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Long-Period Variations in the Magnetic Field of Small-Scale Solar Structures

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Abstract—Thirty small-scale structures in the solar atmosphere, i.e., facula nodes at ±(20°–46°) latitudes, have been studied in order to analyze quasi-periodic variations in the magnetic field. SDO/HMI magnetograms have been used for this purpose. Long-period variations in the magnetic field strength of the considered objects in the 60–280 min range have been revealed as a result of data processing. It has been shown that there are no dependences between the magnetic field and period, nor between the magnetic field and object area. It has been assumed that the discovered variations are not natural oscillations of the magnetic field strength.

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1. INTRODUCTION

Since the appearance of spacecraft equipped with up-to-date instruments, it has become possible to obtain data with a high spatial resolution that make it possible to study small-scale structures in different layers of the solar atmosphere.

As is known, magnetic fields are responsible for the processes proceeding on the Sun in many respects (Kobanov and Pulyaev, 2011). Therefore, it is necessary to study these fields in order to analyze the structure and nature of all elements of the solar atmosphere.

We can obtain the representation of the magnetic field dynamics, affecting the physical parameters of any structure, by studying the field quasi-periodic variations. Similar variations were previously detected in different frequency ranges for a number of solar structures: sunspots, pores, coronal loops, and facula sites (Gelfreikh et al., 2006; Abramov-Maximov et al., 2011). Three- and 5-min oscillations on the solar photosphere, the interpretation of which is related to the propagation of MHD waves, have been studied most completely (Kobanov and Pulyaev, 2011). Long periods lasting 40 min or more were also found in active regions and sunspots with ground and space instruments (Nagovitsyna and Nagovitsyn, 2002; Efremov et al., 2007; Nagovitsyn and Nagovitsyna, 2011; Smirnova et al., 2013). Some researchers relate the long-period component in the frequency spectrum to the studied structure motion singularities (Nagovitsyn et al., 2012), natural oscillations of these structures (Solov'ev 2015), and propagation of magnetosonic waves in the solar atmosphere (Gelfreikh et al., 2006; Bakunina et al., 2009). However, the interpretation of long-period variations in solar structure is still discussed.

This work is devoted to the study of variations in the magnetic field of long-lived small-scale photospheric formations, the magnetic field of which is concentrated at much more compact nodes than sunspots (their characteristic scale is 7–10 arcsec).

We focused on the determination and analysis of long periods (40 min or more), which are the most interesting for researchers since they have been insufficiently studied (Nagovitsyn and Nagovitsyna, 2008; Efremov et al., 2007].

2. OBSERVATIONS AND DATA ANALYSIS

2.1. Data Selection

The data on the facula node magnetic field used by us were obtained using the Helioseismic and Magnetic Imager (HMI), which was installed on the Solar Dynamics Observatory (SDO) spacecraft (Couvidat et al., 2012). HMI observes the solar disk at a wavelength of λ 6173 Å with a special resolution of 1 arcsec. The maximal time resolution of the obtained magnetograms is 45 s.

We selected the following dates in order to search and continue analyzing small-scale structures:

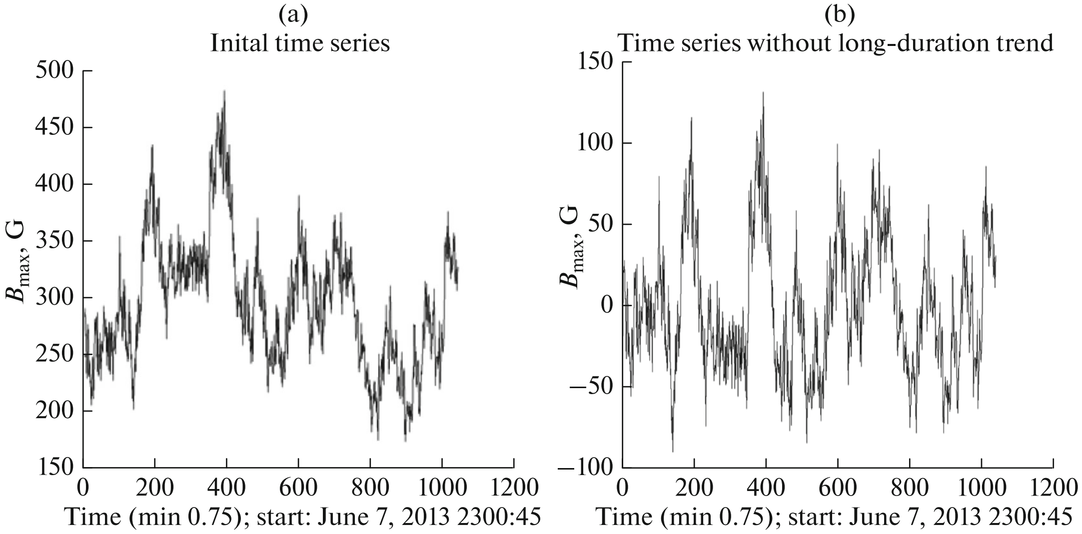

Fig. 1. Time variations in the magnetic field strength maximum for a facula node with coordinates in the projection onto the x, y plane: [102, −577] arcsec: (a) the initial plot; (b) the plot with the subtracted trend.

(1) January 5, 2013, 0300:00 to January 5, 2013, 1300:00, time step of 3 min.

(2) June 7, 2013, 2300:45 to July 7, 2013, 1200:45, time step of 45 s.

We studied the variations in the maximal magnetic field strength value for 30 magnetic structures at latitudes of ±(20°–46°) with the 7–10 arcsec characteristic scale of the structures, the magnetic field of which varied within 380–930 G. We additionally studied the variations in the average magnetic field of these structures in different contour (150–350 G).

2.2. Main Data Processing Methods

Figure 1a presents the initial time variations in the magnetic field strength maximum for a magnetic structure with coordinates in the projection onto the x, y plane: [102, −577] arcsec (hereafter, the processing results for this object are presented as examples). We expanded the time series into the constituent harmonics using the empirical mode decomposition method (Huang et al., 1998). This method was used to calculate the long-period trend subtracted before an analysis.

Figure 1b presents the time series without the trend.

To reveal the periodicity, we used the Morlet wavelet of order six.

3. RESULTS

Table presents the processing results for 30 objects in order to search for quasi-periodic variations in the magnetic field strength.

We found periods of quasi-periodic variations for the maximal (column 4) and average (column 5) magnetic field strength values for the studied small-scale structures. The table presents only the longest periods revealed in the time series, which lasted 10–13 h. However, we also found that periods in the 4–6 and 20–40 min ranges stably exist in these time series.

Figure 2 illustrates the wavelet spectrum for the maximal magnetic field strength of the studied object (the time series in Fig. 1). The power spectrum (Fig. 2b) shows the periods in the 60–100 and 140–235 min intervals.

Based on the data presented in table, we constructed the distributions of the longest periods, from the maximal and average, in the magnetic field value contours for each object. Neither distribution shows any relationships between the magnetic field value and the period, at least for this range of periods.

One more important part of our study consisted of verification of the result achieved by us previously (Strekalova, 2015): the absence of an unambiguous correlation between the average object magnetic field value in a contour and the contour area. The correlation coefficient of these functions for a given object is **0.1**. A cross correlation analysis of the field and area for the remaining objects studied by us showed that the correlation is absent in this interval of oscillation periods. The histogram of the correlation coefficient occurrence frequency for all 30 cases is presented in Fig. 3. On average, the correlation coefficient magnitude is not larger than **0.5**, which confirms our previous results.

Table

Ser. no.	Maximal field strength, G	Average field strength maximum in 150–350 G contours	Periods for maximal magnetic field strength, min	Periods for average magnetic field strength, min
January 5, 2013, 0300:00–January 5, 2013, 1300:00, step of 3 min				
1	680	500	25–35, 45–60, 80–140	40–50, 80–120, 200–235
2	560	350	60–100, 160–250	40–50, 70–120, 160–235
3	390	240	40–60, 100–160	40–50, 60–80, 100–160
4	420	210	50–80, 100–140	40–80, 160–235
5	510	290	25–40, 90–160	40–80, 100–235
6	620	110	25–40, 90–160	50–70, 100–160
June 7, 2013, 2300:45–July 7 2013, 1200:45, step of 45 s				
1	930	340	40–80, 140–235	50–80, 90–120, 140–235, 250–280
2	460	300	70–100, 235–280	70–100, 235–280
3	480	290	60–100, 140–235	60–100, 200–250
4	530	170	100–160	100–160, 235–280
5	420	210	40–60, 120–140, 200–250	40–60, 120–200
6	540	230	40–80, 100–160, 200–280	80–120, 200–280
7	–570	–300	120-200, 250–280	120–200, 250–280
8	–600	–330	80–120, 200–250	80–120, 200–250
9	–550	–320	80–120, 140–235	70–100, 120–200
10	–570	–320	50–80, 100–120, 200–250	80–160
11	–710	–350	70–120, 235–280	70–100, 140–200
12	–380	–140	70–120, 140–235	70–120, 140–235
13	700	290	100–200	100–200
14	430	210	60–100, 140–235	50–70, 140–235
15	520	220	30–50, 140–235, 250–280	50–80, 120–200
16	560	200	40–50, 140–200	40–60, 100–160
17	560	240	7–100, 140–200	50–70, 140–235
18	540	240	25–40, 50–80, 100–140	25–40, 50–80, 100–140
19	480	220	30–60, 90–140, 235–280	30–60, 90-140, 200–280
20	520	210	40–60, 100–140	50–100, 120–235
21	390	180	35–50, 120–200	70–100, 200–280
22	–730	–330	20–50, 100–140, 235–280	60–100, 200–250
23	–540	–310	40–70, 120–140, 180–260	40–70, 80–120, 140–250
24	–640	–330	40–50, 80–100, 120–200	40–70, 100–140, 200–250

Explanations:
Columns 2 and 3: the maximal and average values of the magnetic field strength in the contour.
Columns 4 and 5: the periods of quasi-periodic variations for the maximal and average values of the magnetic field strength in the contour.

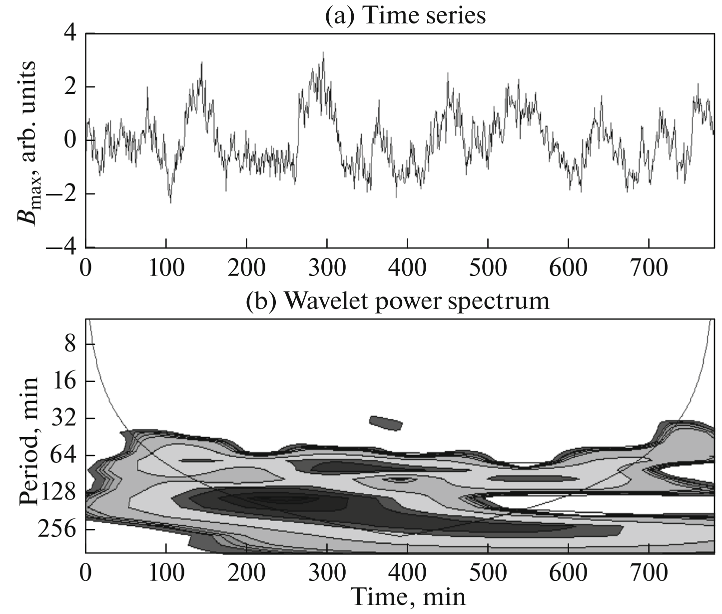

Fig. 2. Example of the wavelet spectrum for the maximal magnetic field strength of the facula node.

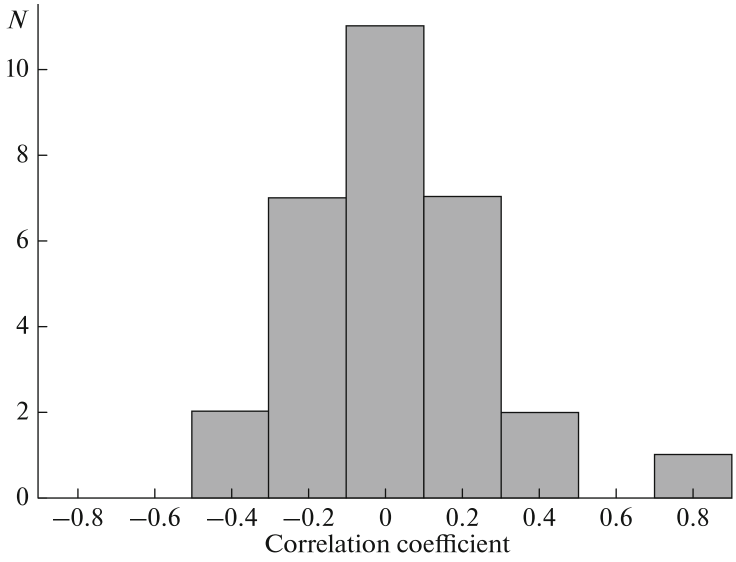

Fig. 3. Occurrence frequency histogram for the average magnetic field correlation coefficients and the area in the contour.

4. DISCUSSION

The absence of a relationship between the magnetic field, on the one hand, and the oscillation period and area, on the other, allows us to assume that the magnetic field is not critical in the appearance of the detected quasi-periodic variations in the small-scale structure magnetic field. This result may indicate that the 60–280 min variations are induced and are related to external oscillatory actions on the observed structures. What can be the cause of these variations? We can assume that an interaction exists between a thin magnetic tube with a relatively small magnetic field below the photosphere and on the photospheric level and the dynamic structure of supergranules. The characteristic structures related to the supergranulation are clearly defined in the chromosphere and can specifically be distinguished in the 304 Å line. This line is observed with the AIA/SDO instrument. Figure 4 shows the intensity distribution map according to the AIA 304 Å data. The magnetic structures with a magnetic field strength of 200—600 G are marked by con-

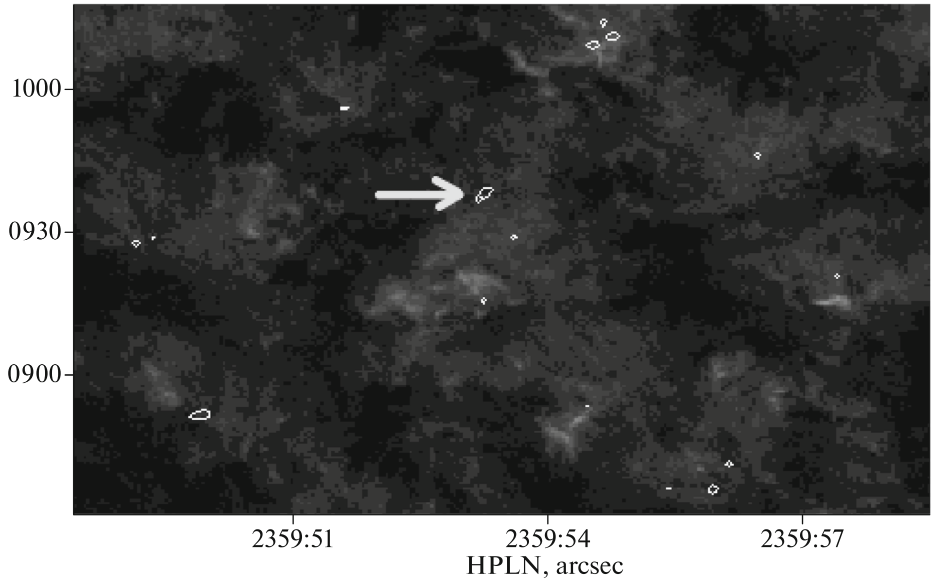

Fig. 4. Intensity distribution map according to the AIA 304 Å data with the superposed magnetic field strength contours.

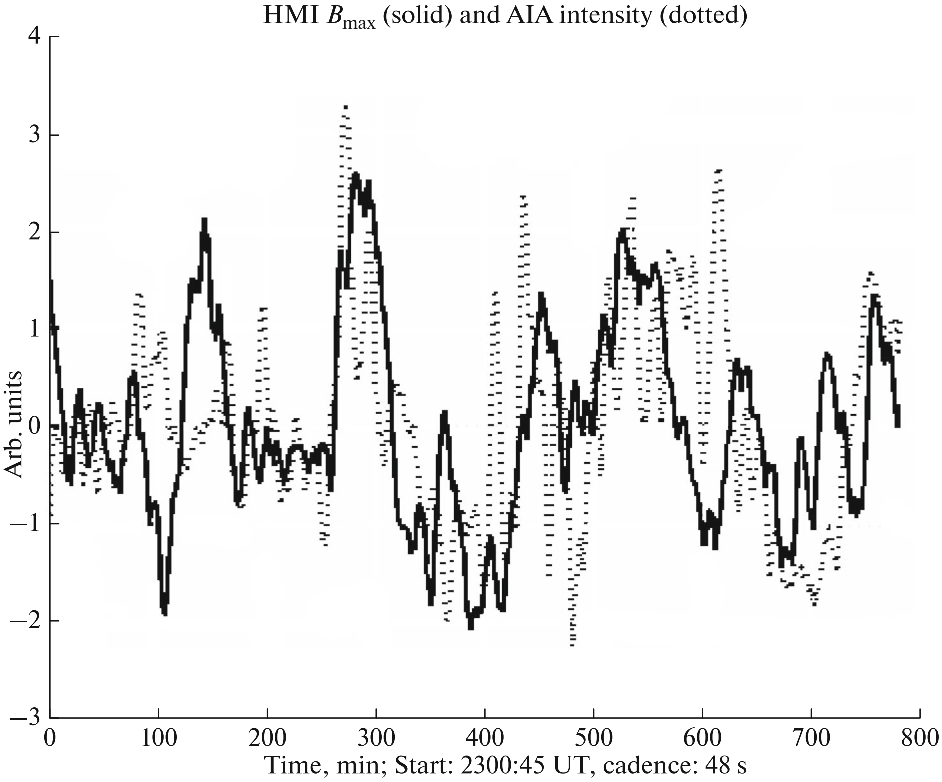

Fig. 5. Superposed time series of the variations in the maximal magnetic field strength (a solid line) and intensity (a dotted line).

tours. An arrow shows the studied object described in an example. The observations were performed on June 7, 2013, at 2300:45.

Figure 4 demonstrates that the magnetic structures observed by us are located near the regions of increased brightness in the 304 Å line.

We obtained intensity maps with a time resolution of 12 s for 13 h when the magnetic element was observed. The [10 × 10] pixel region of increased brightness, including the selected magnetic element, was identified on the maps. We studied variations in the intensity of this region as compared to the varia-

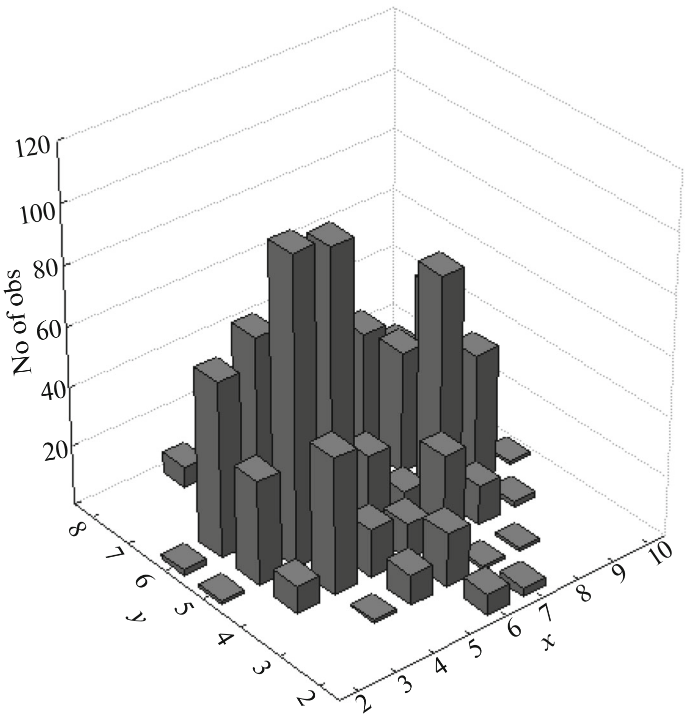

Fig. 6. Statistical distribution of the maximal reading position along coordinates.

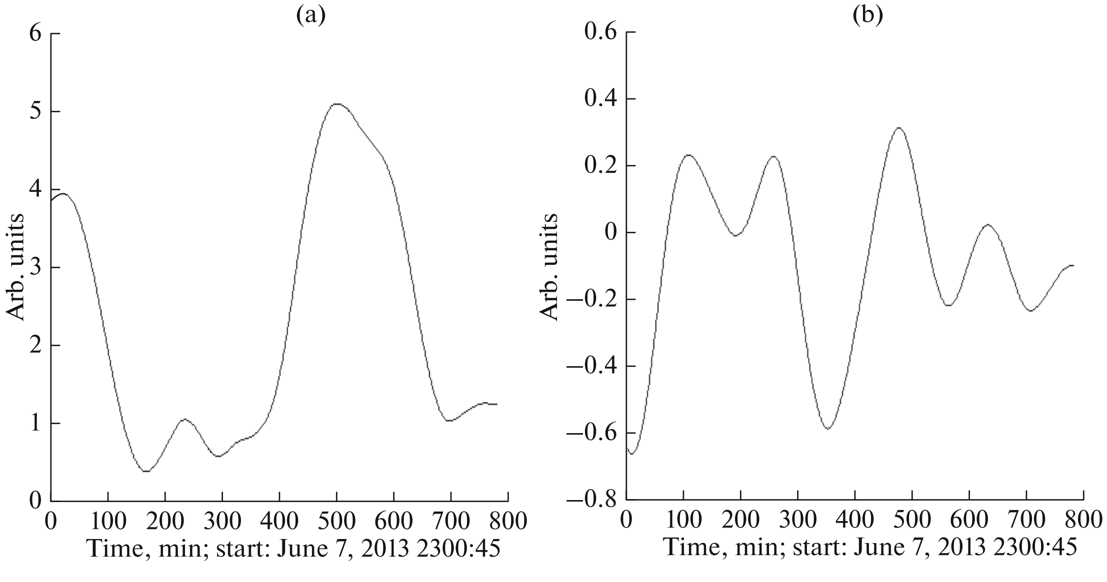

Fig. 7. (a) Change in the maximal reading of the radius vector relative to the equilibrium probable position point; (b) a change in the deviation angle of the maximal reading radius vector.

tions in the maximal strength of the object magnetic field. The time series of variations in the maximal magnetic field strength and the intensity are superposed in Fig. 5.

The correlation coefficient of the time series is 0.6. The periods of quasi-periodic variations for the 304 Å intensity series are in the 140–200 min interval, which is close to the periods obtained for the maximal magnetic field strength of the studied object. This result indicates that magnetic elements on the photosphere can be related to flocculi, i.e., bright chromospheric formations that are observed at the boundaries of the chromospheric grid.

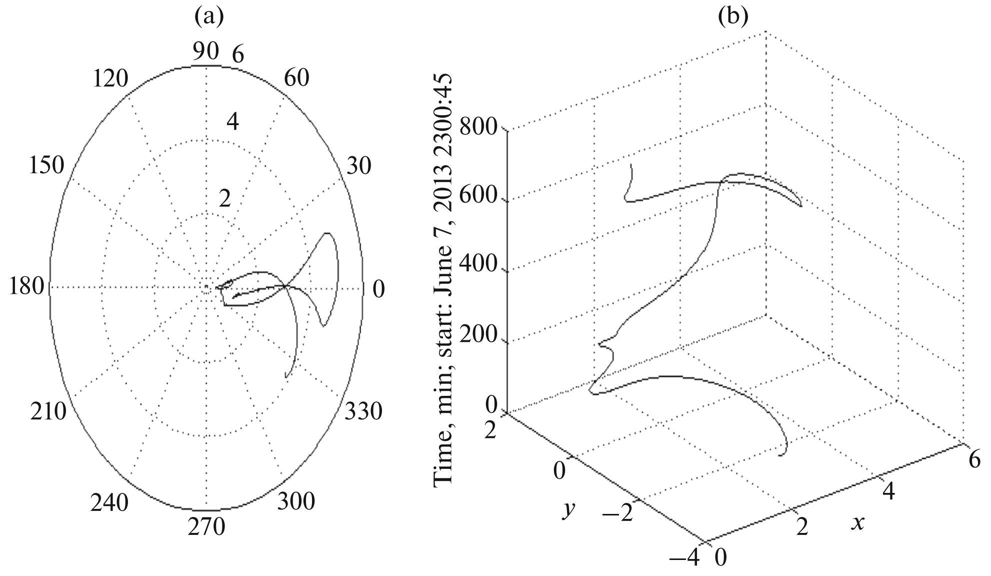

Fig. 8. Maximal reading motion trajectory: (a) in polar coordinates; (b) in plane coordinates.

How do the detected magnetic field variations manifest themselves in the horizontal velocity field (Nagovitsyn et al., 2012)? We analyzed a change in the position of the maximal magnetic field value relative to CCD matrix pixels (the maximal reading). This position was specified by reading coordinates *x*, *y* (in pixel) for each instant.

We analyzed each magnetic element in a small (relative to solar disk) box. This box had identical dimensions at each instant and moved with an empirically calculated velocity typical of the selected object. The box coordinates were related to the origin on the magnetogram at each instant.

Analyzing the behavior of the maximal reading coordinates [*x*, *y*] within the box, we obtained the statistical distribution, which indicated the most probable equilibrium position for this maximal reading, i.e., the point where the maximal reading appeared most frequently (Fig. 6). This is the point at which the relative coordinates were *x*, *y* [4, 6].

To estimate the maximal reading motion character, we performed a plane-parallel translation of the box origin, where the maximal reading at point [4, 6] was analyzed. We then calculated the length of radius vector $|a| = \mathrm{sqrt}(x^2 + y^2)$, which characterizes the distance over which the maximal reading moved from its probable equilibrium position at each next instant (Fig. 7a).

We additionally calculated the deviation angle (Phi) of radius vector |a| as Phi = arctan $(\tan(x/y))$.

The time variations in angle Phi presented in Fig. 7b. Figures 7a and 7b can be used to trace the maximal reading trajectory in the course of time (Figs. 8a, 8b).

It is evident that the maximal pixel shows recurrent motions (oscillations) in the selected coordinate grid. Typical quasi-periods are 150–200 min (which is close to the magnetic field oscillations found by us) and several hundreds of minutes. This fact indicates that variations in the magnetic field value and spatial oscillation modes took place for facula structures and sunspots (Nagovitsyn et al., 2012).

Figures 8a and 8b show the maximal reading trajectory (a) in polar coordinates and (b) in plane ones, where the trajectory is traced in the course of time.

5. CONCLUSIONS

1. We studied 30 small-scale magnetic elements (facula nodes in the photosphere) with a maximal strength of magnetic fields within 400–900 G in order to search for long-period variations in the time series lasting 10–13 h.

2. We found the periods of quasi-static variations for the maximal and average magnetic field strength of the selected elements in the 150–350 G contours within 60–280 min. We showed that a pronounced relationship between the longest observed periods and the magnetic field is absent.

3. We showed that an ambiguous correlation between the variations in the average magnetic field strength in the contour and an area in a given contour is absent for the selected objects.

4. A comparison of the data on the intensity variations in the 304 Å line and the magnetic field strength for one object indicated good agreement of the quasi-periodic variation periods.

5. Analysis of the maximal reading motion along coordinates indicates that the selected objects have horizontal oscillation modes.

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