Short-Period Variations in the Proper Motions of Sunspots from SOHO (MDI) Observations

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Abstract—Short-period (1–60 min) variations in the coordinates of the centers of gravity of isolated sunspots are analyzed. The sunspot coordinates were determined using two sets of observational data—magnetograms and intensities—obtained by SOHO (MDI) on December 6, 1998, from 01:00 to 21:57 UT with temporal resolution 60 s and spatial resolution 0.6°/pixel. A slow drift in the sunspot coordinates was removed using a low-frequency filter with a 61-min integration window. The guiding errors (RMS = 0.014") were determined by analyzing correlated motions in pairs of sunspots, and were removed from the time series before determining the sunspot proper motions. Based on the calculated power spectra for the sunspot proper motions, two period intervals containing appreciable power were identified. One coincides with the well-known 5-min acoustic solar oscillations. The concentration of power in this interval is greater for the coordinate variations derived from the magnetograms than those derived from the intensities; the harmonic amplitude for some peaks reaches ~±30 km. The other spectral interval corresponds to periods exceeding 30 min. Overall, the rms short-period variations in the sunspot proper motions are 9.9 ± 2.2 and 16.7 ± 7.6 km (0.014° ± 0.003” and 0.024° ± 0.010”) for the magnetogram and intensity data, respectively. © 2000 MAIK “Nauka/Interperiodica”.

1. INTRODUCTION

After the discovery of sunspot proper motions [1], they became an important basis and then instrument for studying the motions of material in subphotospheric layers, as well as interactions of this motion with magnetic fields. Initially, a slow meridional drift of sunspots was revealed [1–4], with an estimated velocity of several tens of cm/s. As instruments and methods for solar observations improved, it became possible to study more rapid displacements of sunspots against the background of their rotational motion. It was later established that the character of sunspot proper motions depends on the dynamics both of the sunspot (active region) itself and of the interaction of large-scale plasma motions with solar magnetic fields. In particular, proper motions depend on the structure of the active region, its location on the disk, the age of the sunspots, the phase of the solar activity cycle, and other manifestations of solar activity. After Gnevysheva [5] concluded that the similar trajectories of closely-spaced sunspots reflected their common drift, associated with large-scale vortex plasma flows under the photosphere, Stepanov and Klyakotko [6] attempted to estimate the velocity and spatial structure of these flows.

A series of studies of latitudinal variations in the rotational velocity [7–9], meridional motions of sunspots [10] and small photospheric magnetic structures [11], and proper motions in the network of bright points and magnetic fluxes [12, 13] have demonstrated differences in the motions of sunspots with respect to the motions of other observable structures. This testifies to a complex interrelation between these proper motions and processes occurring beneath the photosphere. Variations in sunspot proper motions with periods less than one day [14] can provide important information about the structure and dynamics of subphotospheric layers [15]. However investigation of relatively small and rapid variations in sunspot proper motions requires high-quality observations with very good spatial and temporal resolution, such as that provided by MDI [16] installed on the SOHO space telescope.

The aim of the present paper is to investigate rapid variations (with periods of several minutes) in the proper motions of sunspots derived from MDI measurements of the magnetic field and intensity.

2. OBSERVATIONAL DATA

The observational data are images of part of the solar disk near its center, 1024 × 500 pixels in size, with a spatial resolution of 0.605’/pixel. We analyzed images obtained on December 6, 1998 from measurements of the intensity and magnetic field with temporal resolution 60 s for two time intervals of duration ~6 and 5 h (356 and 286 images, respectively). The observations were carried out in the Ni I 6768 Å line; the intensity measurements were conducted in the continuum near this line. Figure 1 shows the positions of the sunspots SP1, SP2, and SP3 at the starting times for each of the two intervals. To determine the contribution to variations in the sunspot coordinates from guiding errors, we considered the sunspots in pairs, assuming that the main contribution of guiding errors to sunspot motions...
should be manifest as simultaneous correlated changes in the coordinates of different sunspots.

3. PRELIMINARY ANALYSIS

Portions of the solar images where sunspots were shifted by the photospheric rotation were identified and set apart for further analysis. To decrease the influence of rapid signal fluctuations (inherent in the pixels around sunspots and their penumbrae) on the calculated values, the coordinates of the sunspot centers of gravity \( X_0 \) and \( Y_0 \) were determined using the most stable parts of the sunspots, in their umbrae. The intensity and magnetic field umbrae were bounded by the values \( S_I = 2000 \) and \( S_M = 500 \), respectively. These values can be changed to reflect the motion of the sunspot as a whole, including the penumbra, but this does not appreciably influence the results. We calculated the center-of-gravity coordinates \( X_0 \) and \( Y_0 \) for pixels \( S_{kn}(t) \) whose signal \( P_{kn}(t) = S_I - S_{kn}(t) \) (intensity) or \( P_{kn}(t) = S_{kn}(t) - S_M \) (magnetic field) was positive:

\[
X_0(t) = \frac{\sum_{k,n} P_{kn} k}{\sum_{k,n} P_{kn}}, \quad Y_0(t) = \frac{\sum_{k,n} P_{kn} n}{\sum_{k,n} P_{kn}}. \tag{1}
\]

Preliminary analysis of the time series \( X_0(t) \), \( Y_0(t) \), and \( P_{kn}(t) \) showed that, in some cases, there was a correlation \((|R| > 0.5)\) between variations in the coordinates and the average intensity or magnetic-field signal in a specified sunspot zone. These correlations are due to redistribution of the signal within the analyzed zone of the sunspot umbra, and can produce spurious signals in the coordinate variations, which are associated neither with guiding errors nor with proper motion of the sunspot. To elucidate the importance of these variations on the spectral composition of the proper motions, we used another model for the sunspot umbra in which the distribution of the signal was flat (which does not correspond to the actual observed signal distribution), with a constant level of \( S_M \) for pixels whose magnetogram signal exceeded \( S_M \) or whose intensity was less than \( S_I \) (i.e., in the sunspot umbra, where the \( P_{kn}(t) \) were positive). The signals for other pixels, not satisfying the condition \( P_{kn}(t) > 0 \), were assumed to be zero. In this case, the center-of-gravity coordinates were calculated using the formulas

\[
X_0'(t) = \frac{\sum_{k,n} S_M k}{\sum_{k,n} S_M}, \quad Y_0'(t) = \frac{\sum_{k,n} S_M n}{\sum_{k,n} S_M}. \tag{2}
\]

The variations of the sunspot coordinates were also calculated in a coordinate system fixed to the Sun, in which \( X_0 \) and \( Y_0 \) were transformed into longitude and latitude. As an example, Fig. 2 presents the time variations in the latitude of the center of SP1 in both magnetic field and intensity, along with the corresponding changes of the average signals used to calculate the coordinates. These average signals were calculated as

\[
\sum_{k,n} P_{kn}(kn). \tag{3}
\]

A preliminary analysis of the correlation coefficients for the coordinates of sunspots SP1 and SP2, SP3 and SP1 showed that (1) there is some correlation between the coordinate variations derived from the intensity and magnetic-field signals for the same sunspot \((0.15 < R < 0.87)\); (2) the relations between variations of the coordinates and signals have a wider interval of correlation coefficients \((-0.69 < R < 0.71)\); and

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**Fig. 1.** Images of the intensity (left) and magnetic field (right) obtained by SOHO–MDI at the beginning of the two analyzed time intervals—01:00 UT (top) and 17:12 UT (bottom)—on December 6, 1998. Two pairs of sunspots used in the analysis—(SP1–SP2) and (SP3–SP1)—are marked.