MAGNETICALLY DRIVEN MOTIONS IN SOLAR CORONA

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Abstract. Solution of the nonlinear MHD problem of plasma flow in an increasing dipolar magnetic field is obtained in the approximation of a strong field. The distributions of plasma velocity, displacement, and density are calculated. The situation when the magnetic dipole is 'increased' by rapid process of magnetic reconnection or current sheet rupture is illustrated. Possible applications are discussed in connection with plasma ejections from chromosphere in corona.

In the upper chromosphere and low corona the conditions of a strong magnetic field are valid (see Syrovatskii and Somov, I979). During flares and other nonsteady phenomena, magnetic field undergoes rapid local changes. Under the condition of high conduction these changes propagate at a rate close to the Alfven velocity and lead necesserily to plasma motion.

We consider, as example, plasma motions in the increasing dipolar magnetic field (Somov and Syrovatskii, I972). The MHD equations for an axially symmetric flow in the approximation of a strong field and cold plasma take the following form in the spherical coordinates r, θ and φ:

$$\varepsilon^2 \, d\vec{v}/dt = K(r,\theta,t) \text{ grad } G, \qquad (I)$$

$$dG/dt = 0, \qquad (2)$$

$$d\rho/dt = -\,\rho \text{ div } v. \qquad (3)$$

Here $G = G(r,\theta,t)$ is the dimensionless 'stream function' related to the single nonvanishing φ component of the vector potential $\vec{A}$ by

$$G(r,\theta,t) = A(r,\theta,t)\, r \sin\theta. \qquad (4)$$

Let j be the φ component of the dimensionless current $\vec{j}$, then

$$K(r,\theta,t) = j(r,\theta,t)/(\rho\, r \sin\theta). \qquad (5)$$

In zeroth order in the small parameter ε^2, the Equation (I) yields

$$K^{(o)}(r,\theta,t) = 0 \quad \text{or} \quad j^{(o)}(r,\theta,t) = 0. \qquad (6)$$

This corresponds to a time-dependent potential field described by the

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stream function $G^{(o)}(r,\theta,t)$. For the dipolar magnetic field

$$G^{(o)}(r,\theta,t) = m(t)\sin^2\theta/r. \tag{7}$$

According to the Equation (2) this function is an integral of motion:

$$m(t)\sin^2\theta / r = m_o \sin^2\theta_o / r_o. \tag{8}$$

The subscript 'o' designates the initial values of the Lagrange coordinates $r(r_o,\theta_o,t)$ and $\theta(r_o,\theta_o,t)$ of a 'fluid particle'.

From Equation (I) it follows that

$$d\vec{v}^{(o)}/dt = K^{(I)}(r,\theta,t)\ \mathrm{grad}\ G^{(o)}. \tag{9}$$

Dividing the radial component of (9) by the angular component eliminates $K^{(I)}(r,\theta,t)$. We also eliminate $r = r(r_o,\theta_o,t)$ by means of (8). The resulting ordinary differential equation for $\theta(\theta_o,\dot\theta_o,t)$ is of the form:

$$m(t)a(\theta)\ddot\theta + m(t)b(\theta)\dot\theta^2 + 2\dot m(t)a(\theta)\dot\theta + \ddot m(t)c(\theta) = 0, \tag{IO}$$

where $a(\theta)$, $b(\theta)$ and $c(\theta)$ are the known functions.

The analytic solution for the linearized equation (Syrovatskii, I969) and the numerical solution of nonlinear problem for an increasing dipole (Somov and Syrovatskii, I972) show that the magnetic moment growth results in the 'raking-up' of plasma to the dense feature accelerated along the dipole axis. Platov et al. (I973) applied this mechanism to the formation of a surge in the initial exponential atmospere with the scale height h_{oo}. Figure Ia presents the calculated isodensity curves for m=5, IO and 20. The dipole axis is inclined to the vertical at 30°. For comparison Figure Ib shows several successive optical contours for the growing surge observed on October 23, I970. However, to obtain observed velocities of surge a rapid change of the magnetic field is required. The needed characteristic time is of order IO s (see Platov et al., I973).

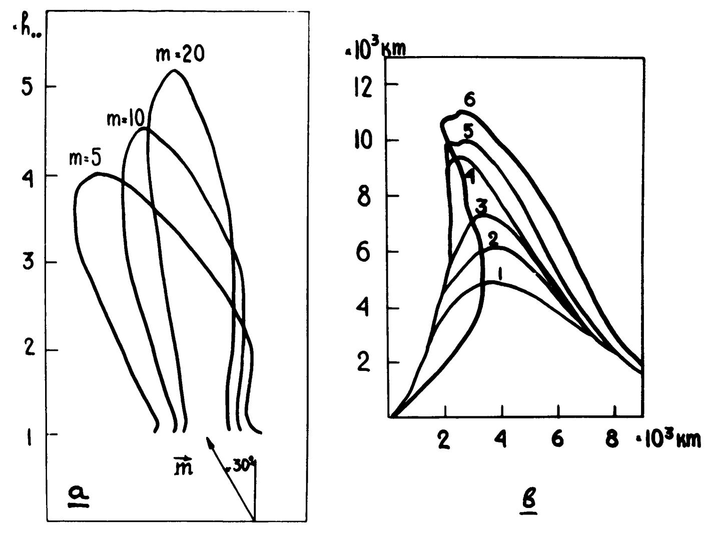

Figure I. (a) Isodensity contours for the inclined increasing dipole. (b) Constant brightness curves for some observed surge.

As yet, there are no data (see, however, Tanaka, I978) which can confirm or reject the possibility of so rapid changes in the photosphere. But these changes possibly can result from the reconnection in the corona.

Let us consider as example the picture of the magnetic field lines in the case when a new flux (N,S) emerges in the region between two sunspots N_I and N_2 (Figure 2).

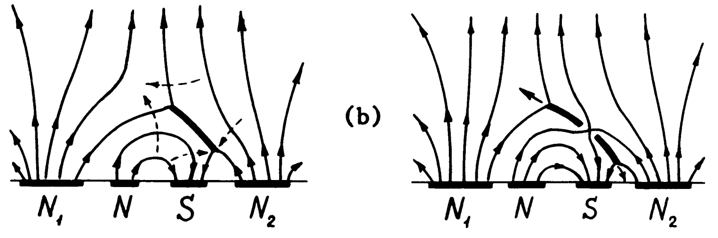

Figure 2. The straightening of field lines above the spot N_I. (a) Quasi-steady reconnection, (b) rapid field reconstruction at the current sheet rupture.

The quasi-steady magnetic reconnection in the current sheet provides some straightening of field lines above the spot N_I. The density of field lines is growing here. That corresponds in our model to the growth of the effective dipolar moment of this spot. If the current sheet is suddenly ruptured, this process is especially fast and is accompanied also by additional plasma ejection from the current sheet. Hence one should expect the plasma ejection (like a surge or spray) above the spot N_I. Note here that the model makes it possible to explain plasma ejections on the periphery of the developing spots and their connection with flarelike phenomena (sudden brightenings) in the chromosphere.

REFERENCES

Platov, Yu.V., Somov, B.V., and Syrovatskii, S.I.: 1973, Solar Phys. 30, pp. 139-147.

Somov, B.V. and Syrovatskii, S.I.: 1972, Soviet Phys. JETP 34, pp. 332-335.

Syrovatskii, S.I.: 1969, Astrophys. Space Sci. 4, pp. 246-251.

Syrovatskii, S.I. and Somov, B.V.: 1979, Physical driving forces and models of coronal responses (Invited paper presented at this symposium).

Tanaka, K.: 1978, Solar Phys. 58, pp. 149-163.