Dynamic Characteristic of Zinc Feeder

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***Abstract* — The paper deals with the mathematical and computer modeling of dynamic characteristic of an electromagnetic zinc feeder, which is a device for exact dosing of molten zinc. The first step is investigation of electromagnetic field distribution for a series of levels and corresponding Lorentz forces acting on it. The second step is determination of the dynamic behavior of the device consisting in finding the parameters of motion of the zinc level. Computations of an illustrative example were carried out by the professional FEM-based codes FEMLAB, SIMULINK and a number of single-purpose user procedures written by the authors**

INTRODUCTION

ZINC feeder is a device for pumping a prescribed amount of molten zinc from a container into a mould. Its basic arrangement is shown in Fig. 1. Liquid zinc flows from the container through the inlet channel into a ring-shaped tank. Several coaxial inductors wound round the magnetic core and carrying harmonic currents generate periodic magnetic field that in molten zinc produces eddy currents flowing in the circumferential direction. These currents (in interaction with primary magnetic field) produce the Lorentz forces making molten metal rise upwards, above the level of the outlet. Liquid zinc then flows through the outlet into a mould. Distribution of electromagnetic field and overall efficiency of the device is improved by presence of the magnetic core that enlarges axial magnetic forces acting on zinc. The core consists of the bottom part and limb.

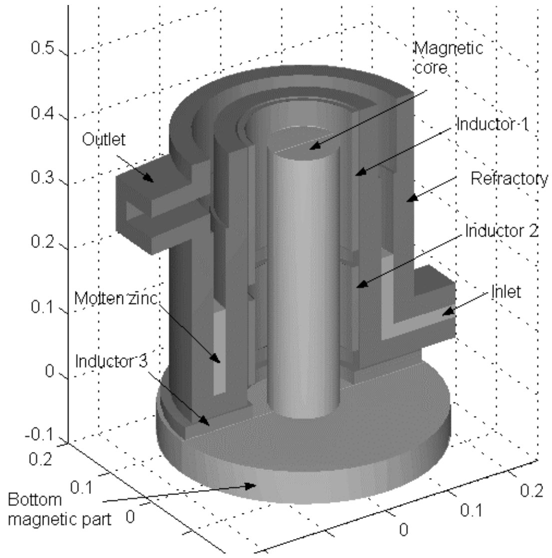

Fig. 1. Basic disposition of the electromagnetic feeder

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The feeder works in two regimes: dozing and heating. During the regime of dozing the molten metal is pumped into a mould. Magnetic field in this regime is produced by inductors **2**, **3** (Fig. 2) and its principal aim is to transport zinc upwards from level h_1 to h_2. In the regime of heating the molten metal in the feeder has to be kept at an approximately constant temperature. Thus, zinc in the device is now only inductively heated. This is realized by inductors **1** and **2** (Fig. 2). The electrodynamic forces in zinc produced during this regime are substantially lower.

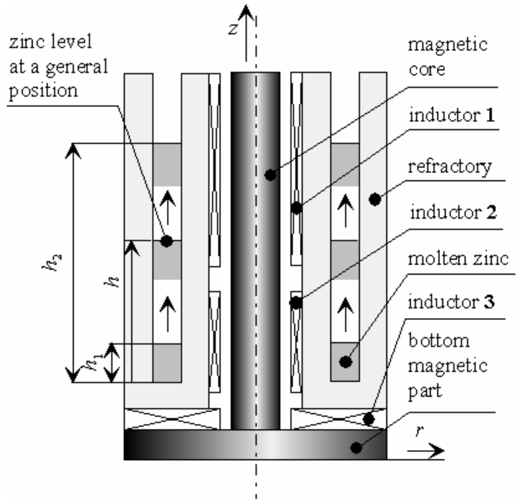

Fig. 2. A simplified (2D) arrangement of the feeder (without the inlet and outlet)

The paper deals with the mathematical and computer modeling of dynamic process associated with raising the zinc surface level. The computations start from finding the static characteristic of the device, i.e. dependence of total axial electrodynamic force acting on zinc on the height of its level. A model of dynamical behavior of zinc level, particularly velocity of its rise, is then suggested. The model starting from the balance of all existing forces acting in the system is described by a strongly nonlinear ordinary differential equation.

Solution of an illustrative example was carried out by the professional FEM-based code FEMLAB, program SIMULINK and a number of single-purpose user procedures written by the authors in the environment of MATLAB.

FORMULATION OF THE TECHNICAL PROBLEM

For an axisymmetric zinc feeder (depicted in Fig. 2) it is necessary to find its dynamic characteristic in the regime of dosing. Its knowledge will be used for determination of the velocity of zinc at the moment when it reaches the outlet (level h_2). This is of fundamental importance for determining the time of filling the mould.

MATHEMATICAL MODEL AND ITS SOLUTION

The definition area of the model in common with the principal geometrical dimensions is in Fig. 3. As the problem is characterized by open boundary, a substitutive artificial boundary MNOPM with the Dirichlet condition has been suggested at a sufficient distance from the device.

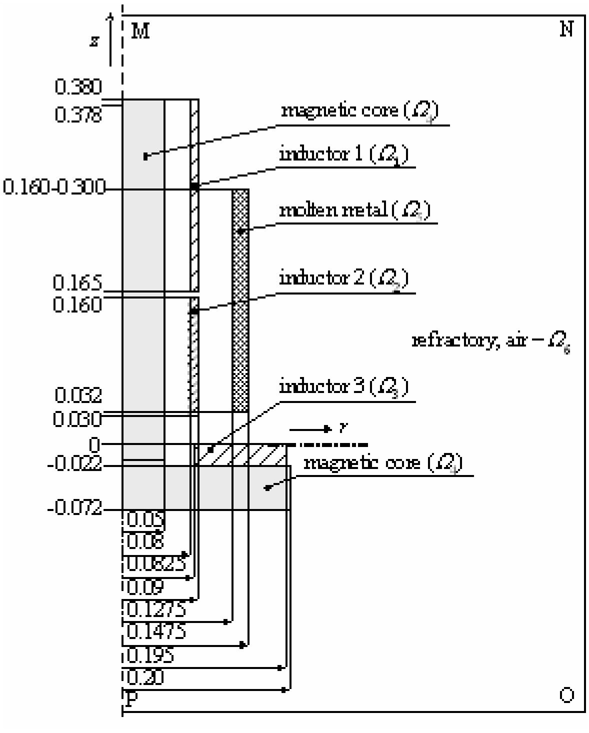

Fig. 3. Geometry of the zinc feeder

The magnetic core is not expected to be fully saturated (which was confirmed by a series of preliminary numerical computations) so that all material parameters may be considered approximately constant and the model linear. This simplifying assumption allows the computations of electromagnetic field to be carried out using the harmonic analysis.

Now the distribution of electromagnetic field in the area is described by equation [1]

$$\mathrm{rot}\,\mathrm{rot}\,\underline{\boldsymbol{A}} - \mathrm{j}\cdot\omega\gamma\mu\,\underline{\boldsymbol{A}} = -\mu\,\underline{\boldsymbol{J}}_{\mathrm{ext}} \qquad (1)$$

where $\underline{\boldsymbol{A}}$ is the vector potential, μ the permeability, γ the electrical conductivity, ω the angular frequency and $\underline{\boldsymbol{J}}_{\mathrm{ext}}$ the current density of external (feeding) currents. This equation was supplemented by the Dirichlet condition $\underline{\boldsymbol{A}} = \mathbf{0}$ along the boundary MNOPM.

As the inductors are not wound by too massive conductors, the skin effect in them was neglected and external current density was modeled as uniformly distributed over their areas.

Distribution of the magnetic field represents the first step for computation of the specific Lorentz forces acting in zinc. These forces are given by formula

$$\boldsymbol{f}_{\mathrm{L}} = \mathrm{Re}\left\{\underline{\boldsymbol{J}}_{\mathrm{eddy}} \times \underline{\boldsymbol{B}}^{*}\right\} \qquad (2)$$

that may be rewritten in terms of vector potential $\underline{\boldsymbol{A}}$

$$\boldsymbol{f}_{\mathrm{L}} = \mathrm{Re}\left\{\mathrm{j}\cdot\omega\gamma\underline{\boldsymbol{A}}\times\left(\mathrm{rot}\underline{\boldsymbol{A}}\right)^{*}\right\}\cdot \qquad (3)$$

The total vertical component F_{L} of the electrodynamic force acting on zinc is then

$$F_{\mathrm{L}} = \int_{\Omega_3} \mathrm{Re}\left\{\underline{\boldsymbol{J}}_{\varphi} \times \underline{\boldsymbol{B}}_{r}^{*}\right\}\mathrm{d}V\,. \qquad (4)$$

Lifting of zinc was simulated with exploitation of the obtained dependence of the total axial electrodynamic force F_{L}.

The process is governed by a nonlinear ordinary differential equation in the form

$$F_{\mathrm{a}} = F_{\mathrm{L}} - F_{\mathrm{g}} - F_{\mathrm{fr}} - F_{\mathrm{d}} \qquad (5)$$

where F_{a} is the accelerating force, F_{g} the weight of the zinc column, F_{fr} the friction and F_{d} the drag force. All these quantities depend either on the height of the zinc level or on its derivatives (velocity v and acceleration a). Particular forces can be described as follows:

$$F_{\mathrm{a}} = \rho S\left(h - h_0\right)a \qquad (6)$$

is the total force in the zinc column causing its acceleration. Here S denotes the value of cross-section of the zinc container, h_0 is the level of the zinc container bottom and h the general level.

$$F_{g} = \rho S\left(h - h_1\right)g \qquad (7)$$

is the gravity force, where h_1 is the level of zinc in the basin, from which the zinc is pumped.

$$F_{\mathrm{fr}} = \xi 2\pi\left(r_1 + r_2\right)\left(h - h_0\right)v \qquad (8)$$

is the friction force, where ξ is coefficient of friction and r_1, r_2 are the inner and outer radii of the zinc container. Finally

$$F_{\mathrm{d}} = \frac{1}{2}S\rho v^2 \qquad (9)$$

is the force necessary for continual accelerating zinc from zero velocity in the basin to velocity v.

ILLUSTRATIVE EXAMPLE

The algorithm was tested on a simplified model of a real zinc feeder whose geometrical dimensions are indicated in Fig. 3. Some other parameters important for the regime of dosing follow:

- currents in the windings I_{ext} = 300 A,
- frequency f = 50 Hz,
- relative permeability of the magnetic cores μ_{r} = 1000,
- electrical conductivity of molten zinc $\gamma = 3.4 \cdot 10^6$ MS/m,
- specific mass of molten zinc ρ = 6690 kg/m^3,
- cross-section of the container S = 0.0173 m^2,
- lowest level of zinc h_1 = 0.16 m.

Computation of the static characteristic was carried out by professional program FEMLAB. Distributions of electromagnetic field and Lorentz forces for the regime of dozing (and for the lowest possible level of zinc in the feeder) are depicted in Figs. 4 and 5.

Repeated calculations of (4) for a series of zinc levels then provided the static characteristic of the device that is depicted in Fig. 6.

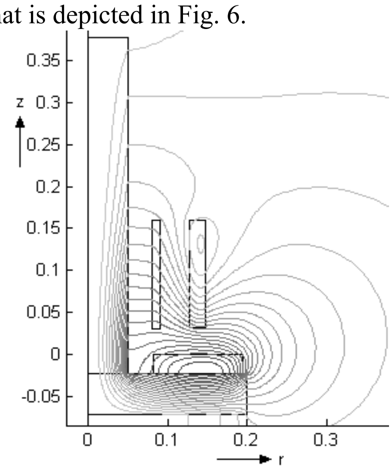

Fig. 4. Distribution of electromagnetic field during the dosing regime (for the lowest level of zinc)

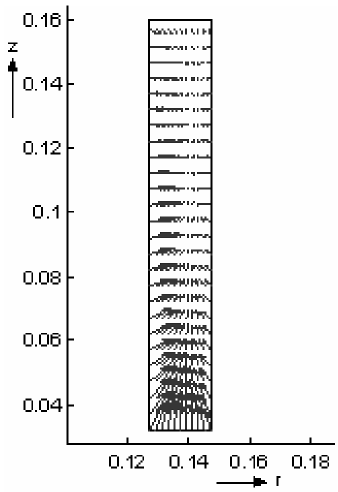

Fig. 5. Distribution of the Lorentz forces during the dosing regime (for the lowest level of zinc)

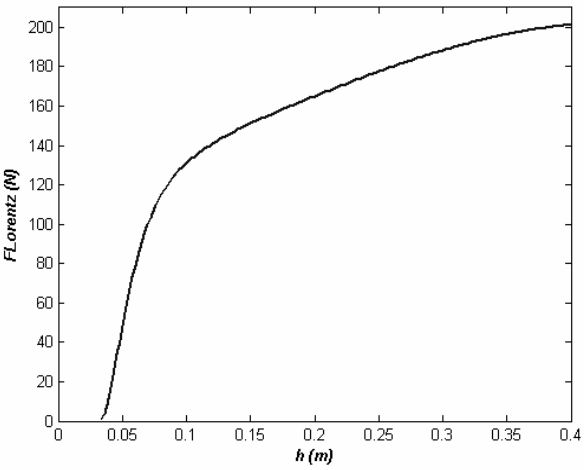

Fig. 6. Dependence of the total vertical Lorentz force in the zinc level

The equation describing lifting of the zinc level was computed by SIMULINK. The corresponding model is depicted in Fig. 7.

The upper part of the model bounded by the larger ellipse computes the accelerating force from the known zinc level h. This computation is performed by evaluating formulae 4, 7, 8 and 9.

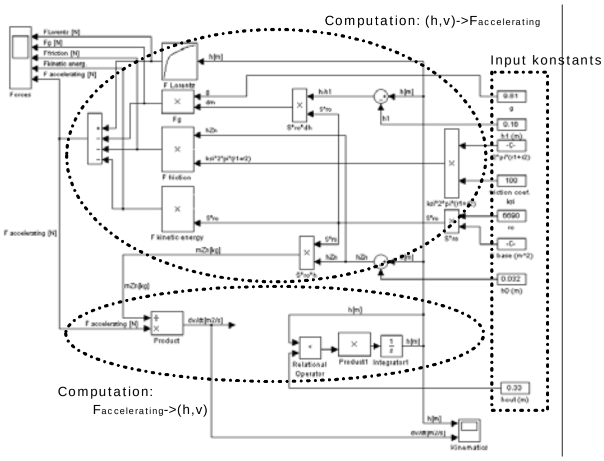

Fig. 7. Computational model built in SIMULINK.

The lower part of the model bounded by the smaller ellipse computes backwards the zinc level h and velocity v integrating the acceleration a obtained from the accelerating force.

The results depend on the friction coefficient that cannot unfortunately be determined without sophisticated experiments. In order to demonstrate its influence, computations were done for its three different values of 0, 1000 and 2000.

The resultant time dependencies of zinc level h, velocity v and acceleration a are depicted in Fig. 8.

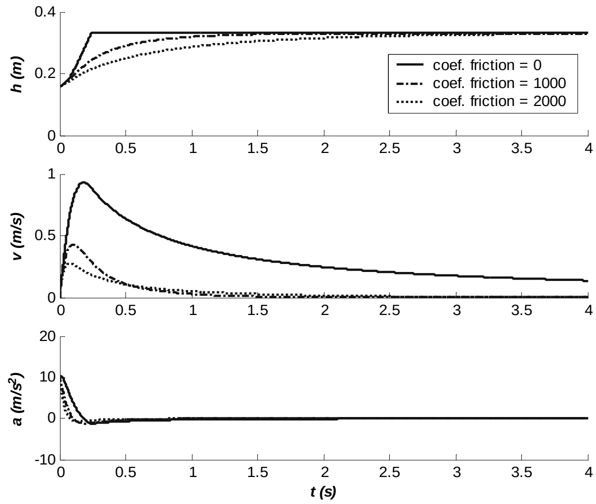

Fig. 8. Time evolution of height of the zinc level, velocity and acceleration at the beginning phase of dosing for three different friction coefficients

Fig. 9 contains the time evolution of all forces occurring in (5). For better mutual comparison of forces all of them (but only for friction coefficient 2000) are depicted in Fig. 10.

In the results for zero friction coefficient we can see the influence of the maximum zinc level limitation, due to the respecting the outlet, which is expected at the level of 0.33 m.

CONCLUSION

A mathematical and computer model of an electromagnetic zinc feeder was developed. The model was used for computation of electromagnetic field in the feeder and its dynamic behavior in the regime of dosing. The algorithm was tested on an example of a real zinc feeder. The example was solved for three different friction coefficients to show its influence.

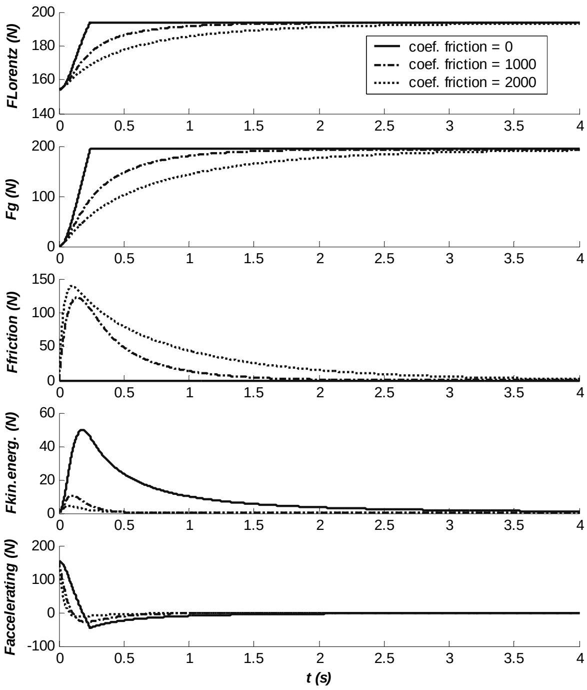

Fig. 9. The time dependence of forces occurring in (5) at the beginning of dosing for three different friction coefficients

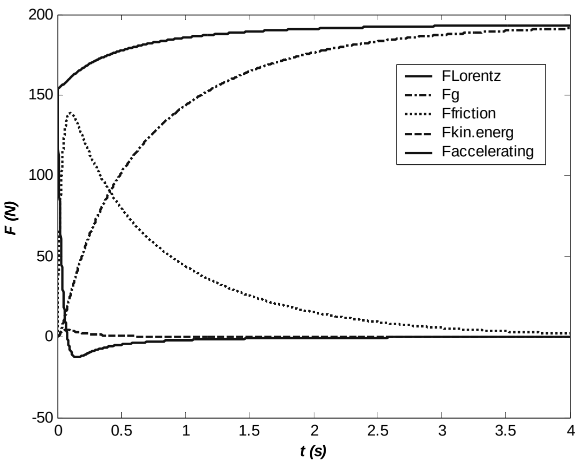

Fig. 10. The time dependence of forces occurring in (5) at the beginning of dosing for friction coefficients 2000.

ACKNOWLEDGMENT

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