EXTERNAL AND INTERNAL SOLUTIONS FOR THE TWISTED, FLUX-TUBE, PROMINENCE MODEL

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Abstract. In this paper the twisted flux-tube model for the support of a prominence sheet with constant axial current density, given by Ridgway, Priest, and Amari (1991), is considered.

The model is extended in Section 2 to incorporate a current sheet of finite height. The sheet is supported in a constant current density force-free field in the configuration of a twisted flux tube. The mass of the prominence sheet, using a typical height and field strength, is computed. Outside the flux tube the background magnetic field is assumed to be potential but the matching of the flux tube onto this background field is not considered here.

Instead our attention is focussed, in Section 3, on the interior of the prominence. An expanded scale is used to stretch the prominence sheet to a finite width. We analytically select solutions for the internal magnetic field in this region which match smoothly onto the external force-free solutions at the prominence edge.

The force balance equation applied inside the prominence then yields expressions for the pressure and density and a corresponding temperature may be computed.

1. Introduction

Solar prominences are notoriously difficult to model theoretically since they require solutions to the nonlinear, magnetohydrostatic equations that include the effect of gravity. Quiescent prominences are classified as either normal polarity or inverse polarity depending on whether the magnetic field passes through the prominence in the same direction or inverse direction when compared to the photospheric magnetic field. The classical normal polarity prominence is the Kippenhahn-Schlüter model (Kippenhahn and Schlüter, 1957) and the classical inverse polarity prominence was proposed by Kuperus and Raadu (1974).

Theoretical prominence models have tended to fall into one of two groups. These are current-sheet and internal models. Current-sheet models assume that the prominence thickness is so small, when compared with coronal length scales, that it is replaced by a current sheet. This allows a surface with a jump in the vertical magnetic field component. If the external coronal field is potential, then complex variable theory can be used to describe this field and the current sheet becomes a branch cut in the complex plane. This technique has been used by several authors (see, for example, Anzer, 1972; Malherbe and Priest, 1983; Démoulin, Malherbe, and Priest, 1989). The basic idea of replacing the prominence by a current sheet has been used by Amari and Aly (1990) for a linear, force-free coronal field and by Ridgway, Amari, and Priest (1991, 1992) for a constant current density coronal
field. All of these authors have assumed Cartesian geometry that is invariant in the axial direction.

Recently it has been proposed that a prominence can form inside a large, twisted, flux tube. Priest, Hood, and Anzer (1989) suggested that slow twisting motions could create the necessary magnetic field line dip for the formation of a prominence. They proposed that, after the formation of a cool condensation, a current sheet would form but now in cylindrical geometry. Depending on the source of twist either a normal or inverse polarity prominence can be formed. Van Ballegooijen and Martens (1989) suggested that a twisted flux tube could be formed by suitable shearing and converging photospheric flows and magnetic reconnection. The resulting prominence will always be of the inverse polarity type. Inhester, Birn, and Hesse (1992) extended this idea of flux-tube formation in a detailed numerical simulation. A natural result of the formation of a twisted flux tube is an enhanced density that could trigger prominence formation.

An investigation of a current sheet prominence model in a twisted flux tube was carried out by Ridgway, Priest, and Amari (1991). Their model was based on a constant axial coronal current density and contained no singularities near the origin. They showed that a current sheet could be in equilibrium out to the edge of the flux tube. Anzer (1989) explains that this equilibrium is of fundamental importance and can only be achieved if the Lorentz force is directed vertically upwards at every point in the sheet. However, one weakness of their model, that will be rectified in this paper, in Sections 2.3 and 2.4, is that the current sheet does not vanish at the outer edge. This will create problems when matching to an unsheared external field.

One important drawback to all current-sheet models is that the internal prominence structure is not considered and quantities, like the density and pressure, are determined from horizontal and vertical force balance and are not free to be chosen. **Internal models** consider the local behaviour within the prominence without worrying about matching onto a suitable external magnetic field. The isothermal models of Menzel (1951) and Brown (1958) have been extended to a non-isothermal model proposed by Hood and Anzer (1990) that links the internal and external fields in a self-consistent manner giving the typical structure of a normal polarity prominence. A two-temperature prominence, of finite height, has been investigated in the numerical studies of Fiedler and Hood (1992, 1993). Thus, it is important that any internal solution matches onto a realistic external equilibrium solution. This will be considered in this paper.

There have been many publications on magnetic equilibria of coronal fields that could be used in a prominence model. The main requirement is the existence of a dip in the field. Some of the recent 3-D equilibria presented by Low (1991, see references within) offer real possibilities of modelling realistic coronal fields.

This paper is concerned with the twisted, magnetic, flux tube model of prominences. The flux tube is represented in cylindrical coordinates and is assumed independent of variations in the axial direction. In Section 2 the basic equations