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VARIATION OF MAGNETIC FIELDS AND ELECTRIC CURRENTS ASSOCIATED WITH A SOLAR FLARE

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INTRODUCTION

It is well accepted that the source of energy for flares arises in the non-potential magnetic field from the dynamic evolution of active regions above the photosphere. So far, however, contradictory results have been suggested for the question of whether the occurrence of flares results in detectable changes of the magnetic fields and electric currents in the regions (Svestka, 1976)

The early researches of Severny's group showed that the longitudinal and transverse magnetic fields in active regions change evidently after flares, which are characterized by the simplification of magnetic configuration as well as the decrease of magnetic strength and gradient (Severny, 1962, 1969). Then, after studying the magnetograms of two active regions measured by the Kitt Peak's magnetograph, Harvey suggested that there were changes in longitudinal magnetic fields with a time scale of hours, but they could be attributed to the global evolution of active regions and not directly related to the occurrence of flares (Harvey et al., 1970). Moreover, from the analyses of the Kitt Peak's magnetograms for the big flare of 3B importance on 4 August 1972, Livingston indicated that the longitudinal magnetic fields before and after the flare remained unchanged (Livingston, 1973). On the other hand, from the study of the magnetograms obtained by the Big Bear Observatory's video magnetograph before and after a 2B flare in the region McMath 13225 on 10 September 1970, Tanaka reached the conclusion that in weak field areas of less than 100G, the longitudinal field changed about 30-100% at the onset of the flare, and this change was associated with the flare (Tanaka, 1978). In recent years, some authors have investigated in detail the magnetograms of the well known region AR2372 on 6 April 1980 obtained with the video magnetograph of the Marshall Space Flight Center (Krall et al., 1982; Hagyard, 1984; Ding et al., 1985; Lin and Gaizauskas, 1987). Their results showed that the change of the magnetic fields occurred before a $1B/X2$ flare. Therefore we have a rather confused picture about the variation of magnetic fields associated with flares.

Our purpose is to carry out a further investigation on this problem by using the high quality vector magnetograms and H_β filtergrams of the Beijing Astronomical Observatory, and to clarify some of the existing contradictory results.

OBSERVATIONAL DATA AND INFERRED ELECTRIC CURRENTS

During 0050-0110 UT on 7 October 1987, a small flare (Solar-Geophysical Data, 1987, No. 519, Part I, p.14), with its maximum at 0055 UT and a total apparent area (five kernels) of 27 × 10^{-6} of the solar disk, occurred in the active region AR4862 (N33, E16). The chromospheric filtergrams (in H_β) as well as the photospheric longitudinal and transverse magnetograms (in FeI 5324) were obtained with the solar telescope magnetograph of the Beijing Astronomical Observatory around the flare period (Lin et al., 1989).

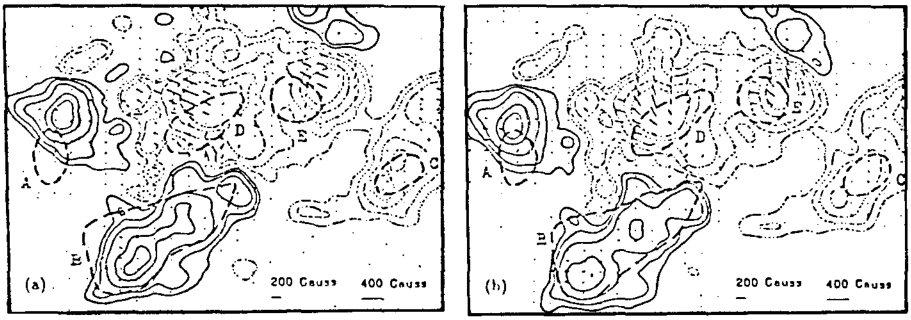

Fig. 1 The vector magnetograms of AR4862 on 7 October 1987. (a) The magnetogram before the flare: $B_{//}$(0035UT), $B_\perp$(0019UT). (b) The magnetogram after the flare: $B_{//}$(0114UT), $B_\perp$(0124UT).

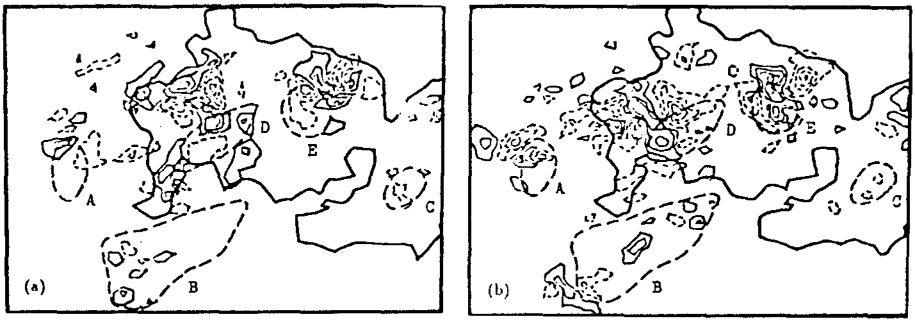

Fig. 2 The distribution of longitudinal electric current density J_z. (a) The distribution of J_z before the flare(0019UT). (b) The distribution of J_z after the flare(0124UT).

Figure 1 shows the vector magnetograms of the active region before and after the flare. In the figure, the solid and dotted contours indicate the areas of positive and negative polarities, respectively, for longitudinal field $B_{//}$. The contour levels are $\pm40, \pm80, \pm160, \pm320, \pm640, \pm960$ and ±1280 G. The length and direction of line segments represent the strength and orientation of transverse field $B_\perp$. The five broken bold contours indicate the H_β flare kernels at its maximum (0055UT). The view field shown is 65 × 46 square arcsec. The heliographic north and west directions are up and to the right, respectively.

Taking the photosphere as the (x,y) plane of rectangular coordinates with z-axis toward the observer, the longitudinal electric current density, J_z, can be calculated according to the Ampere's law. The calculation formula for discrete data is

$$J_z = \frac{1}{\mu_o}\left\{\frac{B_y(x+\Delta x,y)-B_y(x-\Delta x,y)}{2\Delta x} - \frac{B_x(x,y+\Delta y)-B_x(x,y-\Delta y)}{2\Delta y}\right\},$$

where B_x and B_y are, respectively, the projections of $B_\perp$ on the x and y axes, $\mu_o = 1.2 \times 10^{-2} G.m.A^{-1}$ is the permeability in free space. In our case $\Delta x = \Delta y = 1''.5$, hence the calculated J_z has a spatial resolution of $2\Delta x = 2\Delta y = 3''$. Two criteria proposed by Krall et al. (1982) were adopted to eliminate the 180^o ambiguity in the azimuth of B_x and B_y.

Figure 2 shows the distribution of J_z. The solid and dotted contours in the figure indicate, respectively, the areas of positive and negative currents. The levels of J_z are $(\pm 1.5 \pm 2.3n) \times 10^{-3} A{\cdot}m^{-2}$, where n is an integral. The five broken bold contours show the H_β flare kernels at its maximum (0055UT). The bold solid line presents the polarity reversal of the longitudinal field. The view field shown is 65 × 46 square arcsec. The heliographic north is up, west to the right.

ANALYSES AND CONCLUSIONS

The following results can easily be obtained from the comparison among the figures shown in the paper.

(i) The comparison between Figure 1a and Figure 1b shows that the contours for the longitudinal fields at 0035UT and 0114UT are rather similar, and it indicates simply that before and after the flare, the longitudinal fields in the region remain nearly unchanged.

(ii) Comparing the transverse field in Figure 1a with that in Figure 1b, obvious differences can be seen between the fields before and after the flare. The most remarkable difference is that the directions of the strong transverse fields near the upper left part of the flare kernel D and the upper right part of the flare kernel E changed from basically an east-west orientation to a north-south one. From the comparison between Figure 2a and Figure 2b, in correspondence with that in Figure 1, a large variation can be found between the longitudinal electric current densities before and after the flare.

(iii) Figure 2 indicates that the five flare kernels are located basically in the vicinity of the peak J_z, and the location coincidence between the kernels and the peaks of J_z in Figure 2b is better than that in Figure 2a. This is probably related to the time difference of the observations between the flare and the transverse field in Figure 2b being shorter than that in Figure 2a. So it is very possible that a better coincidence between the flare kernels and peaks of J_z would reached if they were observed simultaneously. This result confirms the conclusion obtained previously that solar flare kernels coincide with peaks of longitudinal electric current densities (Lin and Gaizauskas, 1987). More importantly, this result shows also that the observed variation of the transverse magnetic field and the longitudinal electric current are closely related to the occurrence of the flare, and are not a result of the natural evolution of the active region.

Finally, as the region was located near the center of the solar disk (N33,E16), the $B_{//}$ and $B_{\perp}$ correspond approximately to the B_r and B_s, which are parallel to solar radius and solar surface, respectively. Therefore, the conclusions (i) and (ii) might be combined to state that in an active region, the component of magnetic field parallel to the solar surface, B_s, tends to change after a solar flare, while the component vertical to that, B_r, tends to be unchanged. The result obtained by Livingston (1973), that for the 3B flare on 4 August 1972 no change of longitudinal magnetic field in the region was detected after the flare, could be attributed to the region being near the center of the solar disk where the longitudinal field $B_{//}$ is equivalent to B_r, and thus his result is consistent with our conclusion. On the other hand, for the active region McMath 13225, Tanaka found that at the beginning of a solar flare in the areas of weak field, the longitudinal field showed a variation of 30-100%. As the angular distance between the region and the center of the solar disk was 60^o, the longitudinal component of the field, $B_{//}$, must contain the component B_s, so that the variation of $B_{//}$ might come from the variation of B_s. Thus his result is also consistent with ours.

Generally, solar flares do not affect the thermodynamic condition at the photosphere except in the case of white light flares. It is certainly true for the small flare studied here. Therefore the measured variations of magnetic field and electric current after the flare can not be caused by the change of the FeI5324 line profile due to the flare.

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