THE EFFECT OF SHEAR ON NUMERICAL MODELS OF QUIESCENT NORMAL-POLARITY PROMINENCES

R. A. S. FIEDLER and A. W. HOOD

Department of Mathematical and Computational Sciences, University of St. Andrews, St. Andrews, Fife, KY16 9SS, U.K.

(Received 6 January, 1993; in revised form 2 March, 1993)

Abstract. The equilibrium structure of normal-polarity, quiescent prominences is investigated and the influence of magnetic shear in response to a slow, shearing, photospheric velocity discussed. The results show that the overall field structure predicted by Fiedler and Hood (1992) is largely unaffected but that magnetic shear reduces the plasma beta and lengthens and flattens the magnetic field when viewed from the side. The flatness of the field suggests that the initial condensation can form and, when the mass is sufficient, deform the field slightly into the equilibrium structure calculated here. Thus, it is postulated that the field must be highly sheared for the radiation (or condensation) time to be less than the free-fall time along the field. A simple estimate predicts that the field must lie close to the polarity inversion line with an angle in agreement with observations. Hence, it is apparent that normal polarity prominences will always be observed with a highly sheared field.

It is shown that the line-of-sight field component depends on the imposed shear profile and the viewing angle and in certain cases it is possible for this field component to appear to increase with height. Any observed increase of the line-of-sight magnetic field with height may then be due to the angle of the prominence to the line of sight.

1. Introduction

The modelling of solar quiescent prominences has tended to divide into two main lines of research, namely (i) simple analytical models and (ii) more complicated numerical models.

Analytical models are restricted in that many simplifications are necessary in order to produce a solution in closed form. However, they do illustrate, quite clearly, the basic physical mechanisms for magnetic support. Recent prominence models include those by Low (1984), Hood and Anzer (1990) and the twisted flux tube models of Priest, Hood, and Anzer (1989) and Van Ballegooijen and Martens (1989). Fine-scale structure in prominences has been modelled by Priest, Hood, and Anzer (1991) and Hood, Priest and Anzer (1992).

Numerical models have more flexibility but there has been no real attempt to model well-developed prominences in a realistic manner. For example, Zwingmann (1987) investigated the quasi-static evolution of a coronal arcade in response to a slow photospheric velocity whereas Choe and Lee (1992) examine the initial development of a condensation in the corona and the response of the magnetic field. Similar investigations of the initial formation of prominences have been carried out by An et al. (1988), Poland and Mariska (1988), Mok et al. (1990), and Antiochos and Klimchuk (1991) but no attempt has been made to study the final stable prominence equilibrium.
Fiedler and Hood (1992) assumed that a prominence had condensed in the corona and investigated how the magnetic field could support the dense plasma. By assuming typical height, widths, and temperatures for the prominence they found static equilibrium solutions. They found that there was a range of coronal plasma \( \beta \) values, in the approximate range \( 0.05 < \beta < 1.0 \), for which solutions could be found. If the \( \beta \) is too small there is no dip in the magnetic field and, hence, no prominence. If the \( \beta \) is too large then the dip in the magnetic field becomes excessive and the subsequent increase in the prominence pressure and density produces downward forces that the magnetic field is unable to oppose. However, Fiedler and Hood (1992) did not consider any shear in the magnetic field. Since observations indicate that the magnetic field is nearly parallel to the prominence direction (Leroy, 1989) it is important to include this effect. This paper investigates three different photospheric shear profiles to see how the equilibrium solutions are influenced.

Section 2 outlines the equations and the method of solution, which is discussed in more detail in Fiedler and Hood (1992). The next section presents the results for the different shear profiles and the final section discusses the results and their relevance to normal-polarity prominences.

2. Equations and Method of Solution

The prominence is modelled as a cool plasma of finite width and height that is embedded inside the hot corona. In this paper the magnetic support is investigated and so heat conduction, optically thin radiation and thermodynamic effects are ignored. Instead it is assumed that the prominence has formed and it is the magnetic equilibrium properties that are addressed here. As an initial attack on the problem the equilibrium is assumed two-dimensional but with an imposed photospheric footpoint distribution that has resulted from a slow photospheric shear velocity.

Thus, the equilibrium satisfies

\[
\nabla^2 A = -\mu \left( \frac{\partial p}{\partial A} \right)_z - \frac{1}{2} \frac{dB_y^2}{dA},
\]

where \( p \) is the plasma pressure, \( \mu \) is the magnetic permeability, and \( A(x, z) \) is a flux function for the magnetic field

\[
B = \left( -\frac{\partial A}{\partial z}, B_y(A), \frac{\partial A}{\partial x} \right).
\]

Note that \( (\partial p/\partial A)_z \) is obtained by differentiating with respect to \( A \) while keeping the explicit \( z \) dependence of \( p \) fixed. \( B_y(A) \) is determined from the imposed footpoint displacement, namely