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Fragmentation and Coalescence of Magnetic Flux Tubes in Weakly Ionized Plasmas

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Abstract

We investigate the dynamical fragmentation of magnetic flux tubes during two tubes collision, by changing the radius as well as the current intensity of the flux tubes. Our simulation results show that there occurs fragmentation of a magnetic flux tube with weak current and small radius, when it collides with a flux tube with strong current and large radius. The heating process during the collision of two flux tubes would be important for understanding complicated dynamics of magnetic bright points (MBPs) in the quiet photospheric network.

Keywords:

collision of two loops, fragmentation, magnetic reconnection, Magnetic Bright Points (MBPs), photospheric network

1. Introduction

Recent high-resolution observations from photospheric magnetograms made with the SOHO/MDI instrument and Swedish Vacuum Solar Telescope on La Palma showed that concentrations of magnetic flux in the quiet photospheric network of solar photosphere are highly dynamic objects with small-scale substructures [1].

Some results discussed by Schrijver *et al.* (1997) [2] show that the photospheric magnetic field outside of active region is in a continuous state of replenishment, with flux emerging from below and disappearing when collision of flux concentrations with opposite polarity occurs. It is evident from the SOHO/MDI magnetograms that flux concentrations brake into fragmentation which then collide with other flux concentrations of opposite polarity (resulting in partial or total flux cancellation) or the same polarity (resulting in newly merged concentration).

In the present paper, we show the simulation results of two colliding flux tubes in weakly ionized plasmas with high plasma beta ($\beta \simeq 1$), in oder to explain the observed phenomena. We focus on the collision of unsymmetric two loops; one has stronger current and larger radius than the other. We find that a flux tube with weak current and small radius splits into two small flux tubes through magnetic reconnection [3], and along the splitted small flux tubes there appear strong opposite flows.

2. Basic Equations and Simulation Model

In this section we present the basic equations and simulation model. We use a 3-D neutral- MHD code (Suzuki and Sakai,1996 [4]).

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \boldsymbol{v}) = 0, \qquad (1)$$

$$\rho\left[\frac{\partial \boldsymbol{v}}{\partial t} + (\boldsymbol{v} \cdot \nabla)\boldsymbol{v}\right] = -\beta \nabla p + (\nabla \times \boldsymbol{B}) \times \boldsymbol{B}, \qquad (2)$$

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$$\frac{\partial \boldsymbol{B}}{\partial t} = \nabla \times (\boldsymbol{v} \times \boldsymbol{B}) + \frac{1}{R_m}\Delta \boldsymbol{B} + A_D \nabla \times \{\frac{1}{\rho}\boldsymbol{B} \times [\boldsymbol{B} \times (\nabla \times \boldsymbol{B})]\}, \quad (3)$$

$$\frac{\partial p}{\partial t} + \boldsymbol{v} \cdot \nabla p + \gamma p(\nabla \cdot \boldsymbol{v}) = \frac{\gamma - 1}{\beta R_m}(\nabla \times \boldsymbol{B})^2, \quad (4)$$

where the plasma beta is $\beta = v_s^2/v_A^2$ and $v_s = (p_0/\rho_0)^{1/2}$ is the sound velocity and $v_A = B_0/(4\pi\rho_0)^{1/2}$ the Alfvén velocity. The magnetic Reynolds number is defined by $R_m = \tau_B/\tau_A$, where τ_B is the magnetic diffusion time, $\tau_B = 4\pi\sigma L^2/c^2$ and τ_A is he Alfvén transit time, $\tau_A = L/v_A$. The coefficient A_D in Eq. (3) is defined as $A_D = B_0^2\tau_A/4\pi\gamma_c\rho_0\rho_i L^2$.

The plasma density, magnetic field, and velocity are normalized by ρ_0, B_0, and by v_A. Space is normalized by L, and time is normalized by the Alfvén transit time. The system size is $0 \le x \le 4\pi L$, and $0 \le y \le 4\pi L$. The numerical schemes used here are the modified two-step Lax-Wendroff method, and implicit ADI method for solving the magnetic diffusion equation.

The parameters we choose are ; $R_m = 10^3$, $A_D = 10^{-3}$ and $\gamma = 5/3$. Initially, one loop has 1.5 times stronger current and twice larger radius than the other loop. The two loops have the same strength of magnetic field ($B_{z0} = 1$) along each loop (see Fig.1). We take an initial condition of current loops to satisfy an equilibrium. The magnetic fields for each loop are given by

$$B_\theta = \frac{B_m r/a}{1 + (r/a)^2},$$

$$B_z = \frac{B_{zo}}{1 + (r/a)^2},$$

where a is radius of the loop. We take $B_m = 0.8$, 1.2 for each loop. The initial density $\rho = p$ is taken to satisfy an equilibrium as follow;

$$p = 1 + \frac{B_m^2 - B_{z0}^2}{2\beta\{1 + (r/a)^2\}^2}.$$

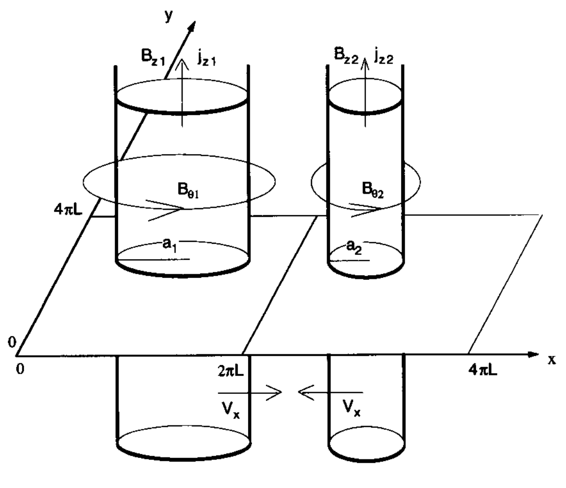

Fig. 1 Schematic picture showing initial configuration of two current loops.

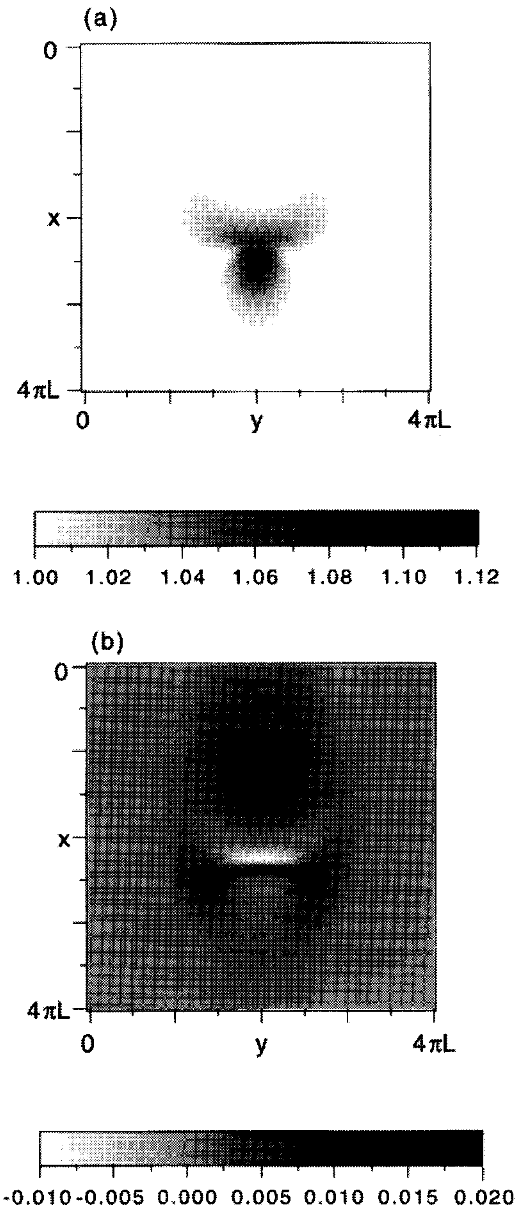

Fig. 2 (a) Temperature distribution, and (b) electric current J_z at $t = 6\tau_A$

3. Simulation Results

For the case of symmetric two current loops collision, there occurs no fragmentation of the loops. We study here what are important factors to control fragmentation of flux tubes and also for heating process in the case of unsymmetric two current loops.

Figures 2 (a), and (b) show the spacial distributions of temprature, and intensity of current J_z in the x-y plane at $t = 6\tau_A$. In this time strong current loop is located around on $(x,y) = (1.25\pi L,\ 2\pi L)$, while week loop is located around on $(x,y) = (2.5\pi L,\ 2\pi L)$. As seen in Fig. 2 (a), strong heating region appears near where weak current loop touches with strong current loop. In this period ($t = 6\tau_A$) the temperature reaches to a maximum value $T = 1.12T_0$ (T_0 is the initial value). Figure 2 (b) shows the fomation of reverse current sheet where magnetic reconnection occurs.

Figure 3 shows the time history of magnetic field

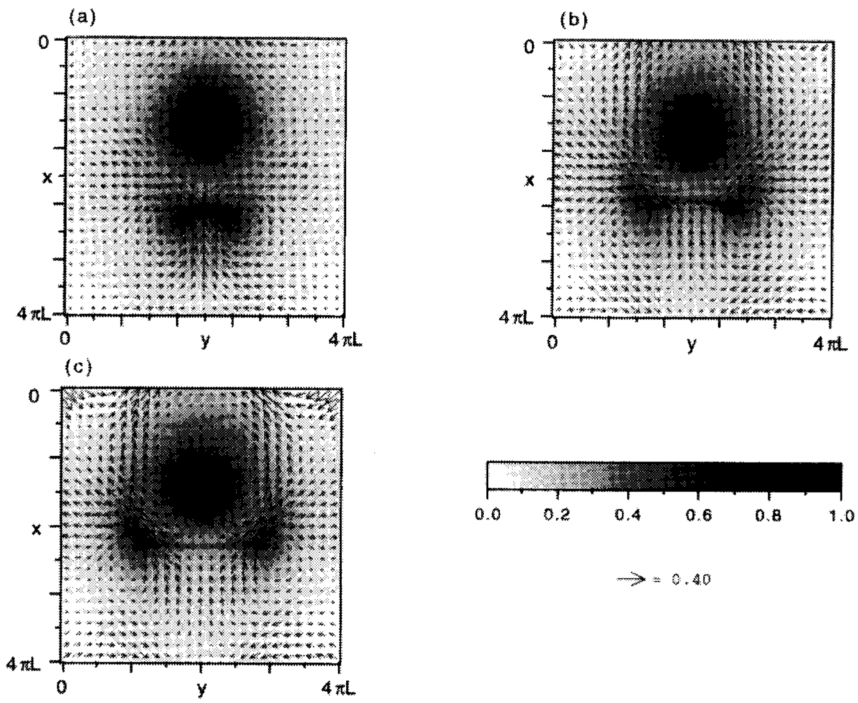

Fig. 3 Time history of distributions of magnetic field B_z and vector plots of $v_x - v_y$ at (a) $t = 4$, (b) 7 and (c) 9 τ_A.

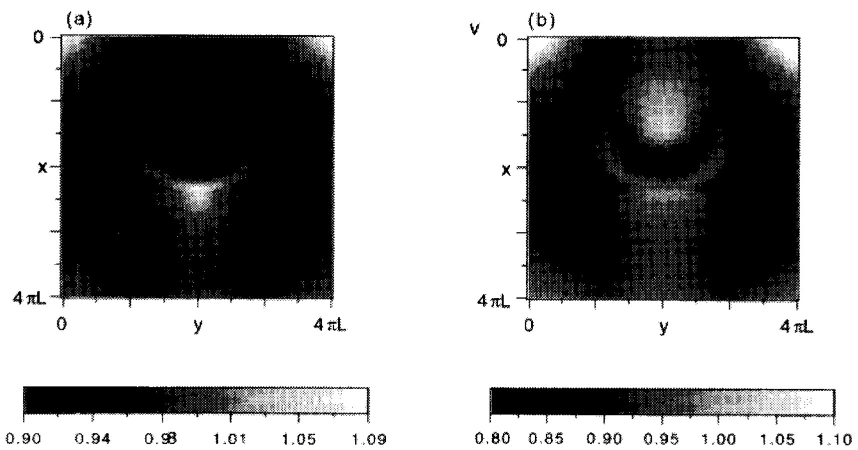

Fig. 4 (a) Temperature and (b) pressure distribution at 9 τ_A.

B_z and flow velocity field ($v_x - v_y$) at (a) $t = 4$, (b) 7 and (c) $9\tau_A$. During close approach of two loops, weak current loop is attracted to strong current loop. And finally they collide each other and the weak loop begins to make fragmentation. While strong current loop is not affected by weak current loop during the collision. As seen in the velocity field, because of converting magnetic energy to plasma kinetic energy through magnetic reconnection, there appears the strong flow in the y-direction. With separation of two fragmenting loops, we can see that the flow velocity in the x-direction becomes gradually weak by decrease of the attractive force due to the fragmentation.

Figures 4 (a) and (b) show the distributions of the temperature and pressure at $t = 9\tau_A$. As seen in Fig. 4, the temperature is still high, while there appear cooling regions of low pressure near where two fragmented loops exist.

Figure 5 shows the time history of flow velocity v_z at (a) $t = 4$, (b) 7, and (c) $9\tau_A$. We find that fragmentation of weak current loop generates strong opposite flows along the loops. Observed flow velocity is about $v_z \sim 0.4\ v_A$, which plasma flows should be observed.

4. Conclusions

Our simulation results show that there occurs fragmentation of a magnetic flux tube with weak current and small radius, while strong current loop keeps to be unaffected during the collision. There appears a point-like heating region where magnetic reconnection occurs. We also find that these fragmented loops have strong opposite plasma flows along the loops, which will be observed by high resolution doppler images.

Acknowledgement

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References

[1] T.E. Berger and A.M. Title, Astrophys. J. **463,** 365 (1996).

[2] C.J. Schrijver and A.M. Title, Astrophys. J. **487,** 424 (1997).

[3] S.V. Bulanov and J.I. Sakai, Astrophys. J. Suppl. **117**, 599 (1998).

[4] M. Suzuki and J.I. Sakai, Astrophys. J. **465**, 393 (1996).

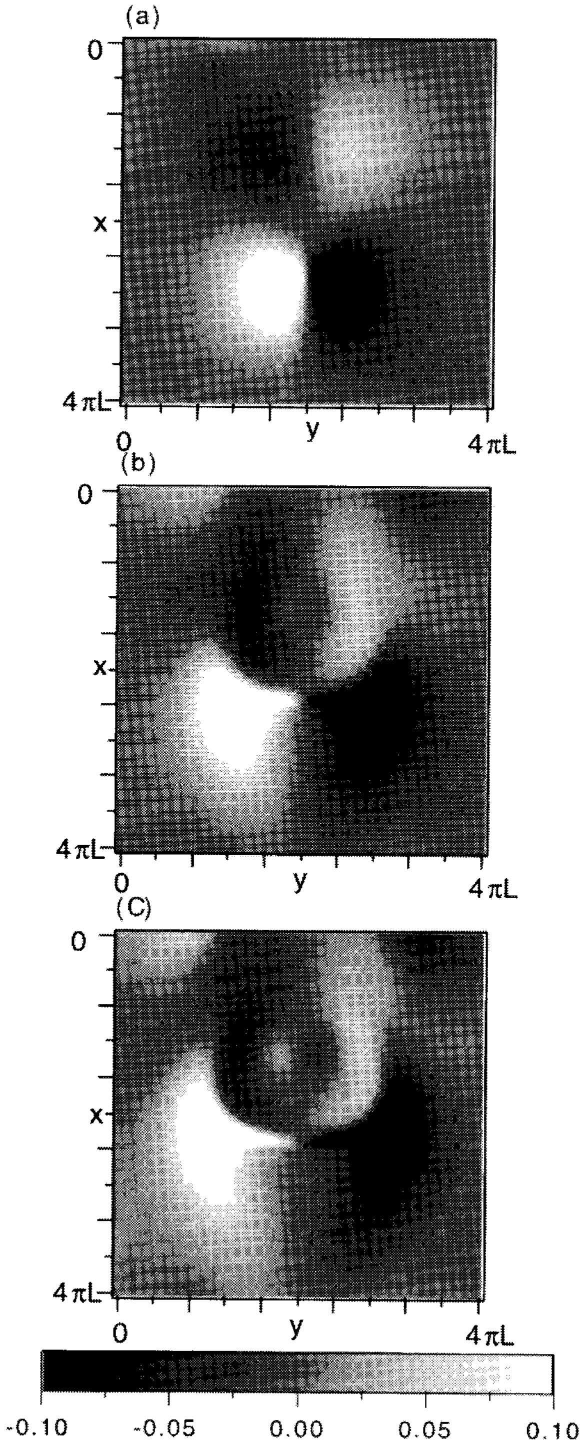

Fig. 5 Time history of distributions of velocity field v_z at (a) $t = 3$, (b) 7 and (c) $9\tau_A$.