ISSN 0135–3748

АКАДЕМИЯ НАУК СССР

СИБИРСКОЕ ОТДЕЛЕНИЕ

СИБИРСКИЙ ИНСТИТУТ ЗЕМНОГО МАГНЕТИЗМА, ИОНОСФЕРЫ И РАСПРОСТРАНЕНИЯ РАДИОВОЛН

ИССЛЕДОВАНИЯ

ПО ГЕОМАГНЕТИЗМУ, АЭРОНОМИИ И ФИЗИКЕ СОЛНЦА

Выпуск 91

·НАУКА·

Заключение

Дискретные периоды вращения указывают на возможность существования глубинных источников фонового поля. Такие свойства фонового поля, как квазипериодические вариации энергии поля, изменения секторной структуры, видимо, обусловлены динамикой взаимодействия источников и связанных с ними поверхностных полей. К сожалению, без предварительной обработки синоптические карты фотосферного поля мало пригодны для исследования этой динамики.

Возможны различные варианты крупномасштабной фильтрации исходных данных. В представленной работе по данным синоптических H_α-карт анализировалась динамика полюсов диполей широтных зон N- и S-полушарий.Оказалось, что характер динамики различен в начале и конце цикла. До некоторого момента времени вращение структур разных зон происходит независимо и согласуется с периодами вращения источников, установленными по данным спектрального анализа магнитографических измерений. Затем диполи вращаются совместно с некоторым средним периодом, происходит формирование единых структур поля. В зависимости, возможно, от степени взаимодействия глубинных источников новые образования оказываются устойчивыми (20-й цикл) или периодически разрушаются (2I-й цикл).

Изменение периодов вращения дипольных составляющих фоновых полей приходится на аномальные явления на Солнце: вариации энергии фонового поля, усиление вспышечной и геомагнитной активности, что, вероятно, говорит о взаимодействии источников в эти интервалы времени, оказывающем влияние на вращение фоновых полей. Так, в 2I-м цикле в конце I98I г. - начале I982 г. дипольные составляющие фонового поля начали вращаться совместно со средним периодом, близким к кэррингтоновскому; в 20-м цикле во второй половине I972 г. наблюдается замедление вращения диполей низкоширотных зон и ускорение - среднеширотных.

Литература

I. Котов В.А. // Изв.Крымск. астрофиз. обсерв. I987. Т.77.С.39-50.
2. Antonucci E., Hoeksema J.T., Scherrer P.H. Rotation of the Photospheric Magnetic Fields: A North-South Asymmetry. Center for Space Science and Astrophysics Stanford University. CSSa-ASTRO-89-14. Aug.1989. P.10.
3. Мордвинов В.И. // Исследования по геомагнетизму, аэрономии и физике Солнца. М.: Наука, I989. Вып.87. С.90-I00.
4. Мордвинов В.И., Пиконова М.В. // Солнечные магнитные поля и корона. Тр.XIII Консультативного совещания КАПГ по физике Солнца. Новосибирск: Наука, I989. Т.I. С.359-362.
5. Мордвинов В.И. // Наст. сборник. С.28-33.

СибИЗМИР СО АН СССР

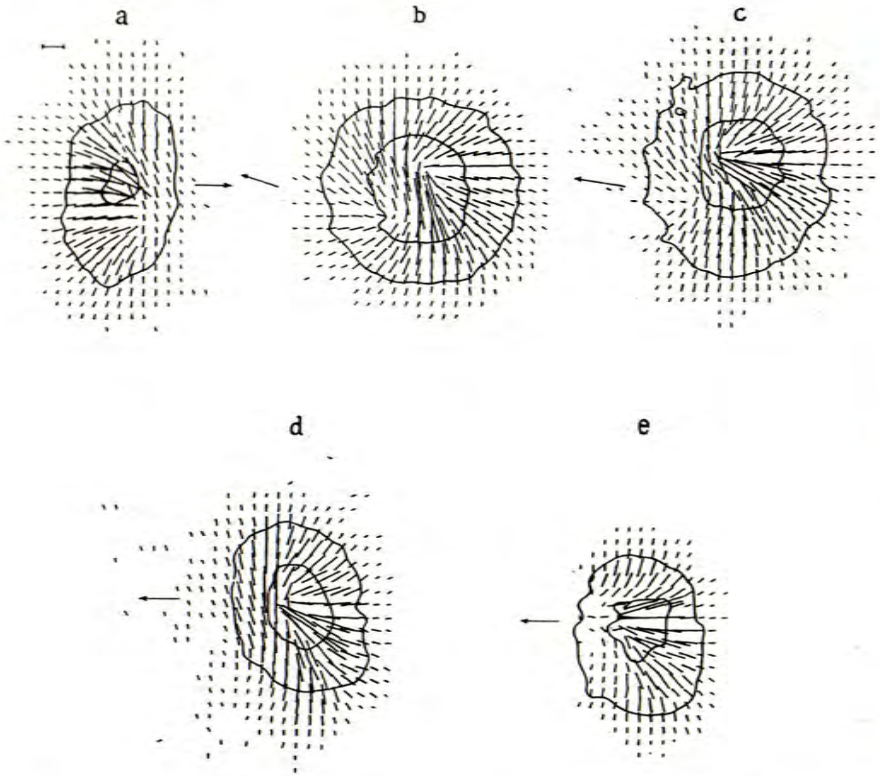
UDC 523.98

NONRADIAL STRUCTURE OF AZIMUTHS OF TRANSVERSE MAGNETIC FIELDS IN THE SUNSPOT PENUMBRA

A.A.Pevtsov

Presented are the observations of transverse magnetic fields of a unipolar sunspot (No.42/86 according to "Solnechnye dannye") obtained at the Sayan observatory vector-magnetograph. Near the disk center the azimuths in the sunspot are distributed radially, but with increasing heliocentric distance in the penumbra closest to the disk center, radiality is violated (up to 90°). The picture is symmetrical about the solar disk center. Besides, projections of magnetic field vectors, reconstructed in cylindrical symmetry, show a tendency to increase the field line verticality in the penumbra as the sunspot moves away from the disk center. A qualitative explanation of these two factors is proposed. It is supposed that, in view of the averaging of the fine structure by the magnetograph aperture, two components are present in the layer of spectral line formation: a vertical field which threads this layer entirely, and a horizontal field which occupies its lowest part only. The contribution of these components to the measured field varies as the sunspot travels on the solar disk. With a certain position of the sunspot, when the line of sight falls on the same plane with most of the magnetic field vectors in the penumbra, projections of these vectors in the picture plane will show a significant deviation from radial directions.

The question of the distribution of azimuths (χ) of a transverse magnetic field ($H_\perp$) in sunspots was addressed by many authors. According to publications, which are reviewed in the monographs by A.B.Severny [1] and V.N.Obridko [2], in many sunspots the azimuths of transverse fields in the picture plane differ appreciably from the radial direction, and deviations increase with the distance from the sunspot center. The observed nonradiality χ was attributed at least to three factors: magneto-optical effects (rotation of the plane of polarization), eastward inclination of the sunspot axis by 10-15°, and the probable rope-like character of the magnetic field in the penumbra. Understanding the reasons for the deviation of azimuths $H_\perp$ from the radial direction is important for a correct representation of the magnetic field structure in the sunspot penumbra. In the study of electric currents, when it is necessary to differentiate the transverse field compo-



F i g. 1. Maps of transverse magnetic fields and of their azimuths: a - 25 August, θ = 58°, 03.59-04.12 UT; b - 30 August, θ = 8°, 01.59-02.18 UT; c - 31 August, θ = 23°, 08.08-08.29 UT; d - 1 September, θ = 35°, 01.02-01.21 UT; e - 2 September, θ = 50°, 05.36-06.10 UT

nents, this issue becomes of crucial significance.

In this paper we shall give some examples of the observations of nonradiality χ, which - we believe - cannot be explained by anyone of the above factors.

This study has used observations of a unipolar sunspot (NOAA No. 4744) obtained at the Sayan observatory vector-magnetograph on 25 August and during 30 August to 2 September, 1986. The observations were made in the line FeI λ525.022 nm, with the 2x2" entrance slit and with the scanning rate of $2'' \cdot s^{-1}$; the time constant was 1 s. A detailed description of the observing procedure and of the subsequent data processing is given in /3,4/.

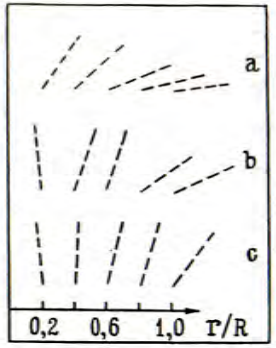
Fig. 1 presents examples of the distributions of azimuths $H_\perp$ which we obtained. North is upward, and East is to the left. The length of bars is proportional to the magnetic field strength

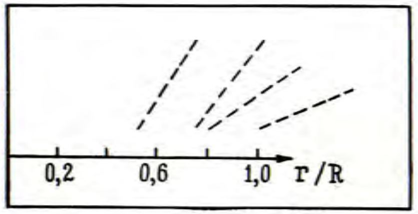
(the scale segment in Fig.1,a corresponds to 500 Gs); at points with $H_\perp$ < 100 Gs, the azimuths were not drawn. The sunspot umbra and penumbra are also shown, and the arrow indicates the direction toward the solar disk center. Near the center of the solar disk (θ = 8°) the picture of the azimuths was virtually the same as the axisymmetrical radial distribution (Fig. 1,b), and the radiant, or the point, toward which all azimuths are directed, roughly corresponded to the sunspot center. With increasing angular distance (θ = 23°), the part of the penumbra, closest to the disk center, showed deviations of χ from the radial directions, and the radiant displaced to the penumbra in this case. The azimuths on the opposite side of the sunspot remained radial (Fig. 1,c). On 1 September (θ = 35°) nonradiality χ reached 90° (Fig. 1,d), and on 2 September (θ = 50°) the picture of the azimuths $H_\perp$ in the penumbra, closest to the disk center, became such as if one were observing at a large angle a funnel and saw its outer side (Fig. 1,e). The only one observation of a sunspot eastward of the central meridian (on 25 August, θ = 58°) shows a similar picture of the azimuths $H_\perp$ (Fig. 1,a).

It was found subsequently that such a picture of the azimuths for large sunspots was also observed at other vector-magnetographs (for example, /5,6/); it was ascertained in this case that the deviations of the azimuths are the largest in the direction toward the disk center.

An examination of the map (30 August) of the inclination angles of the magnetic field vector to the line of sight reveals that near the disk center the axis of the magnetic rope that formed the sunspot, was perpendicular to the solar surface. Further, nonradiality χ manifests itself differently in different parts of the penumbra. Thus, for the observations of 1 September (Fig. 1,d), the azimuths $H_\perp$ in the south-eastern part of the penumbra are rotated counter-clockwise with respect to the radial direction, whereas they are rotated clockwise in the north-eastern sector (this same also applies for Fig. 1,a). This contradicts the interpretation of the nonradiality of azimuths in terms of the rotation of the plane of polarization because in this case, for the entire area of the penumbra with a like-polarity longitudinal field, a rotation of the plane of polarization (of the azimuth $H_\perp$) of one direction must take place.

The simplest and, we believe, logical explanation of the observed picture of the azimuths is thus. Imagine that the magnetic field throughout the entire penumbra has the same inclination to the normal of about 35°. With an angular distance of the sunspot of 35°,





F i g. 2. Inclination angles of field lines in cylindrical symmetry: a - θ = 8°; b - θ = 35°; c - θ = 50°; r/R - distance from the spot center in fractions of its radius

F i g. 3. Inclination of the sunspot magnetic field lines along the distance to the zero line of the longitudinal field

when the line of sight enters the same plane with magnetic field vectors in the penumbra, one would get the impression that in the picture plane the transverse field azimuths deviate strongly (up to 90°) from the radial direction. As the sunspot moves farther from the disk center, the picture of the azimuths in this case will resemble Fig. 1,d.

Let us now try to explain such a nonrealistically high verticality of the magnetic field in the penumbra. For this purpose, we shall examine (Fig. 2) the distribution pattern of inclination angles of the magnetic field vector to the normal in the sunspot obtained from the longitudinal field ($H_{\parallel}$) under the assumption of cylindrical symmetry [7]. Near the disk center (see Fig. 2,a) the inclination of the magnetic field vectors in the sunspot corresponds quite well to a classical picture, but with increasing heliocentric distance the field in the penumbra becomes ever more vertical (see Fig. 2,b,c). In order to remove the possible doubts about the applicability of cylindrical symmetry, we have determined the inclination angles of the field to the vertical also from the position of the zero line $H_{\parallel}$ for different heliocentric distances of the sunspot. The results of this determination (Fig. 3) confirm, in fact, the conclusions of cylindrical symmetry.

Thus, it seems likely that, as the sunspot travels across the solar disk, the magnetic field in its penumbra has a tendency to become more vertical. Let us try to explain this. In actual observations, penumbra elements with a different direction of the magnetic field are averaged for the magnetograph entrance slit; in the general case one can say about elements with a vertical and horizontal field. The spectral line, from whose splitting the mean magnetic field is measured, is formed in a certain layer of the solar atmosphere. Suppose that the vertical field threads this layer entirely, and the horizontal field covers only its lower part. The direction of the measured averaged field depends on the relationship of the vertical and horizontal fields in the layer of spectral line formation. Near the disk center one observes deeper atmospheric layers and, consequently, the more horizontal magnetic field is recorded. With increasing distance from the center, there is an increase of the contribution of the higher layers, where the field is a more vertical one. According to [8], when the angular distance of the sunspot from the disk center changes to θ = 50°, the effective formation height of the line FeI 525.022 nm increases by about 100 km; hence, it might be anticipated that the horizontal field in the sunspot penumbra does not penetrate in the photosphere above 100 km from the formation level of this line at the disk center of the Sun. The vertical component is, possibly, the field which from the photosphere penetrates the chromosphere and the corona in the form of a single magnetic tube.

I am grateful to Drs V.M.Grigoryev, V.L.Selivanov, B.F.Osak, and L.V.Ermakova for their co-operation when carrying out the observations as well as to all those staff members of this Institute, who maintained the vector-magnetograph operational.

R e f e r e n c e s

1. Severny A.B. Some problems of solar physics. Moscow: Nauka, 1988. 224 p.
2. Obridko V.N. Sunspots and complexes of activity. Moscow: Nauka, 1985. 256 p.
3. Grigoryev V.M., Kobanov N.I., Osak B.F. et al. // Bull. Abastum. astrofiz. observ. 1985. N 60. P.159-175.
4. Grigoryev V.M., Kobanov N.I., Osak B.F. et al. // NASA Conference publication 2374. 1985. P.231-256.
5. Kotov V.A. // Astron.zhurnal. 1971. Vol.48, N 4. P.869-871.
6. Solar vector magnetograms 1986 - Okayama astrophysical observ., Tokyo astronomical observ., 1987. 178 p.
7. Dialetis D., Mein P., Alissandrakis C.E. // Astron.Astrophys. 1985. Vol. 147, N 1. P.93-102.
8. Demidov M.L. // Issledovaniya po geomagnetizmu, aeronomii i fizike Solntsa. Moscow: Nauka, 1980. Vol. 52. P.3-13.

Siberian Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation

Received in January 1990