The Development of Magnetic Shear

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Abstract

The current concept of magnetic shear is visualized from a global sense. The external linkage or compression of two sets of current-carrying magnetic loops seems to be the basic topology of sheared magnetic field. Internal twisting of magnetic lines of force has not been incorporated into the shear presentation. As a fully three-dimensional phenomenon, more efforts are crucially needed to understand the characteristics of magnetic shear in the higher atmosphere.

Two modes of shear creation are suggested. One is named as *Tanaka mode* according to which the strong sheared field emerges from below the photosphere. The other is the *generation mode* in which the interaction between plasma motion and the magnetic field is responsible for the local changes of shear status.

1 Introduction

The concept of magnetic shear has occupied a central position in the study of flare-associated changes in the magnetic field since early of 1970's (Zirin and Tanaka, 1973). Particularly after the introduction of a quantitative measure of magnetic shear by Hagyard et al.(1984), the shear observation has become one of the most important aspects in flare research. However from physical sense, what is meant and what kind of magnetic topology is implied by the term of magnetic shear, and what causes the changes of the shear status? On the other hand, from observational point view, how could we describe the magnetic shear more accurately? All these questions are addressed in this paper with the purpose to provide possible guidance for further studies in this working area.

2 Topology of Sheared Magnetic Field

The magnetic shear was first recognized from the morphology of H_α fibrils or filaments, which were in alignment with the magnetic neutral line in flare studies (Zirin and Tanaka, 1973). A quantitative measure of magnetic shear was suggested then by Hagyard et al.(1984). They defined the angular shear, $\Delta\phi$, on the photosphere as the azimuth difference between the observed vector field and a potential field which shares the line-of-sight field with the observed one. The following studies were almost entirely concentrated on the angular shear on the magnetic neutral line. Intrinsically, the shear is represented by a bundle of strong transverse field, or a sets of flux loops aligned with the magnetic neutral line. However, the magnetic neutral line, in fact, is specified by

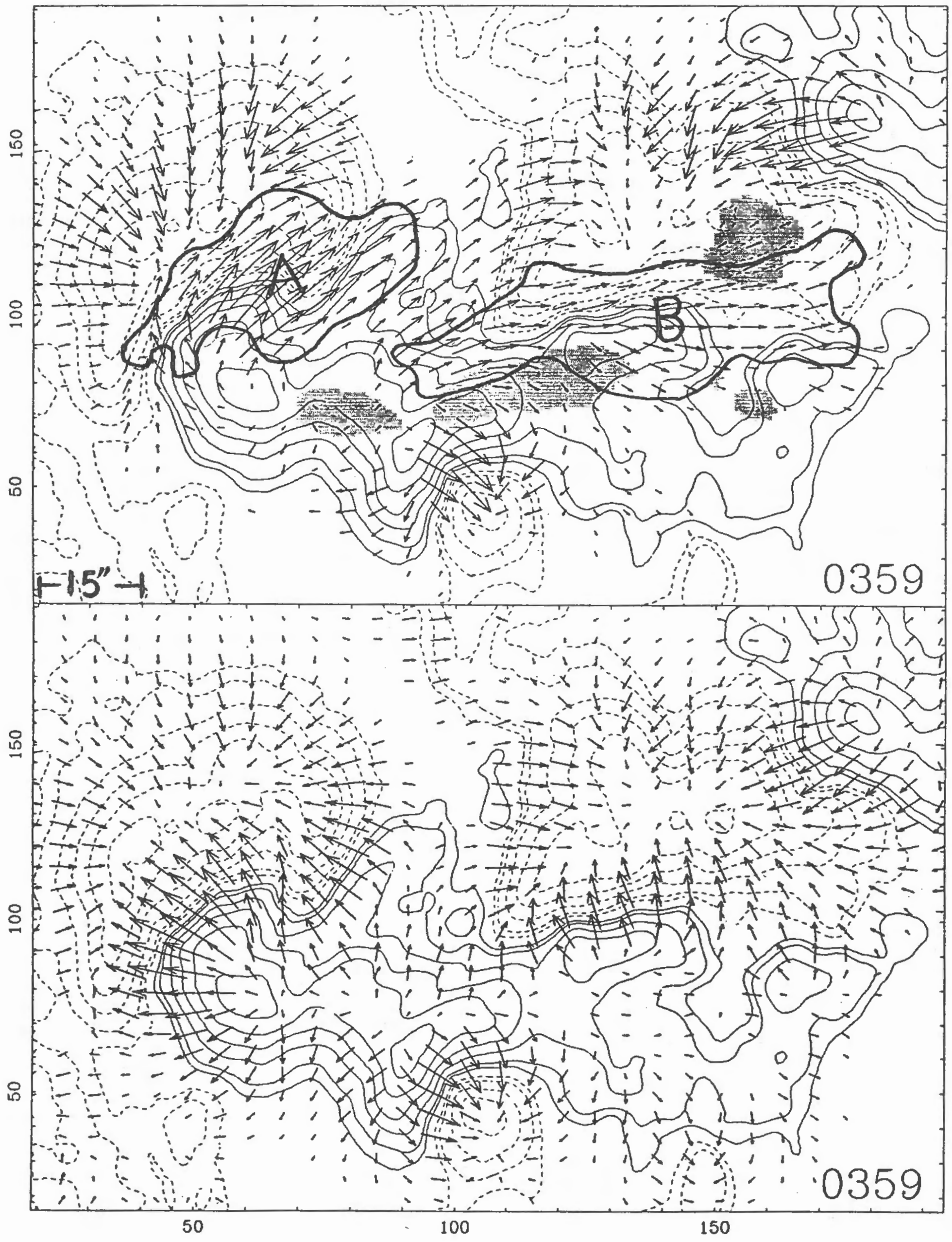

Fig.1 An example of strong sheared field in AR 6233. The upper part is the observed vector magnetogram with removed ambiguity in field azimuth. Line-of-sight field is represented by isogauss contours with solid (dashed) lines for positive (negative) polarity. The transverse field is represented by arrows with length proportional to the relative field strength. The lower part is the corresponding potential field. Two strong sheared zones 'A' and 'B' are shown by thick contours.

the global distribution of line-of-sight magnetic field. Therefore, the magnetic shear is basically visualized from a global sense. As a fact of matter, the internal twisting of magnetic line of force has been ignored in the shear presentation. Magnetic field is a vector field. In a narrow sense, the term of shear commonly means that either some external forces have pushed the vector away from the the status of minimum stress to some new status in a certain volume, or some discontinuity has been created in a certain scope of the vector field. Thus, the real shear angle of the vector magnetic field should be that suggested by Lü et al.(1993), while the angular shear of Hagyard et al.(1984) is merely its projection on the photosphere. The deviation from the minimum stress, or the discontinuity of the magnetic field, clearly indicates that currents are flowing in a certain volume of the vector magnetic field.

In Figure 1, a typical example of strong sheared field in AR 6233 is shown by observed vector magnetogram (upper part) and the corresponding potential configuration (lower part). The line-of-sight component is presented by isogauss contours with solid (dashed) lines for positive (negative) polarity, the transverse component is presented by arrows with length proportional to the relative field strength. Two strong shear zones 'A' and 'B' are marked by thick contours indicating the sites of higher free magnetic energy (Wang et al., 1993). Flare ribbons of a 1M flare is superposed as grey patches. Now the question is what we really observed in the case for the strong shear zones. In the example 'B', the strong transverse field lines are aligned with the main neutral line. This can only means that currents are flowing from the northern side of the zone 'B' – the negative field area, into the southern side – the positive field area. The vertical current deduction has supported this speculation exactly (Wang et al., 1993). However, we know that anti-parallel to the currents there must be magnetic lines of force-free field. Moreover, the low-lying magnetic loops of strong shear zone 'B' themselves might be current-carrying as well. Hence, we actually observed the linkage of two sets of current carrying loops in this example. The strong shear zone 'A' could interpreted in the same way. The external linkage of current-carrying loops appears to be the basic topology of strong sheared field.

This example shows that shear takes place in a fully three-dimensional domain in a certain volume of the vector field. However, so far, only the shears on the photosphere have been studied. Even two-dimensional mapping of magnetic shear is rare in the solar literature. No information on the shear development in the vertical extent, or, in the higher atmosphere has been extracted seriously. For this, we suggest that to study the shear development in the higher atmosphere is of greatest importance, and Yohkon soft X-ray images are extremely useful for this study. With regard to the analysis of vector magnetogram on the photosphere, two-dimensional mapping of the magnetic shear is necessary for getting accurate information on the shear development.

3 Shear development

3.1 Observations

Observational studies have shown that the magnetic shear can be created by the following ways.

(1) Shear motion of magnetic footpoints with opposite polarity on both sides of the magnetic neutral line;
(2) Collision of opposite polarity fields from two independent magnetic loops, particularly between new emerging flux to old flux loops;
(3) Emergence of strong sheared field directly from below the photosphere;
(4) Flux cancellation which may convert the line-of-sight field to the transverse field in some cases.

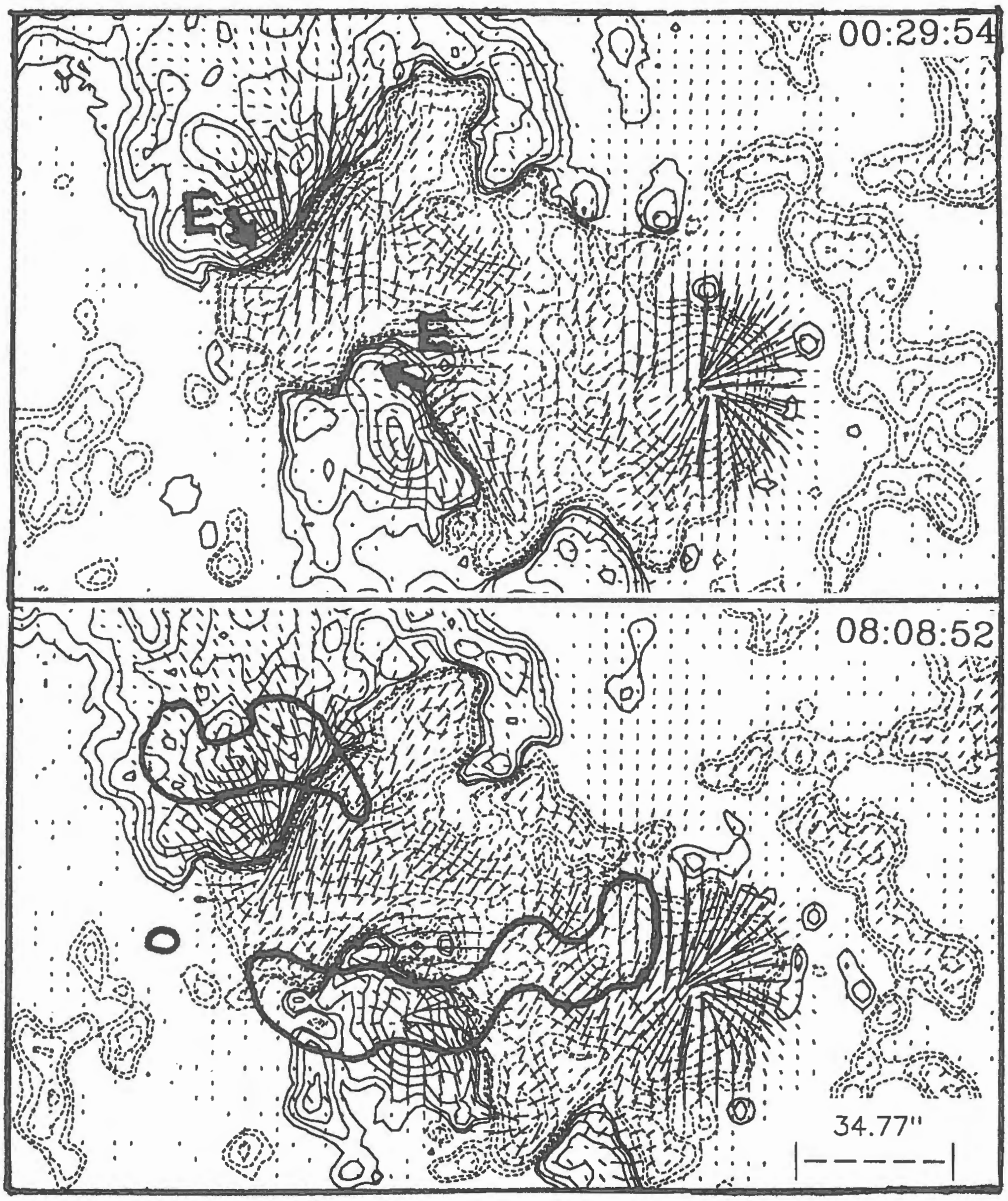

Fig.2 An example of shear development by collision of new EFRs with pre-existing flux loops. EFRs are marked by a letter 'E', collision motion is indicated by arrows.

Excellent examples of category (1) are found in Wang et al. (1991) for AR 5395; Typical examples for category (2) is shown by Gaizauskas and Harvey (1986) and Ai et al.(1991); Tanaka (1991) and Kurokawa (1991) present convincing examples for category

(3); while Martin and Livi (1991) demonstrate the fourth category. Complicated cases including somehow the combination of any two or all above categories are also not uncommon.

In Figure 2, an example of shear development by collision of new EFR (emerging flux region) loops with pre-existing magnetic loops in AR 6089 is shown by Huairou vector magnetograms. The earliest signature of these EFRs may traced back to June 9. The EFR positions are marked by letter 'E', the collision motion is seen at two pieces of neutral line and indicated by arrows in the first panel. It was not until the positive pole crushed into the pre-existing negative flux on June 10 that obvious magnetic shear appeared at these two pieces of neutral line. Shear strengthening can even be found in the interval between taking the two magnetograms in the figure. A major flare appears around 07:12 UT on June 10, which is shown by thick contours in panel 2.

3.2 An analytical discussion

In a previous paper(Wang, 1992), we have demonstrated that magnetic shear can be approximately described by the non-potential character of a force-free field. The force-free factor α, or the normalized current helicity would be a measure of magnetic shear. The temporal evolution of α can be analytically expressed as

$$\frac{d\alpha}{dt} = \frac{1}{B^2}\nabla \cdot \mathbf{G} + \mathbf{V} \cdot \nabla\alpha, \tag{1}$$

where, $\mathbf{G} = \frac{\partial \mathbf{B}}{\partial t} \times \mathbf{B}$. The first term on the right represents the local generation of the shear, and $\mathbf{G}$ serves as the source function of magnetic shear. The second term on the right is the shear transportation caused by the non-uniformity of α in space. It is noticed that the Ohmic diffusion is capable of changing the shear status by virtue of $\frac{\partial \mathbf{B}}{\partial t}$. When Ohmic diffusion is ignored, the generation term appears as

$$\frac{\partial\alpha}{\partial t} = \frac{1}{B^2}\nabla \cdot \{[\nabla \times (\mathbf{V} \times \mathbf{B})] \times \mathbf{B}\}. \tag{2}$$

For not missing the generality, assume the $\mathbf{B} = B\mathbf{e}_z$, then

$$\frac{\partial\alpha}{\partial t} = \frac{\partial}{\partial z}(\frac{\partial V_y}{\partial x} - \frac{\partial V_x}{\partial y}) + \frac{1}{B_z^2}(V_y\frac{\partial}{\partial x} - V_x\frac{\partial}{\partial y})\frac{\partial B_z^2}{\partial z} + \frac{1}{B_z^2}[\frac{1}{2}(\frac{\partial V_y}{\partial x} - \frac{\partial V_x}{\partial y}) + \frac{\partial}{\partial z}(V_y - V_x)]\frac{\partial B_z^2}{\partial z} \tag{3}$$

This equation shows that the gradients of velocity and/or magnetic fields are decisive factors for shear generation. For instance, the first term on the right is the z derivative of *curl*$\mathbf{V}$, which indicates that as long as there is curly motion, the shear status may be altered no matter the motion is sheared, or collided.

For the flare study, the total shear evolution in an active region is more relevant. If the region is isolated from other regions, then the only open surface of the magnetic field would be the photosphere. Thus

$$\iiint_V \frac{d\alpha}{dt} \cdot dv = -\iint_{photos.} [\frac{B_\perp^2}{< B^2 >}\frac{d\phi}{dt} + \alpha V_z] \cdot ds \tag{4}$$

Where, ϕ is the field azimuth, $B_\perp$ is the transverse field on the photosphere, and $< B^2 >$ is some medium value of B^2 in the integration volume. Shear is generated by the plasma motion which either makes the vector field rotate to the sheared configuration, or transports the shear through the open surface. For the convenience, we may divided the shear changes into two modes: the generation mode represented by the first term and the migration mode represented by the second term. Tanaka is the first author who clearly stated that the sheared field was emerged from below the photosphere. Therefore we suggest to name the second mode as Tanaka mode.

4 Concluding Remark

In this discussion, we have suggested that the magnetic shear represents an external linkage of current-carrying magnetic loops. Both observations and analytical deductions show that shear is created by either the local generation from interaction of plasma motion and the magnetic field, or the transportation of strong sheared field directly from below the photosphere.

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