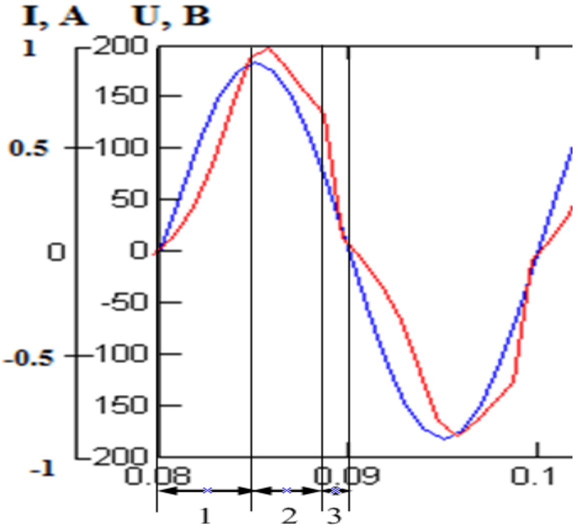

Figure 3: Oscillogram of the arc current and voltage for a half-period (1 - Stages of ionization and ignition of the arc; 2 - Burning stage of the arc; 3 - Deionization stage)

Characteristic presented in Figure 3 refers to the initial stages of the melting when the ionization conditions of the inter-electrode space are poor and the arc burns in the open air.

In the current oscillogram, the stages of electric arc burning were considered for each half-period. The longest belongs to the ionization stage of the inter-electrode space. At this moment, a favorable environment is formed for the arc. Next, the burning stage occurs. The final stage of the arc is related to the moment of deionization of the inter-electrode space. Then, the cathode and anode are reversed, under favorable conditions, the arc ignition is repeated. To analyze the control object, dynamic I – V characteristics and oscillograms were constructed provided that the input effects change. Dynamic characteristics are related to the relationship between changes in input and output values over time. The current-voltage characteristics were determined for sinusoidal curves of the current values and, non-sinusoidal curves of RMS effective values. To do this, the action of one of the inputs was changed by 20%, while maintaining the value of the others unchanged. Graphs are shown in Figures. 4 and 5.

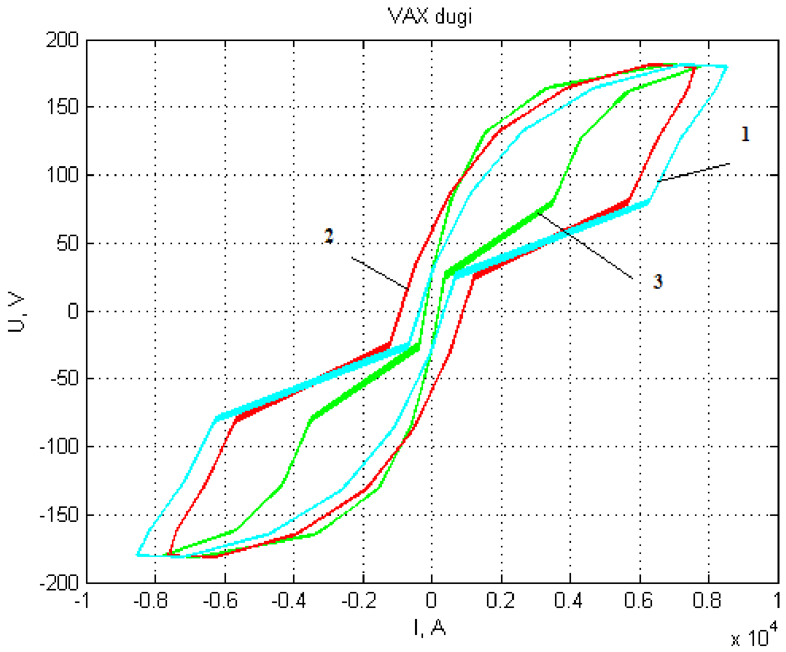

Figure 4: Current-voltage characteristics (1 - Rated; 2 - Voltage variation; 3 - Arc length change)

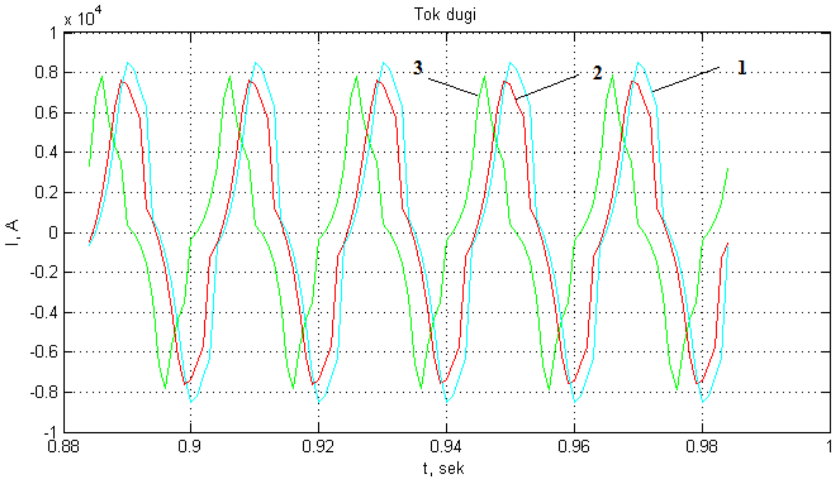

Figure 5: Oscillograms of the arc current (1 - Nominal; 2 - Voltage variation; 3 - Arc length change)

Analysis of the graph data showed the effect of the input actions on the control object. It was also shown that the greatest deviation from the nominal mode occurred with a change in the secondary voltage. On this basis, a change in the secondary voltage can be chosen as a control. However, frequent commutation of the high-current circuits leads to the rapid wear of the equipment, which is considered to be unsuitable for promptly changing the parameters of the arc. Therefore, the change in the secondary voltage is used only a few times during the melting period at the time points determined by the technologist. Therefore, as a control, the change in the arc length is applied as the simplest and most convenient method for control by moving the electrodes. To completely form the concept of the control object, I – V characteristics and oscillograms are considered for different stages of the melting. Also, the effect of the arc length change is determined for each of the modes on the control object. Graphs are shown in Figures. 6-8.

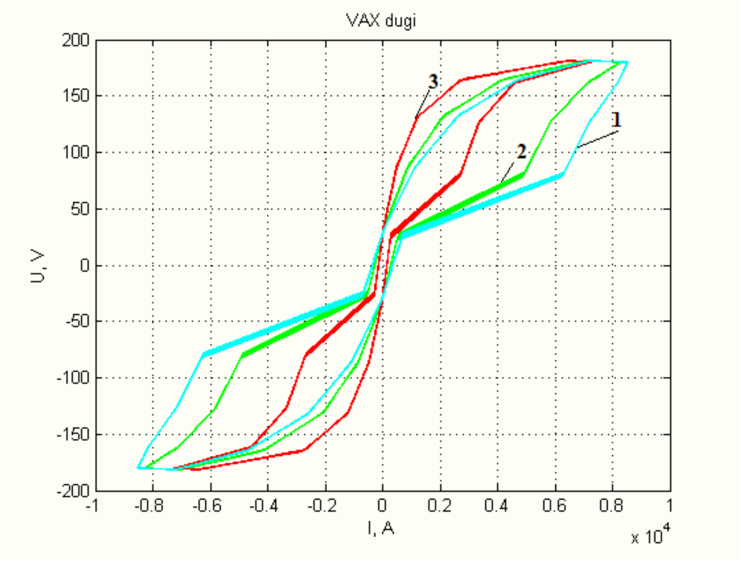

Figure 6: Volt-ampere characteristics of the arc for different arc lengths in the operating range at the initial stages of the melting (1 - Nominal arc length; 2 - Arc length is 10% less than the nominal; 3 - Arc length is30% less than nominal).

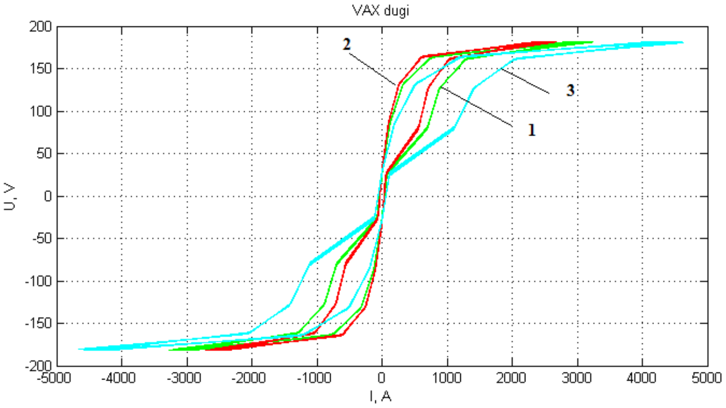

Figure 7: Current-voltage characteristics for different arc lengths at the stages of burning “closed” arcs (1 - Nominal arc length; 2 - Arc length is 10% less than nominal; 3 - Arc length is 30% less than nominal).

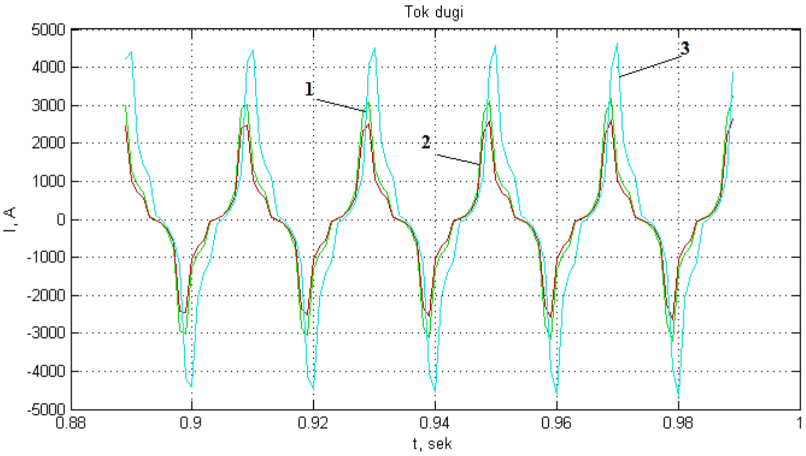

Figure 8: Oscillograms of the arc current for different arc lengths at the stages of burning “closed” arcs (1 - Nominal arc length; 2 - Arc length is 10% less than the nominal; 3 - Arc length is 30% less than the nominal)

Analysis of the graphs showed that during different periods of melting different burning conditions are created, this, in turn, determines the diversity of the waveforms and the current-voltage characteristics of the alternating current arcs. Such changes are associated with the continuously changing inertia of the process, which significantly increases during the smelting. The IVC and oscillograms acquired pronounced increasing and falling portions. More advanced loops in the initial stages approach the shape of the broken line. Ignition voltage peaks necessary for re-ignition of the arc in a cold atmosphere would reduce.

4. CONCLUSION

Using the developed model, the influence of the input parameters was investigated. The obtained results allowed us to analyze the control object and obtain electrical characteristics necessary for further construction and simulation of the control system for the electric arc furnace. Control of this object is possible through various ways using different automatic control systems. Analysis of the dynamic characteristics showed that changing the arc length is the simplest and most convenient way to control.

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