AN OBSERVATIONAL AND CONCEPTUAL MODEL OF THE MAGNETIC FIELD OF A FILAMENT

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ABSTRACT. A conceptual, scale model of the geometry of the magnetic field of a filament was developed primarily from: (1) the observed structure of a filament recorded in H-alpha filtergrams, (2) calculations of the height of the filament (3) the association of the appendages along the sides of the filament with patches of photospheric magnetic flux opposite in polarity to the network magnetic fields on each side of filament, (4) the observed association of the ends of the filament with network magnetic fields of opposite polarity and (5) the assumption that the fine structure of the filament is parallel to the magnetic field in the filament. The model is consistent with the inverse category of quiescent prominences. The three-dimensional geometry of the model is sufficiently simple that wire is used to represent the imaginary magnetic field lines and their relationship to magnetic flux patches on a magnetogram.

1. Introduction

Sequences of time-lapse H-alpha filtergrams of a quiescent filament in the southeast quadrant of the sun were initiated at 1512 UT on 13 May 1992 at the Big Bear Solar Observatory. Observations were continued until 18 May as the filament gradually appeared to cross the central meridian of the sun due to solar rotation. Time-lapse magnetograms were also acquired throughout this interval. During the latter 3 days, 15-17 May, the quality of the images was excellent.

The data acquired during the latter 3 days were selected for studying the geometry and changes in the structure of the filament, for analyzing concurrent changes in the photospheric magnetic fields below the filament, and for determining relationships between the filament structures, chromospheric structures and the line-of-sight component of magnetic flux at the photosphere.

This early results of this study, combined with information learned about the magnetic fields of filament channels and filaments (Martin, Billmoria, and Tracadas 1994), made it possible to conceive a 3-dimensional magnetic field geometry for this filament which is consistent with both new and previously known conditions related to the formation of filaments (Martin 1990). In this

paper we summarize only the preliminary results of the study that are relevant to the construction of the model of the magnetic field of the filament.

2. The Data

The filament was photographed every 30 second at H-alpha -0.3A and at +0.3A through 2 separate birefringent filters on adjacent optical benches with sunlight provided by a ten-inch aperture telescope. The -0.3A images were made using a 1/2 passband Halle birefringent filter and the +0.3A observations were acquired using a 1/4A passband Zeiss birefringent filter. Most of the images were recorded in a field of view of approximately 4X5 arcmin. at the center of the filament. Once each hour the field of view was shifted to briefly observe the two ends of the filament. Also, once an hour at each field of view, a series of images was also recorded in the wings of the H-alpha line at increments of 0.1A from -0.5A to +0.5A.

Magnetograms having nearly the same scale as the H-alpha filtergrams were obtained at an average rate of one image every 5 minutes using the third optical bench fed with light from the same ten-inch aperture telescope. Each magnetogram consisted of 4096 pairs of video frames continuously integrated into a single magnetogram.

3. Analyses of the Filament Dimensions

To determine the height of the filament, it was first necessary to establish, as precisely as possible, a line at the chromosphere and photosphere vertically below the long axis of the filament. We henceforth refer to this line as the ‘baseline’. It was assumed that the filament backbone or spline is well approximated by a vertical sheet that lies above the baseline in the chromosphere. In magnetograms of active regions, the baseline corresponds to the polarity inversion which can be drawn as a narrow line between the opposite polarity magnetic fields on the two sides of a filament. However, on the quiet sun, the polarity inversion is a relatively broad zone of small-scale mixed polarity magnetic fields between the large, dominant areas of positive and negative field on the two sides of a filament as seen in Figure 1. On such magnetograms of the quiet sun, there is no known way to draw a single baseline for the filament between the opposite polarity network magnetic fields and be certain that the filament lies above it.

However, from our experience in studying filament channels (Martin, Bilimoria and Tracadas 1994), we knew that the polarity inversion in the chromosphere beneath some filaments can sometimes be defined very precisely because it lies between fibrils that have antiparallel alignment (Foukal 1971, Martin, Bilimoria and Tracadas 1994). The antiparallel alignment can also be seen in the wings of the H-alpha line out to about 0.75A. In the wings of the H-alpha line, filaments are less visible and often more narrow than at line center. For this filament in the wings of H-alpha, baseline points between the anti-parallel fibrils could be identified even at some locations where the fibrils were obscured by the filament mass as seen in the centerline images. On series of photographs with
the best image quality in the -0.5A to +0.5A range, short line-segments were drawn on the H-alpha photographic prints at the discrete sites between the antiparallel chromospheric structures. To establish the baseline, the line segments were then transferred to a single photograph and connected by a single smooth line beneath the entire length of the filament. The baseline points were also transferred to magnetograms printed to the same image scale as the prints of the H-alpha filtergrams.

If the filament is a long thin sheet and is viewed from an oblique angle, one edge will be the top or highest part of the filament. In Figure 1, the upper edge is interpreted as the top of the filament. The base of the filament, however, is not well approximated by a vertical sheet. This is obvious when the filament is viewed on successive days from different perspectives due to solar rotation. It is clear that the appendages extend away from the filament axis as defined by the upper edge. This is typical for quiescent filaments; the appendages straddle the imaginary baseline. (See Fig. 6 in Martin, Bilmoria and Tracadas 1994.) This geometry of the filament, however, does not inhibit our measuring the height of the filament; the baseline has been established independent of the appendages of the filament. The distance between the top of the filament and any point on the baseline vertically below the top of the filament is a measure of the height of the filament at that location. However, corresponding points at the baseline and top of the filament are not immediately apparent because of our view of the filament in projection against the solar sphere. Such points must be calculated using trigonometry. The height was determined at 20 locations along the top of the filament. The average height of the filament was 33,000 km. The maximum height was 50,000 ± 5000 km at the highest measured point near the east end of the filament. The filament was approximately 250,000 km long throughout the 15-17 May interval of observation.

4. Identification of the Footpoints of the Filament

In observing the dynamics of the appendages of the filament in the time-lapse films, we noted there were times when the filament appendages recurrently extended to a given apparent distance from the filament. We interpreted these sites of maximum extension to be the true chromospheric footpoints of the filament and marked these sites on photographic prints of the H-alpha filtergrams. In no case did we observe the filament appendage connecting to plagettes or plagette fibrils related to the network magnetic fields. The black arrow in Figure 1 points to a patch of network magnetic field avoided by the filament appendages.

We made superpositions of H-alpha prints, marked with the sites of the true footpoints, with magnetograms at closely corresponding times. We found that the larger appendages were rooted in relatively large, conspicuous patches of magnetic field adjacent to the baseline of the filament. In all cases the endpoints of the larger, broader appendages corresponded to patches of magnetic flux that were opposite in polarity to the network magnetic field on the same side of the filament. The white arrow in Figure 1 points to a true foot of a developing appendage. The association of some of the thinnest appendages were uncertain because they were more narrow than the uncertainty of about 5 arc
Fig. 1. The H-alpha filtergram in the top shows the northwest half of the filament. In the magnetogram below, the black arrow points to a patch of positive polarity network magnetic field which the filament appendages avoid. The white arrow points to a patch of negative polarity flux which later became a conspicuous foot of a major appendage of the filament.
seconds in the superpositions of the H-alpha images and the magnetograms. However, in these cases there usually was an opposite polarity patch which could be related to the endpoint of the appendage.

The above finding is consistent with the hypothesis in Martin, Billimoria and Tracadas (1994): that the appendages of filaments are rooted in opposite polarity magnetic field to that of the network on the same side of filaments. This hypothesis was based on: (1) previous observations which revealed an absence of apparent connections of the ends of any appendages of filaments with any network magnetic fields and (2) consistency of ‘inverse’ quiescent filaments with the idea that the magnetic field in the appendages of filaments would be opposite direction to the magnetic field of the coronal arcade overlying filaments.

The extreme ends of this filament were conspicuously associated with network magnetic fields. Positive fields were at the southeast end and negative fields were at the northwest end. The asymmetry of fibrils from the chromospheric plagettes and the asymmetry of the structure of the filament appendages along each side reveal that this filament is of the sinistral type typical of quiescent filaments in the southern hemisphere (Martin, Billimoria and Tracadas 1994)

5. A Model of the Filament Magnetic Field

Knowing the direction of the magnetic field along the long axis, the rooting of the major appendages, and the characteristics of filament channels and filaments found by Martin, Billimoria and Tracadas (1994) provided us with enough information to conceive of a magnetic field configuration for the whole filament by invoking only two assumptions:

(1) that the magnetic field is everywhere parallel to the observed fine structure of the filament, and

(2) that the thinnest appendages are rooted to the same polarity of fields as the relatively large, thick appendages.

In Figure 2, top and side views of the magnetic field configuration are schematically depicted by a wire model attached to a magnetogram mounted on cardboard. The model is scaled according to the measured length and height of the filament. The wires represent typical imaginary field lines. Some field lines run the entire length of the filament magnetic field from the southeast to the northwest end. Other shorter field lines from the positive field end of the filament splay off to the east side and connect to negative polarity fields along the positive network magnetic field side of the filament. Likewise, along the other side of the filament where the negative network is dominant, field lines from small-scale positive magnetic field patches are shown to connect to the negative magnetic field at the northwest end of the filament. A small degree of twist in the filament magnetic field is possible but not essential in this model.

The model is consistent with the following observations:
Fig. 2. Top and side views are shown of this schematic 3D model of the magnetic field of a filament. Wire is used to represent the field lines which are shown in relation to the photospheric magnetogram mounted on cardboard. The representative field lines depict the rooting of the magnetic field of the appendages of the filament in small patches of magnetic flux opposite in polarity to the network magnetic field at the sides of the filament. White and light gray indicate positive polarity; black and dark gray, negative polarity.
the direction of the magnetic field in the filament channel as deduced from the asymmetry of the fibrils associated with plages adjacent to filaments and the corresponding line-of-sight component of the magnetic field of the plages (Foukal 1971)

(2) the 'inverse' category of filament magnetic fields orthogonal to the long axis of filaments (LeRoy 1978, 1988, 1989)

(3) the existence of two structural types of filaments (Martin, Bilimoria and Tracadas 1994)

(4) the dominance of the axial component along most filaments (LeRoy 1988) and the existence of relatively strong magnetic fields at the ends of filaments (this paper and Martin, Bilimoria and Tracadas 1994)

(5) the transverse component of magnetic flux in active regions lying mostly along the polarity inversion when a filament is present in active regions (Gary et al. 1987, Gary and Hagyard 1990)

(6) observed interactions of among small-scale magnetic features beneath filaments (Martin 1988, 1990b) and hypothesized interactions of those fields with the magnetic field of the filament channel and the filament

(7) the existence of an overlying coronal arcade seen in coronal images at the limb and x-ray images (Tandberg-Hanssen 1974, Martin 1990)

This preliminary paper will be followed by a subsequent, more complete paper with the intention of discussing concepts of how different stages in the formation of filament channels and filaments can also lead to similar models of the magnetic fields of filaments and to consistency with observed features.

6. Summary

A conceptual model of the geometry of the magnetic field of a filament has been conceived from knowledge of a variety of observations of prominences magnetic fields (LeRoy 1978), coronal magnetic fields (Tandberg-Hanssen 1974), chromospheric and the photospheric magnetic fields beneath and adjacent to filaments (Foukal 1971), conditions related to the formation and existence of filaments (Martin 1990), newly discovered properties of filaments and filament channels (Martin, Bilimoria and Tracadas 1994) and the observations discussed in this paper. The model is applied in this paper to a specific filament and a three-dimensional wire model was constructed and scaled to the approximate relative dimensions of the filament. The essential characteristics of the model are: (1) a strong magnetic field along the long axis of the filament, (2) rooting of the appendages along the sides of the filament in small inclusions of magnetic field opposite in polarity to the network magnetic fields on both sides of the filament and (3) a simple magnetic field geometry suggested under the assumption that the fine structure of filament is everywhere parallel with the magnetic field within the filament.
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References


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