Magnetic Field Evolution Leading to Solar Flares II. Cases with High Magnetic Shear and Flare-Related Shear Change

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Abstract

Following Paper I in which we considered five solar flares, we have selected another three solar flares greater than GOES X-ray class M/Hα importance 1. The three active regions discussed here are characterized by high magnetic shear. We investigated the spatial relationships among Hα flare ribbons, soft X-ray (SXH) flare loops, and magnetic configurations for the three flares produced in these active regions. Our results show that only one of these three flares satisfies the sufficient conditions for a flare to occur proposed by Hargard (1990, AAA 052.075.047). We also discuss the magnetic shear changes around the flaring time only along the neutral lines associated with the studied flares and over the whole flaring area. The flare-related changes on the neutral line are small (2°–4°) and the association of these changes with the flares is not conclusive. The average shear in the flaring areas of the flares associated with high shear decreases significantly after the flares and it may be a better parameter to characterize the flare-related shear changes in such cases.

Key words: Sun: flares — Sun: magnetic fields — Sun: X-rays

1. Introduction

One of the most probable forms of energy storage prior to solar flares is magnetic shear, which can result from flux emergence (Zirin 1983; Zhang 1995, 1996; Lites et al. 1995; Wang et al. 1998), shear motion between the two poles of opposite polarities (Wang 1992), and fragmentation of a main sunspot (Schmieder et al. 1994). The stored energy may be suddenly released due to a plasma instability or the formation of a current sheet (Vekstein et al. 1991; Schmieder et al. 1994).

Hargard et al. (1984) introduced the concept of angular shear to quantitatively describe the non-potentiality of magnetic fields. This traditionally defined indicator of non-potentiality of a magnetic field has been revealed to be spatially correlated with Hα and Hβ flare ribbons and kernels (e.g., Hargard, Rabin 1986; Moore et al. 1987; Hargard 1990; Canfield et al. 1993; Wang T. et al. 1994, 1998; Fontenla et al. 1995; Wang J. et al. 1996). Based on the angular shear and other related parameters, such as weighted magnetic shear (Wang 1992) and shear index (Ambastha et al. 1993), quite a few authors have reported flare-related shear changes in recent years. Sakurai et al. (1992) qualitatively demonstrated a flare-related shear decrease for a 2B/M4.4 flare based on observations of soft X-ray images and vector magnetograms. Wang H. et al. (1994) studied five flares of GOES X-ray class X, and found that the magnetic shear increased dramatically along a substantial portion of the neutral line during the flares, and that increases ranging from 5° to 40° are impulsive. Chen et al. (1994) studied nineteen GOES M-class flares and one X-class flare from six active regions, and concluded that only in two cases did the weighted shears along the neutral line increase significantly after the flare: 6° increase for an X2 flare and 13° increase for an M1.9 flare. For the rest of the flares studied, the shear changes were within the measurement uncertainty and undetectable. In a study of fourteen flares by Ambastha et al. (1993), eight cases showed a decrease in the shear index around the flare time, followed by an increase; three showed a persistent decrease; two showed only an increase; and one showed no change at all. After carefully investigating the 6-hr time sequence of vector magnetograms of AR 6659 on 1991 June 10, Hargard et al. (1999) stated that only minor changes in the vector magnetic field azimuths in the vicinity of two M-class flares have been revealed, and that the association of these changes with the flares was not
unambiguous. Their calculations showed that the r.m.s. variation of the azimuth of the field had a peak in distribution at around 2° over the field of view of this active region for an interval of 6 hours.

In a previous paper (Li et al. 2000, hereafter Paper I), we studied five flares that are not associated with high magnetic shear, but are associated with an emerging flux. In this paper, we consider the evolution and flare activity of three active regions and their magnetic configurations in which strong magnetic shear is present. We also analyze the flare-related shear changes along the magnetic neutral lines and in the flaring areas for all of these eight active regions and flares. Table 1 lists the flares which we analyzed and their basic parameters.

This paper is organized in the following manner. In section 2, we describe the observation instruments and data for this study briefly, and the procedure of data reduction. The results of a study of the three high shear associated flares are given in section 3. We provide the results from a study of flare-related shear changes in section 4; discussions and conclusions are presented in section 5.

2. Observations and Data Reduction

We described the instruments that were used to obtain the data in our analysis and data reduction in Paper I. They were the Solar Flare Telescope (SFT, Sakurai et al. 1995), which was used to obtain all of the vector magnetograms and Hα images (except those of the flare of 1994 August 17) analyzed in this paper, and the Flare Monitoring Telescope (FMT, Kurokawa et al. 1995), with which the Hα images of the flare of 1994 August 17 were obtained, the Soft X-ray Telescope (SXT, Tsuneta et al. 1991) and the Hard X-ray Telescope (HXT, Kosugi et al. 1991) onboard the Yohkoh satellite (Ogawara et al. 1991).

We invoke the definition of angular shear proposed by Hargard et al. (1984) to discuss the magnetic shear. We look into the magnetic shear (a) along a neutral line and (b) in the flaring area defined by Hα ribbons near the flare maximum. When deriving the shear angle, we, at first, computed the azimuth angle of the observed transverse field vector and that of the calculated potential field, and then calculated the difference to obtain the angular shear. The shear angle $\phi$ derived by this way contains information about not only the azimuth difference, but also the rotation direction (clockwise or counterclockwise) of the observed magnetic field vector with respect to the computed potential one. The threshold value of transverse field to eliminate the consideration of weak fields is 150 G.

We calculated four kinds of average shear angles along the magnetic neutral line and their temporal variations around the flaring time. They are (1) the general averaged shear angle, (2) the average shear angle weighted by the absolute values of the transverse field strength $B_t$, (3) that weighted by the absolute values of the gradient of $B_t$, and (4) that weighted by the absolute values of the gradient of longitudinal field strength $B_l$. They are defined by the following four formulae, respectively:

\[
\bar{\varphi} = \frac{\sum |\varphi|}{n},
\]

\[
\bar{\varphi}_{B_t} = \frac{\sum |\varphi \cdot B_t|}{\sum |B_t|},
\]

\[
\bar{\varphi}_{\nabla B_t} = \frac{\sum |\varphi \cdot \nabla B_t|}{\sum |\nabla B_t|},
\]

\[
\bar{\varphi}_{B_l} = \frac{\sum |\varphi \cdot B_l|}{\sum |\nabla B_l|}.
\]

If we only consider photon statistics noise, the uncertainty in the value of the shear angle, which depends on the transverse field strength, is about 2° when the transverse field is 500 G and 1° when the transverse field is 800
3. Flares Associated with High Magnetic Shear

In this section, we consider three flares associated with strong magnetic shear. We describe the evolutions of respective active regions and their magnetic configurations, and also discuss the spatial correlation among Hα ribbons, SXR flare loops and magnetic configurations for these flares.

3.1. 1N/M1.0 Flare of 1992 October 27

3.1.1. Evolution of AR 7321 and its magnetic configurations

The large active region NOAA 7321 was a new emerging flux region (EFR), which suddenly appeared near to the central meridian of the Sun on 1992 October 24 and rotated out of the solar disk on November 1. During this period it underwent a remarkably fast evolution. Its polarity alignment was inverted with respect to the Hale–Nicholson law. The inclination angle of the magnetic axis of the main poles of the active region to the solar equator is about 60° (Zhang 1995).

Figure 1 shows the evolutions of this active region and its magnetic structures. On October 25, it simply comprised the main poles, N and S, and a satellite sunspot,
S1, was located at the northeastern part of the active region. It was a simple dipole with a magnetic configuration resembling a potential field. The shear angle defined by Hargrove et al. (1984) was small for most points on the neutral line. As several satellite sunspots continuously emerged from between the main poles, the magnetic configuration became ever-more complicated, which was characterized by the strong shear along the magnetic neutral line. As the main poles, N and S, of opposite polarity moved away at about 0.4 km s\(^{-1}\), the emerging flux of N1 and S1 increased significantly on both sides of the neutral line (figure 1b). Meanwhile, the transverse field in the middle of the neutral line gradually became parallel to the magnetic neutral line. See Zhang (1995) for details.

On October 26, S1 evolved further and its magnetic flux increased markedly. At the same time, new sunspots, N1 and N2, appeared in between N and S. This greatly enhanced the shear at the two segments, P1 and P2, of the magnetic neutral line (figure 1b). The non-potential feature was already strong on October 26 due to the emerging flux near the neutral line. From the magnetogram on this day we can discern the following magnetic connection patterns. N1 was connected to S1 across the P2 segment of the neutral line by L2, and N2 was connected to S across P1 by L1. These connections, L1 and L2, were later identified by SXR loops.

N2 was evidently enhanced on October 27. Due to the appearance of S4, S5, and a new pair (S3 and N3), the magnetic shear near P1 increased further and the neutral line near S4 changed significantly (figure 1c). The shear angles near P1 and P2 were almost 90°. The emerging flux pushed the neutral line segment, P1, southwards and increased the shear there, and caused the magnetic structure of N to be rotated about 20° clockwise (Wang et al. 1999). Compared with one day before, S1 showed a running-away motion toward the east. The magnetic connection pattern, L1, was also changed, and L1 now connected N2 and S5 across P1. Another pattern, L4, which was not seen on the previous day, connected N2 and the newly emerged S4. However, L2 did not change much and the shear remained high. All of these magnetic connection patterns corresponded to the SXR loops, and were confirmed by Hα flare ribbons, as described later (figure 4b).

The active region was fully developed on October 27, and then a series of flares took place in the flux-emerging area with strong shear.

3.1.2. Hα and X-ray flare

The Hα flare was initiated at 00:13 UT, reached its maximum at 00:18 UT and ended at 01:09 UT according to the Solar Geophysical Data. At the flare onset, the first Hα ribbon B1 started to brighten almost in the north-south direction, and virtually consisted of four small bright areas (figure 2). It spanned across the neutral line segment P1 and came to its maximum at about
00:21 UT. About three minutes after flare onset, the second Hα ribbon, B2, which was nearly perpendicular to B1, began brightening. Another bright point appeared amidst the second and third points of B1. These three points eventually merged at about 00:20 UT and formed a short ribbon. B2 reached its maximum at about 00:30 UT, and B1 and B2 decayed at the flare end.

We have no SXR image for the period between 00:12 UT and 00:56 UT from Yohkoh SXT due to its orbital night. However, on the SXR image at 00:11:25 UT (figure 3), we can see that there were already two SXR loops, L1 and L2, before the flare onset. Loop L1, whose two footpoints are rooted in N2 and S5, is a highly sheared bundle and spatially coincident with B1 (figure 4). Loop L2, with its two footpoints anchoring in N1 and S1, is a weak loop with low magnetic shear and spatially consistent with B2. During the flare, L2 was strengthened. Meanwhile, the third SXR loop, L4, connected N2 and S4 and shared the same footpoint with the first SXR loop L1 at N2.

We can establish the following scenario for this flare from what we mentioned above (see figure 5). The emerging pair, N3+S3, pushed segment P1 of the neutral line southwards markedly, and created a highly sheared configuration. The current sheet might also have existed above the emerging flux. The energy release occurred in the forms of rapid plasma heating and electron acceleration, which lightened up loop L1 and formed the Hα ribbon B1. We may hypothesize that the brightenings of loop L2 and Hα ribbon B2 were a secondary effect, which stemmed from energy transfer along L2 from the initial flaring site, by considering the timing of the brightenings.

By comparing the SXR image at 00:11:25 UT and 01:28:13 UT, we can tell that the shear relaxed after the flare. This has been confirmed by a calculation of the shear angle along the magnetic neutral line and in the flaring area (section 4). The shear began to increase about 20 min after the flare end.
3.2. 1B/M2.1 Flare of 1992 October 10

3.2.1. Evolution of AR 7306 and its magnetic configurations

Active region NOAA 7306 produced five GOES M-class flares during its passage across the solar disk from 1992 October 4 through 16. It was fully developed and most active on October 7, and four M-class flares took place on this day. It then began decaying. Due to the appearance of new sunspots to the north of the preceding positive sunspot on October 9 to 10, the active region became slightly more complicated and active. The flare which we studied occurred on October 10. On this day, the region comprised a main positive preceding sunspot, N, with two small sunspots, N2 and N3, east of it, and...
a small negative following sunspot, S. A δ-spot (N1+S1) was located in between them (figure 6).

We have no magnetic field data before October 10 for this active region due to bad weather conditions. However, as can be seen on the magnetograms of this region extracted from Kitt Peak's full disk magnetograms, it underwent great changes from October 6 to 10, and there was continuous emerging flux activity.

The magnetic configuration of AR 7306 did not change much on October 10 in accordance with the magnetograms we have for the period of 01:36 UT to 07:15 UT. However, by a careful comparison of the magnetograms at 01:48 UT and 05:24 UT (figure 6), we see some changes. The magnetic fields in N1 of the δ-region and S weakened, which implies that they could be a pair, while the fields in the preceding sunspot did not change much and those in N2 and S2 strengthened slightly. Meanwhile, the peninsula structure of the δ-region became narrowed and prolonged due to emerging flux. The emerging flux twisted the magnetic neutral line there, resulting in a shear increase at some points on the neutral line, even though the average angular shear did not show an apparent increase.

It is worth mentioning that the transverse field in the negative polarity region near the neutral line northeast to N1 almost reversed the direction during this period. We determined the azimuth of transverse field vector by supposing that the angle between the observed transverse field vector and the computed potential one is less than 90°. Therefore, a false resolution of the 180° ambiguity of transverse field might be suspected. However, calculations of the potential fields by the Green's function method (Sakurai 1982) also demonstrate this change (figure 7). Figures 7a and b correspond to figures 6a (01:48 UT) and b (05:24 UT). The field lines in the two figures start from the same footpoints arranged on a regular grid. Field lines that have changed the connectivity are shown by thick lines.

As can be seen there, this area was mainly connected to N1 at 01:48 UT, while a considerable part of this area was reconnected to N at 05:24 UT. Therefore, we conjec-
ture that there was a separatrix separating two magnetic systems, one of which was dominated by N and another by N1. As the flux connecting N1 and S weakened, either due to dispersive motion or due to submergence, the corresponding flux tube might have shrunk. On the other hand, due to this shrinkage and field decrease, the flux tube of the magnetic system dominated by N expanded, which led to magnetic lines of force that moved closer to N1. The direction change of the transverse fields could be a projection effect of the above-mentioned changes.

The average shear angles did not show any detectable change.

3.2.2. Hα and X-ray flare

The Hα flare started at 05:37 UT, peaked at 07:19 UT and lasted until 10:05 UT. We only have Hα images before 07:28 UT. There are four Hα ribbons on the image at 06:01 UT (figure 8), which were located on either side of two segments of the long neutral line, implying that two segments of the neutral line were involved in this flare. The northwestern two ribbons (A and B) brightened first at 05:37 UT (flare onset) and decayed at 06:33 UT; the southeastern two ribbons (C and D) began brightening at 05:54 UT and reached their maximum at flare maximum.

Before 06:58 UT, SXR images showed a wide, short and loose loop L1 that actually consisted of several small loops close each other. The feet of L1 was found to be anchored in Hα ribbons A and B after coalignment was made between the Hα image at 06:01 UT and the magnetogram at 05:24 UT (figure 8a). L1 weakened at 08:17 UT and three other SXR loops (L2, L3, and L4) became more evident, which connected B and the south of N2, B and N4, and N4 and S4 respectively.

We did not see any SXR loop connecting Hα ribbons C and D. This is possibly because the loop was too low to reach the coronal level, due to the short distance between Hα ribbons C and D. The potential fields in figure 7 also show this point.
3.3. 1N/M1.5 Flare of 1993 December 26

3.3.1. Evolution of AR 7640 and its magnetic configurations

Active region 7640, passing across the solar disk from 1993 December 20 to 1994 January 2, was a newly born active region, which was characterized by a continuous emergence of new magnetic flux. Seven M-class flares were produced during this period.

Figure 10 shows the evolutions of AR 7640 and its magnetic configurations. AR 7640 is an extended active region whose main preceding sunspot, S, and following sunspot, N (not shown in figure 10), were separated by about 14° in longitude, although they were almost at the same latitude on December 24. More than ten satellite sunspots were scattered around the preceding sunspot. Another small active region, AR 7641, was located just to the south of AR 7640. The magnetic configuration was relatively simple, and no strong shear was present on this day, even though there was a positive polarity region in the main negative polarity and a negative one in the main positive polarity, which complicated the magnetic configuration. The main connection patterns were that N1 was connected to S1 and S5, and N2 was connected to S and S3 (figure 10a).

Both the active region and its magnetic configuration underwent phenomenal changes from December 24 to December 25. More satellite sunspots and several pairs of emerging flux appeared and grew in size in the area to the southeast of the preceding sunspot. The significant emerging fluxes were N5 and S6, N4 and S7, N3 and S8. The growth of N2 and S5 was particularly extensive (figure 10b). As a result, N3 was separated from the main positive polarity, and N1 and N4 were almost merged.

This flare may be explained by strong shear on the neutral line segment near the positive peninsula magnetic feature and the emerging flux near S2 and N2. The main energy release site should be in or near loop L1. The brightening of L2, L3, and L4 could be secondary effects of the flare energy release. Figure 9 schematically shows this interpretation.
Fig. 13. Temporal variations of the four kinds of average shear angles defined in section 2 along the flaring neutral line for all of the eight active regions. The NOAA active region number, observation date and flaring time are indicated in each figure. The flare peak times are indicated by arrows. The numbers (1)–(4) labeled besides the curves represent the four kinds of average shear angles respectively.
The flux emergence increased the magnetic fields and changed the magnetic connection patterns in the region, and established strong magnetic shear along the magnetic neutral line. From the magnetogram at 04:31 UT on December 25, we can see that the connection patterns were rather complicated compared with the day before. S6 was mainly connected to N5 instead of N1, and N1 was connected S5, while N4 was connected to S7 and N2 was connected to S.

On December 26, the disappearance of N5 resulted in a new connection of S6 to N1, though N1 was still connected to S5 and S4. A new δ-spot appeared near N6 where the studied flare occurred. Meanwhile, a new pair of emerging flux, N7 and S9, appeared near this area. N1, N2, N4, and N6 were mingled while N2, N4, N6, S2, and S7 were squeezed (figure 10c).

From the connection patterns we can distinguish two magnetic-flux systems on December 26. The first, characterized by its high shear, consisted of N1, N4, S4, S6, and S7; the second was composed of already-existing N2, S5, and newly emerged N7 and S9. The shear along the neutral line around the second flux system showed some variation around the flare time, probably due to the varying seeing coupled with the small size of the structure.

The active region AR 7640 was characterized by strong magnetic shear on the neutral line. The average shear in the flaring area decreased significantly after the flare (see section 4). However, the average shear angle on the magnetic neutral line did not change much after the flare. On the contrary, it has a tendency to increase.

3.3.2. Hα and X-ray flare

The Hα flare studied here was initiated at 04:02 UT on December 26, reached its maximum in 11 min, and ended at 04:44 UT according to the Solar Geophysical Data. After coaligning Hα image with the magnetogram obtained by the SFT, we found the following facts. At the flare onset, the area around the δ-spot began brightening first and became the main Hα brightening A. About 7 min later another Hα bright area, B, appeared near S4. A and B spanned across the neutral line near the δ-spot and S4 respectively, and each of them comprised two small ribbons, one located in positive magnetic polarity and the other in negative magnetic polarity (figures 11b and 12).

We have no SXR image for the flaring period, but SXR images about 30 min before the flare onset allow us to study the pre-flare SXR configuration. After coaligning the SXR image at 03:33:27 UT, Hα images at 04:13 UT and 04:15 UT with the magnetogram from the SFT at 04:00 UT, we can see several SXR loops in this area. One of them was located close to (but not exactly at) the flare ribbon B. There is no loop connecting (or within) A. A possible reason for this is that the magnetic flux did not reach the coronal level, or no pre-flare loop was present there.

A schematic interpretation of this flare is given in figure 12. Possible locations of loop footpoints are indicated by hatched areas. The high magnetic shear along the neutral line is responsible for this flare. The energy of the flare may come from not only the strongly sheared transverse components of the magnetic fields, but also the highly stressed longitudinal components (Wang 1995).

4. Flare-Related Shear Changes

In this section, we describe the flare-related changes of the average shear angles on the neutral lines and flaring areas responsible for the eight flares which we studied.

4.1. Shear Changes on the Neutral Lines

We calculated the four kinds of average shear angles defined in section 2 along the flaring neutral lines for all of these active regions. We computed the average shear angles for all magnetograms that were obtained in the period from about an hour before the flare onset to about an hour after the flare end to study their temporal variations. There are exceptions, namely, the flare of 1992 October 10 that ended at a time beyond our observation and the flare of 1998 November 28 that lasted until just before the end of our observing day. The curves of their temporal variations are presented in figure 13. The flare-related average shear changes on the neutral lines for these flares are quantitatively given in table 1.

As can be seen in figure 13 and table 1, the four kinds of shear angles have almost the same trend of temporal variation, even though their values may differ considerably, as that of AR 7321. The average shear angles increased 2°−4° after four of the eight flares, and decreased 2°−4° after two flares, and did not show any detectable changes after the other two flares. The average shear angles on the neutral lines of AR 7461, AR 7640, and AR 7912 showed a continuous increase from about one hour before the flare onset. Those of AR 7321 and AR 7765 decreased before and increased after the flare onset, and then began decreasing again in the decaying phase of the flares. The average shear angles increased before the flare onset and started decreasing after the flare onset in AR 8395.

4.2. Shear Changes in the Flaring Area and the Full Field of View

We also calculated the shear changes in the full field-of-view of SFT for these active regions. We chose two magnetograms of high quality for each active region, which were obtained at times with good weather condition before and after the flare, to compute the overall shear changes of the active region. The results are given in
Fig. 14. Shear changes after the flares for all the eight active regions studied. The shear changes are displayed as background images and the longitudinal fields as thin black contours with the same contour levels as in figure 1. Hα flare ribbon locations near the flare maximum are plotted as thick dark contours. The flare-related shear changes for AR 7306, AR 7321, AR 7461, AR 7640, AR 7765, AR 7834, AR 7912, and AR 8395 are given in (a) through (h) respectively. The scale of shear changes in degrees is shown at the top of figure 14a. The observation times of magnetograms and Hα images used are presented in table 2.

figure 14, where the flare-related shear changes are displayed as background images and longitudinal fields as contours. Hα flare sites are also shown as thick dark contours in these figures to indicate their spatial relationships, and we use these Hα contours to define the flaring area of each active region. The FOV of our observation is 340″ × 320″. To be more precise, we show a portion of the full FOV in figure 14, except for AR 8395, due to the wide range of the Hα ribbons of the corresponding flare. The observation times of selected magnetograms and Hα images are tabulated in table 2.

To illustrate the flare-related shear changes quantitatively, we calculated the average shear change over the flaring area of each active region defined by Hα ribbons. Meanwhile, we also computed the ratio of the number of points undergoing shear decrease in the flare to the total
number of points in the flaring area. The results are tabulated in Table 2. We also give the maximum shear angle on the portion near to the Hα ribbons of the neutral line for each active region listed in Table 2.

Figure 14 demonstrates the flare-related shear changes qualitatively. We noticed that the shear changes in the displayed area could be positive and negative. The shear changes in Figure 14 show discontinuity at some points (jump from positive to negative or from negative to positive). The difficulty in resolving the 180° ambiguity of the transverse field leads to these discontinuities. As can be seen in Table 2, the average shear in flaring areas of AR 7321 and AR 7640, which are characterized by high magnetic shear, decreased significantly after the flare. Calculations show that more than 80% of the points in the flaring areas of these two active regions underwent shear decrease after the flares. The shear change in AR 7306 did not show this tendency, but this may be because we used a magnetogram just before the flare maximum to derive the shear change, because the flare end is out of our observation time.
Table 2. Flare-related shear changes in the flaring area of the studied active regions.

<table>
<thead>
<tr>
<th>Active region</th>
<th>Maximum shear angle* (degree)</th>
<th>Time of magnetograms (UT) Before flare</th>
<th>After flare</th>
<th>Time of Hα image (UT)</th>
<th>Average shear change in flaring area (degree)</th>
<th>Points of shear decrease (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7461 ..........</td>
<td>58</td>
<td>00:50</td>
<td>01:50</td>
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<td>4.78</td>
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<td>64</td>
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<td>01:05</td>
<td>3.66</td>
<td>46</td>
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<td>60</td>
<td>01:29</td>
<td>02:26</td>
<td>01:49</td>
<td>7.06</td>
<td>40</td>
</tr>
<tr>
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<td>50</td>
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<td>05:36</td>
<td>05:04</td>
<td>−9.30</td>
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</tr>
<tr>
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<td>05:42</td>
<td>−1.88</td>
<td>56</td>
</tr>
<tr>
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<td>87</td>
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<td>06:12</td>
<td>06:01</td>
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<td>88</td>
<td>00:00</td>
<td>01:18</td>
<td>00:23</td>
<td>−28.5</td>
<td>81</td>
</tr>
<tr>
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<td>03:42</td>
<td>05:00</td>
<td>04:15</td>
<td>−26.5</td>
<td>86</td>
</tr>
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</table>

*Maximum shear angle on the portion of the neutral line near the Hα ribbons.

5. Discussion and Conclusions

We considered five flares greater than X-ray class M/Hα importance I in Paper I, which are associated with low magnetic shear, but are associated with emerging flux. In this paper, we have presented the evolutions of three active regions characterized by strong magnetic shear, while considering the spatial relations among Hα ribbons, SXR flare loops and magnetic configurations for three M-class flares produced in these active regions. All three flares occurred near to the segments of the neutral lines where angular shear is high and the transverse components of magnetic fields are strong. The maximum values of the transverse field strength on the neutral lines are 700–900 G. The maximum angular shear on the neutral lines for all three flares are over 85° before the flare. However, the interval along the neutral line in which the angular shear remains greater than 80° extended for 10000–12000 km only in the case of AR 7321. The interval reduced to about 6000 km after the flare, implying that the highly sheared magnetic fields had been relaxed during the flare. In the other two cases, the interval of high shear was only about 2000–3000 km, even though strong shear was present in the two active regions. Therefore, only the 1N/M1.0 flare of 1992 October 27 satisfies the sufficient conditions for a flare to occur prescribed by Hagyard (1990). However, our results are still consistent with Hagyard (1990), since she suggested that those conditions are sufficient conditions.

The formation of high magnetic shear in all three active regions was due to the emerging flux in the active regions. Meanwhile, the separating motion of sunspots in AR 7321 may have contributed to the formation of the corresponding high shear. Actually, it was the strong emerging flux responsible for the birth of this big active region near to the solar meridian on 1992 October 24. The continuous flux emergence in AR 7321 and AR 7640 resulted in the appearances of new sunspots, brought in the formation of high shear and complex magnetic configurations, and enhanced the magnetic field strength in these regions. Moreover, the flux emergence in AR 7640 also separated the main polarity, leading to the appearance of a δ-spot, which was the place where the studied flare occurred. As the flux emergence continued, the high shear formed gradually and the energy to drive the flares was stored consecutively in the transverse components of the magnetic fields. On the other hand, highly stressed longitudinal fields may have had a contribution to the required energy (Wang 1995). In conjunction with what we discussed in Paper I, emerging fluxes are a common feature in all eight flares listed in table 1.

The flare-related changes of the four kinds of average shear angles on the neutral line are not significant for all eight active regions, as shown in figure 13. The average shear angles have different behaviors in these active regions, even though in each active region they have similar temporal profiles with some difference in value. In two cases, AR 7321 and AR 7765, the average shear angles showed a decrease before and an increase after the flares, followed by a decrease in the decaying phase of the flares. In three cases (AR 7461, AR 7640, and AR 7912), they showed a continuous increase before and after the flare. In AR 8395, they showed an increase before and a decrease after the flare onset. In the other two cases, they were on the order of the noise level. However, these changes were about 2°–4°, and we can hardly assure that they were associated with the flares. There are a few factors that may contribute to these changes, such as variable seeing, the photospheric oscillation, the ongoing evolution of the active region, and the observation instrument, itself (Hagyard et al. 1999).

We use the Hα ribbons near to the flare maximum to
define the flaring area for an active region. The average shear changes in the flaring areas are different from that on the neutral lines. As can be seen in table 2, they evidently decreased after theflares which can be associated with strong magnetic shear, as in AR 7321 and AR 7640, even though the average shear angles on the neutral lines showed only small changes. This indicates that, in the high-shear-associated cases, all of the points in the flaring area have their own contributions to the energy required to power the flare, and the highly sheared magnetic fields are relaxed markedly for these points after the flare. The average shear change in the flaring area may be a better parameter to characterize the flare-related magnetic shear changes in such cases. In the cases associated with low magnetic shear, they once again showed small changes after the corresponding flares, exhibiting both positive and negative changes.

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References

Hagyard M.J., Rabin D.M. 1986, Adv. Space Res. 6, 7
Li H., Sakurai T., Ichimoto K., Ueno S. 2000, PASJ 52, 467 (Paper I)
Sakurai T. 1982, Sol. Phys. 76, 301