A MECHANISM FOR THE BUILD-UP OF FLARE ENERGY

JAN OLOF STENFLO*

Astronomical Observatory, Lund, Sweden

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Abstract. It is shown how the kinetic energy of the rotational motion of a sunspot can be transferred to electromagnetic energy in filamentary currents. The time needed for preconditioning the solar atmosphere for a flare varies within wide limits. For small flares it may be of the order of minutes; for large flares, of the order of hours or days.

Filamentary currents are likely to be of essential importance in many problems of astrophysics. In fact, it has been suggested that all filamentary structures which are observed are produced by electric currents (Alfvén and Fälthammar, 1963; Alfvén, 1968). Recent magnetograph observations support the idea of filamentary currents and indicate their importance for the interpretation of solar phenomena (Severny, 1965; Stenflo, 1966; Moreton and Severny, 1968; Stenflo, 1968). Measurements of the transverse magnetic field indicate the existence of vertical electric currents of the order of $10^{11} - 10^{12}$ amp in the solar atmosphere. The currents tend to bunch the magnetic-field lines and produce 'microspots' (Stenflo, 1968; Beckers and Schröter, 1968).

With the concept of filamentary currents as a starting point, a theory of solar flares has been developed (Alfvén and Carlqvist, 1967; Carlqvist, 1969). The instability of a current-carrying plasma causes a circuit interruption, which produces a flare.

The electric currents may be generated in different ways. In the present paper we shall discuss how a rotational motion of a sunspot will produce a current system and build up the flare energy in filamentary currents.

Rotational motions of and around sunspots have been observed by many authors (Evershed, 1910; St. John, 1913; Abetti, 1932; Maltby, 1964; Gopasyuk, 1965; Bhatnagar, 1967). The magnitude of the rotational velocity seems to vary with time and also from spot to spot. Gopasyuk (1965) found a close correlation between the rate of rotation of a large sunspot and the frequency of surges in the region. Mostly the rotational velocities are smaller than 1 km/sec and often of the same order as the observational errors (100–30 m/sec).

Let us as an approximation consider a sunspot as a circular region in which the vertical magnetic field is $B_v$. We further assume that in the region between $R_1$ and $R_2$ from the centre of the spot the tangential (rotational) velocity has the value $v_t$. Hence there is a voltage difference $V$ between the central region ($R < R_1$) of the spot and the environment ($R > R_2$), which has the value

$$V = \frac{1}{c} v_t B_v (R_2 - R_1).$$

* Presently Guest Investigator at the Mount Wilson and Palomar Observatories.

Putting \( v_t = 10^4 \) cm/sec, \( B_t = 2000 \) gauss and \( R_2 - R_1 = 10^9 \) cm, we find
\[
V = 2 \times 10^8 \text{ volt}.
\]

Suppose that a magnetic-field line joins the central region of the spot with the environment. According to the picture of filamentary currents, we can then regard this as an electric circuit with inductance \( L \approx 10 \text{ H} \), if the distance between the foot points of the field line is \( 5 \times 10^9 \) cm (CARLOVIST, 1969).

At the moment when the assumed conditions are established, the current \( I \) increases at the rate
\[
\frac{dI}{dt} = \frac{V}{L}.
\]

With our values we thus have \( \frac{dI}{dt} = 2 \times 10^7 \text{ amp/sec} \).

The current in a semistationary filament can be calculated from the equation (ALFVÉN and FÄLTHMÄR, 1963)
\[
I = 88 \frac{\kappa c b B_0}{c},
\]
where \( \kappa \approx 2.6 \), \( c \) is the velocity of light, and \( b \) is a characteristic size. The component of the magnetic field parallel to the axis of the filament decreases from the value \( B_0 \) at the axis to 0.2 \( B_0 \) at a distance of 2\( b \) from the axis.

BECKERS and SCHROTER (1968) found more than 2000 microspots around a large unipolar sunspot. The magnetic fluxes from the microspots balanced the flux from the sunspot. The field strengths in the microspots were found to be between 600 and 1400 gauss, and the typical size of a microspot was about 1000 km. Let us therefore assume as a typical diameter and maximum field strength for a current filament \( 10^8 \) cm and \( 10^9 \) gauss, respectively. This would give an electric current of about \( 10^{11} \) amp in each filament if Equation (3) is applied. The magnetic energy in such a filament, \( LI^2/2 \), would then be about \( 10^{30} \) ergs.

From a detailed investigation of the magnetic-field structure of a big sunspot, STEPANOV and GOPASYUK (1962) found a variation of the vertical and azimuthal field components with distance from the spot centre practically identical to that expected if the spot as a whole is regarded as a current filament. The same spot was found to rotate, and the rate of rotation was strongly correlated to the appearance of surges (GOPASYUK, 1965). If we apply Equation (3) to this spot (with \( B_0 = 3000 \) gauss and \( b = 5000 \) km), the total current comes out to be \( 10^{13} \) amp.

The time required to reach a current of \( 10^{10} \) amp, i.e., what is needed for a small flare, is about 8 min if we use our earlier estimate \( \frac{dI}{dt} = 2 \times 10^7 \text{ amp/sec} \). With this value for \( \frac{dI}{dt} \), it would take about 6 days to generate a current of \( 10^{13} \) amp through the sunspot. This time may be reduced substantially if there are a large number of filaments coming out from the spot. The electric circuit will then essentially be of a type similar to that in Figure 1. The non-filamentary part of the circuit has the inductance \( L_0 \). All the filaments, each of inductance \( L_1 \), are coupled parallel to each other. It is assumed that the mutual inductance can be neglected. If there are \( N \) filaments, the total inductance of the circuit will be
\[
L = L_1/N + L_0.
\]