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Eruption of a large quiescent prominence on January 14, 1993

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Abstract. In this paper an analysis of a large quiescent prominence which erupted on January 14, 1993 is carried out. Observations of this prominence were initiated on January 12, 1993 when it made its first appearance on the east limb. One interesting phenomenon which we noticed was that on January 13, 1993 there was a flare-like brightening of the prominence and it attained maximum volume with twisted structure. It seems that on January 14, 1993 the structure became more compact and dense with highly twisted flux tubes. The activation of the prominence seems to have been triggered by the plage brightening in the near by active region. At the initial phase the velocity was low but oscillatory in nature. Later on it rose sharply reaching about 1400 kms^{-1} in the final stage, disappearing away. The prominence material was visible upto a height of 6.4×10^5 km. Thereafter it faded out. A surge-like activity was also observed during the decay phase at the foot point. The strongly sheared flux tubes due to large scale mass motions in the prominence channel, underwent some reconnections. As a consequence, the magnetic system of the prominence got transformed into a huge arch which finally erupted. The morphology and evolution of the prominence is given in the light of existing models.

Key words : eruptive prominence—flux tubes—reconnection

1. Introduction

Prominences have been described by Hirayama (1985) as fascinating objects, abundant in variety, beautiful and above all mysterious. The motion of the filaments as eruptive prominences can be seen most clearly near the limb or in the lower corona. The filamentary knots and helical structures are common in active prominences (Ohman 1972; Rompolt 1975). The most important factor in the instability of filaments is due to the twisting of the flux tubes. This is the mechanism for energy injection (Sakurai 1976; Colgate 1978). The results of Raadu (1972), Giachetti *et al.*, (1977), Hood & Priest (1979) and Van Hoven *et al.*, (1983) indicate that weakly twisted flux tubes are magnetically stable but when the degree of twist exceeds a certain value instability sets in, resulting in the eruption of the prominence.

In the following we have given details of the evolution of the eruptive prominence and also in brief some of the physical parameters i.e. mass, energy, velocity, mass loss factors and also the Lorentz forces.

2. Observations

The observations formed a part of the Solar Maximum Year Programme for monitoring solar activity on a daily basis. The instruments consisted of a 15 cm f/15 Zeiss coude refractor accessories, a 0.5 Å/0.7 Å Bernhard Halle H-alpha filter capable of tuning ± 1Å on either side of the peak wavelength in steps of 0.1 Å and an Olympus camera body which takes up 35 mm Kodak Tech Pan 2415 film. During the early hours of monitoring, observations of the prominence were taken on 12 January 1993 when it appeared like a bush with several bright knots on the east limb at S 25 E90, no significant changes were noticed, but on the following day (13 January), the structure started growing assuming a conical shape with twisted filaments. At the base of the structure was located an active region NOAA 7402 and at 15° north of it was another active region NOAA 7401 (SGD 1993). Magnetogram of this region shows that the prominence was lying on the neutral line of the active regions where sheared magnetic field lines exist (Moore 1988). A characteristic feature of the event was the appearance of impulsive brightening on 13 January at the footpoints near and above the limb. This indicated the dynamic behaviour of the prominence with active centres playing an important role in bringing about changes in the magnetic field. Locationwise therefore, we can say that it was an active region prominence (ARP). On 14 January 1993, the ARP condensed to a smaller size, assuming a hook-like shape. The flux tubes seemed to be tightly wound round the axis of the ARP. This showed that a noticeable change had taken place within 24 hours. But on 14th January, the rate of twisting increased sharply, producing constrictions in the ARP trunk. An enhanced twisting within the ARP trunk implied an increased magnetic energy density. The whole process can be broken up into three distinct phases, namely:

(1) Containment of the prominence plasma by magnetic forces giving a picture of a compact and fairly low-lying prominence.

(2) A higher reaching action triggered off by some mechanism near the photosphere and by detwisting of the lines of force, resulting in:

(3) Detachment of the prominence from the rest of the system.

The observations were mostly taken with an exposure time of 3 sec and filter pass band 0.7 Å. The wavelength shift-placement of the Halle filter was varied on either side of the peak wavelength to detect finer details or movements of the prominence parts.

In our observations we noticed drastic changes in the ARP structure before its final eruption and also thereafter. The structure became diffused and after eruption the prominence started showing helical structure. In Fig.2 we have plotted the projected height above the solar limb verses time. The projected outward velocity increases in the beginning then attains a zero value followed by negative trend. Finally it increases again outward resulting in the disappearance of the prominence (Fig. 3). This indicates that the prominence had a connection with the denser underlying layers of the solar atmosphere which tried to pull down the prominence. However, it appears that the presence of an active region below, especially that of a surge was responsible for overcoming the downward pull on the prominence. This can be clearly seen on the filtergrams.

We made an inspection of the frames on the film through a spectrum projector which magnified the images about twenty fold. The run of the frames on the projector panel and visual inspection of the images clearly indicate a non-uniform distribution of the twist of the flux tubes indicating a high gradient in the azimuthal component of the magnetic field, increasing with time. This is noticeable in those regions where there is a break in the flux tubes from the region below, indicating a variation in both the azimuthal as well as in the axial magnetic field components. A rapid change in these components could result in the detachment and eruption of the prominence.

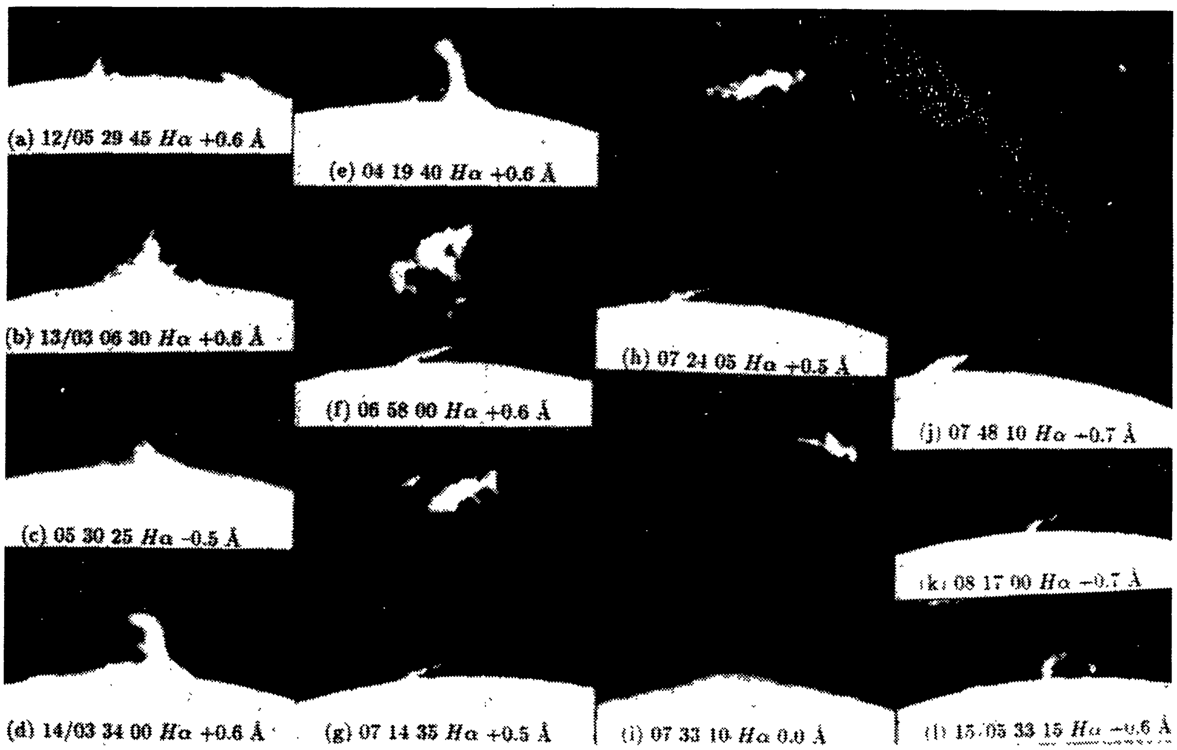

Figure 1. Selected filtergrams of the eruptive prominence of 12-15 January 1993.

3. The parameters

In our observations the helical structure parameters could not be measured as the structure could be seen only faintly in our filtergrams. However, we have been able to estimate the mass and energy contents. We enlarged the image on the film twenty-fold and made line drawings frame to frame. As the shape and size of the feature change rapidly with time, we divided the feature into parts which could be measured for calculating the volume. We used the frames whose printouts are 1f and 1j (14 January). From 1f the mass of the prominence before eruption comes out to be 9.16 x 10^{16} gm, in close agreement with Engvold *et al.* 1976. In the eruptive phase (Fig. 1j) the mass comes out to be 1.63 x 10^{16} gm indicating a mass loss. Following Engvold *et al.* 1976, we assume that the Lorentz force at a height *h* may be represented by

$$F_1 = m_0 g_0 \left(\frac{h_0}{h_1}\right) \tag{1}$$

where h_0 is the initial height of the prominence at which there was zero net force, m_0 is the initial mass of the prominence and g_0 is the gravitational acceleration on the sun at distance h_0 above the photosphere. Using appropriate values, we get

$$F_1 = 5.84 \times 10^{20} \text{ dynes} \tag{2}$$

At height h_1 the acceleration of the prominence mass m_1 is given by (Engvold *et al.* 1976),

$$a_1 = \frac{1}{m_1}\left\{m_0 g_0 \frac{h_0}{h_1} - m_1 g_0 \left[\frac{h_0 + R_\odot}{h_1 + R_\odot}\right]^2\right\}, \tag{3}$$

from which

$$a_1 = 2.4 \times 10^4 \text{cm sec}^{-2}. \tag{4}$$

The mass loss factor m_0 / m_1 at height h_1 is

$$\frac{m_0}{m_1} = \left\{\frac{a_1}{g_0} + \left[\frac{h_0 + R_\odot}{h_1 + R_\odot}\right]^2\right\} \frac{h_1}{h_0}. \tag{5}$$

Inserting appropriate values, we obtain

$$\frac{m_0}{m_1} = 6.15. \tag{6}$$

The kinetic energy K.E. of the prominence at height 3.56 x 10^5 km is 3.04 x 10^{30} ergs and the potential energy P.E. 1.45 x 10^{31} ergs giving a total energy of 1.76 x 10^{31} ergs. For the energy buildup rate we took the reference point from 12 Jan. 1993 05 30 UT to 06 30 UT on 14 Jan. 1993, that is, just before eruption. This comes out to be 9.96×10^{25} ergs sec sec–1.

4. Explanation of the prominence eruption on the basis of flux tube models

According to Priest, Hood & Anzer (1989) in a quiescent prominence or in an active region prominence the basic geometry is a large scale curved flux tube (Fig. 2). Twist of the tube may be created by Coriolis forces. The initial untwisted field lines are concave downwards (Fig. 2a) and are not conducive to prominence formation by injection or by radiative condensation, since any cool plasma at the flux tube summit will tend to drain down the legs before it accumulates. The extra component introduced by twist, however, is concave upwards and so, when the twist is large enough its curvature will dominate that of the axial component and will produce a dip in the field line with upward curvature at the flux tube summit. Then the prominence can begin to form by injection or condensation in the magnetic dip. As the twist continues, so the region of upward curvature expands along the flux tube and the prominence grows in length (Fig. 2c). Eventually when the twist is too large (Hood & Priest 1980; Einaudi & van Hoven 1981) the prominence may lose equilibrium or go unstable and erupt, undergoing a metamorphosis. The prominence then appears like a giant butterfly and reveals its true form as a flux tube for the first time.

If we compare the observations taken on 12th and 13th January and on 13th and 14th January, there is a large number of flux tubes in small arch shapes emerging out in one day from the base, forming a conical shape. On the following day, i.e., on 14th January the multiflux tubes got aligned along a common axis due to the rotation of the footpoints and due to flux cancellation/reconnection, into well-defined compact twisted and curved huge arch system. It seems, that at this stage the magnetic field becomes highly sheared and non-potential (Bhatnagar & Tripathy 1994), implying the presence of a very high current. This is the stage of a highly sheared magnetic field structure in which a high energy can be stored. This results in stretching of the huge arch and it seems that the prominence attains an active phase leading to its eruption in a few hours.

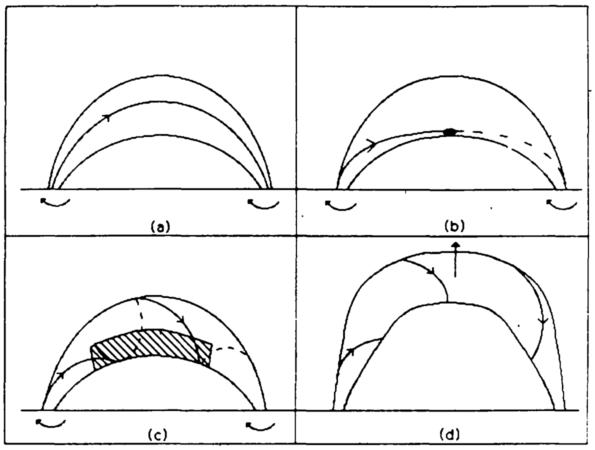

Figure 2. The twisted flux tube model for prominences (from Priest, Hood & Anzer, 1989).

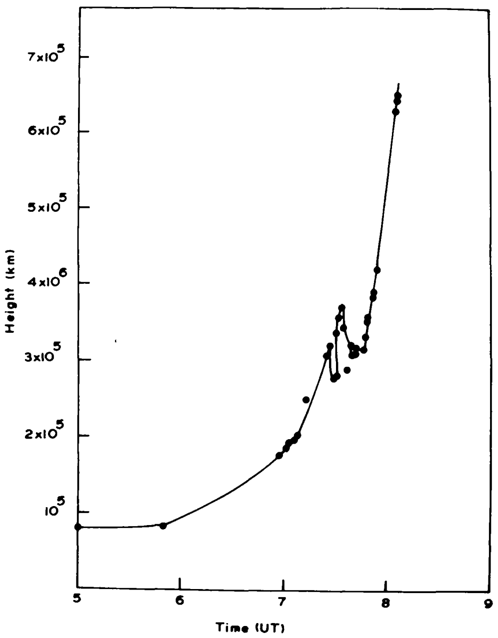

Figure 3. Curve showing the height versus time for the prominence on 14 January 1993.

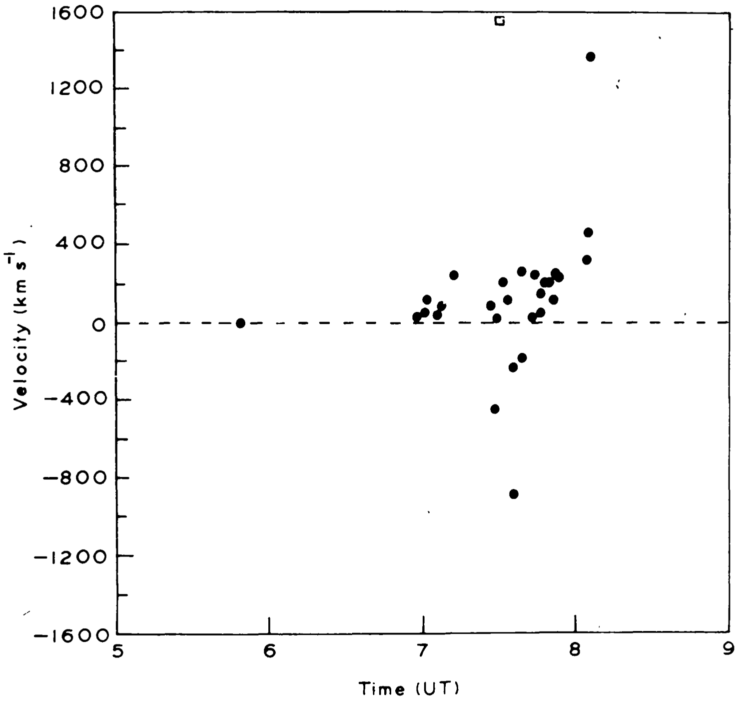

Figure 4. Curve showing the velocity versus time for the prominence on 14 January 1993.

5. Discussions and conclusions

The event that we observed as an eruptive prominence started as a quiet insignificant event on 12 Jan, 1993 gradually increasing its size and at the same time rapidly changing its shape. The inclination of the prominence with respect to the photosphere changed by about 40° during the eruptive evolution period till before eruption. The total mass of the matter before eruption has been estimated to be of the order of 10^{17} gm, having kinetic energy of the same order as that of a typical flare (Webb *et al.* 1994). Our filtergrams show that even after eruption, the prominence maintained a link through both matter and magnetic field with the active region in the photosphere below. This can be faintly seen in Figs. 1(h) and 1(i). The presence of a surge with helical structure at the photosphere clearly confirms the connection. This also indicates a probable emergence of a new flux in the vicinity and below the erupting prominence. The new flux acts as a destabilizing agent.

Soft X-ray images of the above event taken aboard the Japanese Satellite YOHKOH show a non-potential field configuration (Bhatnagar & Tripathy 1994) just before the eruption. It is implied therefore that very high current flows are involved which are responsible for the reconnection and for the instability.

It has been pointed out by Webb *et al.* (1994) that there is a high probability that a filament will erupt, likely leading to a CME, when major new flux emerges within or adjacent to the unipolar magnetic fields astride a filament in an orientation favourable for reconnection. It has also been pointed out by Munroe *et al.* (1979) that mass ejection coronal transients are well correlated with prominence or filament activity-with or without an observed flare. However, a much better correlation exists between coronal mass ejections and the eruptions of Quiescent Region Prominence (QRP). Many of the magnetic field lines in the coronal mass ejection are anchored into the photosphere, so that when the ejection moves outwards the field lines are stretched and become extended to form a field structure analogous to the geomagnetic tail (Kopp & Pneuman 1976). Our observations are indicative of this appearance. Changes in the magnetic field structure throughout the occurrence of the event can be inferred very well from the shape and changes in the structure of the prominence.

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References

Bhatnagar A., Tripathy S.C., 1994, Annual Report, Phys. Res. Laboratory, (1993-94), p.1.
Colgate S.A., 1978, ApJ, 221, 1068.
Einaudi G., van Hoven G., 1981, Phys. Fluids, 24, 1092.
Engvold O., Malville J. M., Rustad B.M., 1976, Solar Phys., 48, 137.
Giachetti R., Van Hoven G., Chiuderi C., 1977, Solar Phys., 55, 371.

Hirayama T., 1985, Solar Phys., 100, 415

Hood A.W., Priest E.R., 1979, Solar Phys., 64, 303.

Hood A.W., Priest, E.R., 1980, Solar Phys., 66, 113.

Kopp R.A., Pneuman G.W., 1976, Solar Phys., 50, 85.

Moore R.L., 1988, ApJ, 324, 1132.

Munroe R.H., Gosling J.T., Hildner E., MacQueen R.M., Poland A.I., Ross C.L., 1979, Solar Phys., 61, 201.

Ohman Y., 1972, Solar Phys., 23, 134.

Priest E.R., Hood A.W., Anzer U., 1989, ApJ, 344, 1010.

Raadu M. A., 1972, Solar Phys., 22, 425.

Rompolt B., 1975, Solar Phys., 41, 329.

Sakurai T., 1976, PASJ., 28, 177.

Van Hoven G., Steinolfson R.S., Tachi T., 1983, ApJ, 268, 860.

Webb D.F., Forbes T.G., Avrass H., Chen J., Martens P., Rompolt B., Rusin V., Martin S.F., 1994, Solar Phys., 153, 73.