THE ASTROPHYSICAL JOURNAL, 487:437–446, 1997 September 20

EVOLUTION OF ERUPTIVE FLARES. I. PLASMOID DYNAMICS IN ERUPTIVE FLARES

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Received 1996 December 31; accepted 1997 April 15

ABSTRACT

We investigate the resistive processes of plasmoid dynamics in eruptive flares by performing 2.5-dimensional resistive MHD numerical simulations. We start with a linear force-free field arcade and impose the localized resistive perturbation on the symmetry axis of the arcade. Then the magnetic fields begin to dissipate, producing inflows toward this region. These inflows make the magnetic fields convex to the symmetry axis and hence a neutral point is formed on this axis, leading to a formation of a magnetic island around the symmetry axis. At the first stage, the magnetic island slowly rises by the upflow produced by the initial resistive perturbation. Then, once the anomalous resistivity sets in, the magnetic island begins to be accelerated. This acceleration stops after the fast MHD shock is formed at the bottom of the magnetic island, which implies that the upflow around the central part of the magnetic island is no longer strong. These three stages in the evolution of the plasmoid are confirmed to exist in the observational results. Moreover, a time lag between the start time when the magnetic island begins to be accelerated and the peak time of the neutral-point electric field can be explained by the inhibition of magnetic reconnection by the perpendicular magnetic field. We also study the difference of the initial rise motion of the plasmoid between the simulation results and the observational ones, and we conclude that, in actual situations, the initial resistive perturbation proceeds very weakly and at many positions inside the arcade.

Subject headings: MHD — Sun: corona — Sun: flares — Sun: magnetic fields

1. INTRODUCTION

We can observe many activities in the outer atmosphere of the Sun. Solar flares are one of the most popular active phenomena and hence have been so attractive to both theorists and observers that much work has been done with these objects. Solar flares are highly energetic and complicated phenomena in which mass eruptions occur, energetic particles are generated, and soft or hard X-rays are radiated. In this paper, we study the dynamics of mass eruptions associated with solar flares, which are sometimes called plasmoid eruptions or filament eruptions (observed in Hα).

Theoretically, these eruptive phenomena have been considered to be related to an instability or a loss of equilibrium of the coronal magnetic field. Since the magnetic force is much stronger than both the gas pressure and the gravity force in the corona, coronal structures are mainly controlled by the magnetic field. Therefore, unless a magnetically driven event occurs, the coronal structures evolve in a series of quasi-static states, but once an instability develops or a loss of equilibrium is achieved, they no longer stay in a static state and enter on a dynamical stage. This scenario has made it important to study the stabilities and natures of the equilibrium configurations of the coronal magnetic field. Zweibel (1981, 1982) investigated the stabilities of two-dimensional magnetohydrostatic configurations. Cargill, Hood, & Migliuolo (1986), Velli & Hood (1986), and Hood & Anzer (1987) studied the MHD stabilities of the cylindrically symmetric magnetic arcades. Viscous effect was discussed by van der Linden, Goossens, & Hood (1988) and Bogaert & Goossens (1991). Zwingmann (1987) showed a series of equilibria of the coronal magnetic field and explained the onset conditions for the eruptive phenomena, which were reconsidered by Platt & Neukirch (1994). Priest (1988) and Steele et al. (1989) discussed a loss of equilibrium from the viewpoint of CME (coronal mass ejection). Forbes, Priest, & Isenberg (1994) estimated the amount of released energy when a loss of equilibrium occurs. An approach to this kind of problem by using the complex analyses is found in Priest & Forbes (1990) and Forbes (1990), for example.

Recently, the rapid development of computers enabled us to trace the temporal evolution of the coronal magnetic field directly by means of numerical simulations. Such work is found in Mikic, Barnes, & Schnack (1988), Biskamp & Welter (1989), Finn, Guzdar, & Chen (1992), Inhester, Birn, & Hesse (1992), Kusano, Suzuki, & Nishikawa (1995), Choe & Lee (1996), for example. These papers studied how the coronal magnetic field evolved under those situations where the shearing or converging motion was imposed in the photosphere.

Turning to the observations, the satellite *Yohkoh* has brought us many intriguing data of the corona since its launch in 1991 August (Masuda 1994; Sakao 1994; Hara 1996). These data are of good quality, so that they can be used to confirm the preproposed theories of several solar phenomena, for example, the reconnection model of solar flares (Tsuneta et al. 1992; Magara et al. 1996), as well as to propose some new theoretical predictions (Shibata et al. 1994, 1995). As for the plasmoid eruptions, Ohyama & Shibata (1997) analyzed the time-varying behavior of the plasmoids in detail and clarified their dynamical natures. The aim of our paper is to understand theoretically what is the basic mechanism working in the plasmoid eruption by taking into account some new results obtained by *Yohkoh*. For this purpose, we perform 2.5-dimensional resistive MHD simulations and compare the simulation results with the observational ones.

Basic formulations are in the next section. Main results are presented in § 3, and § 4 is used to mention the observational results. In § 5 we discuss both the obtained results

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