MHD ANALYSIS OF THE EVOLUTION OF SOLAR MAGNETIC FIELDS AND CURRENTS IN AN ACTIVE REGION

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ABSTRACT

We have used a self-consistent magnetohydrodynamics model to study the evolution of solar magnetic fields in an active region. The problem has been cast as an initial boundary-value problem based on explicit mathematical formalism (i.e., method of projected characteristics), whereby a variety of horizontal photospheric motions can be treated. In this paper we deal specifically with photospheric shear motions in the active region. Our results show the evolution of the magnetic energy, the electric current systems, including the distributions of $J_{\perp}$ (current perpendicular to the magnetic field) $J_{||}$ (current parallel to the magnetic field), the magnetic field configuration and a comparison between the build-up of magnetic energy in a pre-twisted field and in an initial untwisted field due to photospheric shearing motions. From these results we conclude that the energy build-up is confined within a certain region near the neutral line at the photospheric level. The possible location of the particle acceleration also can be studied.

INTRODUCTION

Recently, Wu et al. (1982) developed a non-planar magnetohydrodynamic (MHD) model to study coronal dynamics. Mathematically, this numerical model pertains to a spherical coordinate system for global studies. To study localized phenomena, Wu et al. (1983a) utilized the same theory with different techniques (Hu and Wu, 1983) to develop a MHD model in rectangular coordinates. This model has been used to study wave/mass motions in the solar atmosphere (Wu et al., 1983a) due to photospheric shear motions and to assess the energy build-up in an active region (Wu and Hu, 1981; Wu et al., 1984). However, the detailed structure of magnetic properties has never been presented.

In this paper, we use this newly developed non-planar MHD model to investigate the field and electric current structures due to shear motions in an active region. The numerical results presented are the magnetic

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energy intensity, electric current intensity, and magnetic field configuration. Further details are presented in Wu et al. (1983b).

ANALYSIS AND RESULTS

The governing equations and the method of solution have been reported by Wu et al. (1983a) and Hu and Wu (1983), and will not be repeated here. Since we are studying an active region, the initial magnetic field is represented by a twisted configuration (Wu et al., 1984). In particular we use a force-free magnetic field representation with a 40° twist in this investigation. The initial undisturbed atmosphere is isothermal and in hydrostatic equilibrium and is characterized by $n_o = 6.5 \times 10^{14}$ cm^{-3} and $T_o = 5 \times 10^4$ K; where n is the number density and T the temperature, and where a subscript "o" refers to the value at the lower boundary, which is the level immediately above the transition region. The initial magnetic field strength (B_o) at the lower boundary is 1,500 G leading to an initial plasma beta (β_o) of 0.1, where β is the ratio of plasma pressure to magnetic pressure (i.e., $\beta = 16\ nkT/B^2$). In this initial state a shear motion of 1.0 km s^{-1} is introduced, and our MHD model reveals the ensuing responses.

Figure 1a,c,d show the two-dimensional structures for magnetic energy intensity, line and electric current intensities (i.e., $J_{||}$ and $J_{\perp}$) in the vertical X-Y plane. The simulation domain is 8,000 km x 8,000 km. We note that concentrations of magnetic energy (ergs km^{-3}) and of electric current (A km^{-2}) develop in similar ways. The location of these concentrations is in the neighborhood of the neutral line and in the lower parts of the atmosphere. Furthermore, the hill-valley type structures of the magnetic energy intensity and the current intensity are also observed during this development state. In general the development of the magnetic energy and electric current intensity is much like that of twisted ropes. It has been shown theoretically (Sokolov and Kosovichev, 1978) that magnetic field gradients of the order of 1 G km^{-1} will trigger instability, and we propose that the type of shear motion under study will lead to a catastrophic state of energy release which may be identified as a flare. In addition, the present self-consistent MHD model gives the physical parameters as functions of time and space and therefore can be tested by observations.

Figure 1b shows the initial magnetic field configuration (solid lines) and magnetic field configurations twenty minutes after introduction of the shear motion (broken lines). Some interesting physical phenomena are revealed, e.g., the lower portions of the magnetic field lines are lifted up and the higher portions of the lines are pushed downward. This may possibly be interpreted as one of the sources of atmospheric oscillations.

Finally, we compare the build-up of excess magnetic energy in an initially pre-twisted (i.e., force-free) field with the build-up in an untwisted (i.e., potential) field configuration due to photospheric shearing motions, see Figure 2. The excess magnetic energy build-up in an

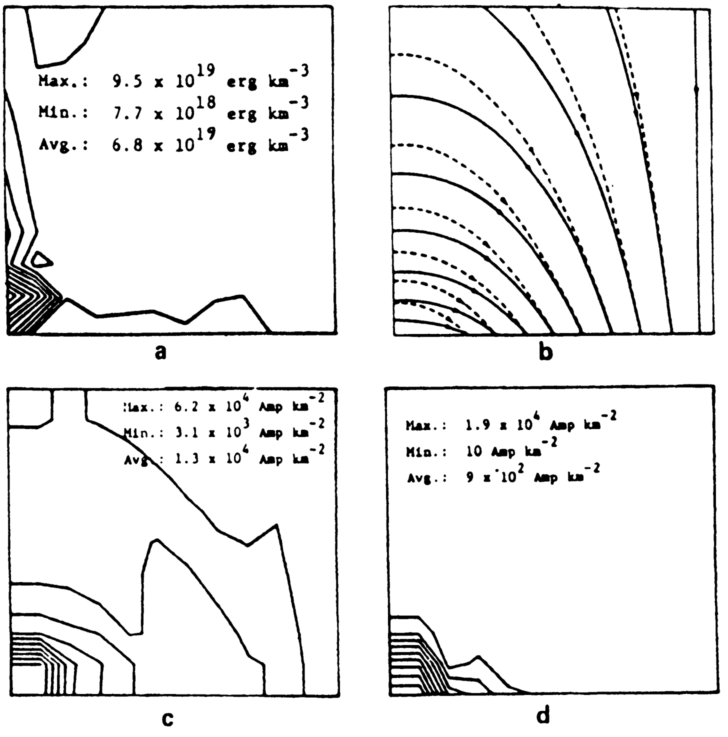

Fig. 1. Two-dimensional distribution of (a) magnetic energy intensity (b) magnetic field lines, (c) parallel current ($J_{||}$) intensity and (d) perpendicular current intensity 1200 s after introduction of a photospheric shear motion (1 km s^{-1}) in a pre-twisted magnetic field (i.e., force-free field).

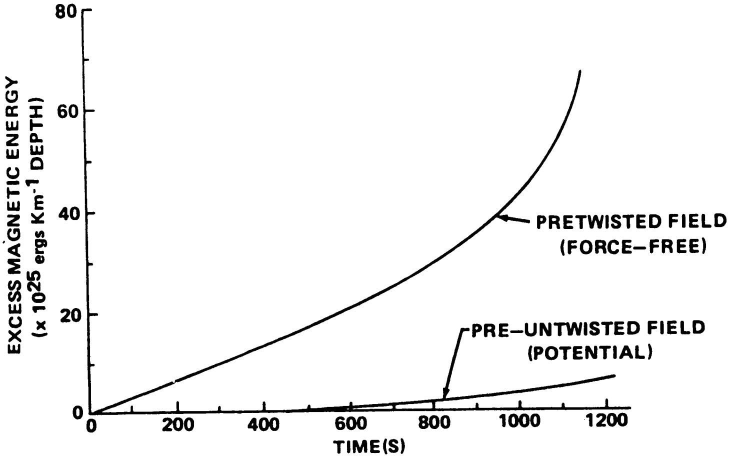

Fig. 2. Magnetic energy build-up due to photospheric shear motion (1 km s^{-1}) for both pre-twisted (force-free) and (un-twisted) (potential) magnetic field configurations.

initially pre-twisted field is almost two orders of magnitude higher than in the case of an initially un-twisted field. Specifically, the excess magnetic energy built to 8 x 10^{30} ergs in twenty minutes after the solar motion was introduced. This energy would be enough to produce solar activity in the active region.

CONCLUDING REMARKS

In this paper, a self-consistent model was used to investigate the evolution field and current structures due to photospheric shearing motions. It has been demonstrated that this model is capable of predicting physical parameters that may help improve our understanding of the evolution of field and current structures in an active region. We have not shown any results concerning the typical plasma parameters (i.e., density and temperature) since, it has been demonstrated earlier that the variation of these parameters in this particular case is negligibly small Wu and Hu (1981). This implies that the photospheric plasma parameters remain unchanged during this particular energy build-up process (i.e., for β_o = 0.1 and a shearing motion of 1.0 km s^{-1}). In addition, we have shown the distribution of parallel and perpendicular current systems which may help in the analysis of the evolution of particle acceleration in an active region. These results will be discussed further in Wu et al. (1983b).

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