EXPLORATIONS OF ELECTRIC CURRENT SYSTEM IN SOLAR ACTIVE REGIONS

I. *Empirical Inferences of the Current Flows*

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Abstract. In this paper we explore techniques to identify sources of electric current systems and their channels of flow in solar active regions. Measured photospheric vector magnetic fields (VMF) together with high-resolution white-light and Hα filtergrams provide the data base to derive the current systems in the photosphere and chromosphere. Simple mathematical constructions of fields and currents are also adopted to understand these data. As an example, the techniques are then applied to infer current systems in AR 2372 in early April 1980. The main results are: (i) In unipolar sunspots the current density may reach values of 10^3 CGSE, and the Lorentz force on it can accelerate the Evershed flow. (ii) Spots exhibiting significant spiral pattrn in the penumbral filaments are the sources of vertical major currents at the photospheric surface. (iii) Magnetic neutral lines where the transverse field was strongly sheared were channels along which strong current system flows. (iv) The inferred current systems produced oppositely-flowing currents in the area of the delta configuration that was the site of flaring in AR 2372.

1. Introduction

Electric current systems are presumed to exist in solar active regions, perhaps in the form of filamentary currents proposed by Rabin and Moore (1984) as the source of heating the lower transition region, or as large-scale current systems in solar prominences. Indeed, currents are required to flow in upper atmosphere above sunspots, providing the superpotential energy that is ultimately released in the form of flares. Observational evidences for current system is derived from studying the morphology of solar features where magnetic fields are known to play fundamental roles. For example, by studying high-resolution white-light photograms of sunspot groups, scientists have inferred the presence of vertical electric currents flowing from spots that exhibit pronounced spiral patterns in the penumbral filaments (Solar Division of Yunnan Observatory, 1974a, b). Numerical estimates of currents on the Sun can be derived from VMF observation using the relation between current and the field rotation (curl), but these measurements give us information only on the vertical component of the current. However, even this limited information has proven valuable since scientists have found correlations between the locations of these current concentration and various manifestations of solar activity such as flares (Moreton and Severny, 1968; Hagyard *et al.*, 1984) and heating leading to enhanced ultraviolet emission (DeLoach *et al.*, 1984).

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In this paper we present an observational study to determine the large-scale current systems flowing in active regions. Some simple mathematical constructions for the current and fields are also adopted in case of necessity. In the next section we discuss first the current systems in a simple unipolar sunspot using an observational model of magnetic fields. In Section 3 we extend the model to the case of a simple bipolar field and show the difference that result when the observed transverse field has either a 'potential' or a sheared configuration in the vicinity of the neutral line. In Section 4 we indicate how observations of Hα fibrils can be used to trace chromospheric current systems and how these are connected to photospheric currents. In the last section we apply these techniques to infer large-scale currents flowing in a flare-productive active region.

2. Electric Currents in Unipolar Spots

2.1. Current Expressions

To investigate currents in sunspots, as a starting point we research the observational model of cylindrically-symmetric VMF in unipolar sunspots (Allen, 1973) given by the equations:

$$\left.\begin{aligned} &\mathbf{B} = (B_r, B_\varphi, B_z)\,, \\ &B_r = B_z \tan\theta\,, \\ &B_\varphi = 0\,, \\ &B_z = B_0 \exp(-a\zeta^2) f(\zeta, h)\,, \end{aligned}\right\} \qquad (1)$$

where $a = 2.1$, $\zeta = r/R$, $h = z/R$, $\theta = \theta_0 \zeta$ with $\theta_0 = 75° = 1.309$ arc deg, R is the outer penumbral radius, B_r, B_φ, and B_z are the radial, azimuthal, and vertical components of the magnetic fields, respectively, B_0 is the field strength at the center of the sunspot and at $h = 0$. The function $f(\zeta, h)$ is determined from the condition that the field have zero divergence:

$$\nabla \cdot \mathbf{B} = 0\,. \qquad (2)$$

This leads to the following differential equation for $f(\zeta, h)$:

$$\frac{\partial \ln f}{\partial h} + \tan\theta \,\frac{\partial \ln f}{\partial \zeta} + \frac{1}{\zeta} \tan\theta + \theta_0/\cos\theta - 2a\zeta \tan\theta = 0\,. \qquad (3)$$

The boundary conditions on $f(\zeta, h)$ are:

$$\left.\begin{aligned} &f(\zeta, h) \to 0 \quad \text{for large } h\,, \\ &f(\zeta, 0) = 1\,, \end{aligned}\right\} \qquad (4)$$

so $B_z(\zeta, 0) = B_0 \exp(-a\zeta^2)$ is consistent with values derived from the observed line-of-sight magnetic field. An algebraic expression of $f(\zeta, h)$ or $f(\theta, h)$ that satisfied these conditions is:

$$f(\theta, h) = \frac{\xi \cos\theta}{\theta\eta} \exp\left[\frac{a}{\theta_0^2}(\theta^2 - \xi^2)\right] \tag{5}$$

with

$$\xi = \arcsin[\sin\theta \exp(-\theta_0 h)], \tag{6a}$$

$$\eta = [\exp(2\theta_0 h) - \sin^2\theta]^{1/2}. \tag{6b}$$

Using Ampère's Law,

$$\mathbf{J} = (c/4\pi)\nabla \times \mathbf{B}, \tag{7}$$

we can calculate the currents from the field:

$$\left.\begin{aligned} &J_r = 0, \\ &J_z = 0, \\ &J_\varphi = \frac{cB_0\theta_0\xi}{4\pi R\theta\eta^2}\exp(-a\xi^2/\theta_0^2)\left(\frac{2a\xi}{\theta_0^2} - \frac{\sin\theta}{\eta} - \frac{\theta - \xi\eta\cos\theta}{\theta\xi}\right). \end{aligned}\right\} \tag{8}$$

Thus, for an unipolar sunspot with no azimuthal field described by Equation (1), the radial and vertical components of the currents **J** could not exist. The only azimuthal one J_φ shown in Figure 1 can occur, flowing along the isogauss contours of B_z in accordance with the right-hand rule (Figure 3) and crossing the field. It might be understood that below the height of $z = 200$ km the magnetic field does not have to be force-free because of the plasma beta being of 0.22–0.61.

2.2. How to understand the current presence

We discuss the problem of the current presence still based on the observations. One can see from Figure 1 that the estimated J_φ will reach its maximum value of 2×10^3 CGSE = 7×10^{-3} A m^{-2} in outer part of the penumbra, while $B_0 = 3000$ G, $R = 15$ arc sec, and $h = 0.01$ ($z = 100$ km). And the higher the current density J_φ is weaker. Denisenko *et al.* (1982) have found the currents with much higher values of 10^5 CGSE in an unipolar sunspot with very long-life. They obtained three magnetic fields in the lines of Fe I 4808 Å, Ca 6103 Å, and Hα. The current densities were derived in the space between levels of the line formation. Denisenko *et al.* concluded that the sunspot magnetic field below lower chromosphere deviated strongly from potential configurations.

It is well known that the Lorentz force on the currents could drive mass motions which might be observed in sunspots. The dynamic equation in stable sunspots is

$$\rho(\mathbf{v}\cdot\nabla)\mathbf{v} = -\nabla P + \frac{1}{c}\mathbf{J}\times\mathbf{B} - \rho\mathbf{g}, \tag{9}$$

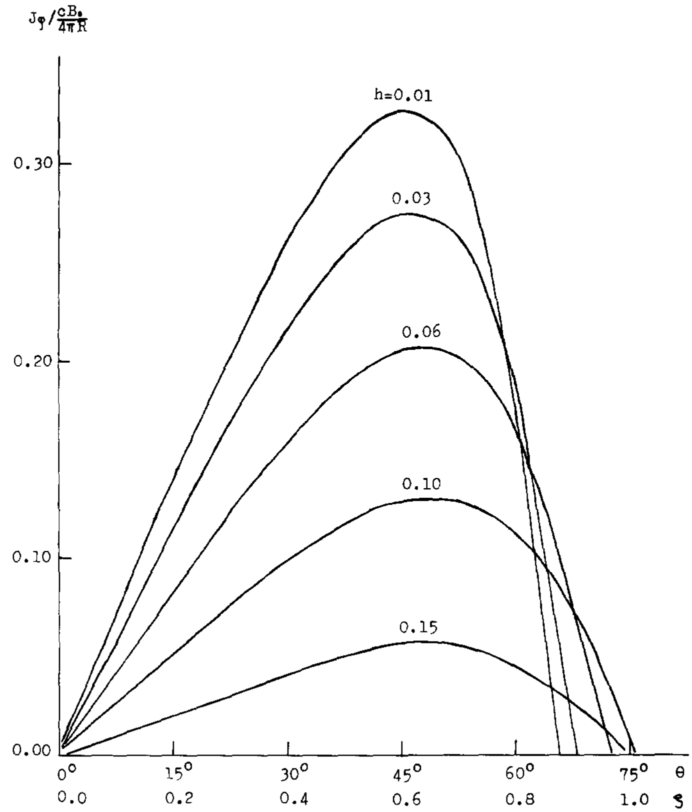

Fig. 1. Variation of the azimuthal current density J_φ with radius and height in simple unipolar sunspots.

where ρ is the material density, P is atmospheric pressure, **v** is velocity of flows, **g** is gravity acceleration at the photospheric surface. Simplifying Equation (9), we remind that $B_\varphi = 0$ and $J_z = J_r = 0$ in Equations (1) and (8), respectively. On the other hand, the observations of line-shift with an absolute wavelength reference showed neither vertical outflows nor vortex flow exceeding 50 m s^{-1} in unipolar sunspots (Beckers, 1977, 1981; Adam, 1979). But the radial velocities of Evershed flow in the photosphere average about 1–2 km s^{-1} at maximum. However, local outflow velocities in dark penumbral channels can reach values of 4–6 km s^{-1} (Athay, 1981; Bumba, 1960; Holmes, 1963; Mattig and Mehltretter, 1968; Beckers, 1969); then we get

$$v_r \gg v_z \approx v_\varphi \approx 0 . \tag{10}$$

Sunspot atmospheric models (Allen, 1973; Zwaan, 1974; Staude, 1981; Schatten, 1981) enable us to derive magnitudes of $\partial P/\partial z$ and ρg being in order of 10^{-2} dyne cm^{-3}, whereas the Lorentz force in Equation (9) is merely of 10^{-4} dyne cm^{-3} and can be negligible. So the vertical gradient of the pressure is balanced by the gravity, and the materials should be in magnetostatic equilibrium (Hu, 1984). Therefore, only the radial component of Equation (9) remains:

$$\rho v_r \frac{\partial}{\partial r} v_r = -\frac{\partial P}{\partial r} + \frac{1}{c} J_\varphi B_z . \tag{11}$$

Supposing that the distributions of the material density and the temperature in the umbra and in dark penumbral channels of a sunspot are nearly homologous via r, but in bright penumbral channels are the same as those in the surrounding photosphere, then the radial gradient of the pressure could be negligible and the Equation (11) can be reduced. The solution will be

$$\frac{1}{2} \rho v_r^2 = \frac{1}{c} \int_0^r J_\varphi B_z \, \mathrm{d}r . \tag{12}$$

Obviously, the kinetic energy of the Evershed flow is mainly generated by Lorentz force. We rewrite the solution using $\beta_E(\theta, h)$:

$$\beta_E(\theta, h) = \frac{1}{2} \rho v_r^2 \Big/ \frac{B_0^2}{8\pi} = (v_r/v_A)^2 , \tag{13}$$

where

$$\beta_E(\theta, h) = 2 \int_0^\theta \frac{\xi \cos\theta}{\theta^2 \eta^3} \left(\frac{2a\xi}{\theta_0^2} - \frac{\sin\theta}{\eta} - \frac{\theta - \eta\xi\cos\theta}{\theta\xi} \right) \exp(-2a\xi^2/\theta_0^2) \, \mathrm{d}\theta . \tag{14}$$

The numerical integral of $\beta_E(\theta, h)$ shown in Figure 2 tells us that the calculated velocity of flow reaches maximum value of $v_r = 0.45 v_A \approx 4$ km s^{-1} near the outer part of the penumbre while $B_0 = 3000$ G, $h = 0.01$, and $v_A \approx 9$ km s^{-1}. And the higher the velocity of flow is lower. Our value is close to that observed in dark penumbral channels, and higher than the average ones. Perhaps, in the bright channels the higher pressure decreases the velocity of the flow coming from the umbra. And the magnetic strength there is much lower, leading to a powerless accelerator because of the Lorentz force being proportional to B^2, so the average value should be a low one. It is the same reason that velocities of radial flows outside sunspots decrease to be zero.

Summarizing mentioned above, we can understand that: (i) The currents in sunspots below lower chromosphere is realy existant, and could be detected by use of different observations. (ii) The Lorentz force on the currents is too small to cause the unipolar sunspots into instabilities, however, strong enough to accelerate the Evershed flow there.

Finally, we should note that the assumption of a linear function ($\theta = \theta_0 \zeta$) is reasonable only in case of very small heights. So in the other cases the expressions of $f(\theta, h)$ and J_φ are not correct.

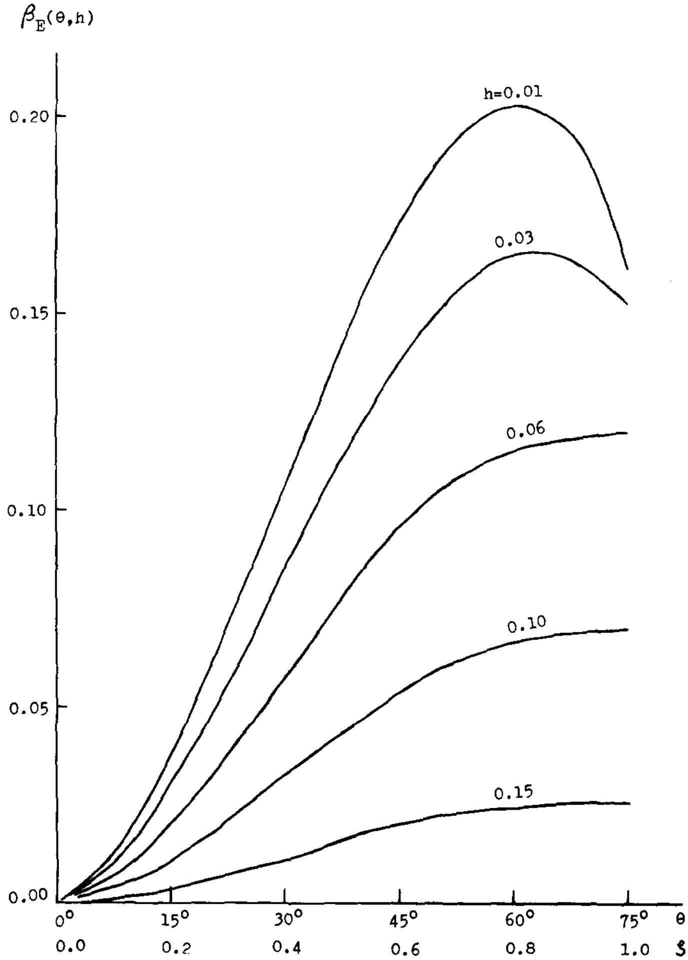

Fig. 2. The calculated relative energy $\beta_E(\theta, h)$ of Evershed flow generated by Lorentz force varies directly as ζ or θ in unipolar sunspots and at different heights below lower chromosphere.

3. Electric Currents in Simple Bipolar Regions

Single unipolar sunspots are rarely observed, more often two sunspots with opposite polarities are visible in close proximity, forming a bipolar group. How do the currents rearrange in these cases? If the magnetic fields of the two sunspots forming a bipole were similar to those of Equation (1), they would produce two circular current systems on both sides of the neutral line (the contour of $B_z = 0$) at lower levels, as indicated in Figure 3. The total horizontal current system flowing between the two sunspots (A and C) is given by

$$I_\varphi = \iint_{\square ABC} J_\varphi \, \mathrm{d}s \tag{15}$$

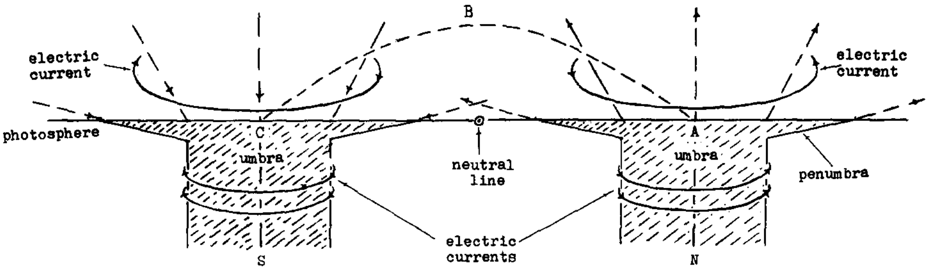

Fig. 3. A sketch of the azimuthal currents in a bipolar sunspot group.

or

$$I_\varphi = \frac{c}{4\pi} \int_{\overset{\frown}{ABC}} \mathbf{B} \cdot \mathrm{d}\mathbf{l} + \frac{c}{4\pi} \int_{\overrightarrow{CA}} \mathbf{B} \cdot \mathrm{d}\mathbf{l} \,, \tag{16}$$

where the integral path is chosen along an arbitrary arch $\overset{\frown}{ABC}$ from A to C and a straight line $\overline{CA}$ from C to A. If the magnetic field of this bipole could be described by a model similar to Equation (1), Equation (8) shows $J_\varphi(\theta, h) > 0$ everywhere in the area $\triangle ABC$. The total integral I_φ must be greater than zero by virtue of Equation (15). In any case, it is manageable to take the arch $\overset{\frown}{ABC}$ nearly along lines-of-force from the positive A to the negative polarity C, then the first term in Equation (16) should be positive whenever. For the radial transverse fields of the spots, the second term integrated along the path $\overline{CA}$ should be negative since the field $\mathbf{B}_t$ and the path increment $\mathrm{d}\mathbf{l}$ are oppositely directed. Therefore, in simple bipolar regions the first term must be larger than the second one.

In many active regions, however, the field between opposite-polarity sunspots appears non-radial or sheared in observations of transverse magnetic field or of penumbral filaments; this is especially true along the neutral lines where flaring occurs. To underscore this difference, we reconstruct Equation (16) in a manner similar to the technique of Hagyard *et al.* (1981), and write the total current as the sum of two terms, I_0 and I_{sh}:

$$I_\varphi = I_0 + I_{sh} \,, \tag{17}$$

where

$$I_0 = \frac{c}{4\pi} \int_{\overset{\frown}{ABC}} \mathbf{B} \cdot \mathrm{d}\mathbf{l} - \frac{c}{4\pi} \int_{\overrightarrow{AC}} B_t \, \mathrm{d}l \tag{18}$$

and

$$I_{sh} = \frac{c}{4\pi} \int_{\overrightarrow{AC}} B_t (1 - \cos \gamma) \, \mathrm{d}l \,, \tag{19}$$

where γ is the angle between $\mathbf{B}_t$ and $\mathbf{dl}$ along $\overrightarrow{AC}$. The current I_0 is that which would be evaluated for the total current I_φ if the field B_t along $\overline{AC}$ appears 'potential' or non-sheared, i.e., the field crosses radially over the isogauss contours and the neutral line between the two spots. It should be noted that the field is not necessarily 'potential' throughout, but only appears to be 'potential'. For this reason, we call I_0 the 'groundstate' current. Generally, the total current I_φ is the sum of I_0 and I_{sh}. For example, a new flux emerging along the channel of a present neutral line can cause the transverse field to turn sheared immediately, but the field high above the group might keep unchanged for tens of hours. In this reconstruction for I_φ, I_0 involves the magnetic field at heights where the field is difficulty measured, and we have to avoid calculating it either the shear along $\overline{AC}$ has or has not any influence on the field along the arch $\overset{\frown}{ABC}$. Whereas I_{sh} can be evaluated from the observed transverse magnetic field along the photospheric path $\overline{AC}$, and it is the direct result of the shear in the field independent of the integral over the arch $\overset{\frown}{ABC}$. I_{sh} represents an 'excess' current caused by the sheared transverse field; it flows along the sheared neutral line and in the direction of I_0. The value of I_{sh} can be estimated as

$$I_{sh} = 1.2ab \times 10^{12}\ \mathrm{A}\,, \tag{20}$$

if $B_t = a \times 1000$ G, $\overline{AC} = b \times 20$ arc sec and the angle γ is 90°.

4. Chromospheric Currents and Their Photospheric Sources

The above model of bipolar groups is very simplistic. Generally, the magnetic fields observed in active regions are much complex, particularly in regions where flares occur. In these regions with realistic magnetic structures, there should be radial and vertical currents (J_r and J_z) as well as the azimuthal one J_φ discussed above. Along a sheared neutral line, we would expect a large 'excess' azimuthal current I_{sh} to exist; but such a current system needs to be connected to the vertical currents flowing through the photospheric surface. Observations for the photosphere can tell us something about J_z and I_{sh}, but not J_r. Also, the morphology of their connections at this height is obscure since the field is not constrained to be force-free and currents can flow across the magnetic field.

The situation is less complex at the chromospheric levels where the field is force-free so that the currents must be parallel to the magnetic field (Nakagawa *et al.*, 1971; Raadu and Nakagawa, 1971). It is well established that the fibril structures seen in Hα filtergrams trace the horizontal field lines in upper chromosphere (Veeder and Zirin, 1970; Foukal, 1971). And we should say that they must trace the horizontal current systems there also. Particularly, the Hα fibril structure above old unipolar sunspots is generally visible to be radial; we interpret this as indicating there are no azimuthal currents flowing in the chromosphere, even if the Equations (8) and (15) give a large $I_\varphi = I_0 \gg 0$ there. Conversely, we expect that azimuthal currents will be present only when we observe a spiral structure in Hα fibrils of a sunspot; or sunspot filaments are visible to be located in the channels of sheared neutral lines of photosphere. It implies that in spite of I_0 constrained to lower heights where the field is not force-free, the sheared component I_{sh} in Equation (17) could be present at chromospheric heights. Besides I_{sh}, we expect the radial component J_r to flow along the radial Hα fibrils in the chromosphere, but we could not distinguish whether J_r is strong or weak only by use of this morphological data.

The footpoints of Hα fibrils connecting into areas of opposite-polarity indicate areas where vertical currents J_z of opposite flows should exist; these areas should be observed in photospheric measurements of J_z unless they are too weak to be detected. Wherever, the value of J_z in an area is higher, the current strength in Hα fibrils connecting it is stronger.

Summarizing Sections 2–4, we show that:

(i) Proposed techniques in this paper is to use observations of the VMF, white-light and Hα features to infer the large-scale current systems in the active regions.

(ii) The transverse magnetic field allows us to calculate J_z and I_{sh}.

(iii) The sunspot filaments along sheared neutral lines trace the paths of flow of I_{sh}.

(iv) The radial and azimuthal Hα fibrils connecting into areas with high values of $\pm J_z$ will be important current systems in active regions.

5. Inferred Electric Current Systems in AR 2372

During the last SMY, the Solar Observatory of the Marshall Space Flight Center operated the MSFC vector magnetograph (Hagyard *et al.*, 1982) on a regular basis, thereby obtaining VMF data for a large number of active regions, many of which produced significant flares. One of these was AR 2372 which was on the solar disk in early April 1980 (Figures 4–7). As discussed by Wu *et al.* (1984), the field interconnections observed on 5th were realigned as a result of the internal motions of the spots L_{21} and F_2. Initially two large spots L_{11} and F_1 formed a connected bipole, as did the two small spots L_{21} and F_2 but formed a delta configuration. Other possible magnetic connections were between the eastern portion (L_{22}) of L_{21} and F_1, and between F_3F_5 and L_{11}. During the period 5th to 6th, L_{21} moved westward sweeping up negative field ahead of it and forming a new delta configuration (L_{21}, F_3F_5), and F_2 which was originally to the north of L_{21} moved eastward toward F_1. In Figure 5(a) the VMF map reveals the sheared nature of the interconnections between L_{21} and F_2, and L_{22} and F_1. This is especially evident when the VMF is compared with a potential field (Figure 5(b)) derived using the line-of-sight field of Figure 5(a). Figure 6 is the vertical current map derived by Krall *et al.* (1982), positions of these spots F_1, F_2, F_3, F_5, L_{11}, L_{21}, and L_{22} are marked in it. These spots are also identified in Hα filtergram provided by Dr Zirin (Figure 7). The set of data (Figures 4–7) has been utilized in conjunction with the analytical constructions developed previously to infer the current systems in AR 2372.

(i) A current system (I) from $L_{21}(+J_z)$ to $F_2(-J_z)$ along a sheared neutral line. A spiral spot L_{21} with a predominantly counterclockwise penumbral pattern (Figure 4) was located at the same position of a counterclockwise vortex of the observed transverse

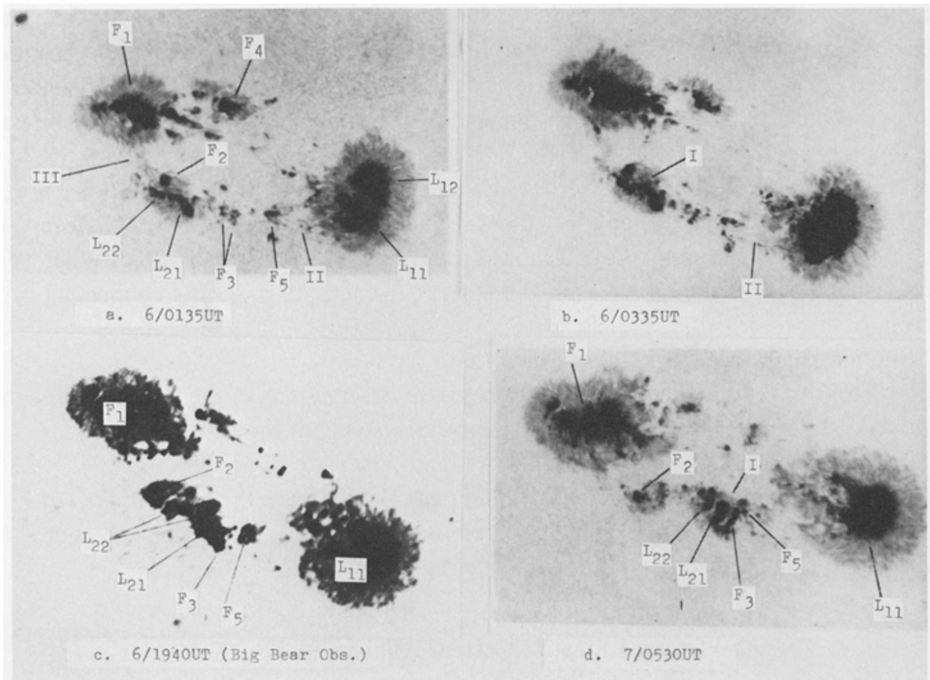

Fig. 4. The sunspot group forming AR 2372 on April 6 and 7, 1980. (a) The sunspots' grouping on April 6 at 01 : 35 UT. (b) The sunspot group at 03 : 35 UT on the 6th. (c) Hα off-band filtergram at 19 : 40 UT on the 6th (courtesy of Dr H. Zirin). (d) The group early on the 7th at 05 : 30 UT.

magnetic field (Figure 5(a)) and of a positive J_z concentration (Figure 6). The current direction in L_{21} is consistent with the direction of the spiral pattern derived by right-hand rule. By estimating the average current density and the area in Figure 6, the current strength in L_{21} was of about $+1 \times 10^{12}$ A. In Figure 5(a) along the neutral line segment indicated by I, the sheared transverse field was very similar to the sheared penumbral filaments (I) persisting for 28 hr in Figures 4(a), 4(b), and 4(d). Deviating as they did from the configuration of a potential field, they suggest that a strong 'excess' current I_{sh} was flowing eastward along the segment I in the lower chromosphere. By taking $a = 0.7$, $b = 0.5$, and $\gamma = 90°$, Equation (20) reports I_{sh} being of 0.4×10^{12} A. In Hα filtergram (Figure 7) the same area marked again by I shows some dark fibrils connecting L_{21} with F_2, from which we infer that a current system was fluently flowing at the chromospheric height and along the Hα fibrils I from $L_{21}(+J_z)$ to $F_2(-J_z)$. Since both the photospheric and chromospheric currents flowed in the same direction and along the same neutral line, we infer that the two currents belonged to one current system that was gradually rising upwards. The estimated current flowing into F_2 was -0.3×10^{12} A and approximately equal to I_{sh} but less than that for L_{21}, part of which, perhaps, was flowing into the neighbouring areas such as $F_3 F_5(-J_z)$.

(ii) A current system III flowing from $L_{22}(+J_z)$ to $F_1(-J_z)$ along a sheared neutral

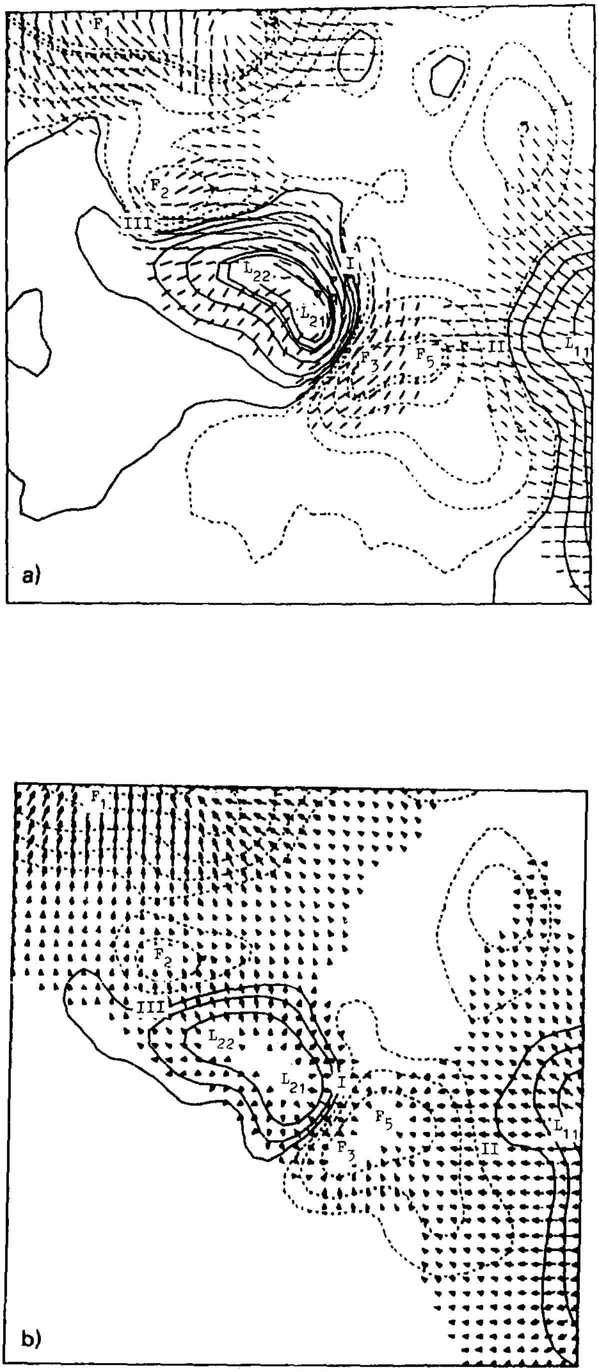

Fig. 5. The vector magnetic field in the area of the magnetic delta configuration of AR 2372 on April 6. The contours represent the line-of-sight component of the magnetic field with solid (dashed) contours depicting positive (negative) fields. The line segments represent in length and direction the magnitude and orientation of the transverse component of the magnetic field. (a) The observed field at 21 : 00 UT on the 6th. (b) A potential field calculated from the line-of-sight field of (a).

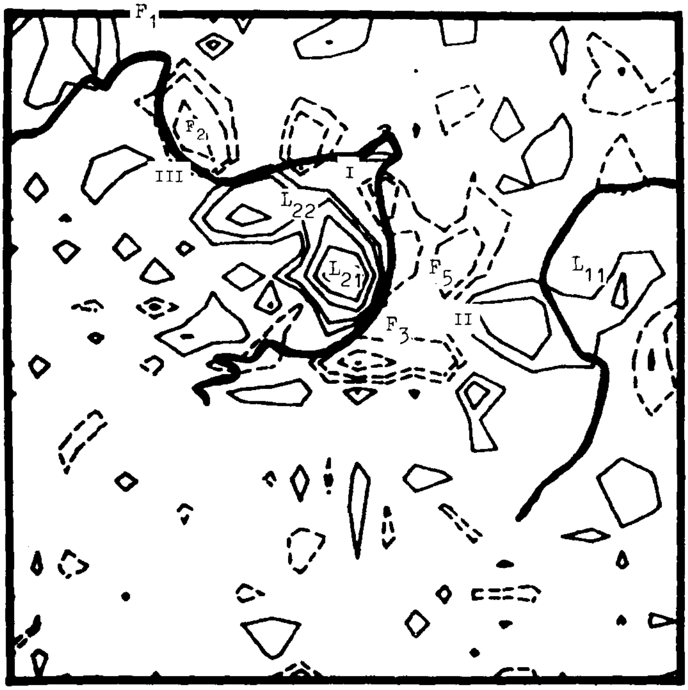

Fig. 6. The distribution of the vertical electric current densities in the area of the magnetic delta configuration on April 6, 1980 at 19 : 08 UT. Solid (dashed) contours represent currents flowing out from (into) the photosphere. The heavy solid line represents the magnetic neutral line to aid in orientation with the magnetic field (from Krall *et al.*, 1982).

line. Sheared penumbral filaments and a sheared transverse field were observed along the segment III of the neutral line indicated in Figures 4(a) and 5(a). These data again suggest an 'excess' current I_{sh} flowing eastward from L_{22} to F_1. Equation (20) will report the I_{sh} along III being less than that along I since the transverse field strength here was weaker. A positive vertical current was estimated to be $+5 \times 10^{11}$ Amp flowing upwards from L_{22}. Because of a negative vertical current being in F_1, we suggest that a lower atmospheric current flowing from L_{22} to F_1 along III. The Hα data show a dark sunspot filament lying along III and connecting L_{22} and F_1. Thus we again infer that the photospheric and chromospheric currents formed a single current system that was rising upwards.

(iii) A radial current system II flowing from $L_{11}(+J_z)$ to $F_3F_5(-J_z)$. Some dark penumbral-like filaments were observed at 01 : 35 UT on 6 April in the area II indicated in Figure 4(a). From this observation we infer that the fibrous magnetic field linking the bipolar group L_{11} and F_3, F_5, etc., had just emerged from the convection zone upto the photosphere prior to 01 : 35 UT. In the Hα filtergram we see several long, radial fibrils connecting L_{11} with F_3 and F_5. Calculated J_z in Figure 6 are positive in L_{11} and negative in F_3 and F_5. Thus we infer a radial current system flowing along the fibrils from L_{11} to F_3 and F_5.

(iv) In Figure 8 we show a sketch of these three major current and magnetic systems

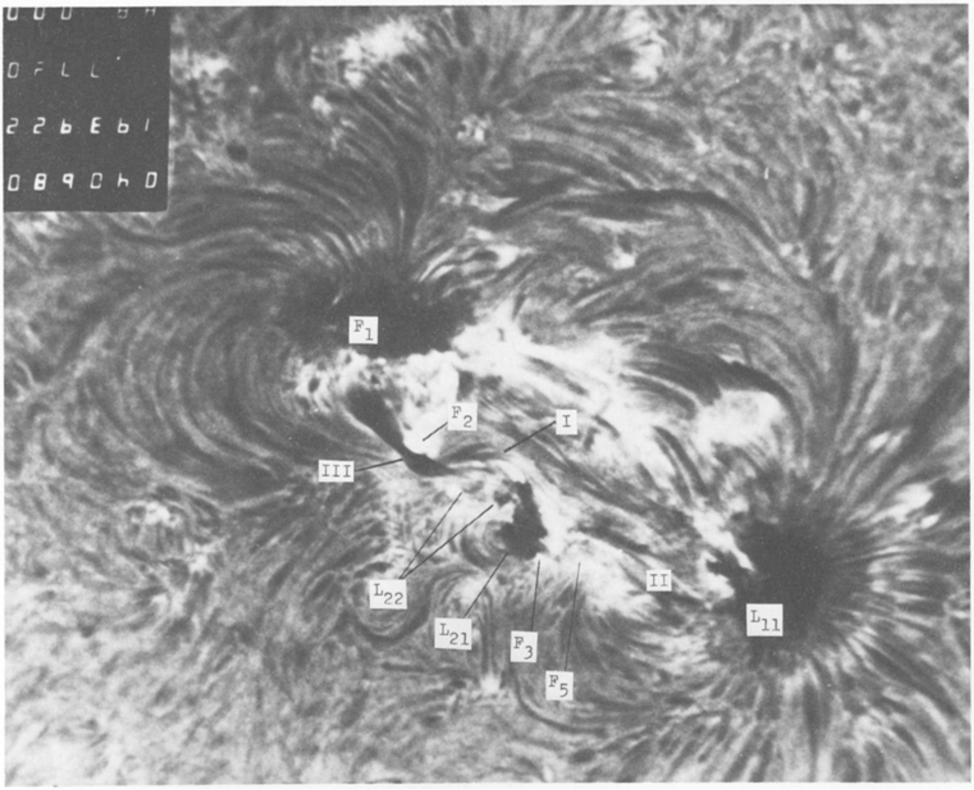

Fig. 7. Centerline Hα filtergram of AR 2372 on April 6, 1980 at 19:39 UT (from Big Bear Solar Observatory, courtesy of Dr H. Zirin).

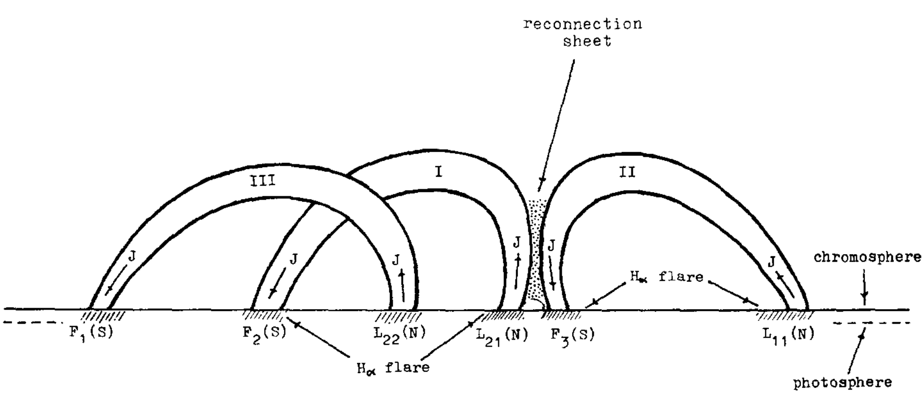

Fig. 8. A sketch of the three major current and magnetic loop systems inferred from observational data. Locations of Hα flare brightenings are indicated at the footpoints of the loops.

which we have inferred from the observed data. The flare activities (Krall *et al.*, 1982; Machado *et al.*, 1983) in this region during the period April 5 to 7 were concentrated in the area of the new delta configuration (L_{21} and F_3) that was formed by the emergence of system II and the westward motion of the footpoint L_{21} of system I. In addition to the delta configuration, complexity in this area of the neutral line was enhanced by the oppositely-directed currents and magnetic fields in the footpoints L_{21} and F_3 of systems I and III, respectively. We shall give a study about evolutions of the current/magnetic systems and their relationship to the Hα and X-rays flares in the next paper.

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