MHD FLOW IN A CLOSED CYLINDRICAL VESSEL EXPOSED TO CONCURRENT INFLUENCE BY DIFFERENT ALTERNATING ELECTROMAGNETIC FIELDS

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Introduction. The influence by different types and combinations of alternating and steady magnetic fields on electrically conducting liquids significantly expands the possibilities for controlling their hydrodynamic and heat/mass transfer characteristics [1]. Previous investigations have demonstrated then a possibility to drive pronounced 3D stirring flows in the melt, to resolutely vary the direction and strength of the flows in the middle and at the walls of a vessel, to control the distribution of temperature and concentration within the melt bulk, and so on. In some situations, combinations of electromagnetic fields allow to utterly avoid some negative from the practical point of view phenomena by a concurrent action of magnetic field of other type [2, 3, 4].

All studied so far combinations of electromagnetic fields are shown in Fig. 1. Dash-lines in Fig. 1 mark previously not yet investigated combinations of rotating

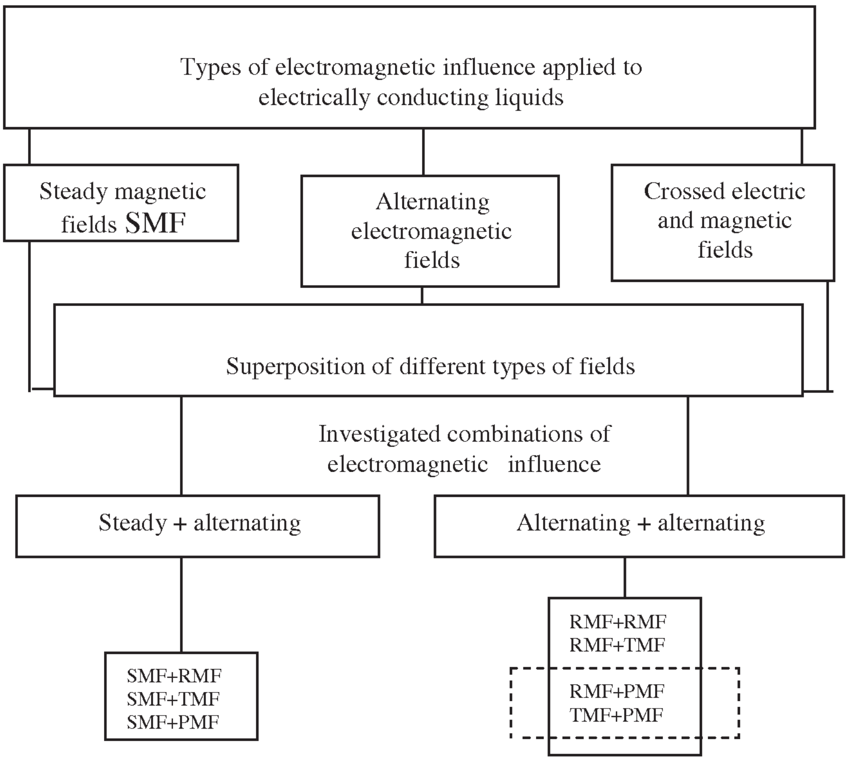

Fig. 1. Versions of combinations of electromagnetic fields of different types.

and travelling magnetic fields with a pulsating magnetic field. The action of these combined electromagnetic fields on the hydrodynamic characteristics of the flows driven in molten metals is the object for study in the current paper. Note that superpositions of a pulsating magnetic field (PMF) with a travelling (TMF) or a rotating (RMF) magnetic field are rather topical because metals are often heated and melted with the use of an alternating (pulsating) electric current, and the melt hydrodynamics is controlled by the TMFs or RMFs.

1. Numerical procedure. As in previous works, the general problem of the interaction of electromagnetic fields with a conducting liquid was solved in a non-inductive approximation and had two parts: a calculation of electromagnetic forces, affecting the molten metal, and a calculation of velocity patterns, driven by the above forces in the melt. A liquid-filled cylindrical volume of radius R_0, height h and electric conduction σ, arranged co-axially in a cylindrical inductor of radius R and height h_0, inducing rotating, pulsating and travelling magnetic fields, is considered in all cases. The liquid is characterized by a density ρ, an electric conductivity σ and a kinematic viscosity ν. The RMF is assumed to be induced by an inductor with the number of pole pairs $p = 1$. Inductors to generate the TMF and the PMF are sets of cylindrical coils arranged co-axially about the conducting cylinder.

Distributions of electromagnetic forces were found for every type of the fields and every position of the inductors. The electromagnetic forces were used as external forces in the Navier–Stokes equations for calculating the velocity patterns, occurring in the liquid. The applied in the current work method for numerical simulation of the combined magnetic field influence on the melt hydrodynamics is described in detail in [5].

2. Numerical results. The distribution of velocity and the pattern of flows driven in the melt under the concurrent action of two types of electromagnetic fields are determined by the ratio of their intensities and the zone, where each field acts. Apparently, when one type of the fields dominates, its influence is determining. A more complex situation should take place when the zone of field action is localized. Hence, most attention in the paper was attracted to such situations.

Fig. 2 illustrates the calculation of the streamlines of the flows driven in the meridional plane of the liquid volume being exposed to a simultaneous action of the RMF and PMF. In particular, Fig. 2a shows a situation when the zone under the PMF action spreads over the entire side surface of the vessel, and Fig. 2b shows a situation when the PMF is localized only in the middle of the side surface of the cylinder. One can see that in both cases a symmetric two-vortex flow pattern with an increased velocity in the vortex, which coincides in direction with the vortex driven by the RMF, remains. The streamlines in Fig. $2c - d$ also show variations of the velocity pattern within the liquid volume when the action of the PMF is localized, respectively, on the side surface in the zone adjacent to the vessel's bottom and under the vessel's bottom in the zone of radius $r = R_0/2$. The figures vividly illustrate that the characteristics of the driven flows can be controlled by different combinations of the RMF and PMF by shifting them over the liquid cylindrical volume.

Fig. 3 illustrates similar calculations for a situation when the melt is subjected to a concurrent action of the TMF and PMF. Fig. $3a - b$ shows that if the PMF is symmetrically positioned, a two-vortex velocity pattern always appears on the side surface of the cylinder independent on the PMF inductor length. Some differences are found only in sizes of the vortices and in flow velocity values. Just non-

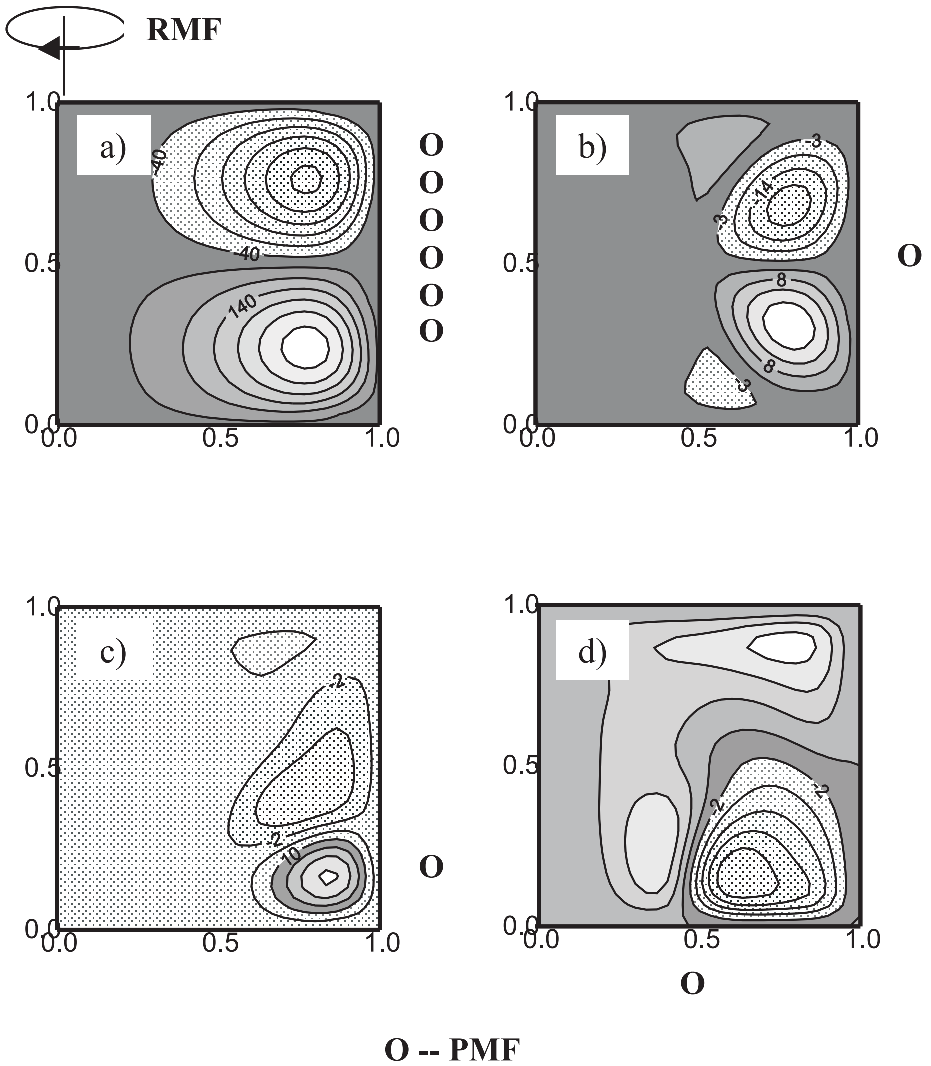

Fig. 2. Stream functions of the meridional flows under the action of RMF and PMF on the melt.

symmetrical position of the zones under the action of the TMF and PMF can drive diversified flow patterns that are illustrated in Fig. $3c-d$.

It should be emphasized that the resultant flows in the vessel under superimposed TMF and PMF greatly depend on the TMF direction (see Fig. $3c-d$). When the direction of the flows driven by the TMF mainly coincides with the direction of the flows driven by the PMF, the values of the resultant velocities increase there, and vise versa. Even in case of TMFs directed towards each other and acting under the vessel's bottom, the action from the PMF significantly affects the pattern of driven flows.

3. Conclusions.

- Combinations of the RMF and TMF with the PMF can be applied to control flow velocity patterns by varying the strength and direction of the flows in any zone of the liquid volume.
- The technique used for calculating the flows under the above mentioned com-

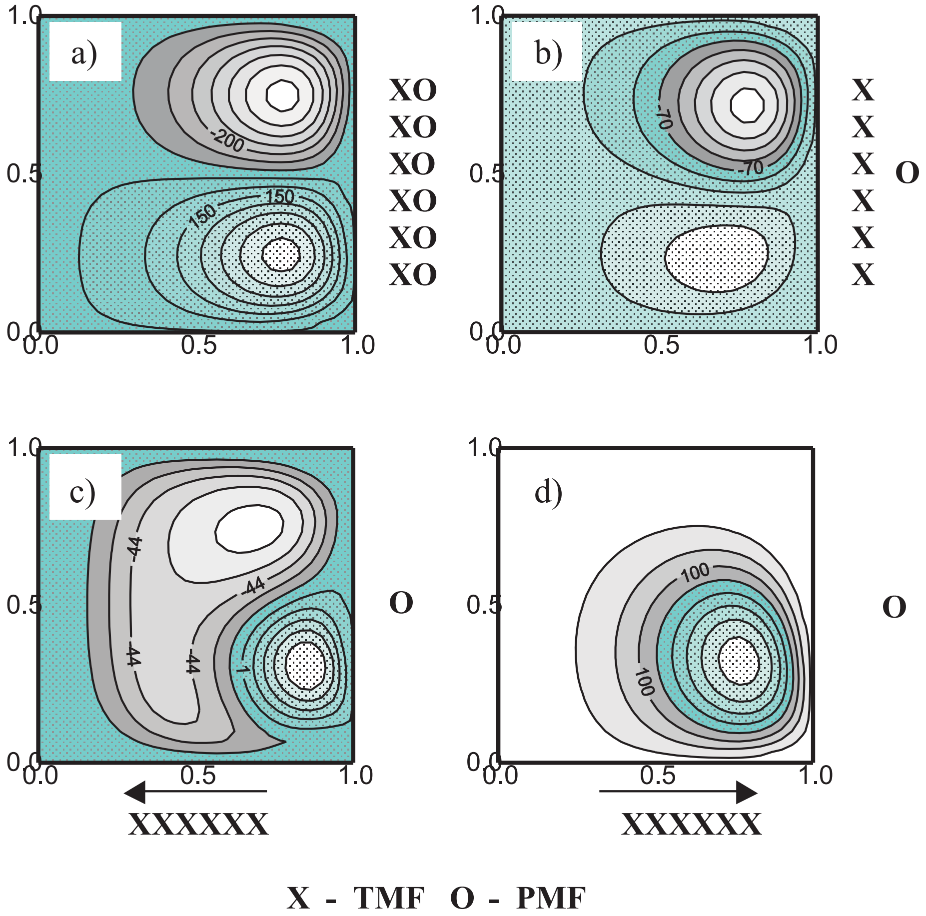

Fig. 3. Stream functions of the meridional flows under the action of TMF and PMF on the melt.

binations of magnetic fields can be applied to practical tasks for analysis and evaluation of required velocity patterns.

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