THE HELICAL PROMINENCE OF MAY 26, 1982

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ABSTRACT: The observation of a prominence with helical structure is described and interpreted. Dynamics, stability and the internal structure of the prominence are discussed. The lower limit of the magnetic field strength is estimated as 20 G. The dependence of pitch angles on helix radii is analysed and a linear relation of the form \( \cot \theta = 0.86r/R \) was found. The total internal current is estimated as \( 2 \times 10^{11} \) A.

1. Introduction

Some prominences exhibit helical structures which sometimes enable to obtain information about the characteristics of the magnetic field configuration (Vršnak and Ruždjak, 1982), internal current (Engvold et al., 1976) and about stability of various field configurations (Chandrasekhar et al., 1958; Kruskal and Tuck, 1958; Vršnak, 1984). On the other hand, the dynamics of helical structures can give an insight into magnetic field behaviour when the prominence is exposed to different disturbances (Valniček, 1968). Analysing the behaviour and structure of helical prominences, cylindrical prominence models (Anzer and Tandberg-Hanssen, 1970; Parker, 1979; Lerche and Low, 1980 a,b; Kuperus and Raadu, 1974; Malherbe and Priest, 1983) can be tested.
2. Observation

On May 26, 1982, one typical helical prominence appeared on the East limb, and was observed at Hvar Observatory from 08 55 UT to 10 08 UT. At 08 55 UT the prominence consisted of a bright and compact main part, and a number of thin filaments protruding northwards (Figure 1), through which matter was flowing from the main part of the prominence to the chromos-

Fig. 1. The development of the prominence. a) 08 55 UT: mass loss through northward streamers and slow rising motion of the main part of the prominence. b) 09 01 UT: start of the mass flow in southward direction. c) 09 21 UT: The cylindrical arch with helical structure. d) 10 08 UT: almost all visible material was concentrated near the southern leg of the prominence.
The flow of matter to the chromosphere was accompanied by a slow rising motion of the main part of the prominence from 08 55 to 09 01 UT (Figures 1 and 2). At 09 01 UT the mass motion started in southward direction too, disclosing helically twisted filaments which were not visible before.

![Graph showing height versus time](image)

**Fig. 2.** The height of the prominence body versus time. The thick full line schematically represents the two distinct phases of the prominence activity. The dashed lines represent upper and lower edges of the visible prominence body, while thin full line represents the height of the main part of the prominence.

Afterwards, the prominence shape transformed into a cylindrical arch $2 \cdot 10^5$ km long and $4,5 \cdot 10^4$ km high, and was constituted of a bundle of helically twisted streamers (Figure 1c). From 09 07 UT to the end of the observations, individual
streamers could be indentified and traced on the filtergrams.

The activity in the prominence can be divided in two parts: first, the motion and gradual disappearance of the main part of the prominence (08 55 - 09 13 UT) and second, the mass motion with velocities of order of 100 km s\(^{-1}\) along the stable helical streamers, from the top towards both legs of the prominence.

3. Interpretation

The mass was flowing from the main part of the prominence to the chromosphere mainly through two filaments in the northward direction and four filaments in the southward direction each having the diameter of about 3000 km. The mass which passed through the streamer \(m_f\) can be estimated by:

\[
m_f = v \cdot t \cdot R^2 \pi \rho_f
\]

where \(v\) is the mean velocity of the flow, \(t\) the duration of the flow, \(\rho_f\) mass density in the flow and \(R\) the radius of the streamer. The sum of values \(m_f\) estimated for each streamer gives the total mass \(M_f\) which fell to the chromosphere. A rough estimate gives the value \(M_f = 5 \times 10^{27} \rho_f\) g.

On the other hand, the total mass contained in the main part of the prominence can be roughly estimated by:

\[
M_p = D \cdot A \cdot \rho_p
\]

Where \(A\) is the visible area of the main part, \(D\) the average thickness along the line of sight, and \(\rho_p\) the mass density. Taking \(A = 5 \times 10^8\) km\(^2\) (Figure 1a), and assuming the value of \(D\) as \(10^4\) km, equation (2) gives the estimate \(M_p = 5 \times 10^{27} \rho_p\) g.

Assuming that \(\rho_p \approx \rho_f\) one can conclude that the whole mass which was flowing along the streamers came from the main part of the prominence.
4. Dynamics

The motions of different blobs of material are shown in Figure 3. Taking into account the curvature of the streamers, it can be concluded that the motions were driven more or less only by gravity, i.e. that all other forces had negligible effect. To prove this, the motion of a blob along one of the

![Graph showing motions of blobs](image)

Fig. 3. Motions of several blobs of matter along the streamers. The distance from the footpoints of the prominence is on the ordinate. The mean velocities of blob motions are marked in km s$^{-1}$.

streamers was simulated taking into account only the gravitational force, and the result was compared with the actual motion of one well defined blob (Figure 4). It is worth noting that mass motions along magnetic tubes are generally influenced strongly by other forces (Platov, 1973; Loughhead and Bray,
Fig. 4. The observed height of one blob moving along the streamer (circles connected with dashed line), compared with the calculated height of the blob moving along the same streamer, taking into account only the gravitational force (crosses and full line).

1984), but sometimes it happens that they are negligible (Ruždjak, 1981).

The rising motion of the main part of the prominence was actually the prominence activation, and was probably caused by mass loss through northward flows of material which were present at the very beginning of the observation. Afterwards, when the main part reached a certain height, the southward streams were enabled too, and soon all the material from the main part leaked away and filled the helical streamers.
The motions of the material in the prominence were controlled by the magnetic field (matter was moving along magnetic tubes without distorting them), or in other words, the kinetic energy density was lower than the energy density of the magnetic field:

$$\frac{B^2}{8\pi} > \frac{\rho v^2}{2}$$  \hspace{1cm} (3)

where \( B \) is the magnetic induction in the prominence, \( \rho \) the mass density, and \( v \) the velocity of moving material. Using the particle density as \( n = 10^{11} \text{ cm}^{-3} \) (Tandberg-Hanssen 1974) and the highest observed velocity \( v = 120 \text{ km s}^{-1} \), the lower limit of \( B \) determined by the condition (3) is about 20 G.

5. Internal structure of the prominence

When the prominence simplified to the cylindrical arch, the helical structure was clearly defined and it was possible to measure the pitch angles (\( \phi \)) of the helical streamers as a function of the helix radii (\( r \)). The results are presented in Figure 5 where \( \text{ctg} \phi \) is plotted against helix radii. The pitch angle is defined as:

$$\text{ctg} \phi = \frac{2\pi r}{h}$$  \hspace{1cm} (4)

where \( h \) is the pitchlength of the helix. Assuming linear dependence of \( \text{ctg} \phi \) on \( r \), the least square fit gives:

$$\text{ctg} \phi = 0.043 \ r$$ \hspace{1cm} (5)

where \( r \) is radius of the helix expressed in \( 10^3 \text{ km} \).

The pitch angle can be related to the ratio of azimuthal (\( B_{\phi} \)) and longitudinal (\( B_z \)) component of the magnetic field:

$$\text{ctg} \phi = \frac{B_{\phi}}{B_z}$$ \hspace{1cm} (6)

Taking for \( B_z \) the value determined by condition (3) and assuming that it is uniform over the cylinder cross section.
Fig. 5. The dependence of the helix pitch angle ($\phi$) on the radius $r$ of the helix (open circles). When $\ctg \phi$ is represented versus radius $r$, the least square fit for linear dependence (full line) gives:

$$\ctg \phi = 0.86 \frac{r}{R},$$

where $R$ is the radius of the prominence cylinder ($R = 2 \times 10^4$ km).

(Anzer and Tandberg-Hanssen, 1970), the equations (5) and (6) give the value of $B_r$ on the surface of the prominence cylinder ($r = R = 2 \times 10^4$ km) as $B_r(R) = 20$ G.

The relation (5) and the assumption that $B_r$ is uniform implies that electric current flowing along the prominence can also be approximated as uniform over the cross section.
of the prominence. In that case the total current \( I \) flowing along the prominence is:

\[
I = \frac{1}{\mu_0} \int B_\phi(R) \, dl = \frac{2R\gamma}{\mu_0} B_\phi(R)
\]

(7)

where \( R \) is the radius of the prominence cylinder. Using the estimated value \( B_\phi = 20 \, G \), equation (7) gives the value:

\( I = 2 \times 10^{11} \, A \).

The value \( B_\phi(R)/B_\phi = 0.86 \), as estimated here, is lower than the value \( (B_\phi/B_\phi = 1) \) assumed by McKim Malville and Schindler (1981) for a loop prominence, while it is larger than in the case of helical prominence described by Vršnak and Ruždjak (1982). However, this value is still lower than the critical value \( B_\phi/B_\phi = \sqrt{2} \) when the prominence becomes unstable (Kruskal and Tuck, 1958; Chandrasekhar et al, 1958; Vršnak 1984).

6. Conclusion

The observed prominence was a typical prominence with helical structure showing change of magnetic field configuration by nonviolent activity. During the activation the shape of the prominence simplified indicating that the magnetic field configuration changed to a new one, closer to the potential field configuration than the initial. The process was performed by mass loss from the prominence body i.e. decreasing the total gravitational force on the prominence which enabled the magnetic field to approach closer to the force-free configuration.

Comparing the estimated total current in the prominence with other analyses one can find that it is larger than \( 10^{10} \, A \) as found by Engvold et al (1976), lower than \( 6 \times 10^{11} \, A \) as proposed by Anzer and Tandberg-Hanssen (1970), and close to the value of \( 10^{11} \, A \) which the observed parameters would give using the Kuperus and Raadu (1974) model. For some other estimations
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one can look in the summary presented by Ballester (1984).

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SAŽETAK: Promatranja prominencije sa helikoidalnom strukturom su opisana i interpretirana. Diskutirana je dinamika, stabilnost i interna struktura prominencije. Određena je donja granica jakosti magnetskog polja na 20 G. Ovisnost kuta navoja helise o njenom radiusu je linearna i može se prikazati ovisnošću: ctgθ = 0,86 r/R. Utvrđeno je da je ukupna struja koja teče prominencijom I = 2·10^{11} A.