THE RELATIONSHIP BETWEEN THE LONGITUDINAL MAGNETIC FIELD AND THE LINE-OF-SIGHT VELOCITY AT DIFFERENT ANGULAR POSITIONS OF SUNSPOTS

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Abstract. Using observational data on 14 sunspots from the Sayan Observatory vector magnetograph, a study was made of the relationship between the sunspot magnetic field and the Evershed motions. It is shown that the central area of the solar disk is dominated by an anti-correlation of the longitudinal magnetic field $B_{\parallel}$ and the line-of-sight velocity $V_{\parallel}$ when a maximum of $V_{\parallel}$ corresponds to the neutral line of the longitudinal field. Near the limb there usually is a coincidence of the field and velocity neutral lines. There is evidence for the possible asymmetric character of the effect with respect to the central meridian.

1. Introduction

The spatial anti-correlation effect of the longitudinal magnetic field $B_{\parallel}$ and line-of-sight velocity $V_{\parallel}$ (when one of the $V_{\parallel}$ maxima corresponds to the neutral line $B_{\parallel} = 0$, which is brought about by projection) was reported as long ago as the first observations at the Crimean magnetograph (for example, Kuklin and Stepanov, 1963). Rayrol (1967) and Semel (1967) found that the neutral line of the longitudinal magnetic field did not coincide with that of the line-of-sight velocity in the sunspot penumbra. Beckers and Schröter (1969) pointed out that for sunspots with the angular location $40^\circ < \theta < 60^\circ$, the neutral line of the longitudinal field $B_{\parallel}$ often runs near the velocity maximum of Evershed motions. Later, the $B_{\parallel}$ and $V_{\parallel}$ anti-correlation was treated by a number of authors (for example, Berton, 1985; and Grigoryev and Pevtsov, 1987). Some observers (for example, Kotov, 1976), on the contrary, pointed to a good longitudinal field and velocity correlation. The appearance of line-of-sight velocities on the neutral line of the longitudinal field was interpreted by Kuklin and Stepanov (1963) in terms of the motion of the field itself. Stellmacher and Wiehr (1971) associated the appearance of this effect with the influence of penumbral fine structures. We demonstrated (Pevtsov, 1988) that the spatial anti-correlation of $B_{\parallel}$ and $V_{\parallel}$ can be explained by invoking a two-component penumbral model, consisting of elements with differently directed field and velocity. Averaging of these fine-structure elements by the magnetograph aperture will lead to the above-mentioned effect. We have interpreted the formation of the mean spectral line profile in this case as the superposition of profiles from bright (BR) elements of the penumbra with the nonhorizontal magnetic field and from dark (DR) elements with the horizontal field. The field strength in BR is less by 200–400 G than in DR. In DR material flows out from the sunspot with a maximum velocity of 4 km s$^{-1}$, and in BR material descends into the sunspot with a maximum velocity of 1 km s$^{-1}$. Numerical
calculations have shown that a change in projection is accompanied by a change in the contribution of fine-structure elements of the penumbra into the mean profile, and the dependence of the anti-correlation effect on the heliocentric angle appears. According to our calculations, the anti-correlation of field $B_\parallel$ and velocity $V_\parallel$ must occur near the center of the solar disk, and their correlation must be observed near the limb.

It is for verifying these model calculations that this study has been undertaken.

2. Observations

In this paper we have used 49 magnetograms (21 for sunspots eastward of the central meridian, and 28 for W-sunspots) obtained at the vector magnetograph of the Sayan Observatory (VMSO) for 14 sunspots (9 unipolar sunspots and 5 sunspots from bipolar groups) during 1984–1989. For our study we selected regular sunspots with a well-defined penumbra, since the accuracy of determining the position of the velocity neutral line depends on the complexity of the sunspot group. The observations were made in the line FeI 525.022 nm, with different spatial resolutions ($2 \times 2''$ and $4 \times 4''$). Line-of-sight velocity measurements were made with the help of the line-of-sight velocity compensator (Doppler-compensator) of the vector magnetograph, simultaneously with magnetic field observations. The map for a chosen active region was constructed by sequentially scanning the image parallel to the solar equator, and the scanning rate was set in accordance with a chosen spatial resolution (thus, for a pixel $2 \times 2''$, the scanning rate is $2''$ s$^{-1}$, with a time constant $\tau = 1$ s). The time of obtaining one magnetogram was 30–40 min.

Line-of-sight velocities in the active region were calculated with respect to the neighbouring undisturbed photosphere. When calculating the level of zero velocity, the first four scan rows of the magnetogram were averaged. The averaged set was used to construct a quadratic polynomial, and this was chosen as the level of zero velocity for the first scan row. A similar procedure was carried out for the last four scan rows. The zero-velocity level for the other points on the map was calculated by a linear interpolation of two given polynomials. Observational practice shows that such a procedure performs well for scanning areas as large as 200$''$ long.

The level of zero velocity calculated in this way is, in the photosphere, displaced with respect to that in the sunspot due to the limb red shift. We did the processing both with and without this correction taken into account.

The accuracy of measurement of line-of-sight velocities with the vector magnetograph Doppler compensator of the Sayan Observatory is 30 m s$^{-1}$, and the r.m.s. spectrograph noise amplitude is 80–100 m s$^{-1}$. The accuracy of measurement of the longitudinal magnetic field is 10 G.

A detailed description of the magnetograph, the observing procedure and of the subsequent data treatment is given by Grigoryev et al. (1985).