AN ENERGY STORAGE PROCESS AND ENERGY BUDGET OF SOLAR FLARES

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The flare energy is generally considered to be stored in stressed (twisted or sheared) magnetic fields. Origin of the stress may be either intrinsic or due to horizontal shear motion (Tanaka and Nakagawa 1973) or due to propagation of twist from below (Piddington 1974). Characteristic magnetic configurations in the great activities (inverted, twisted δ-configuration; Zirin and Tanaka 1973) suggest an inherent shape of fluxtube for these regions: a twisted magnetic knot. Further, evolutionary characteristics such as rapid growths of spots and growth of twist in parallel with apparent shear motion of spot, together with the fact that the shear motion is associated with upward velocity (Tanaka and LaBonte 1979), suggest a continuous emergence of such a twisted knot from below throughout the activity (Tanaka 1979). In this model (Fig. 1) the flare energy may be supplied directly into the corona as the twisted portion of the fluxtube emerges out. The amount of energy supplied between t_0 and t may be equated to the energy contained in the twist(ϕ) between z_1 and z_2,

$$M(t) = 1/4\pi \int_0^r r\phi B_\phi B_z 2\pi r dr. \qquad (1)$$

Observationally ϕ may be evaluated from the growth of the penumbral twist, which is related empirically to the apparent horizontal shear velocity v by $r\phi=1.5v(t-t_0)$ (Tanaka 1979). Assuming the force-free field we have $\langle B_\phi B_z\rangle \simeq 0.22B_p^2$ with B_p equal to the peak field strength of the moving spot. Then,

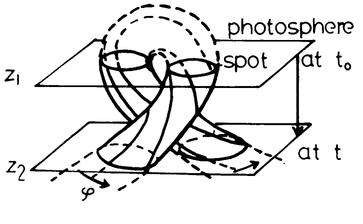

Figure 1. An emerging twisted magnetic knot.

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$$M(t) \simeq \int_{t_0}^{t} 0.0173\ B_p^2 Av\ dt, \quad (2)$$

where A is area of the moving spot. Eq.(2) is equal to the evaluation of accumulated energy due to the horizontal shear motion except numerical factor (cf. Tanaka and Nakagawa 1973).

We evaluated the energy supply for a very flare-rich and fast-evolved active region McMath 13043 (1974 July) which showed three successive sunspot motions in good spatial and temporal correlations with the activities, and compared it with released flare energies (thermal and kinetic). Time-integrated thermal energy was evaluated from the total radiated energy:

$$E_T(t) \simeq \int_{t_0}^{t} F_{obs}(1\text{-}8A)\cdot C(1\text{-}8A,T)\cdot F(\text{total},T)/F(1\text{-}8A,T)\ dt \quad (3)$$

$$\simeq \int_{t_0}^{t} 12.4\ F_{obs}(1\text{-}8A)\ dt, \quad (4)$$

where $F_{obs}(1\text{-}8A)$ is the observed flux in the 1-8A band (GOES), C is a correction factor to obtain true flux (Dere et al. 1974), the last term is a theoretical ratio of the total to the 1-8A fluxes (Raymond et al. 1976). We adopted eq.(4), an empirical result from eq.(3) for a well-studied 2b flare of Sep.7 1973 (Withbroe 1978). The kinetic energy was evaluated from the interplanetary shock wave data (IMP 7 and 8). From the potential and kinetic energy fluxes shown in Fig.2 the integrated kinetic energy was obtained assuming a constant area S equal to a solid angle $\pi/2$ at 1 A.U. and correcting for transit times of the shock waves:

$$E_K(t) = S \int_{t_0}^{t} \rho v^3/2\ dt \ + \ S \int_{t_0}^{t} dt \int_{R_\odot}^{1AU} \rho v GM/r^2 dr. \quad (5)$$

For three periods corresponding to the three motions, $M(t)$, $E_T(t)$, and $E_K(t)$ are shown in Fig.3. $M(t)$ proves to show quite consistent time profiles with $E_T(t)$ and $E_K(t)$. In particular remarkable is the similarity between $M(t)$ and $E_T(t)$ shown in Fig.4. $E_T(t)$ scales half of $M(t)$ precisely in the whole period. For 8 major flares net increase of $M(t)$ between the flares are compared with total thermal (E_T) and kinetic (E_K) released energies in Table 1.

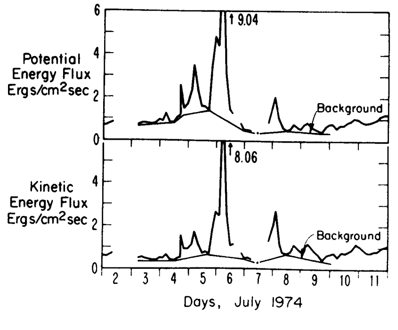

Figure 2. Potential(upper) and kinetic(lower) energy fluxes of shock waves at 1 A.U.

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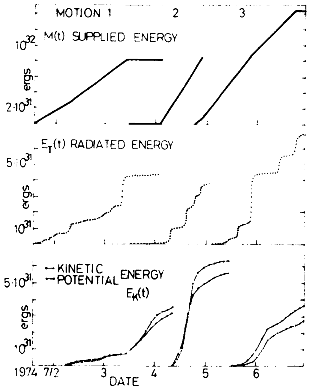

Figure 3. $M(t)$,$E_T(t)$ and $E_K(t)$, respectively.

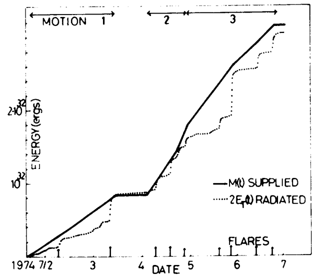

Figure 4. $M(t)$:thick line and $E_T(t)$:dotted line in the whole period: July 2-July 7 1974.

Table 1. Energy Budget of 8 Major Flares

flare July	2(1n)	3(2b)	4(1b)	4(1b)	4(1n)	5(2b)	6(1b)	6(1b)
$M(10^{30}$ergs)	26	56	22	28	34	98	32	22
E_T	13	30	9	11	15	43	11	14
E_K	9	43		115		32	7	14
E_T+E_K	22	73		150		75	18	28

One finds $E_T/M = 0.46\pm0.09$, $E_K/M = 0.61\pm0.42$, $(E_T+E_K)/M = 1.09\pm0.45$. Note the small scatter in E_T/M. Similar ratio ($E_T/M = 0.57\pm0.19$) is obtained for the 1972 August flares (Tanaka 1979). Large scatter in E_K/M may be due to the assumption of constant area for different shock waves. The solid angle of $\pi/2$ may be suggested from this result. We note that agreement between energy input and output was obtained using qualitativel different sources of data. Present result may support the direct energy supply due to the emergence of the twisted fluxtube which is produced in the convection zone by some flow patterns.

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DISCUSSION

Stix: Concerning your last figure, is there any symmetry (or anti-symmetry) with respect to the equator of the tilt of newly formed sun-spot pairs?

Tanaka: In the past cycles most of the great flare-producing regions appeared in the north hemisphere, so no statistics exist concerning your question. But in a few examples there is antisymmetry with respect to the relative orientation of the P-and f- polarity.

Pneuman: The picture you showed was of a two-ribbon flare. To explain such a flare totally in terms of emerging untwisting flux would require enormous changes in the photospheric field distribution. I don't believe such large scale changes are observed in the magnetograms.

Tanaka: The changes of magnetic fields which would occur when the once-emerged twisted fluxtube relaxes are mainly changes of magnetic field orientations, and so to detect them we need high time and spatial resolution observation by the vector magnetograph. (Large scale changes of magnetic field orientations have been reported in the magnetograph observation of a large flare near the limb, by Tanaka, Solar Phys., 58.)