THE MODEL OF LUMP CHARGING IN THE MOVING MAGNETIC FIELD

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Abstract **– In the article, the electromagnetic model of the multiphase induction furnace at the fusion initial stages (furnace loading represents a set of metal pieces, electrically not connected or connected with each other, possessing or not possessing magnetic properties, depending on temperature) is considered.**

Key words – Electromagnetic model, lump charging, the induction furnace, a multiphase inductor, a method of detailed magnetic equivalent circuits

In heating lump charging in the inductor with a moving or rotating magnetic field, the non-uniform space distribution of the induction components is observed; this distribution depends upon the physical properties of the medium. Modeling these processes, using conventional field packs, turns out to be rather time consuming. Quick and accurate solution can be achieved using the method of detailed (up to tooth pitching or an inductor winding) equivalent circuits [1].

Lump charging can be represented by a number of cylinders and can be both homogeneous and non-homogeneous. In a general case of lump charging, the properties of an averaged lump charge are isotropic. For a two-dimensional field, an averaged charge lump can be represented as a conventional object possessing the isotropy of magnetic properties in two directions – regular (the direction perpendicular to the crucible axis) and tangential (mutually perpendicular to the preceding vector and the vector of the magnetic field strength), as well as the isotropy of electrical properties in the tangential coordinate (in solving problems in cylindrical coordinates).

The object to be suitably used to model a charge lump is shown in Fig. 1. It is of a cylinder shape, having the same weight, density, specific electrical resistance as those of an averaged charge lump. In calculating, the axis of this rated cylinder magnetic conductor *1* (Fig.1) always coincides with the direction of Φ_τ or Φ_n accordingly. If the contact resistance between elementary cylinders is taken into account, a cylinder electric conductor *3* is built into the model charge lump, and the tangential current density *4* is calculated.

Complex magnetic resistance of the cylinder magnetic conductors is calculated using a well-known Bessel function method.

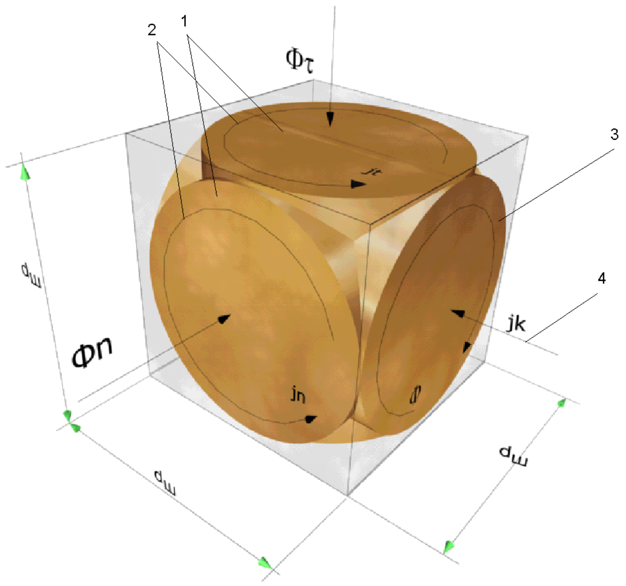

Fig. 1 An elementary cylinder

In solving a two-dimensional problem in cylindrical coordinates, for example, for a multiphase crucible induction furnace, within the crucible space, elementary cylinders are grouped into rings the size of which is limited by the turn height and the radius pitch chosen.

The combined magnetic resistance of the layer is calculated as a series-parallel combination of the conducting cylinders' magnetic resistances calculated:

$$\underline{Z}_{Mrad} = \underline{Z}_{M0} \cdot \frac{N_{rad}}{N_{axe} \cdot N_{ckl}}$$ - for the layer resistance in the radial direction,

$$\underline{Z}_{Maxe} = \underline{Z}_{M0} \cdot \frac{N_{axe}}{N_{rad} \cdot N_{ckl}}$$ - for the layer resistance in the axial direction accordingly. Here, $\underline{Z}_{M0}$ is complex magnetic resistance of an elementary cylinder in terms of Bessel function; N_{rad} is the number of elementary cylinders in the layer in the radial direction; N_{axe} is the number of elementary cylinders in the layer in the axial direction; N_{ckl} is the number of elementary cylinders in the circle layer.

The model of lump charging presented here also takes into account ring currents induced in the charge

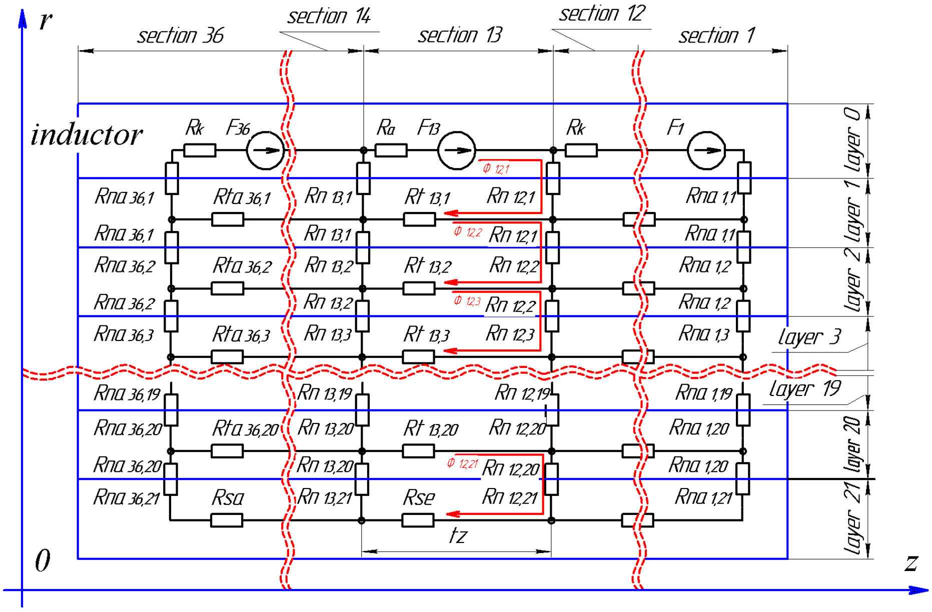

Fig. 2 Detailed equivalent circuit

through the contact resistances. The cylinders-electric circuits *3* combined with cylinders-magnetic circuits are arranged in the ring-type direction. As a whole, they produce a ring-type electric circuit the resistance of which $\underline{Z}_{Eckl}$ is made up of connected in parallel internal resistances of $\underline{Z}_E$ cylinders, as well as connected in series (along the ring) N_{axe} internal resistance*s* of Z_E cylinders and the same number of resistances R_{Ek} of the contact between these cylinders:

$$\underline{Z}_{Eckl} = \underline{Z}_E \frac{N_{ckl}}{N_{axe} \cdot N_{rad}}, \tag{1}$$

$$R_{Ek} = \rho_k \cdot \pi \cdot \frac{d_{ш}^2}{4} \cdot \frac{N_{ckl}}{N_{axe} \cdot N_{rad}}, \tag{2}$$

where $\underline{Z}_E = R_{E0} \frac{m_c}{\sqrt{2}} \cdot \frac{J_0(\sqrt{-2jm_c})}{J_1(\sqrt{-2jm_c})}$ is the cylinder-electric circuit resistance, R_{E0} is the resistance of the cylinder-electric circuit to direct current, ρ_k is the cylinders' contact resistivity, Ω/m^2, J_0 и J_1 are the first kind Bessel functions of the zero and first orders.

The ring resistance calculated from those of cylinders –electric circuits is added to the combined magnetic equivalent circuit of charging (Fig. 2) as a magnetic resistance:

$$\underline{Z}_{Mckl} = \frac{j\omega}{\underline{Z}_{Eckl} + R_{Ek}}. \tag{3}$$

The system of algebraic equations for loop flows is further solved; and both tangential and regular flow components in every charge lump are calculated. Within the crucible space, regular and tangential magnetic resistances R_n и R_t are replaced by complex magnetic resistances of lump charging $\underline{Z}_{Mrad}$ and $\underline{Z}_{Maxe}$ accordingly. $\underline{Z}_{Mckl}$ is taken into account in the model in "contracting" the detailed equivalent circuit.

The results of the research made, which illustrate the field behavior in lump charging and the melt, are given in Fig. 3.

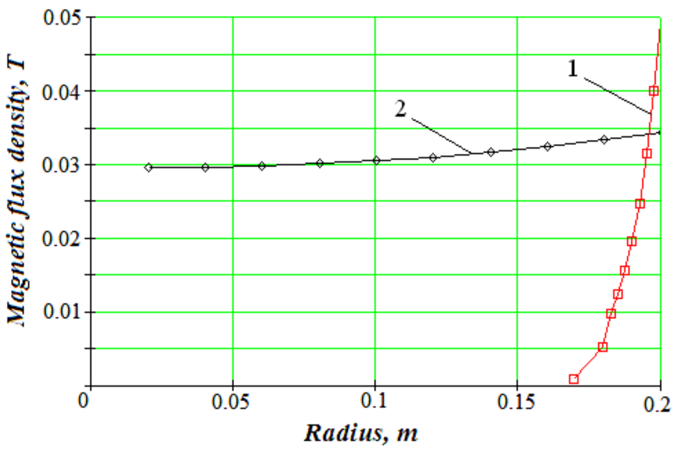

Fig. 3. Distribution of the induction tangential component along the crucible radius: (1) for solid charging; (2) for lump charging.

A conclusion can be made as to: 1) the technique presented allows to consider the behavior of the moving electromagnetic wave in the non-homogeneous conducting medium, both ferromagnetic and nonmagnetic; 2) the technique presented ensures the same level of extension as the finite element methods, but using less computational efforts; 3) the technique presented enables the integral parameters of the inductor to be easily calculated for the further analysis of the unit operational conditions in combination with the static compensator, power supply, unit control system, etc.

[1] Operation of a linear magnetohydrodynamic induction pump. Sarapulov F.N., Sarapulov, S.F., Sokunov, B.A. / Russian Electrical Engineering. Volume 76, Issue 9, 2005, Pages 69-73