A 3D Hall-MHD study of reconnection and filament formation from magnetic flux emergence in the sun: Preliminary results

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Using a three-dimensional Hall-magnetohydrodynamic (Hall-MHD) model in Cartesian coordinates, we investigate the emergence of magnetic flux rope into the solar atmosphere near a large-scale single polarity region with a uniform and vertical magnetic field. Cases with different relative orientations and strengths of the emerging field and background magnetic field are studied. A concentrated current sheet with the shape of an arch is formed at the interface that marks the positions of maximum jump in the field vector between the two systems. A kind of instability, seemed as Kelvin-Helmholtz instability, is excited near the current sheet, developing continuously to bring the extremely asymmetry of the plasma density in the surface of the emerging rope. The local accumulating of plasma is speculated to be the mechanism of filament formation.

1. Introduction

Magnetic fluxes of opposite polarities often collide and cancel on the solar surface (Martin, Livi, and Wang, 1985). Flux cancellation appears to play an important role in various kinds of dynamic activities in the upper atmosphere of the Sun, as seen from its observed associations with flares (Livi et al., 1989; Wang and Shi, 1993; Zhang et al. 2001), erupting mini-filaments (Hermans and Martin, 1986), filament formation (Martin, 1986; Chae et al., 2000), filament activation and eruption (Wang, Shi, and Martin, 1996; Kim et al., 2001), coronal mass ejections (Zhang et al., 2001) and so on.

The formation and disintegration of filament is an important problem in the study of the photospheric magnetic field and the associated solar activity. However, flux cancellation has been frequently observed in association with the formation of a preflare filament prominence (e.g., Chae et al. 2001; Zhang et al. 2001). A number of recent numerical experiments (Hu and Liu 2000; Fan 2001; Magara and Longcope 2001, 2003; Archontis et al. 2004; Manchester et al. 2004) have studied the rise of buoyant magnetic flux tubes initially below (but close to) the photosphere into a nonmagnetized corona. But the solar corona has a space-filling and dynamically important magnetic field. Hence, the rise and expansion of newly emerging magnetic flux cannot proceed unimpeded (Fan and Gibson 2003). Based on these, we try to understand further the properties of low-atmosphere reconnection using 3-D MHD simulation model. Specifically we are going to simulate the filament formation, which are proposed to exist along the interacting boundary between the main background magnetic polarity and the emerging flux rope.

2. Model Description

The initial building of the experiments follows previous papers (Ma and Lee 1999; Fan 2001; Archontis et al. 2004, Galsgaan et al, 2005 and references therein). Our numerical simulation solves the ideal Hall-MHD equations. We assume that the plasma is an ideal gas with the ratio of specific heats $\gamma=5/3$ and that it evolves adiabatically. The gravitational acceleration $-g\mathbf{z}$ is assumed constant. We non-dimensionalize the equations using the following normalizing constants: $\rho_{ph} \approx 3 \times 10^{-7} \cdot \text{g} \cdot \text{cm}^{-3}$ (photospheric density), $H_{ph} \approx 170 \text{km}$ (pressure scale height at the photosphere), $T_{ph} \approx 5600 \text{K}$ (photospheric temperature), $P_{ph} \approx 1.4 \times 10^{-2} \cdot \text{J} \cdot \text{cm}^{-3}$ (photospheric thermal pressure), $B_{ph} \approx 1300 \text{G}$, $V_{A} \approx 6.8 \text{km/s}$, and $\tau_{A} = H_{ph}/V_{A} = 25$ as the units for density, length, temperature, pressure, magnetic field, velocity and time respectively.

We consider an isothermal plane-parallel multilayered atmosphere in hydrostatic equilibrium. The background magnetic field is zero except that $B_z = 0.5$ for $x > 1$, which means the large-scale single polarity region. Assume that a magnetic flux rope of circular cross section begins to emerge at $t=0$ in the central area of the base and has been fully detached from the photosphere after $t=T_E$. The radius of the rope is $a$, and the emergence is uniform. We choose $a=1.0$ in the follow case. The emerged part of the rope is bounded by $x = \pm X_E, y = \pm Y_E$ at time $t$, where $X_E = (a^2 - H_E^2)^{1/2}$, $H_E = a(2t/T_E - 1)$ (Hu and Liu, 2000). The numerical method for solving those equations is a modified Lax-Wendroff scheme that has second-order accuracy in both time and space (Ma and Lee 1999; Magara 2001). The simulation box is $(-5; -5; 0 \leq (x; y; z) \leq (5; 5; 11)$, where x and y are horizontal coordinates and z is a vertical coordinate. At the base of the emerged part of the rope $X_E = \pm X_E, y = \pm Y_E$, $B_z(x, y, 0, t) = -0.3, B_x(x, y, 0, t) \approx 3.0 \cdot a(a^2 + x^2 + H_E^2)^{-1}$, $\rho(x, y, 0, t) \approx 10, V(x, y, 0, t) = 0.1$; The plasma parameters are the same as background values.

3. Preliminary simulation results

Fig.1-3 show the contours of plasma density and the magnetic field lines in the x-z plane at $y=0$ on the simulation time $t=1 \tau_A, 5 \tau_A$ and $13 \tau_A$. A concentrated current sheet with the shape of an arch is formed at the interface that marks...
the positions of maximum jump in the field vector between the emerging flux and the background systems. Some numerical reconnections took place even without the abnormal resistivity in all run time. Fig. 4 shows the current density at in the x-z plane at y=0 on the simulation time t=5 \( \tau_A \). A kind of instability, like Kelvin-Helmholtz instability is excited since t=3.6 \( \tau_A \), first appears near the current sheet, then develops continuously to bring the extremely asymmetry of the plasma density of the emerging flux rope near the interacting boundary. Since t=12.2 \( \tau_A \), the local accumulating of plasma at z=3 near the current sheet has been five times more than the background value. It looks like a filament suspending in the interacting boundary between the main background magnetic field and the emerging flux rope. In The local accumulating of plasma is speculated to be the mechanism of filament formation.

More simulation results and further analysis will be done later.

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**References**


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