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DEVELOPMENT OF STRUCTURE FOR MATHEMATICAL MODEL ARC STEEL-SMELTING FURNACE

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It is offered the structure of the mathematical model of the power circuit for arc steel-smelting furnace, which is serves by basis for creation of a system of control mechanism for moving the electrode. On basis a considering of scheme realization of the model there are highlighted the factors affecting on the increased loss of material for electrodes.

Keywords: arc steel-smelting furnace, electrode, current of electric arc, mathematical model of dynamic arc, structural modeling

Actuality of work. In the conditions of modern domestic plants one of the most powerful aggregates there is an arc steel-smelting furnace (ASSF) which has a row of problems in relation to its energy- and resourse-saving. From it apparently, that an analysis of the regimes of action for ASSF is one of the most perspective directions of their modernization, and also development and adoption of the noted industrial equipment. Even comparatively the insignificant improvement of its action must provide a substantial general economic effect.

Works of S.I. Tel′nov, A.D.Svenchansky, A.I. Sapko, E.Yu. Ephrojmovich and many other authors are sacred the decision of this problem. However, taking into account complication of technological processes in ASSF, becomes the necessity of implementation of more manifold and exact analysis of the regimes of action of the noted equipment and realization on its basis of modernization for control system by it.

Analysis of the regimen state of problem. The existent systems of automatic control for ASSF are enough various and, in a different measure, execute a main task: providing of minimum duration of melting at the minimum expense of electric power. Thus it should be noted that the most charges of electric power take place during the first period of melting - period of melting of charge. For this period the most active moving of electrodes, those results in the least stable electric regime of arc of ASSF are characterized.

Surely important the questions of determination of voltage size U_a, strength of current i_a, length of arc ℓ_a, thermal parameters of melting, and also level of their stability are considered. However almost in all modern algorithms of management by work of ASSF does not take into account influence of conditions of arc burning on the state of electrode (its mechanical properties), although this factor substantially influences on electric and technological parameters. In a first period of melting a charge firstly is melted natively, directly under electrodes with formation of «trunks», where electrodes submerge. The depth of their dip is determined by the action of control system for the mechanism of moving of electrode. Exactly on this stage an arc between an electrode and charge is the least a resistant, its strength of current and length change continuously, and burning is characterized by

frequent faunlts. Being of main mass on change in the hard state and presence of the most active moving of electrodes (lowering, establishment of the regimes) assist their damage. Except for that, it follows to take into account that walls of «trunks» are not homogeneous, but consist of different on mass and temperature of melting of charge pieces, id est. a closeness of charge is different (there is the partial leveling of closeness of charge at its heaping up, however it not always is possible). Bringing down of melt pieces of charge in «trunks» and pressing of them with electrodes assist the origin of short circuits and fault of arc. Such breaches of the regime of melting diminish the useful charges of power and result in splitting off of electrodes (additional expense of electrode material and additional carbidization metal). Such breaches take place several times on a minute (at the not dense heaping up of charge - more frequent), that is why electrodes mechanical durability loses and the term of their fitness diminishes, id est. the charges of electrodes grow. It is necessary to mark that charges on combustion and since electrodes which take place at application of existent algorithms of action by automatic regulators of ASSF, is enough substantial.

It is known that the prime price of ton of the smelted steel consists not only of cast electricity and cost of initial materials (ores or charges); its noticeable part is folded charges on electrodes, which during exploitation it will be to replace [1]. From data of work [2], charges of electrodes for ASSF, which work on traditional technology, fold 8-15 % prime prices of steel that testifies to the necessity of decline of them.

By electric facilities of lowering of such charges are:

- is diminishing of charges on oxidization by limitation of temperature of surface for electrode due to maintenance of the nominal current loading in accordance with its diameter;

- is diminishing of charges of electric power on nebulized due to maintenance of the resistant regime of its consumption;

- is diminishing of charges on candle-ends and wreckages of electrodes by the increase of exactness and sensitiveness of control system for the mechanism of moving of electrodes due to diminishing of quantity, force and duration of collisions of electrodes with a charge.

Except for planned replacements of electrodes enough frequent (at least - several times on a quarter) are cases, when electrodes it will be to replace in the emergency order from their breaking, in the case of inaccuracy of action or insufficient fast-acting of control system by the electro drive of mechanism of moving of electrodes for ASSF. The analysis of work of control system by the noted mechanism shows that reasons of breaking of electrodes, first of all, a loss of control is above speed of moving of electrode (so-called «shunt running»). Except for that, on mechanical durability of electrode, and thus, and on the condition of its action, substantially the unforeseen vibrations of strength of current and level of temperature influence at the emergency faults of arc. The noted emergency faults of arc draw more or less the outages of furnace protracted, which, in turn, violates the technological process of melting and promotes the charges of electric power on the repeated heating of charge. For modern ASSF there is characterized a great number of their shutdowns from a network during melting, that it is related to the requirements of technological process or with abrupt ends (breaking of electrodes, wearing-out of defense, different types of damages of equipment of furnace). The quantity of such shutdowns arrives at five and more on melting, and each an on-current pause lasts from units to ten of minutes.

Problem formulation. Existent algorithms of management by melting the regime ASSF does not have enough effective and need perfection. Except for providing of the

automatic ignition of arc and adjusting of power furnace, it is desirable, that control system by the mechanism of moving of electrodes of ASSF provided prevention or even urgent removal of emergency faults of arc and other emergency situations with the minimum possible damage of electrodes at the drop of charge. Taking into account foregoing, the construction of mathematical model, by means of which it will decide such tasks, seems appropriate.

Main part of researches. It is known that basis of construction of ASSF is a working organ of thermal energy source, electric equipment for control of this organ; heat-insulated working space; additional mechanisms [1]. Thus, a task of receipt of adequate model of ASSF can be divided into the row of tasks in relation to the construction of models of separate component parts of furnace and task from «inferace» of their action in composition an integral model. Development of structure of mathematical models of certain constituents of ASSF is executed by the method of structural modeling [3]. In further the analysis of structure is executed by means of package «Matlab Simulink» [4].

As a working organ of thermal energy source is used by heater elements or electrodes of different type, that create a voltaic arc. Therefore a near-condition question at development of mathematical model of ASSF is a construction of model of subsystem, which describes processes which take place directly in an arc interval.

On this time there are a great number of mathematical descriptions of voltaic arc [5-8]. As the result of their analysis and comparison is choice became electing of mathematical model of dynamic arc (MMDA) for the decision of the put task such model appeared most suitable.

Equation over of MMDA is brought to the canonical kind:

$$\frac{di}{dt} = \frac{1}{L} \cdot \left[U - i \cdot R + i \cdot i_{\theta}^{n-1} \right], \tag{1}$$

where i is a current of arc; t is modeling time; L is inductance of power circuit; U is voltage of source of feed; $i \cdot R$ is a drop of voltage on a resistor which limits a current; i_{θ} is a current of the state of arc, $\frac{di_{\theta}}{dt} = \frac{1}{2\theta} \cdot \frac{i^2 - i_{\theta}^2}{i_{\theta}}$, θ is permanent to arc time; n is an index of degree.

Volt-ampere description of arc in MMDA is inflicted by correlations:

$$U(i) = U_0 \cdot \left(\frac{i_{\theta}}{I_0} \right)^n, \tag{2}$$

where U_0, I_0 are voltage and current of q-point of volt-ampere description of arc; a value of index of degree n is to the variables for the different conditions of arc burning [8].

Then, carrying out transformation of equation (1) on an integral form, get:

$$i_a = \frac{1}{L_S} \cdot \int \left(U_c - i_a \cdot R_b - \frac{i_a}{\sqrt[3]{i_t^4}} \right) dt + i_{a0}, \tag{3}$$

where $i_a = i$ is a «trend» current of arc; $L_s = L$ is inductance of power circuit of arc; $U = U_c$ is regenerate voltage of power system; $i_a \cdot R_b = i \cdot R$ is a drop of voltage on a resistor which limits a current; $i_t = i_{\theta}$ is a «slow» current of arc; $i_t = \frac{1}{2t_0} \cdot \int \left(\frac{i_a^2 - i_t^2}{i_t} \right) dt + i_{t0}$; t_0 is permanent to time of arc conductivity; i_{t0} is a current of the state of arc on an initial mo-

ment; i_{a0} is a current of arc on an initial moment; $t_0 = \theta$ is permanent to time of arc conductivity; $U_a = U$ is voltage of arc; value of factor of degree take $n = -1/3$ on a, that answers the conditions of burning of arc for the period of melting.

Dependence between voltage and current of arc in accordance with equation (2) looks like

$$U_a = U_0 \cdot \left(\frac{i_t}{I_0} \right)^{-1/3}, \tag{4}$$

Uniting equation (3) and (4), get basis for the making of structure for mathematical model, this is represented on fig. 1.

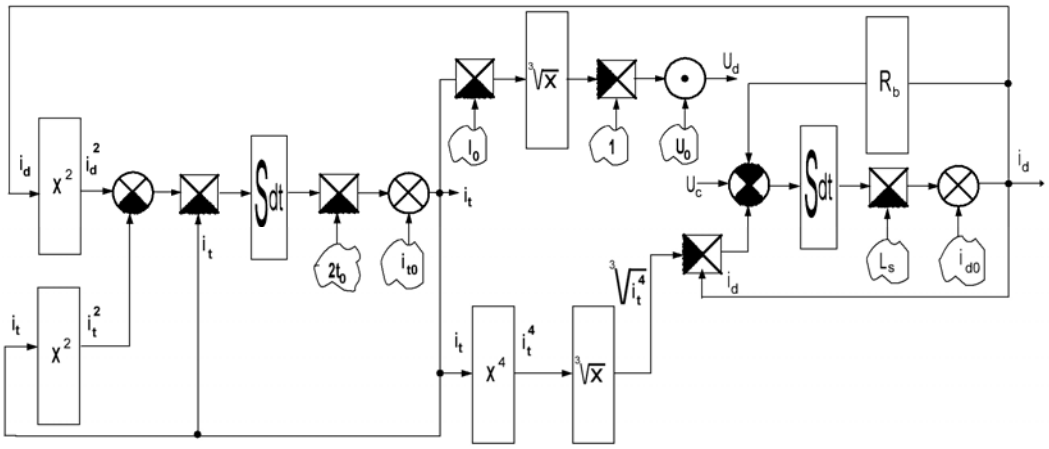

Figure 1 - Structure of mathematical model of arc power circuit for ASSF

On fig. 2 scheme realization of model is given by facilities of «Matlab Simulink». By the impute parameter of power circuit of arc, and also all model of ASSF, there is secondary voltage of power nourishing transformer U_c, which in the first approaching is considered as unchanging. By an initial parameter power to the contour there is a current of arc i_a, which is the basic criterion of tuning of control system by the mechanism of moving of electrode for ASSF.

The offered model allows to expose dependence of current of arc i_a on the conditions of its burning (variation of permanent to time t_0), choice of q-point (U_0, I_0) and size of inductance of power circuit of arc L_s. Built chart of model of power circuit of arc there was parametring in accordance to the regime of melting for ASSF with the capacity of 5.0 t.

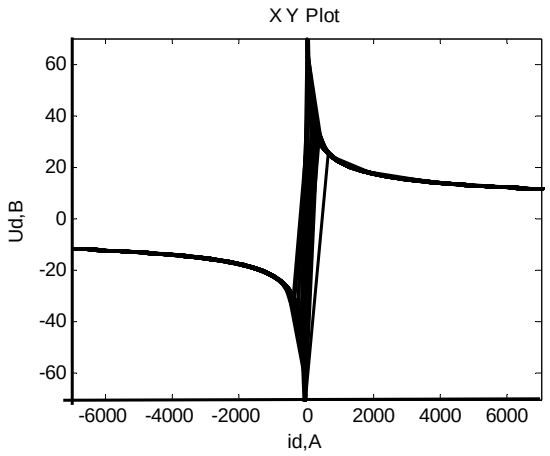

Figure 2 - Scheme to realization of model of power circuit of arc of ASSF

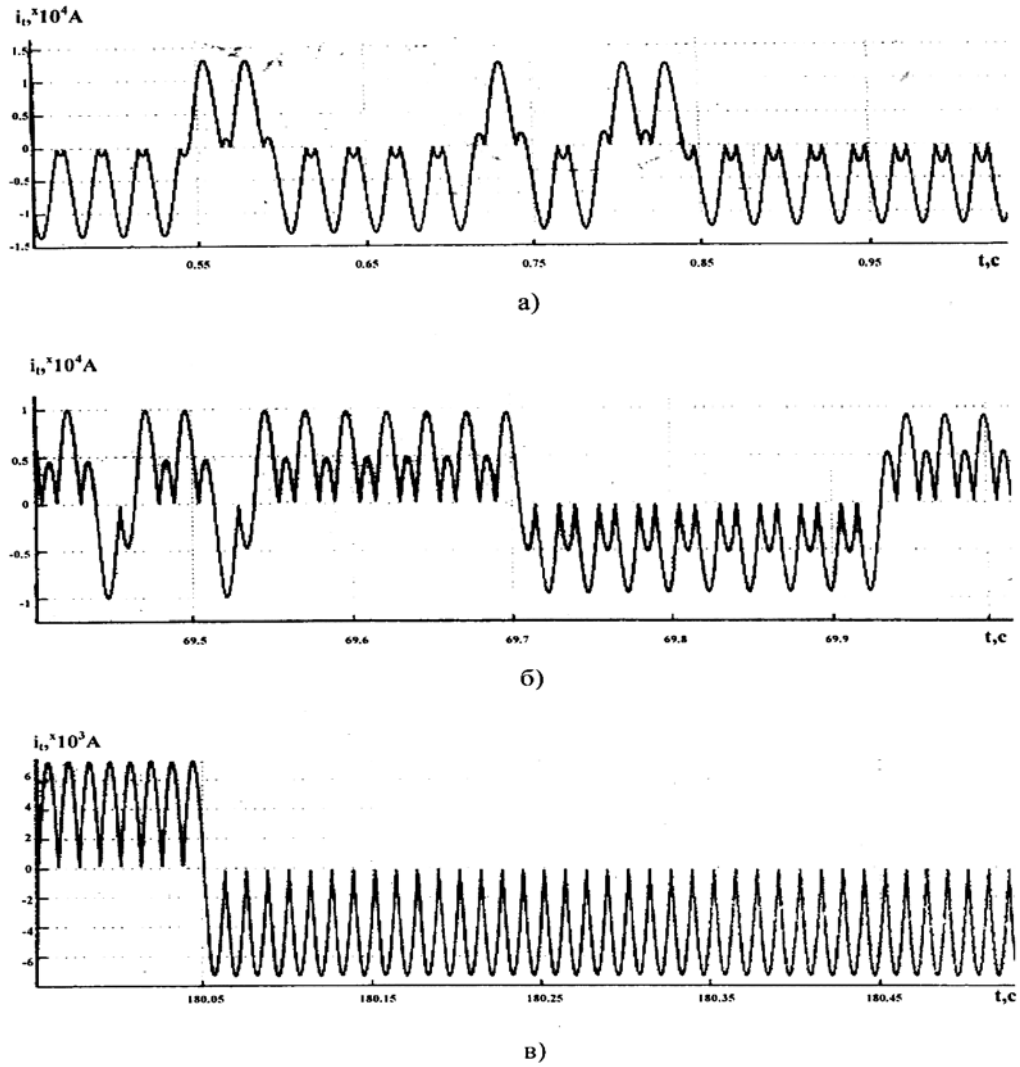

Figure 3 - Volt-ampere characteristic of arcs that it is got by means of scheme realization of model

Results which are got by means of model showed that on the static regime dependence between voltage and current of arc has the appearance of symmetric exponent (fig. 3). In area of currents, where their size presents hundreds ampere, voltage has comparatively large values (tens a volts) and changes sharply enough, at passing to the area of currents, which have a size which folds kiloamperes, voltage falls to the values a 10-20 volt and

changes far slower. Analogical descriptions were got other authors on results experiments on ASSF [9,10].

It is set the executed research (fig. 4) that the «slow» current of arc i_t during the first ten of seconds of its burning changes the polarity rarer than «trend» current and its amplitude hesitates between two values which change by turns. Then gradually amplitude of current i_t is evened and arrives (more slowly than «trend» current) at the set unchanging value, and treasons of polarity of current i_t become less frequent and more periodic. At the same time on completion of process of lighting of arc (a few tens of seconds after presentation of voltage on an electrode) the current of arc i_a every a few seconds has brief throws with small amplitude, but in general an arc (on condition of homogeneity of charge) arrives at the permanent process state.

Figure 4 is oscillograms of «slow» current of arc at its ignition (a), on initial stage of burning (b) and on the permanent regime (c)

Thus, the built model specifies on fundamental possibility of stabilization of permanent arc process which is arrived at by the management of arc parameters. It appears possible on condition of construction of control system, the algorithm of action of which will take into account the factors of violation of the regime of arc and prevent their development. In this case it is possible to expect that the regime of burning of arc will be near to the regime, recreated by the above-mentioned model.

Character of the got dependences in the first approaching answers the physical view of process of burning of arc in ASSF, and, thus, the offered model can be used as basis for the construction of complete model of the noted aggregates.

Conclusions. New direction of increase of economy of action of ASSF by the way of both diminishing of power and material resources (first of all diminishing of charges of electrodes) is offered. There is graphicly dependence shown between the entry parameters of control system moving of electrodes: by the parameters of arc (by its current and voltage). Main factors which influence on the increased destruction of electrodes and them the emergency breaking over are considered, and also actions which must bring to diminishing of expense of electrodes are set. The worked out scheme realization of mathematical model of power circuit of arc can be used as basis for the construction of complete mathematical model of ASSF, which will provide the decline of energy consumption and materials of motion technological process due to the increase of exactness of management of moving for electrodes a mechanism.

REFERENCES

1. Вольфовский, Г. С. Определение экономической эффективности нового электротермического оборудования (методика и практика расчетов) [Текст] / Г. С. Вольфовский. – М. : Энергия, 1969. – 144 с. – Библиогр. : с. 144 (библиотека электротермиста, вып. 34).
2. Кудрин, В. А. Теория и технология производства стали : учебник для вузов [Текст] / В. А. Кудрин. – М. : Мир, ООО «Издательство АСТ», 2003. – 554 с. – Библиогр. : с. 542. – ISBN 5-03-003533-8 («Мир»), ISBN 5-17-013411-8 («АСТ»).
3. Алексієвський, Д. Г. «Основи теорії систем» [Текст] : навч.-метод. посібник для студ. ЗДІА напряму 6.050802 «Електронні пристрої та системи» / Д. Г. Алексієвський. – Запоріжжя : ЗДІА, 2012. – 59 с. – Библиогр. : с. 58.
4. Дьяконов, В. П. Simulink 5/6/7 : Самоучитель [Текст] / В. П. Дьяконов. – М. : ДМК-Пресс, 2008. – 784 с. – Библиогр. : с. 766-770. – ISBN 978-5-94074-423-8.

5. Cassie, A. M. A new theory of rupture and circuit severity [Text] / A. M. Cassie // CIGRE Re-port. – 1939. – Vol. 102. – P. 2-14.
6. Mayr, O. Beitrage zur Theorie des Statischen und des Dynamischen Lichtbogens [Text] / O. Mayr // Archiv für Elektrotechnik. – 1943. – Vol. 37. – P. 588-608.
7. Новиков, О. Я. Устойчивость электрической дуги [Текст] / О. Я. Новиков. – Л. : Энергия, 1978. – 159 с. – Библиогр. : с. 150-155.
8. Пентегов, И. В. Сравнительный анализ моделей динамической сварочной дуги [Текст] / И. В. Пентегов, В. Н. Сидорец // Автоматическая сварка. – 1989. – № 2. – С. 33-36.
9. Утегунов, В. В. Специальные вопросы электротехнологии [Текст] / В. В. Утегунов, И. В. Захаров, А. Д. Ижикова. – М. : Металлургия, 1985. – 227 с. – Библиогр. : с. 226.
10. Манин, А. В. Электротехнологические процессы и установки [Текст] / учебн. пособие / А. В. Манин. – Ч. 1. – Рыбинск : РГАТА им. П.А. Соловьева, 2010. – 188 с. – Библиогр. : с. 186. – ISBN 978-5-88435-353-4.