THE HELICAL PROMINENCE OF MARCH 15, 1977

B. Vršnak and V. Ruždjak

Hvar Observatory, Faculty of Geodesy, University of Zagreb

UDC 523.987

Conference paper

ABSTRACT: The dynamics of a prominence with helical structure is studied. The slow rising motion accompanied by detwisting, indicates that mass loss probably caused the prominence rising and decrease of the azimuthal component of the magnetic field. The radial dependence of current density within the prominence cylinder is discussed.

1. Introduction

Helical structures in prominences are frequently observed in quiescent as well as in eruptive prominences. Simple theoretical models of prominences with helical structure are given by Anzer and Tandberg-Hanssen (1970), and Parker (1975) and in a more rigorous way by Lerche and Low (1980a, 1980b). Prominence eruptions may be triggered by the kink instability due to the presence of the azimuthal component of the magnetic field. Observations of helical structures in prominences, and their dynamics can therefore give some more information about the stability criteria.

2. Observations

One example of a prominence with helical structure was the prominence observed at Hvar Observatory on March 15, 1977. The prominence was composed of two clearly defined helical streamers twisted in a curved cylinder of radius $R=5\times10^3$ km, maximal height $H=6\times10^4$ km and with the separation of the footpoints $L=8\times10^4$ km. The prominence showed a weak activity such as slow motion of mass blobs and brightness changes, but in general it was stable and
Fig.1  a) Behaviour of pitch angles of the two helical streamers. b) Height of upper and lower edge at the top of the prominence.

was observed next day to have more or less the same shape. The interesting point was a slow rising motion accompanied by detwisting, between 13 UT and 16 UT on March 15, 1977 (fig.1).

3. Dynamics

The pitch angle is defined as:

$$\tan \psi = \frac{h}{2RT}$$  \hspace{1cm} (1)

where $h$ is the pitch length and $R$ is the radius of the helix. The behaviour of $\psi$ (averaged over the length of the cylinder) for the helical streamers is given in fig.1a, where RMS of each point is $5^\circ$. Since the prominence material is filling the magnetic flux tubes, $\psi$ gives information about the ratio of the azimuthal ($B_\varphi$) and longitudinal ($B_\parallel$) component of the magnetic
field, i.e:

\[ \tan \theta = \frac{h}{2RT} = \frac{B_z}{B_r} \]  

(2)

As \( h \) was increasing and \( R \) remained roughly constant, the ratio \( B_z / B_r \) is increasing in time (fig.2).

![Graph showing the behaviour of the ratio \( B_z / B_r \) over time.](image)

Fig. 2  Behaviour of the ratio \( B_z / B_r \)

There are two possible causes for the rising motion: the first one is that the prominence mass decreased (i.e. the gravitational force exerted on the prominence decreased) and the second one is that the current flowing along the prominence increased (i.e. the Lorentz force increased).

In the first case, taking the simple model by Anzer and TAMBENG-HANSSSEN (1970), \( \nabla \times \vec{B} \) would decrease (fig.3) during the rise.

![Magnetic field configurations showing higher (a) and lower (b) prominence density.](image)

Fig. 3 Magnetic field configurations for higher (a) and lower (b) prominence density. Heavy circle presents the prominence cross-section.
ing motion, which means that $B_\parallel$ would decrease. Assuming that $B_\parallel$ was a constant, this would lead to the observed increase of the pitch angle. The liberated magnetic energy (taking $B_\parallel = 10$ gauss, one has $E_B = 10^{21}$ J) would be transformed into the kinetic energy of detwisting (rotational motion) and rising motion.

In order to have the Lorentz and gravitational force balanced at the end of the rising motion, the condition

$$B_0 \Delta I = g \Delta m \quad (3)$$

has to be satisfied, where $\Delta I$ is the change of the current, $\Delta m$ the mass loss and $B_0$ is a background field (Anzer and Tandberg-Hanssen 1970) i.e. the field which provides the supporting force for the prominence. In other words, if $B_0$ is constant, condition (3) becomes:

$$\frac{\Delta I}{I_0} = \frac{\Delta m}{m_0} \quad (4)$$

From the equation for the total current:

$$I = \frac{1}{\mu_0} \int B_\parallel dl = \frac{2 \pi R}{\mu_0} B_\parallel \quad (5)$$

taking $B_\parallel$ as constant, one gets:

$$\frac{\Delta I}{I_0} = 1 - \frac{1}{I_0} \frac{1}{m_0} \frac{\mu_0}{\mu} \quad (4)$$

Using equation (4) one finds that the mass loss is 30% of the initial mass. If the change of the prominence potential energy is calculated under this assumptions, one finds that the change is one order of magnitude smaller than the change of the magnetic field energy.

The second explanation is that the current flowing along the prominence was increased, i.e. the rising motion was a result of the increased Lorentz force. In that case $B_\parallel$ has to increase, and in order to have an increase of the pitch angle, $B_\parallel$ has to increase still more. This would lead to an increase of magnetic pressure in the prominence and therefore to an increase of prominence radius which was not observed (the radius even slightly decreased).
4. The structure of the Axial current

The two helical streamers had two different diameters and different pitch angles. This gives a possibility to get a rough in sight into characteristics of the internal structure of the current. In Table I the measured values of \( h_1/h_2 \) for three different times are given, where \( h_1 \) is the pitch length of the helix with larger radius. In Table I one can see that \( h_1 \) is nearly equal to \( h_2 \) in all three cases, i.e. that \( h(r) \) is roughly constant (within 10%). This means that \( B_\phi/B_r \) is constant (equation (2)) across the prominence cross-section. So, the prominence model has to have incorporated a current which is producing such a field configuration.

<table>
<thead>
<tr>
<th>UT</th>
<th>( h_1/h_2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 45</td>
<td>0.94</td>
</tr>
<tr>
<td>15 56</td>
<td>0.90</td>
</tr>
<tr>
<td>16 16</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Conclusion

For a stable prominence the condition:

\[
B_\phi^2 < 2B_r^2
\]

must be valid (Tayler 1957, Krusal and Tuck 1958, Chandrasekhar et. al. 1958, Vršnak 1982), where \( B_\phi \) is the field on the edge of the plasma cylinder, or in other words:

\[
tg \alpha > \sqrt{\frac{1}{2}}
\]

In the case of the observed prominence the smallest value of \( tg \alpha \) was about unity, i.e. the prominence was stable. Changes, such as mass loss, can produce a rising motion and nonviolent relaxation of the magnetic field energy stored in twisted tubes. This is in agreement with the tendency of coronal magnetic fields to reach a force-free magnetic configuration.
References
Vršnak, B: This Issue

HELIKOIDALNA PROMINENCIJA OPAŽANA 17. OŽUJKA 1977.

B. Vršnak i V. Ruždjak

Općervatorij Hvar Geodetskog fakulteta Sveučilišta u Zagrebu

UDI 523.987

saopćenje