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On the Transversal end Effect in the Linear Induction Pump with Large Non-magnetic Gaps

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Abstract

It is usually accepted that the transversal end-effect manifests itself in flat inductive pumps and chute systems as a deformation of the current induced in the working medium that results in decreasing the electromagnetic force, affecting the working medium. This is true at small values of the non-magnetic gap. With large gaps, dissipation fields should be accounted for. This phenomenon is very conspicuous in devices with the one-sided inductor. The paper reports the theoretical and experimental results on definition of electromagnetic forces, affecting electrically conducting bodies subjected to the field induced by a one-sided inductor with different non-magnetic gaps.

Wide application of magnetohydrodynamic (MHD) methods and devices in metallurgical technologies is initially restricted by the necessity to use flow ducts with relatively thick walls. This circumstance determines large non-magnetic gaps between the molten metal and the magnetic field inductor, and, respectively, the significant decrease of MHD device efficiency.

The existing numerical methods for calculating MHD devices, in particular, electromagnetic pumps with a travelling magnetic field (TMF), have been worked out mainly for small non-magnetic gaps and do not yield true results at large gaps. Such disagreement in numerical and experimental results is likely explained by a decrease of the magnetic field induction in the zone with molten metal owing to the so-called transversal end phenomenon, which characterizes field dissipation beyond the inductor magnetic circuit.

In the classic theory of MHD machine, the field dissipation due to the transversal end effect is described by an attenuation coefficient K_{att} proposed by Voldek [1] – this coefficient is defined from a complicated enough expression [2]. Yet, with large non-magnetic gaps, the proposed formula does not illustrate the realistic field distribution and cannot be used for calculating the characteristics of MHD pumps. The objective of the current research is to study how the non-magnetic gap size affects the coefficient K_{att} in a pump with a plane TMF inductor. Investigations were carried out by comparing the numerically calculated and the experimentally found values of the magnetic field induction and induced electromagnetic forces.

Distributions of the magnetic field induction and electromagnetic forces at different distances from the inductor surface were calculated numerically using the ANSYS code. This code allows to consider the final length of the inductor and of the conducting layer, exposed to the field, with account for the impact of the inductor lateral parts on the field actual value. The above circumstances altogether allow to consider in calculations the field induction variation at different distances between the inductor surface and the conducting layer in a 2D approximation not taking into account the transversal end-effects.

Experiments involved measurements of the TMF induction at different distances from the inductor surface as well as measurements of the value of electromagnetic forces, affecting the conducting layer model. The inductor of TMF used in experiments has the following parameters – 30 cm long, 8 cm wide, with a 7.5 cm pole pitch. A rectangular 28 cm long plate of 8x80 mm^2 in cross-section was used as a conducting liquid layer model. The plate, as heavy as 300 g, was made of graphite of specific conductivity $\sigma = 1.125 \cdot 10^5\ \Omega^{-1}\text{m}^{-1}$ (graphite was used to approximate the σ value to the similar parameter of molten metal).

The magnetic field induction was measured by a Hall probe of the universal Teslameter along the longitudinal symmetry axis of the inductor at different distances from its surface. Such measurements along the longitudinal axis must not show the manifestation of transversal end-effect and assumed to be in good agreement with 2D calculations. To measure the electromagnetic force induced by the inductor, the graphite plate was suspended above the inductor by four thin threads fixed at the plate's corners (Fig.1). In different experiments, the distance between the inductor and the plate could be changed.

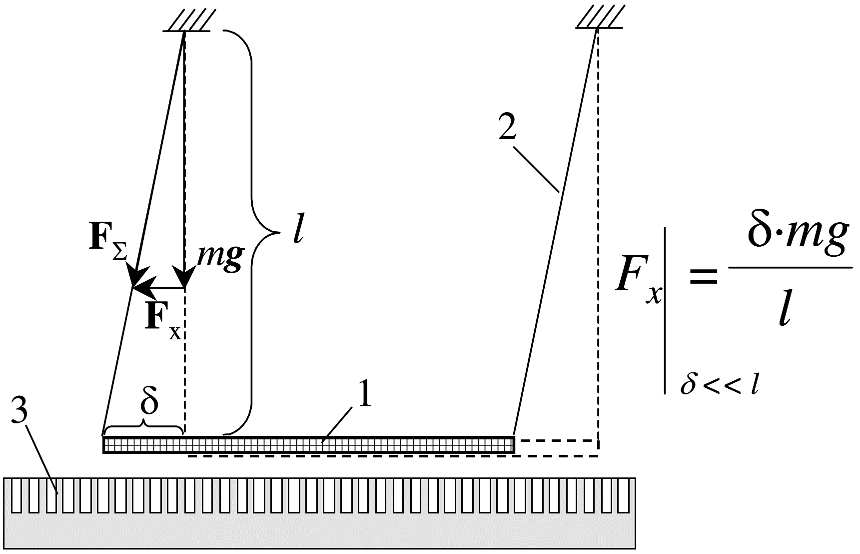

Fig.1. Scheme of the integral electromagnetic force measurements.
1 – graphite plate; 2 – threads; 3 – TMF inductor; $l/\delta > 80$.

When the inductor is switched on, the plate shifts horizontally and, at the same time, moves up at a small height from its initial position. With small intervals of horizontal and vertical plate shifts, it is presumed that at the equilibrium state the electromagnetic force, generated by the inductor, is balanced by the gravity force (weight) of the plate. In this case, the value of integral electromagnetic force $\boldsymbol{F}_x$ can be defined from the formula $\boldsymbol{F}_x = m\boldsymbol{g}\delta/l$, where m is the plate mass, $\boldsymbol{g}$ is the gravity force acceleration, l is the thread length, δ denotes a horizontal shift of the plate under the action of electromagnetic force.

It should be noted that the accuracy of $\boldsymbol{F}_x$ definition is determined by the ratio δ/l: the smaller this ratio, the higher the accuracy of force measurement. In the course of experiments, the value l varied within the range of $500 < l < 800$ mm, and the value of δ did not exceed 40 mm, thus, the measuring error was not more than 10%.

Fig.2 illustrates the results of calculation and measurements of the magnetic field component, normal to the surface of the inductor. To compare the obtained results correctly, the magnetic field induction value B_y was made dimensionless H^*, according to the expression:

$$H^* = \frac{B_y t_x}{\mu_o n I}, \qquad (1)$$

where B_y is the vertical component of the magnetic field induction, t_x is the pole pitch, μ_o is the magnetic permeability of free space, n is a number of turns in an inductor coil, I is the electric current value in an inductor coil.

The numerical and experimental data agree well enough.

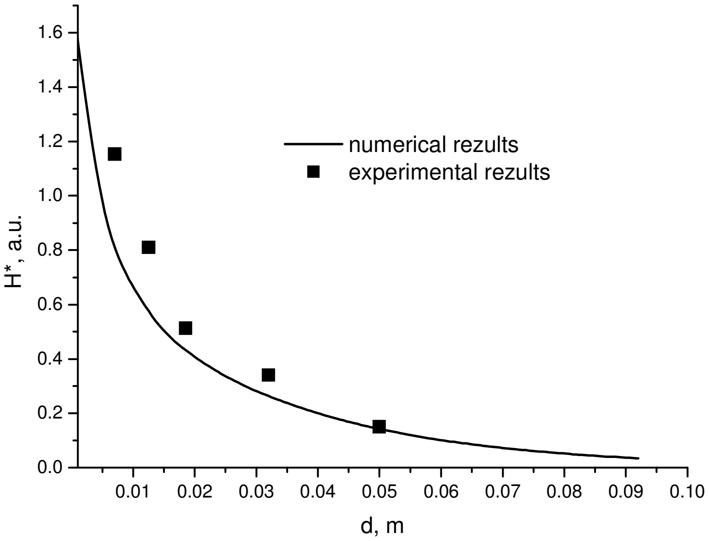

Fig.2. Decay of the dimensionless vertical component of the magnetic field H* vs. the distance form the inductor's surface.

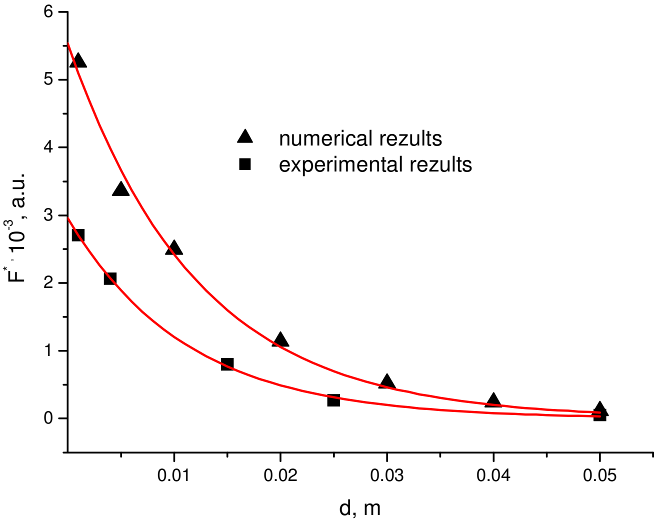

Fig3. Decay of the dimensionless horizontal component of the integral electromagnetic force acting on the graphite plate vs. the value of the non-magnetic gap.

Fig.3 displays numerical and experimental decays of the non-dimensional electromagnetic force ***F****, affecting the plate, versus different sizes of the non-magnetic gap. The value of the horizontal component $\boldsymbol{F_x}$ of the integral force was made dimensionless ***F****, according to the expression [2]:

$$F^* = \frac{F_x a t_x^2}{V \mu_o n^2 I^2}, \tag{2}$$

where *a* is the thickness of the graphite plate, *V* is the volume of the plate. As expected, due to the field dissipation beyond the inductor width, the measured force values have appeared much less if compared to the calculated ones. This difference is very illustrative – see the diagram $\boldsymbol{F_{exp}} / \boldsymbol{F_{cal}}$ in Fig.4. With large non-magnetic gaps (>50 mm), the above difference might be ≥300%.

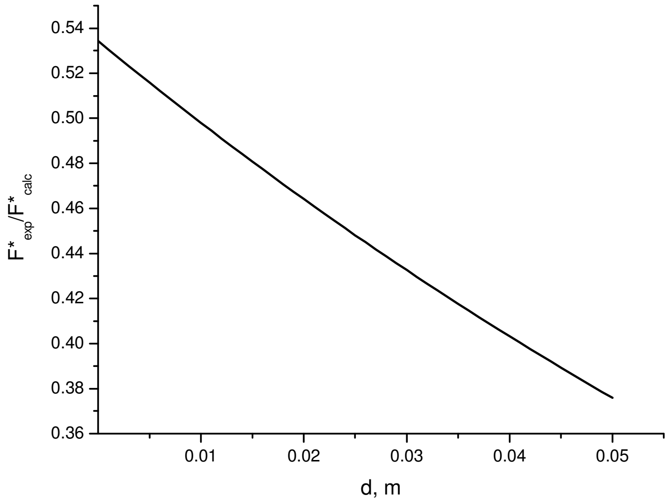

Fig.4. The relation of the experimentally registered horizontal component of the integral electromagnetic force $\boldsymbol{F_{exp}}$ to the numerically calculated one $\boldsymbol{F_{calc}}$.

As a first estimate, the dependence $\boldsymbol{F_{exp}} / \boldsymbol{F_{cal}} = f(d)$ can be approximated by a linear function:

$$f(d) = 0.53 - 3.16d, \qquad (3)$$

which can be used unless $d \leq 0.16$ m.

The obtained results testify to a considerable discrepancy in the data of numerical 2D calculations and experiments for large non-magnetic gaps. Apparently, the performed series of experiments do not allow to extend the obtained data to situations with different ratios of the conducting layer width to the inductor width. Yet, within the range of sizes for the cases investigated to define the realistic force value, one can use the above expression (3).

The influence of different factors on the efficiency of MHD machines with large non-magnetic gaps is an objective of our future investigations.

References

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[2] Krūmiņš J. *Fundamentals of theory and calculations for devices with the travelling magnetic field.* - Riga, Zinātne Publishing House, 1983, 278 p. (in Russian).

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