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EFFECTS OF FLOWS ON VISCOUS AND RESISTIVE MHD STABILITY

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In many solar applications the viscosity appears to be more important than resistivity and the observations show clearly that in some cases the fluid velocity is comparable to the local Alfvén velocity. Equilibrium flows and viscosity can considerably change the properties of resistive instabilities.[1-5]

In this paper it is shown that both the growth rate of the instability and the spatial profile of the mode strongly depend on few relevant parameters, namely the ratio r between the magnetic (a_B) and the velocity (a_V) scale lenghts, the ratio V between the fluid (v_O) and the Alfvén (v_A) velocities and the ratio M between the Lundquist (S) and the Reynolds (R) numbers.

In order to discuss these instabilities in solar conditions, let us consider an idealized configuration in which the plasma is flowing in the z-direction along the magnetic field B_O with a velocity v_O. Both B_O and v_O vary in the x-direction. In order to take into account the shear of the magnetic field possibly induced by photospheric motions, we will consider $B_O \sim \text{tgh}\, x/a_B$, so that resistivity can be important in a layer around $x = 0$.

As far as the velocity is concerned we will discuss two different velocity profiles, with different hydrodynamic stability properties.

Eq. a): $v_O \sim \text{tgh}\, x/a_V+1$ stable against Kelvin-Helmholtz instability

Eq. b): $v_O \sim \text{sech}\, x/a_V$ unstable against Kelvin-Helmholtz instability.

Assuming the perturbations to behave as $\sim \exp\,[i(kz+\omega t)]$, the linear stability analysis of the above configurations shows that the relevant parameters are [4,5]

$$r = \frac{a_B}{a_V}\ ,\quad V = \frac{v_o}{V_A}\ ,\quad S = \frac{\tau_R}{\tau_A}\ ,\quad R = \frac{\tau_\nu}{\tau_A}\ ,\quad \alpha = ka_B.$$

The resistive time τ_R and the viscous time τ_ν are defined as:

$$\tau_R = \frac{4\pi\, a_B^2\, \sigma}{c^2} \qquad\qquad \tau_\nu = \frac{\rho a_B^2}{\eta_1}$$

c is the speed of light, σ the electrical conductivity.

$$\eta_1 = \frac{3}{10}\ \frac{n_i\ T_i}{\omega_{ci}^2\ \tau_i}$$

is the perpendicular viscous coefficient, using the same notations as Braginskii (1965). It can be shown that η_1, which is the smallest of the coefficients appearing in the stress tensor, is the only one important in this calculation.[6]

The results can be summarized as follows:

1) The frequency $\omega = \omega_R + i\gamma$ of the mode is complex and $\omega_R \sim kv(o)$.

2) There exists a transition from a behaviour similar to the static tearing mode to a behaviour similar to a Kelvin-Helmholtz mode. This transition occurs when $\varepsilon = r\ V \sim V^{1/3}$; here ε is a measure of the relative importance of the velocity gradients with respect to the magnetic gradients. When $\varepsilon > V^{1/3}$, we find a stabilization for Equilibrium a and a rapid increase of the growth rate for Equilibrium b. This difference is due to the different stability properties against K.-H. modes of the two configurations.

3) It is well known that the viscosity stabilizes the static tearing mode. In presence of flows this is still true only when $\varepsilon << 1$

or $S/R < 1$. Otherwise we have to distinguish between Equilibrium a) and b).

Equilibrium a) with $\varepsilon \sim V^{1/3}$ and $S/R > 1$:
The growth rate of the mode increases with the viscosity and presents a maximum value for $R \sim 20$ which is independent of the resistivity. For $R > 20$ the viscosity again stabilizes the mode.

Equilibrium b) with $\varepsilon > V^{1/3}$:
The viscosity is important and represents a stabilization factor only when $R \sim 1$.

4) In all cases there is a non-zero x-component of the magnetic field perturbation at $x = 0$ and therefore all these modes are reconnecting modes. The level of reconnection is a function of the growth rate of the mode, being bigger for slowly growing instabilities.

5) When $\varepsilon \gtrsim V^{1/3}$, in all cases the perturbations are not localized close to the resistive layer as in the static tearing mode, and therefore the typical scale length of the mode is a_B and not the width δ of the resistive layer as in the static case.

It is clear that the effects of the instability on the equilibrium configuration can be studied only through a non-linear analysis. Depending on the values of the relevant parameters the non-linear evolution of the instability can be very different.[8] These exist situations (Eq.(b), $\varepsilon > V^{1/3}$, $\alpha \sim 1$) in which the instability can trigger a turbolent cascade with a consequent important dissipation of both the equilibrium magnetic and kinetic energies. In these cases the instability is similar to a Kelvin-Helmholtz instability with growth time few per cent of the Alfvén time and a small level of reconnection. There are other situations (Eq.(a), $\varepsilon \sim V^{1/3}$, $\alpha \lesssim 0.1$)

in which the instability does not produce a strong turbulence and a little amount of energy is involved, but it is easy to accelerate particles through the associated parallel (to B) electric field. In these cases the instability is similar to a resistive instability with growth time slower than in the previous case but with important effects due to the viscosity.

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