A TWO-DIMENSIONAL MODEL FOR A SOLAR PROMINENCE: EFFECT OF AN EXTERNAL MAGNETIC FIELD

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Abstract. Using analytical approximations we study the effects of different external magnetic configurations on the half-width, mass, and internal magnetic structure of a quiescent solar prominence, modelled as a thin vertical sheet of cool plasma. Firstly, we build up a zeroth-order model and analyse the effects produced by a potential coronal field or a constant-$\alpha$ force-free field. This model allows us to obtain the half-width and mass of the prominence for different values of the external field, pressure and shear angle. Secondly, the effects of these external magnetic configurations on a two-dimensional model proposed by Ballester and Priest (1987) are studied. The main effects are a change of the half-width with height, an increase of the mass, a decrease of the magnetic field strength with height and a change in the shape of the magnetic field lines.

1. Introduction

Quiescent solar prominences are seen at the solar limb as vertical sheets of cool plasma which lie above and along photospheric neutral lines and last from days to months. It has been suggested (Priest, 1989) that prominences and models in which the magnetic field goes through the prominence like a normal magnetic arcade be said to possess normal polarity, whereas those in which it goes through in the opposite direction be said to possess inverse polarity. Reviews of observations and theories of prominences can be found in Poland (1986), Ballester and Priest (1988), Priest (1989), Řuždjak and Tandberg-Hanssen (1990).

Priest, Hood, and Anzer (1989) have suggested that for a quiescent or active-region prominence the basic geometry could be a large-scale flux tube. This model contains several interesting features, namely the formation of a dip in the magnetic field, the flux cancellation in the photosphere (see also van Ballegooijen and Martens, 1989), the possibility of generating different transverse field components, the growth of the prominence as the twist increases and the twisted flux tube shape of the prominence eruption. Other authors have tried to model the magnetic field surrounding a prominence from observational magnetic field data. Anzer (1972) assumed that the field is potential and two-dimensional, but found a downward force rather than a supporting force in the lower part of the prominence. Démoûlin, Priest, and Anzer (1989) have generalised this model allowing for magnetic flux to exist below the prominence and having an upward force everywhere. Recently, Hood and Anzer (1990) have proposed a model for

quiescent prominences with normal polarity, which matches a one-dimensional prominence configuration to an external two-dimensional constant-z coronal field.

Ballester and Priest (1987, hereafter referred as Paper I) proposed a two-dimensional model for a vertical prominence sheet by allowing slow variations of the magnetic field and plasma properties with height. They studied the behaviour of the magnetic field and the width of the prominence with height, and the shapes of magnetic field lines were obtained. Here, we use this model to study how external magnetic configurations (potential and linear force-free) affect the half-width, mass, and internal magnetic configuration. The plan of the paper is as follows. In Section 2, a modified Kippenhahn–Schlüter model is taken as a zeroth-order model and the effects of external magnetic configurations on it are studied. In Section 3, the effects of those magnetic configurations on a first-order model, arising from a perturbation of the zeroth-order model, are obtained. Finally, in Section 4 conclusions are drawn.

2. Zeroth-Order Model

2.1. Potential Field

The classical model by Kippenhahn and Schlüter (1957) represents the prominence as a thin isothermal sheet. It is one-dimensional in the sense that all the variables vary with x (say) across the sheet. The boundary conditions used in that model are:

\[ B_{0z} \rightarrow B_{z\infty} \quad \text{and} \quad p_0 \rightarrow 0 \quad \text{as} \quad x \rightarrow \pm \infty \] (1)

and \( B_{0z} = 0 \) at \( x = 0 \) by symmetry. Using these conditions the basic solutions are:

\[ B_{0z}(x) = B_{z\infty} \tanh \left( \frac{B_{z\infty} x}{2B_{0x} A_p} \right), \] (2)

\[ p_0(x) = \frac{B_{z\infty}^2}{2\mu} \ \text{sech}^2 \left( \frac{B_{z\infty} x}{2B_{0x} A_p} \right), \] (3)

where \( A_p = RT_p/g \) represents the prominence scale-height, with a typical value of 300 km for \( T_p = 10000 \) K.

In Paper I, we modified the distant boundary conditions by imposing them at a finite distance in the x-direction, namely at \( x = \Lambda \). Now we take as the coronal magnetic configuration a potential arcade such as shown in Figure 1, where \( x_0 \) gives the position of the top and \( (L - x_0) \) the half-width of the arcade, so that \( k = \pi/2(L - x_0) \). The coronal potential field is then given by

\[ B_x = B_o \cos k(x - x_0) \exp(-kz), \] (4)

\[ B_z = -B_o \sin k(x - x_0) \exp(-kz), \] (5)

and

\[ p = p_o^c \exp(-z/A_c), \] (6)