LIQUID METAL FLOW UNDER INHOMOGENEOUS MAGNETIC FIELD

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Summary We experimentally investigate the influence of a vertical inhomogeneous static magnetic field on a liquid metal flow in insulating planer channel. The studies show an existence of three regions of flow formation: before, inside and behind magnetic field. In the first region, flow fluctuations are damped; in the second region, new flow with velocity M-shape profile is formed; in the third region, two shear layers near side walls are developed. Distributions of mean velocity, perturbation intensity of velocity and electrical potential and their spectra are presented. The work relates to experimental MHD modeling and industrial applications.

INTRODUCTION

In an industrial and experimental practice in a majority of MHD situations a flow of an electrically conducting fluid is situated in a sufficiently inhomogeneous magnetic field. Owing to the certain technological or design requirements the poles of a magnet system are performed either with a breach of discontinuity or with dimensions that are smaller than a size of a flow. In some MHD machines and devices the poles of magnets are presented by a number of alternating lugs and cavities that caused a periodical distribution of magnetic field. The problem of molten metal control by a spatially inhomogeneous magnetic fields is getting more important for industrial applications in metallurgy and crystal growth. In an industrial facility a magnetic field is created by an electromagnet mounted in the mould of a slab caster where it controls the flow of the hot metal. This method, also known as electromagnetic brake, for example, in the process of continuous casting. Inhomogeneous magnetic field is applied for suppression of undesirable jet-like structures of liquid metal flows. The process of electromagnetic brake, its advantages and drawbacks are broadly described in special publications [1-3]. In principle, an excessive brake effect redistributes the velocity drastically. The velocity vanishes in the central part and increases near periphery of flow. This flow is known as a M-shape. Such a flow is well investigated theoretically and experimental [4-6,8]. In the present study we consider the effects of a vertical inhomogeneous short extent magnetic field on a liquid metal flow in electrically insulating channel.

BEHAVIOUS OF FLOW IN INHOMOGENEOUS MAGNETIC FIELD

In some place on a length of channel we locate magnetic system which consists of two narrow (along the flow) magnet poles creating vertical magnetic field. Before and behind magnets the magnetic field is down. Interaction of the flow and magnetic field induces potential gradient and electric current according to the Ohm’s law. Maximum electric current is concentrated in central area of a gap between magnet poles. By virtue of this effect the electric current is closed in areas of small magnetic field before and behind of the magnetic system.

The Lorentz’s breaking force in the liquid, in plane perpendicular to the magnetic field, generated by interaction of the electric current and magnetic field, is higher in the center of the magnetic gap then the force in the vicinity of the side walls. As a result inhomogeneous M-shape velocity profile arises. Such flow formation we present formally as a generation of a vorticity parallel to the vertical component of magnetic field within the magnetic field region [7]. The vorticity is generated not only by viscosity, but it also occurs at given x-component of electric current and magnetic field z-component gradient along the flow. Downstream behind magnetic system two turbulent shear layers similar to wall jet are developed.

In connection with this, we consider three regions of flow development. The region **I** is characterized by an exposure of inhomogeneous magnetic field to the flow and by a damping of perturbations incoming to the magnetic field. The region **II** is between the front of magnetic system and distance where formation of the velocity profile under inhomogeneous magnetic field is completed. Here, in parallel with the non-homogeneity of profile growth, a vortical structures arises by pressure differential in areas between inlet and outlet of the magnetic field. The region **III** is characterized by a further development of flow M-shape velocity profile without magnetic field. Two shear layers issuing from magnetic field region are propagated nearly the channel side walls.

EXPERIMENTAL SET-UP AND MEASUREMENT TECHNIQUES

The experiments are carried out in a rectangular channel of a half meter long made of Plexiglas with a cross-section 100mm×20mm. As working liquid we use the eutectic alloy Ga68%In20%Sn12% which has a melting temperature of +10.5°C. Two permanent magnets of 20×30×100mm are located above and below the channel. An induction of the magnetic field $B = 0.504$ T is a maximum in the central point of the gap between the poles and essentially changes in x-direction (along the flow).

During the experiments we introduce in flow by alternately a potential probe [4] and a Vives’ probe[7]. By application of the first probe we measure averaged and pulsating potential distributions in area of a magnetic field, region II, and by the use of the second probe we measure averaged and pulsating velocity in regions I and III, where magnetic field is absent.

With this actual setup we vary in experiments the Reynolds number within the range $Re = 500$-16000. The Hartmann number in magnetic gap is $Ha = 400$ for maximum magnetic field induction. The MHD interaction parameter, as a ratio of electromagnetic to inertial forces, is varied within the range of N = 10-320. Here, we use a flow rate mean velocity and the height of flow.

RESULTS AND DISCUSSION

The order of results are: (1) profiles of the mean and root-mean-square (rms) velocity in areas of magnetic field absence; (2) distributions of the mean and root-mean-square (rms) local electric field in region of applied magnetic field presence; (3) flow visualization and amplitude-frequency spectra of electrical potential and velocity fluctuations.

Suppression region I

We start with analyzes of a velocity field of flow incoming to the region of magnetic field at Reynolds number Re = 4000. On the axes before magnetic field, the maximum of mean velocity and fluctuations as well take place. In this region, rms magnitude constitutes 6–7% of the flow rate velocity. As the flow is approached to the magnetic field region, the intensity of pulsations reduces 2-fold in the center and 3-fold nearly sidewalls. The reduces are due to a transformation of mean flow and fluctuations damping in this transition region of magnetic field growth.

Vortical region II

In this region the Lorentz force has perceptible effect on the flow. Maximum of the velocity displaces to the sidewalls. In central domain the flow velocity is halved to a flow rate velocity. We emphasize that the crosswise velocity changes the sign to the right and to the left of flow axis, i.e. the flow coming in magnetic field has a tendency to be separated into two flows directed toward the side walls. Downstream both transversal flows nearly the walls again directed toward the axes. Obvious closed lines confirms the existence of two large-scale vortical structures in the immediate region of the magnetic field. Space measurement of potential distributions shows an existence of these vortical structures two-dimensional in plane perpendicular to the magnetic field. In the vicinity of walls the velocity is 3-fold higher then mean flow rate velocity.

Wall jet region III

In this region a pulsation intensity does not exceed of 5% in axial zone, whereas it increases nearly wall up to 27% at Re = 4000. At high the Reynolds number the intensity perceptibly decreases. For instance, at Re = 16000 the intensity declines to a level of 7.5%. A relative decrease of the intensity of longitudinal pulsation is physically explained by growth of more dissipative high-frequency part in spectrum of perturbations generated by the wall shear flow at given the Reynolds number. Notice that profiles hold their M-shape downstream with the resulting formation of two wall planer shear layers. The existence a basic frequency and double one testifies that a double vortical street forms downstream behind magnetic system. We note also that an active interaction between perturbations generated by both wall shear flows takes place.

CONCLUSIONS

The arrangement studied serves as a physical model for the industrial process, where structure and intensity of flow are controlled by magnetic field. The actual set-up allows measurement the mean and fluctuating both local electric field and velocity in area of applied magnetic field and in a regions of magnetic field absence. Three regions of flow development we consider: (I) a damping of perturbations coming in the magnetic field; (II) generation of vortical structures and M-shape profile formation; (III) development of M-shape wall shear flow. As the flow is approached to the magnetic field, the intensity of pulsations reduces 2-fold in the center and 3-fold nearly sidewalls. In region downstream without magnetic field in area of wall shear flow the intensity increases up to 27% at Re = 4000 and up to 7.5% at Re = 16000. Obtained amplitude-frequency spectra show that in central part of the flow determinant vortices develop downstream from magnet system, their combinations arise in the spectra.

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