INSTABILITY OF PARTIALLY-IONIZED SUPERPOSED PLASMAS

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Abstract. The stability of the plane interface separating two viscous superposed partially-ionized plasmas of uniform densities has been studied. The whole system is assumed to be immersed in a uniform two-dimensional horizontal magnetic field and the stability analysis has been carried out through the normal mode technique. The dispersion relation has been derived for the case of two superposed plasmas of equal kinematic viscosities. The dispersion relation has been solved numerically for different values of the physical parameters involved. It is found that viscosity and collision frequency of ionized plasmas both have stabilizing influence on the growth rate of the unstable mode of disturbance.

1. Introduction

Chandrasekhar (1961) examined the influence of a vertical magnetic field on the instability resulting at the plane interface between two incompressible inviscid and perfectly conducting fluids of different densities when the lighter is accelerated into the heavier. Roberts (1963) extended this stability problem to include the effects of finite kinematic viscosity and magnetic resistivity. However, he considered only the case wherein these quantities are constant, equal to each other, and the same in both the fluids. The investigation of the Rayleigh–Taylor problem in MHD with finite conductivity was reported simultaneously by Jukes (1963). His observations were based on the case of two inviscid fluids of different densities, one supported on the other in a uniform horizontal magnetic field and subjected to a vertical gravitational force. He concluded that finite conductivity introduced new and unexpected solutions.

Since viscosity influences the growth or decay rates of perturbations, study of the case of viscous fluids is imperative for more realistic situations. The Rayleigh–Taylor problem in MHD with finite conductivity and Hall currents has been studied by Singh and Tandon (1969). However, they have also considered the case of inviscid fluids. The problem of the Rayleigh–Taylor instability of two superposed viscous-conducting fluids has been studied by Bhatia (1974). The problem of the instability of the plane interface separating two superposed viscous-conducting rotating fluids has more recently been examined by Bhatia and Chhonkar (1985). These authors have also included the effects of finite ion-Larmor radius (FLR) in their study. All these investigations have been carried out for fully-ionized plasmas.

Plasmas are not frequently fully ionized but instead may be permeated with neutrals and are thus partially ionized so that the interaction between the neutral and the ionized gas becomes important. In cosmic physics, such situations occur in the study of solar photospheres, chromospheres, and cool interstellar clouds. Alfvén (1954) has pointed
out the influence of ion-neutral collisions on the ionisation rate in these regions. It would, therefore, be of interest to study the Rayleigh–Taylor instability of two viscous superposed partially-ionized plasmas of uniform densities. This aspect forms the subject matter of the present paper. Earlier, Ogbonna and Bhatia (1984) have studied this problem in the presence of FLR effects but therein only the transverse mode of propagations has been studied.

2. Perturbation Equations

We consider the horizontal strata of a partially-ionized plasma (the mixture of an ionized plasma of density $\rho$ and a neutral gas of density $\rho_d$) in the presence of a uniform two-dimensional horizontal magnetic field $H = (H_x, H_y, 0)$. It is assumed that the steady-state velocities of the two components (ionized atoms and neutral gas) are equal and also that individual components independently behave as continua. It is also assumed that (i) the frictional force of neutrals on ionized particles and pressure gradient of the ionized atoms, both are of the same order, (ii) the pressure gradient of the neutrals is much less than the frictional force of the ionized atoms on the neutrals, and (iii) gravity has most insignificant effect on the dynamics of the neutral gas.

Under the foregoing assumptions the linearized perturbation equations appropriate to the flow of the mixture of the hydromagnetic plasma and a neutral gas are

$$
\rho \frac{\partial \mathbf{u}}{\partial t} = -\nabla \delta p + g \delta \rho + (\nabla \times \mathbf{h}) \times H + \mu \nabla^2 \mathbf{u} + 2(\nabla \mu \cdot \nabla) \mathbf{u} + \rho_d v_c (\mathbf{u}_d - \mathbf{u}),
$$

(1)

$$
\frac{\partial \mathbf{u}_d}{\partial t} = -v_c (\mathbf{u}_d - \mathbf{u}),
$$

(2)

$$
\frac{\partial}{\partial t} \delta \rho + (\mathbf{u} \cdot \nabla) \rho = 0,
$$

(3)

$$
\frac{\partial \mathbf{h}}{\partial t} = \nabla \times (\mathbf{u} \times H),
$$

(4)

$$
\nabla \cdot \mathbf{u} = 0, \quad \nabla \cdot \mathbf{h} = 0;
$$

(5)

where $\mathbf{u}(u, v, w)$, $\mathbf{h}(h_x, h_y, h_z)$, $\delta \rho$, and $\delta p$ denote the perturbations, respectively, in velocity, magnetic field $\mathbf{H}$, density $\rho$ of the conducting plasma, and pressure $p$, while $\rho_d$ and $\mathbf{u}_d$ denote the corresponding quantities for the neutral gas; $\mu$ and $\mathbf{g} = (0, 0, -g)$ are, respectively, the coefficient of viscosity and the acceleration due to gravity. The symbol $v_c$ denotes the collision frequency which represents the effect of the neutral gas friction.

If we analyse in terms of normal modes we assume that the perturbed quantities have