MODELLING OF 2D DISTRIBUTION OF ELECTROMAGNETIC FORCES IN CONTINUOUS CASTER MOLD WITH DOUBLE-WOUND INDUCTION STIRRER

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Introduction. The finite element method for modelling of electromagnetic forces (EMF) distribution in continuous caster (CC) mold with induction stirrer (IS) is applied in paper [1]. In paper [2] EMF numerical calculation in round mold of laboratory unit is submitted. In the present paper the integral model of electromagnetic processes taking place in system caster mold–double-wound IS at opposite direction of rotating magnetic fields are developed. IS consisted of smooth cylindrical core on internal surface of which two three-phase windings are located. With the help of a program developed on a basis of block algorithm the calculation of eddy currents (EC) and EMF distribution in section of round and square strands are carried out at various frequencies of power supply and at coils various number in IS windings.

1. Task setting. Feature of system mold-IS design of CC is a presence of large air-gap between IS and tubular mold. Consequently significant dispersion magnetic fields take place in this system, which essentially have an influence on distribution of EC and EMF in liquid steel. At the same time at modelling of stirring process in mold it is enough to know EMF distribution only in liquid steel. Such model of EC and EMF distribution in considered system is necessary that on the one hand precisely would take into account dispersion magnetic fields and on the other hand allowed to simulate EMF in strand section. Integro-differential model of EC and EMF distribution satisfies to such requirements. Modelling of EC and EMF is carried out in two stages. On the first stage integro-differential equations system concerning determining magnetic field of EC in sections of massive conductors and magnetization currents on boundaries of ferromagnetic core section is solved. On the second stage are calculated EMF in liquid steel on obtained EC distribution [3]. The integro-differential model describes in the general case non-stationary electromagnetic processes, for example, at IS operation in cyclically reversing service.

In the present paper one of this model special cases is considered, i.e. the integral model of sinusoidal EC distribution that are induced in massive conductors of mold-IS system by three-phase currents of two IS windings. In sections of IS coils the complex amplitudes of current average density are set. Complex amplitudes of EC density in section of massive conductors and complex amplitudes of magnetization currents density on borders of ferromagnetic core section are unknowns.

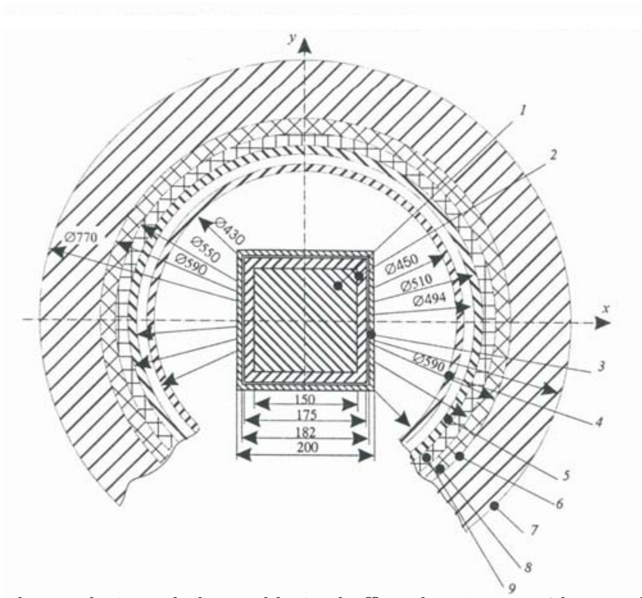

Fig. 1. *1* - steel strand, *2* – tubular mold, *3* – baffle tube, *4* – cartridge mould housing, *5* – fixture, *6* and *7* – internal and external border of ferromagnetic core section, accordingly, *8* – three-phase winding with one pair poles (the first winding), *9* – three-phase winding with two pairs poles (the second winding).

The complex amplitudes of currents phase of the first and the second IS windings are equal accordingly:

$$\dot{I}_{11} = I_{M1},\ \dot{I}_{12} = I_{M1}\mathrm{e}^{-j\frac{2\pi}{3}} = I_{M1}\Big(-\frac{1}{2} - j\frac{\sqrt{3}}{2}\Big),\ \dot{I}_{13} = I_{M1}\mathrm{e}^{j\frac{2\pi}{3}} = I_{M1}\Big(-\frac{1}{2} + j\frac{\sqrt{3}}{2}\Big).$$

$$\dot{I}_{21} = I_{M2},\ \dot{I}_{22} = I_{M2}\mathrm{e}^{j\frac{2\pi}{3}} = I_{M2}\Big(-\frac{1}{2} + j\frac{\sqrt{3}}{2}\Big),\ \dot{I}_{23} = I_{M2}\mathrm{e}^{-j\frac{2\pi}{3}} = I_{M2}\Big(-\frac{1}{2} - j\frac{\sqrt{3}}{2}\Big),$$

where I_{M1},I_{M2} are amplitudes of currents phase in coils of the first and the second IS windings; $j = \sqrt{-1}$.

Transverse section of mold-IS system in Fig. 1 is shown. Such mutual arrangement of windings section and the strand is accepted at that their symmetry axes coincide.

The resulting EC distribution in section of mold-IS system represents the sum of four symmetric components (SC). Under SC such EC distributions on section are understood that are symmetric concerning of geometrical symmetry axes of geometrical symmetry axes of x, y section. SC gives in the sum resulting EC distribution [5].

For everyone SC the integral equations system (SIE) is received that is simpler of initial SIE for resulting EC distribution, as a definition domain is the part of section lying in the first quadrant. Thus the integral model of sinusoidal EC resulting distribution breaks up on symbiosis of four more simple models for SC.

The SIE received in [6] for considered mold-IS system are simplified. As solution algorithm each of four SIE is the same we describe it by the example of one SIE.

2. SIE approximation. Parts of strand section, mold tube, baffle tube, cartridge mould housing, winding fixture, ferromagnetic core, laying in the first quadrant of coordinates $x0y$ system are broken into elements. In case of round strand sections are broken into elements by uniform orthogonal cylindrical grids, and in case of square strand sections are broken into elements by uniform orthogonal rectangular grids. The uniform orthogonal cylindrical grids break into element

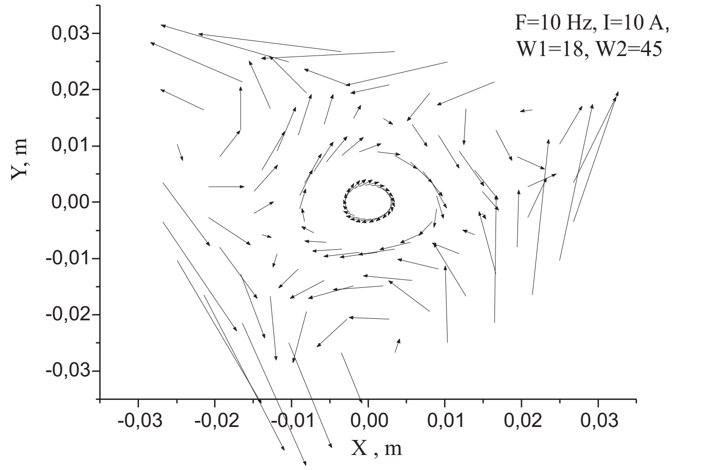

Fig. 2. EMF distribution in round billet transverse section.

section of IS winding. The approximation SIE by an algebraic equations system (SAE) is carried out on a complete averaging method.

3. Block algorithm of SAE solution. The received SAE it is possible to solve by the Gauss block method. The matrix is strongly discharged. To reduce number of zero matrixes and to decrease thus the order of the block matrix it is possible by exception from SAE of column-vectors of complex amplitudes of magnetization currents density.

4. Restoration of eddy currents SC distribution. After EC and magnetization currents calculation is determined distribution of complex amplitudes of a magnetic flux density vector projections on the axis x and y in strand section laying in the first quadrant of coordinates $x0y$ system. Restoration of eddy currents first SC distribution in strand section, mold tube, baffle tube, cartridge mould housing, winding fixture, complex amplitude of magnetization currents density on an internal contour limiting ferromagnetic core section, complex amplitudes of magnetic flux density vector projections in strand section under the received SIE solution further is made. Then the distribution of EC density complex amplitudes in strand section, mold tube, baffle tube, cartridge mould housing, winding

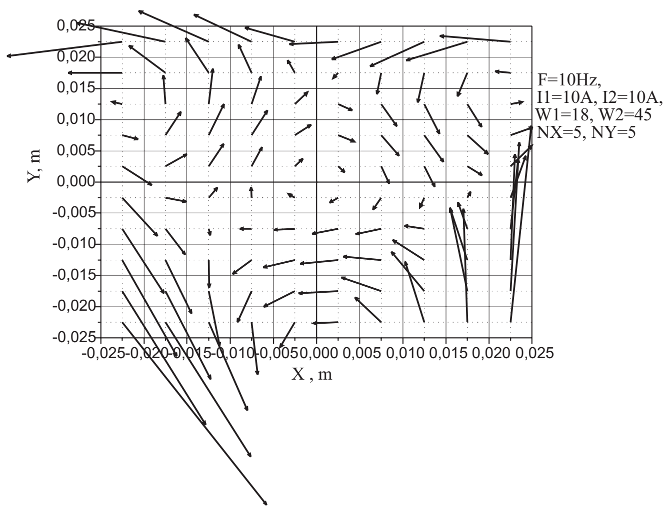

Fig. 3. EMF distribution in square billet transverse section.

fixture and density of magnetization currents on the ferromagnetic core contour, the magnetic flux density vector projections on the axis x and y in strand section at joint action of currents in two windings is founded.

5. Modelling results. With the help of the developed program the modelling of 2D EMF in section of round and strand square for laboratory unit mold–IS is carried out. Suppose that baffle tube, cartridge mould housing, winding fixture have small conductivity and influence of the eddy currents magnetic field induced in these elements on the electromagnetic field in strand it is possible to neglect. The simplified system consists of steel strand with mold tube and two three-phase windings placed in the air cylindrical cavity in unlimited ferromagnetic medium. Dependencies $W2 = f(W1)$ from condition of equality to zero of EMF main moment relative to origin of coordinates are received for frequencies range 3...15 Hz. Where $W1$, $W2$ are number of coils in the first and in the second windings accordingly.

The EMF distribution in round billet is shown in Fig. 2. The influence of the first and second windings at $W1 = 18$ and $W2 = 45$ is commensurable. The forces are directed clockwise in the billet central part and they are directed counter-clockwise in a near-surface layer. The EMF distribution promotes improvement of billet quality at the given parity of coils number of the first and second windings. The numerical computations of EMF distribution in strand section are carried out at $W1 = 18$ in the first winding and at changing of coils number of the second winding $W2 = 10$, 20, 30, 40, 50, 60. The distribution of EMF field in section of billet square is shown in Fig. 3 at 10 Hz current frequency, at 10 A current magnitude in windings IS, at coils number in windings $W1 = 18$ and $W2 = 45$. The forces are directed clockwise in the billet central part. The EMF are directed counter-clockwise in the near-surface layer. The substantial EMF increasing in billet square is observed at constant number of coils in the first winding $W1 = 18$ and increasing of coils number in the IS second winding ($W2 = 30, 45, 60$).

Accuracy of numerical computation by Runge method and for round billets by comparison with analytical solution is confirmed.

6. Conclusions. The block algorithm for realization of integral model of sinusoidal EC and EMF distribution in section of the mold–IS system is developed. Integral model is realized as program for PC. It supposes variation by form of strand section, number of windings, windings design, coils number in phase coils of windings, windings connection, magnitude and frequency of feed currents, direction of magnetic fields rotation created by each winding, sections sizes of CC constructive elements and electrophysical characteristics of materials.

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