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MATHEMATICAL MODEL OF ELECTRIC ARC FOR INVESTIGATION OF THERMAL ELECTRODYNAMIC PROCESSES IN STEEL MELTING FURNACES

SUMMARY

Influent factors on dynamic properties of the a.c. electric arc steelmaking arc furnaces- were shown in the paper. In the simplified furnace circuit model to be applied the dynamic arc model. The whole problem described using the equations system of thermodynamic and electric magnitudes. Finally gave advices how to qualify parameters of models and showed courses of temporary electric magnitudes.

***Keywords**: electric arc, dynamic characteristics, steelmaking arc furnace*

MODEL MATEMATYCZNY ŁUKU ELEKTRYCZNEGO DO BADANIA PROCESÓW CIEPLNYCH I ELEKTRYCZNYCH PIECÓW ŁUKOWYCH

W artykule przedstawiono czynniki wpływające na właściwości dynamiczne łuku elektrycznego stalowniczych pieców łukowych prądu przemiennego. W uproszczony model obwodu pieca włączono dynamiczny model łuku. Całość opisano układem równań wielkości termodynamicznych i elektrycznych. Podano wskazówki sposobu określania parametrów modeli i zaprezentowano przebiegi czasowe wielkości elektrycznych.

***Słowa kluczowe**: łuk elektryczny, charakterystyki dynamiczne, piec łukowy*

1. INTRODUCTION TO THE PROBLEM

Electric arc in arc steel melting furnaces (ACE-AF) can be considered as main source of technological heat. Therefore it is natural to describe its calorific characteristics during arc modeling [1]. At the same time electric arc parameters including thermal parameters vary as random process and are connected with electric parameters. In such a way thermodynamical model of arc does not describe entirely its energy characteristics as converter of electric energy into thermal.

The second feature of arc thermodynamical model is a fact that its characteristic should be modeled as averaged one without consideration of instantaneous changes in the processes.

2. PROBLEM DEFINITION

The mentioned features of arc behavior are caused by changes of fluid dynamic parameters of liquid metal, particularly such as meniscus depth and form on the surface of liquid metal under electrodes, their vibration, parameters variation of electric power supply system circuits and dynamic forces between arc columns of separate phases.

Considering arc electric parameters dynamics makes it possible to model successfully stochastic electromagnetic processes in electromagnetic circuits of electric power equipment of AC-EAF [2] electric supply systems. An equivalent single-line circuit of such electric supply system is shown in Figure 1. Here electric supply system is shown as an equivalent sinusoidal electromotive force $e(t)$ and linear active resistance and inductance of system R_c and L_c, and furnace unit is substituted with equivalent linear active resistance R_{na} and inductance L_{na}. Electric arc is shown as nonlinear resistive element $u_\partial(i_\partial)$.

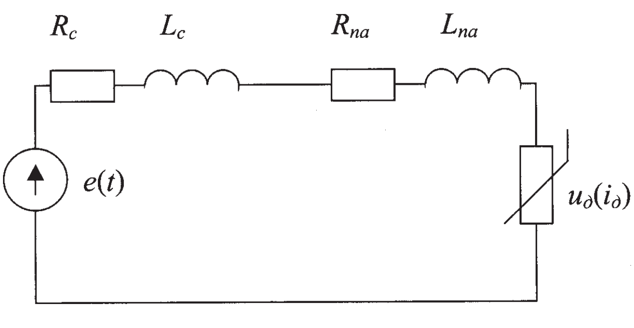

Fig. 1. An equivalent circuit of AC-EAF electric power supply

3. PROBLEM SOLUTION

An expert evaluation has shown that combination of thermodynamical and electrodynamical models that take into consideration laws of electric parameters changes allows us to obtain more adequate thermal characteristics of AC arcs. Dynamic model of electric arc [3] on the basis of full energy equation in general can be written down in the following form

$$\frac{\partial H(g)}{\partial g}\frac{dg}{dt} = \frac{i(t)^2}{g} - P_n(g) \tag{1}$$

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where:

- $H(g)$, $P_n(g)$ – arc enthalpy and power of energy losses caused by conductance of arc column g in unsteady condition respectively;
- $i(t)$ – instantaneous value of arc current.

According to [3] enthalpy and power losses are expressed using the most simple polynomials depending on arc column, particularly:

$$\begin{aligned} H(g(i(t))) &= a_1 g^n(i(t)) + a_0 \\ P_n(g(i(t))) &= b_1 g^m(i(t)) + b_0 \end{aligned} \tag{2}$$

where: a_1, a_0, b_1, b_0, n and m are coefficients of approximation of thermal and energy characteristics of investigated arc.

Those coefficients have particular values for special furnaces and arcs power. They can be estimated experimentally or using technique presented in [3].

Electrodynamic model of arc in general case can be written down using dynamic volt-ampere characteristic with time-dependent parameters, namely

$$\begin{aligned} u_\partial(i_\partial) = U_m \Bigg\{ \Bigg(& \frac{A_1}{A_2 i^*_\partial(t) + A_3 / i^*_\partial(t)} + A_4 \operatorname{atg}(i^*_\partial(t)) + \\ & + \left|1 - i^*_\partial(t)\right| \sin(2n\pi i^*_\partial(t)) \Bigg) \Bigg\} \end{aligned} \tag{3}$$

where:

- $i^*_\partial(t) = i_\partial(t) / I_{\partial m}$ – relational instantaneous value of arc current;
- $I_{\partial m}$ – amplitude value of arc current on interval of some technological stage;
- $A_1, ..., A_4$ – coefficients of approximating function of the arc (their values changes has random character);
- U_m – the greatest voltage value which can be estimated experimentally for arcs of AC-EAF with different power.

Dynamic resistance of the arc can be estimated as derivative of voltage by current. The inverse value to dynamic resistance is dynamic conductance of arc column of alternative current depending on current and time simultaneously and can be written down in the form of equation

$$g(i_\partial(t)) = 1/(du_\partial(i_\partial(t))/di_\partial(t)) \tag{4}$$

Taking into account expressions (1)–(4) extended mathematical model of dynamic arc of alternative current as thermal energy source can be written down in the form of the following equations set:

$$\begin{aligned} & u_\partial(i_\partial(t)) = f(i_\partial(t)) \\ & g(i(t)) = \frac{1}{du_\partial(i_\partial(t))/di_\partial(t)} \\ & H(g(i(t))) = a_1 g^n(i(t)) + a_0 \\ & P_n(g(i(t))) = b_1 g^m(i(t)) + b_0 \\ & \frac{\partial H(g(i(t)))}{\partial g(i(t))} \frac{dg(i(t))}{dt} = \frac{i(t)^2}{g(i(t))} - P_n(g(i(t))) \end{aligned} \tag{5}$$

In the given case simultaneous solving of given equation allows to obtain thermal and electric characteristics of alternative current arc at the same time. On the basis of obtained characteristics it is possible to evaluate energy characteristics of arc. Using generator of random values for modeling of approximation coefficients presented model allows to analyze any stage of technological process of AC-EAF on instantaneous level, and, respectively, to obtain the most important energy characteristics of furnaces which can be used for technical and economic assessment of furnaces.

A set of dynamic volt-ampere characteristic of the AC-EAF electric arc of the phase is shown in Figure 2. AC-EAF was described using model (5) and has a capacity 100 ton.

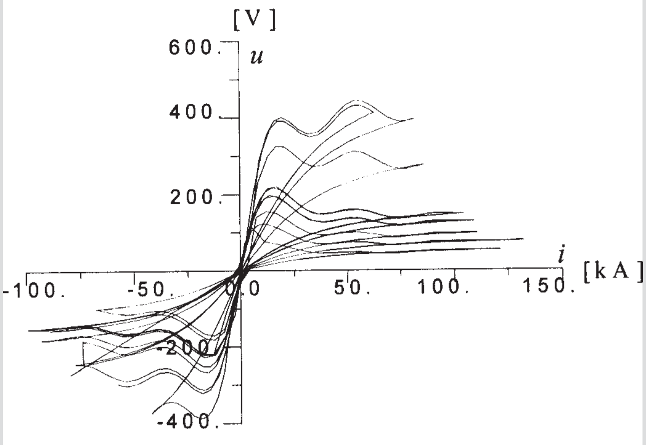

Fig. 2. A set of dynamic volt-ampere characteristic of the AC-EAF electric arc

In the Figure 3 instantaneous current of the arc of AC-EAF-100 on the stage of metal melting on one second intreval is presented. As it can be seen from this figure the arc current contains a wide spectrum of frequencies (different from commercial frequency) besides considerable amplitude deviation caused by accidental short circuits and abruption of the arc.

In order to obtain energetic characteristics of the arc it is necessary to calculate root-mean-square values of voltages and currents and average values of AC-EAF power that can be done easy when computer simulation is used.

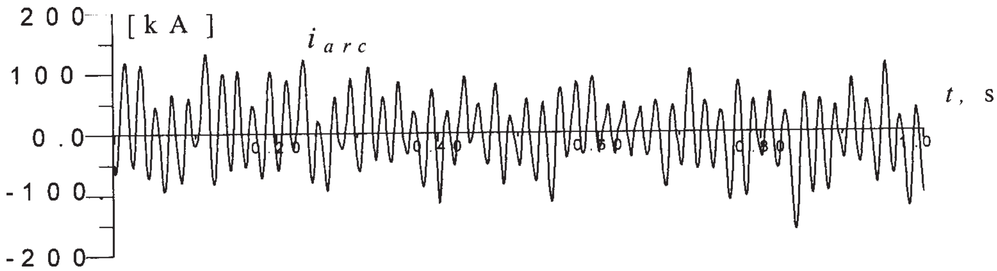

Fig. 3. Instantaneous current of the arc of AC-EAF -100 on the stage of metal melting

4. CONCLUSIONS

Presented generalized mathematical model of alternative current arc in the form of thermodynamic and electromagnetic equations makes it possible to model thermal thermodynamical processes of AC-EAF taking into consideration arc parameters chahges which depend on technological stages of furnaces.

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Prof. dr hab. inż. Wasyl Hudym urodził się w 1944 roku w Drohobyczu w obwodzie lwowskim (Ukraina). W 1975 roku ukończył Lwowski Instytut Politechniczny. W 1989 roku obronił pracę doktorską w Kijowskim Instytucie Politechnicznym, a w 2002 roku pracę habilitacyjną w Instytucie Elektrodynamiki Akademii Nauk Ukrainy. Zajmuje się metodami analizy obwodów elektromagnetycznych trójfazowych, systemami zasilania stalowniczych pieców łukowych prądu przemiennego, kompatybilnością elektromagnetyczną i jakością energii elektrycznej w systemach elektroenergetycznych. Opracował metody i algorytmy konturowo-węzłowe analizy zmiennych stanu obwodów elektromagnetycznych. Jest autorem ponad 90 publikacji naukowych, 42 referatów i 20 patentów. Obecnie jest pracownikiem Wydziału Inżynierii i Ochrony Środowiska Politechniki Częstochowskiej.

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Zenovia Vladimirovna Lesnyak urodziła się 28 lipca 1960 roku. Ukończyła Lwowskie Technikum Radioelektroniczne w 1982, a w 1988 roku – Lwowski Instytut Politechniczny ze specjalnością zautomatyzowane systemy sterowania. Obecnie pracuje w katedrze Geometrii Wykreślnej Uniwersytetu Narodowego „Lvovskaya politechnika" na stanowisku kierownika laboratorium. Naukowo zajmuje się rozwijaniem metod obliczania i analizy obwodów liniowych i nieliniowych w mieszanej bazie współrzędnych. Z tej tematyki wygłosiła referat na konferencji międzynarodowej.