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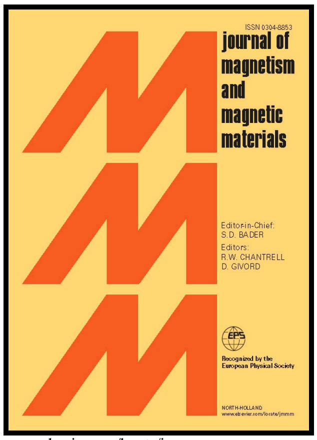

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Formation of rupture in a conducting fluid layer under the action of an oscillating tangential magnetic field

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Abstract –
Possible equilibrium shapes of the free surface of a conducting fluid layer subjected to oscillating tangential magnetic field are studied. Exact solution corresponding to the formation of rupture in a fluid layer is derived using the conformal mapping method. The width of the rupture has been defined; it depends on the problem parameters, viz. the value of the external magnetic field and the surface tension coefficient.

Keywords – ***magnetic field, free surface, conducting fluid, rupture, exact solution, magnetic shaping problem, conformal mapping method.***

1. Introduction

A tangential magnetic field has a stabilizing influence on the surface of a liquid possessing magnetic properties [1,2]. For relatively small deformations of the flat surface of a fluid, the magnetic forces, as well as the capillary ones, tend to return the free surface to its original state. In the situation where the amplitude of the surface deformation exceeds the depth of the liquid layer, the geometry of the system radically changes: the rupture of the layer can appear (see, for instance, experimental works [3,4], where the ruptures of a horizontal layer of ferrofluid were investigated). The question arises: can capillary and magnetic forces be counterbalanced on the free surface in such situation? The problem of finding the equilibrium is difficult to solve analytically because of the nonlinearity of the force balance condition and of a rather sophisticated (with discontinuities) geometry of the perturbed surface.

Consider the simplest situation where the magnetic field does not penetrate into the fluid, and the force lines of the field are tangential to the boundary. This case corresponds to the limit of a perfectly conducting fluid in a constant magnetic field [5]. For a fluid with finite conductivity, a similar situation arises for an oscillating field. A high-frequency magnetic field penetrates only into a thin surface layer of a conducting fluid. If the skin layer thickness is much smaller than the liquid layer depth, it can be assumed that the field does not penetrate into the fluid. At times far exceeding the oscillation period, the problem of finding the equilibrium configurations can be considered as quasi-stationary.

In the present work, using the conformal mapping technique [6], we have found exact solutions describing the formation of a rupture in a horizontal fluid layer for the plane symmetry of the problem. For these solutions, capillary and magnetic forces are mutually compensated on the free surface of a liquid. The dependence of the width of the rupture on the parameters of the problem (namely, on the magnetic field value and the surface tension coefficient) has been established.

2. Basic equations

Consider a conducting liquid layer of finite depth. It is placed on the plane conducting substrate. Let us introduce a rectangular system of coordinates $\{x,y,z\}$ such that the substrate position corresponds to $y=0$ (the y axis is perpendicular to the substrate – see Fig. 1). Assume that the problem has plane symmetry: the surface of a fluid is invariant under shift along the z axis, i.e., the layer is deformed only in the $\{x,y\}$ plane. In this case all quantities depend only on the pair of variables, x and y.

Let an external uniform horizontal magnetic field with the absolute value of the induction equal to B be present. For the plane symmetric case, the vector potential of the magnetic field ($\mathbf{B}=\nabla\times\mathbf{A}$) has only one z component: $\mathbf{A}=\{0,0,\psi(x,y)\}$. Then, the distribution of the magnetic field is governed by the single scalar function ψ: $\mathbf{B}=\{\psi_y,-\psi_x,0\}$. Note that the condition $\psi=\mathrm{const}$ defines the lines of force of the magnetic field.

The magnetic field distribution in space is described by the 2D Laplace equation for the z component of the vector potential,