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FIELD AND CIRCUIT MODELS OF ZINC FEEDER

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Abstract: Electromagnetic feeders of molten metals are used in some industrial technologies, particularly for accurate dosing. Mathematical model of such devices represents a complicated coupled task characterised by interaction of electromagnetic, temperature and flow fields. The paper deals with numerical computation of several important quantities of the device providing its circuit parameters. Theoretical analysis is supplemented with an illustrative example and discussion of its results.

Keywords: Zinc feeder, coupled problem, electromagnetic field, numerical analysis, circuit parameters.

1 Introduction

Optimised design of feeders for molten metals cannot be realised without detailed numerical simulation of their behaviour in various operation regimes. The reason consists in very complicated phenomena associated particularly with pumping of metal by means of the Lorentz forces that is characterised by interaction of several physical fields. Detailed investigation of this process provides, on the other hand, parameters of the equivalent circuits of these devices important for their description from the viewpoint of network.

The paper representing natural continuation of [1] deals with these aspects and illustrates them on an example.

2 Technical description and mathematical model

Feeders of molten metals (Fig. 1) usually consist of three basic parts: tank containing molten metal with appropriate temperature equipped with an inlet, outlet and refractory, several inductors providing both sufficient heat power for

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keeping metal liquid and Lorentz forces for its pumping when required and magnetic cores for reaching suitable distribution of the magnetic field.

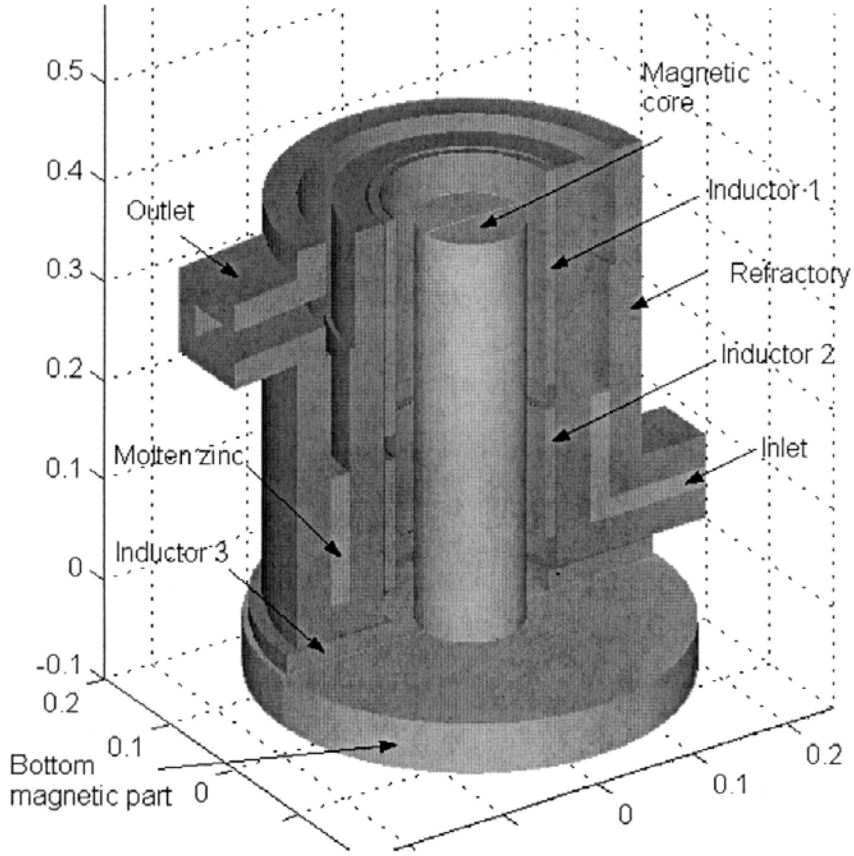

Fig. 1: Basic arrangement of a zinc feeder

Distribution of particular physical fields in the feeder depends on the instantaneous height of electrically conductive liquid metal in the tank. For its fixed level distribution of the magnetic field is modelled by means of the magnetic vector potential $\boldsymbol{A}$ [2]

$$\mathrm{rot}\frac{1}{\mu}\mathrm{rot}\boldsymbol{A} + \gamma \cdot \frac{\partial \boldsymbol{A}}{\partial t} = \boldsymbol{J}_{\mathrm{ext}} \tag{1}$$

where μ is the permeability, γ the electrical conductivity and $\boldsymbol{J}_{\mathrm{ext}}$ the uniform current density within the inductors. In case that permeability of magnetic cores may be considered constant (low saturation), (1) transforms into the Helmholtz equations for the phasors of magnetic quantities

$$\mathrm{rot\,rot}\underline{\boldsymbol{A}} + \mathrm{j}\cdot\omega\mu\gamma\,\underline{\boldsymbol{A}} = \mu\underline{\boldsymbol{J}}_{\mathrm{ext}}. \tag{2}$$

For this case the specific Joule losses and average volume electromagnetic forces follow from relations

$$p_{\mathrm{J}} = \frac{1}{2}\gamma\omega^2\left|\underline{\boldsymbol{A}}\right|^2, \quad \boldsymbol{f} = \frac{1}{2}\underline{\boldsymbol{J}} \times \underline{\boldsymbol{B}} \tag{3}$$

containing the amplitudes of the corresponding phasors. Here $\underline{\boldsymbol{J}}$ denotes the total current density in the structure given as $\underline{\boldsymbol{J}} = \underline{\boldsymbol{J}}_{\mathrm{ext}} - \mathrm{j}\cdot\omega\gamma\underline{\boldsymbol{A}}$. The total Joule losses and all components of electromagnetic force are consequently obtained by integrating the above quantities over the metal area.

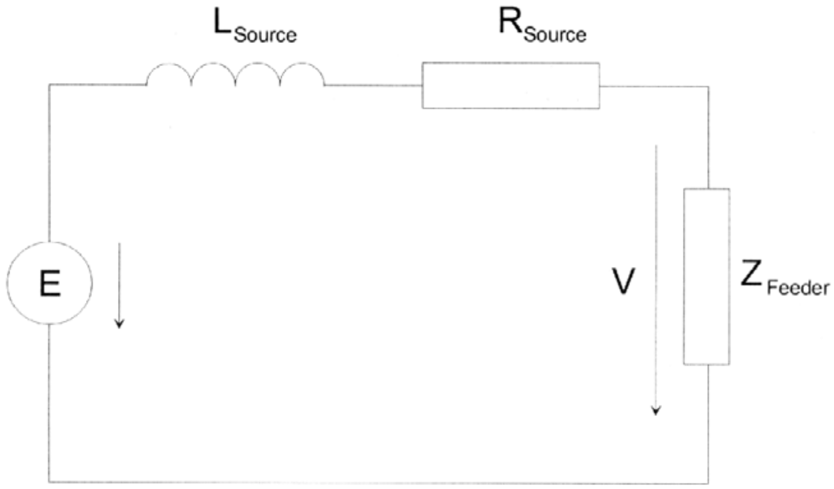

Fig. 2: Equivalent circuit of the device

The equivalent circuit of the feeder is depicted in Fig. 2. It can be described by phasor equation

$$\underline{E} = R_{\mathrm{Source}}\underline{I} + \mathrm{j}\cdot\omega L_{\mathrm{Source}}\underline{I} + \underline{Z}_{\mathrm{Feeder}}\underline{I} \tag{4}$$

where Z_{Feeder} is the total impedance of the feeder. It can be computed from the known distribution of electromagnetic field by integrating the normal component of the Poynting vector over the boundaries of all inductors and dividing the result by the squared current.

$$\underline{Z}_{\mathrm{Feeder}} = \frac{\oint_{\Gamma_{\mathrm{Inductors}}} (\underline{E}\times\underline{H}^{*})\cdot \mathrm{d}n}{\underline{I}^{2}}. \tag{5}$$

Because of linearity of the model the integral in the above formula is exactly proportional to the square of current and accordingly the impedance of the feeder is independent of it. The impedance can, therefore, be computed using any feeding current while the real current follows directly from (4).

3 Illustrative example

A zinc feeder has dimensions according to Fig. 1. Despite its 3D arrangement its model was supposed axi-symmetric (influence of the inlet and outlet was neglected). The skin effect in the field windings was not taken into account.

The regime of dosing was modelled using only inductors 2 and 3 in series and with the same space orientation. The feeding current $I = 100$ A and its frequency $f = 50$ Hz.

Table 1 contains the material parameters used in the model. Computations were realised by means of professional code FEMLAB on a mesh with about 10000 nodes.

Fig. 3 depicts distribution of the magnetic field for phase angle $\varphi = 0°$.

Tab. 1: Material parameters and current densities used in the model

	Magnetic core	Inductor 2	Inductor 3	Liquid zinc	Air
μ_r (-)	1000	1	1	1	1
γ (S/m)	0	0	0	$0.34 \cdot 10^7$	0
J_{ext} (A)	0	20·100/0.0022	12·100/0.0013	0	0
ω (rad·s^{-1})	$100 \cdot \pi$				

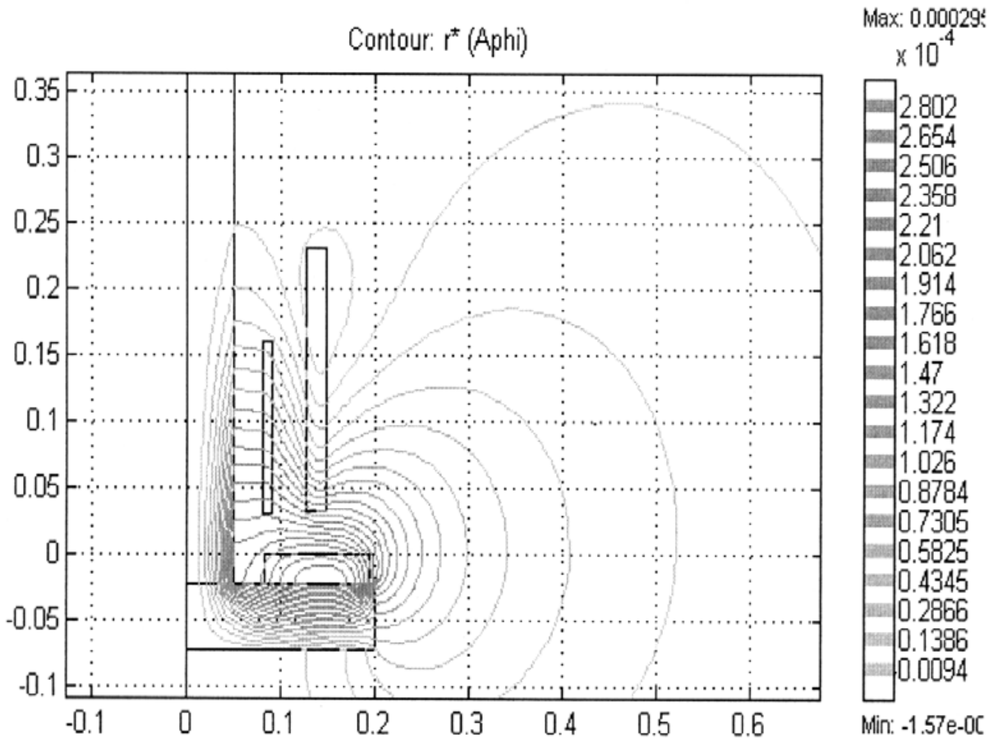

Fig. 3: Distribution of magnetic field in the device for phase angle $\varphi = 0°$

The impedance of the feeder calculated from (4) $Z_{\text{Feeder}} = 0.0921 + j \cdot 0.1440\ \Omega$.

The computations were carried out for several levels of zinc and widths of the ring-shaped container and the obtained dependences of the levitation electromagnetic forces and total Joule losses are depicted in Figs. 4, 5 and 6. It is necessary to remind that both magnetic flux density and Lorentz forces within the melt have only two components in the directions r and z.

4 Conclusion

The electromagnetic field in a zinc feeder both in the regime of dosing and heating has been modelled. The Joule losses and electromagnetic forces have been computed. All these computations have been carried out for series of various geometric, material or feeding parameters so that dependencies on these parameters could be obtained and depicted. In addition, a model of a simple linear feeding circuit has been suggested.

Continuation of the work will be aimed at modelling of the temperature field and the flow of metal. There are, however, several points to overcome. One of them is cooling of the refractory that is difficult to estimate. Computation of the velocity field takes a lot of time and its convergence is very slow.

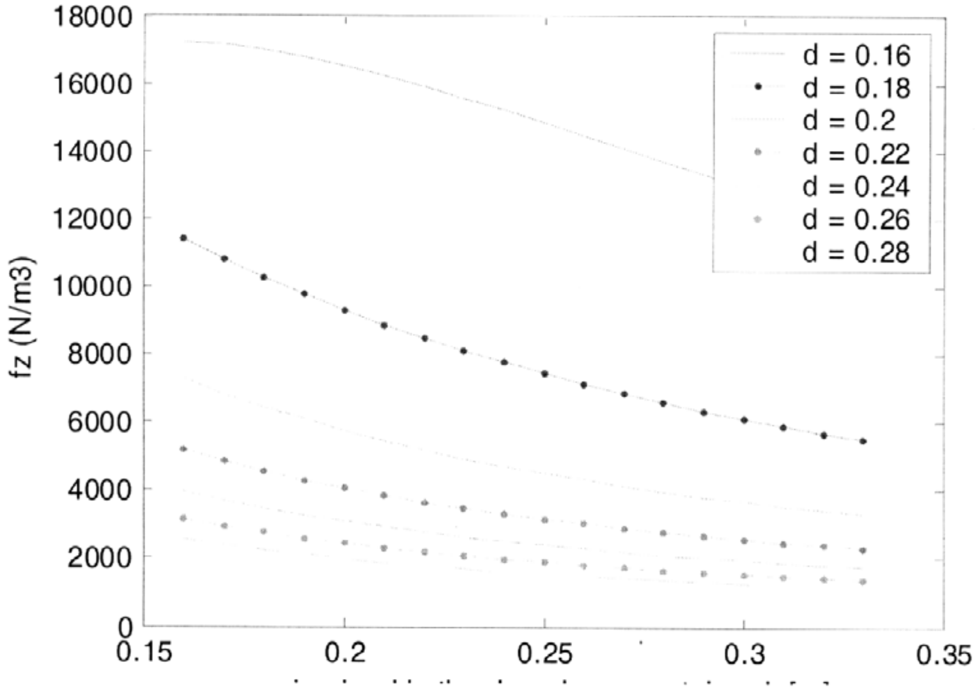

Fig. 4: Dependence of the specific levitation forces on the height of the zinc level for several widths of the ring-shaped container

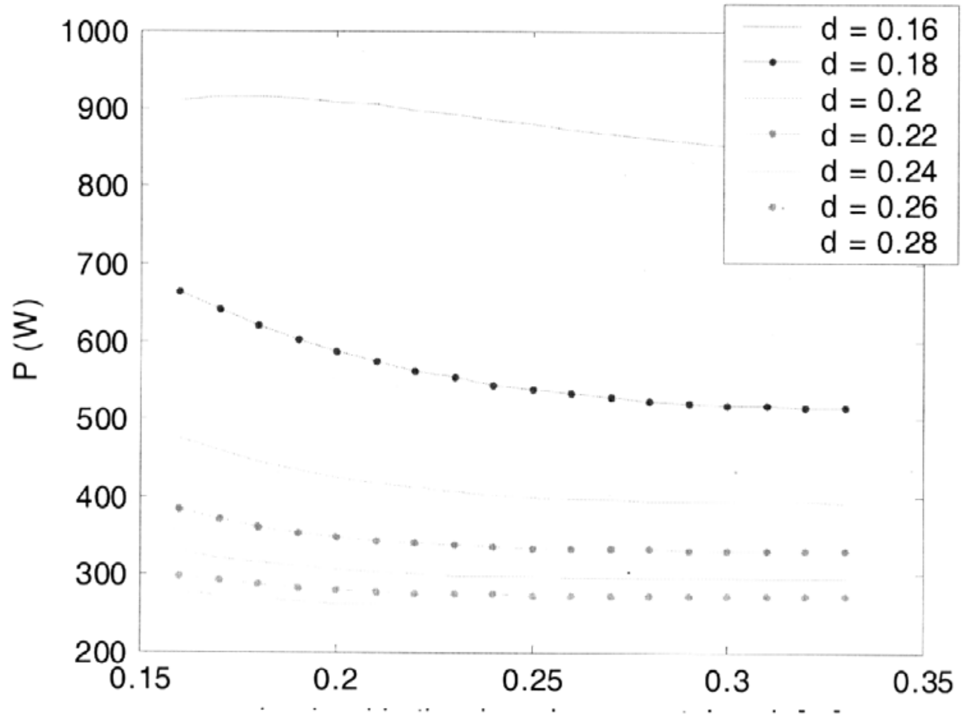

Fig. 5 Dependence of the total Joule losses on the height of the zinc level for several widths of the ring-shaped container

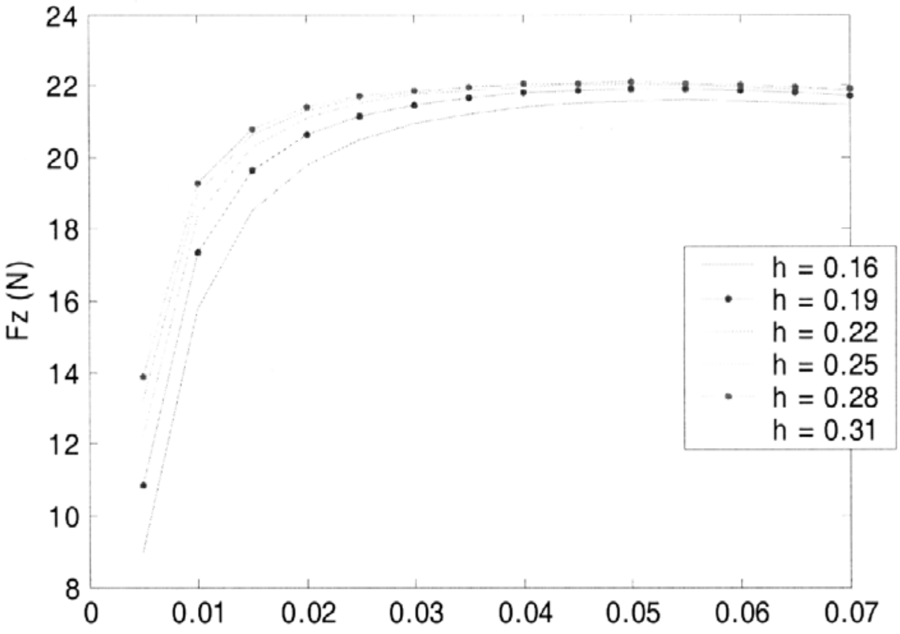

Fig. 6: Dependence of the total levitation force on the width of the ring-shaped container for several heights of the zinc level

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