CONCERNING FIVE-MINUTE VARIATIONS OF THE GLOBAL MAGNETIC FIELD OF THE SUN

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Abstract. For the purpose of identifying five-min oscillations we analyze long-term continuous observations of the solar magnetic field (with a duration from 3 to 11 hours) with 0.5 $D_{\odot}$ spatial resolution obtained with the STOP telescope (Solar Telescope for Operative Predictions) at the Sayan observatory in 1987 and 1989. It is shown that global magnetic field fluctuations with such periods seem to be real, but the character of corresponding power spectra is strongly dependent on the mean field strength in the magnetograph aperture.

1. Introduction

Among an extensive number of problems related to the study of large-scale magnetic fields on the Sun, the problem of investigating their variability on different time-scales is a fascinating challenge. Until recently most attention was focused on the analysis of sufficiently strong, long-term variations with periods from several weeks to annual or multi-annual variations. However, studying shorter-term magnetic field variations (of the order of one day or even less), as pointed out by Severny (1976), is of great interest. It should be noted that present-day measurements of magnetic variability of some stars (Marcy, 1984) give evidence for the existence of rather appreciable (not yet fully explainable), rapid (<1 day) changes of magnetic fluxes there.

It is important to note that, as far as the Sun is concerned, studying the rapid variability of its global magnetic field is a rather complicated (because of a very weak effect) observational task. Earlier, some Crimean authors (Kotov, Severny, and Tsap, 1983) reported, however, on the presence of a 160-min period in the variations of the solar mean magnetic field (henceforth referred to as SMMF), while Demidov, Kotov, and Grigoryev (1989) demonstrated the possible existence of shorter-term (up to 45 min) SMMF variations.

In this paper an attempt is made to solve a still more difficult problem, namely to try to ascertain whether it is possible to observe SMMF fluctuations with periods of about 5 min. While being aware of the extreme complexity of such a problem, we have, nevertheless, ventured to carry out the pertinent investigations, in view of its utmost importance. As is known, the study of 5-min global variations of the Sun forms the basis for modern helioseismology, but until the present such investigations have been restricted mainly to observations of oscillations of two parameters only, namely line-of-sight velocities and brightness; therefore, incorporating a new parameter, the magnetic field, would enrich the available information, thus rendering it more valuable. Besides, results of some theoretical studies (Cram and Wilson, 1975; Venkatakrishnan, 1979) confirm the importance of investigating rapid magnetic field variations.

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It should be noted that, though the existence of 5-min magnetic field oscillations of the Sun as a star was pointed out, for the first time, by Ioshpa, Obridko, and Shelting (1973), due to the scantiness of observational data used the obtained results of measurements cannot be regarded as convincing. Therefore, in order to look for 5-min oscillations, it is justifiable to analyze SMMF observations with much higher accuracy as obtained on the STOP telescope (Grigoryev and Demidov, 1987) at the Sayan solar observatory.

2. Observations and Results

However, before embarking on a detailed analysis, we wish to remember that the existence of local 5-min oscillations of the magnetic field strength which accompany line-of-sight velocity oscillations, was pointed out by Severny (1971) and was convincingly demonstrated by Tanenbaum, Wilcox, and Howard (1971), who showed, in particular, that such oscillations of the field do, indeed, occur, rather than being caused by some other effects such as line profile or brightness variations; oscillation amplitudes were 200–300 μT (but more recently Kobanov (1979) reported on obtaining far larger amplitudes of such oscillations). Significant variations in the course of the 5-min oscillations in the calcium network of the *V*-parameter of the line 846.8 nm Fe I were found by Wiehr (1985).

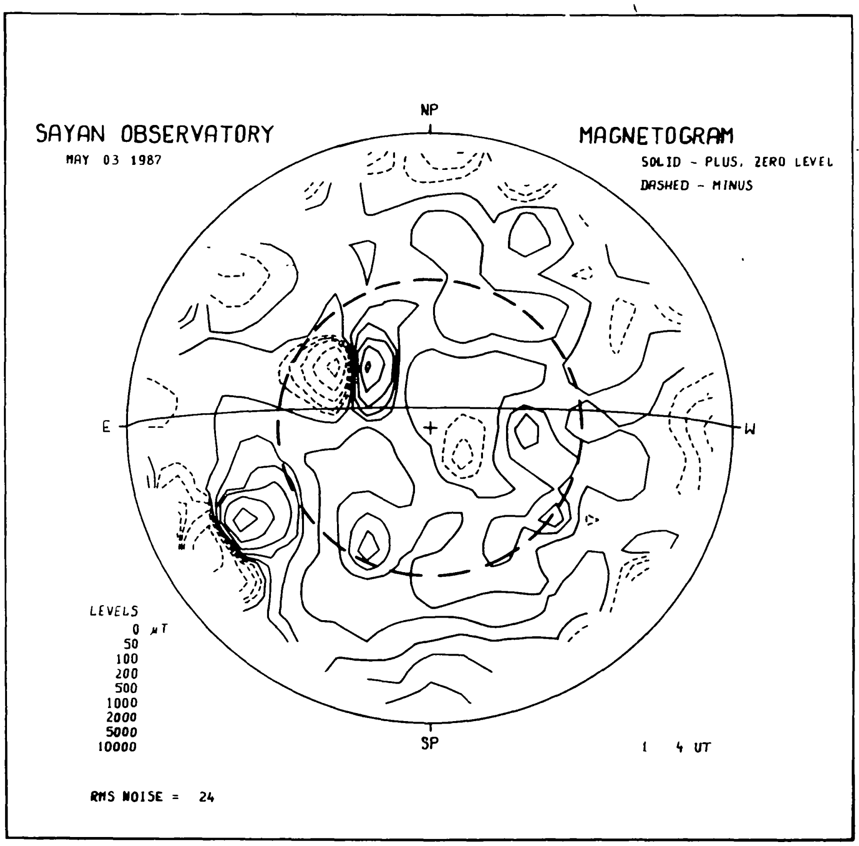

Fig. 1. The background magnetic field magnetogram as obtained on STOP on 3 May, 1987; at the center of the dashed circle one can see the region of averaging for the observations used in this paper.

It is clear that with decreasing spatial resolution of the observations, amplitudes of field oscillations as well as those of line-of-sight velocities (Fossat and Ricort, 1973) must decrease so that in the case of SMMF observations amplitudes of only a few μT might be expected. Hence, in order to improve the accuracy of measurement, we decided to make measurements not of the full solar disk but only for its central area of diameter 0.5 $D_\odot$. To accomplish this, the telescope objective lens was displaced (Grigoryev and Demidov, 1987) at a corresponding distance from the spectrograph entrance slit. On the basis of a magnetogram for 3 May, 1987 the observed area on the disk is shown by a dashed circle in Figure 1. It is important to note that as compared with the usual scheme for SMMF observations at STOP the light flux increased nearly 1.5 times. It should be remembered that, although Scherrer (1973) showed that it is such a zone

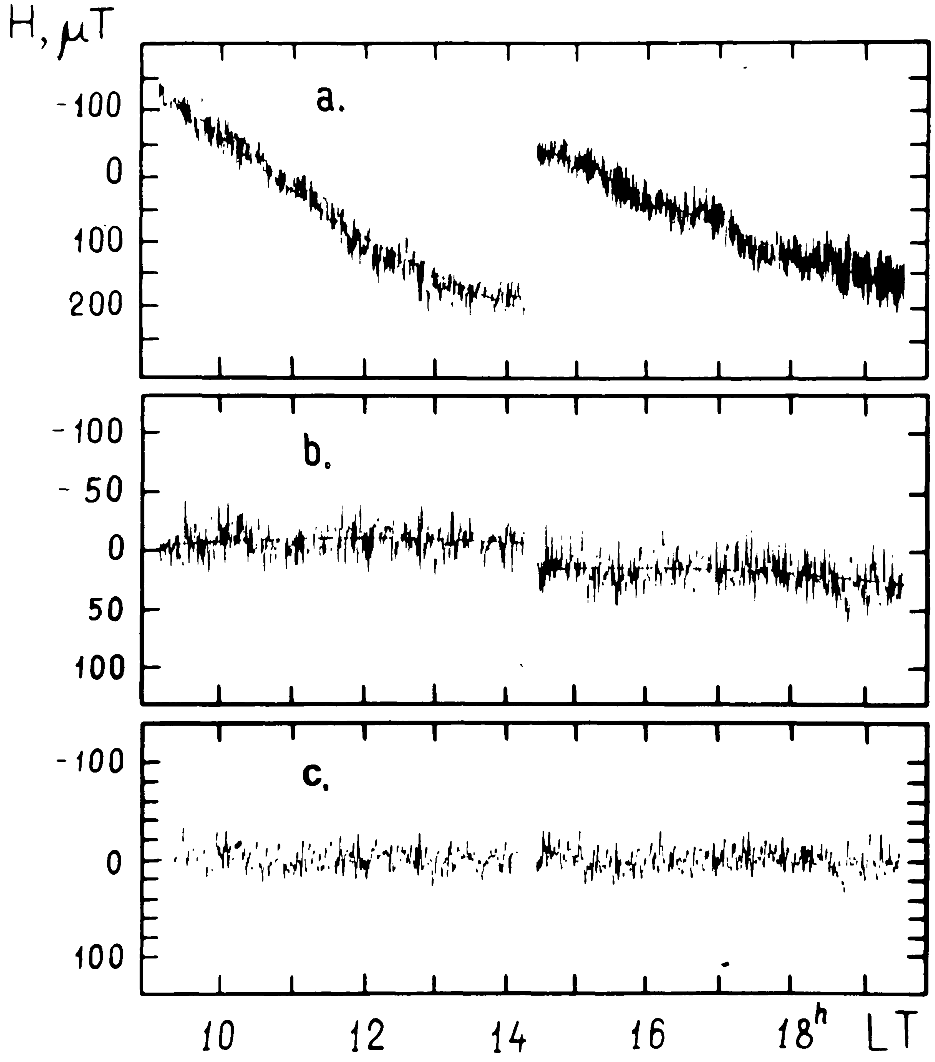

Fig. 2. An example of long-term continuous observations of the magnetic field with an angular resolution of 16 arc min as obtained on STOP of the Sayan observatory on 4 May, 1987. (a) Original data with alternation of measurements made with and without the $\lambda/2$-plate; the abrupt gap is caused by the reverse of the coelostat. (b) 'True' field is the result of data handling (a) by taking account of the zero-level drift of the magnetograph; $H = S_1 - (S_1 + S_2)/2$, where S_1 and S_2 are measurements without and with the $\lambda/2$-plate, respectively. (c) The final data with subtraction from each half of the observations (b) of the corresponding parabolic trend.

which mainly forms the SMMF signal, the variation of the observing scheme described above must lead to some changes in sensitivity of the observations to oscillations of the degree of difference l. Thus, Pallé *et al.* (1989) showed that in velocity observations with a 0.54 $D_\odot$ aperture, instead of maximum sensitivity to dipole oscillations in integral observations of the Sun (Christensen-Dalsgaard and Gough, 1982; Balandin, Grigoryev, and Demidov, 1987), the sensitivity maximum corresponds now to $l = 3$. There is reason for believing that in such observations though not integral, nevertheless global solar parameters are measured.

For the sake of illustrating what such a kind of magnetic field records look like, Figure 2 gives a typical example of original observations obtained on STOP on 4 May, 1987. A detailed description of the observing and processing techniques is given in papers by Grigoryev and Demidov (1987) and Demidov, Kotov, and Grigoryev (1989); therefore, we note here only that the integration time of a single measurement (it is, as usual, line λ525.0 nm Fe I) is 32 s, and that when records were taken, a half-wave phase plate was used to effect continuous zero control of the magnetograph, which, though not very important for 5-min observations, plays a crucial role for longer-period oscillations. In resulting data sets on 'true' field (Figure 2(b)), parabolic trends were determined, and the differences between them and the original measurements (Figure 2(c)) were the subject of a subsequent statistical analysis. In this case, no special spectral filtering of the data was carried out, with the exception of using a sliding smoothing over three points.

A power spectrum of oscillations in the 5-min range for the Figure 2 observations as constructed by the CPGA method (Kopecký and Kuklin, 1971) is shown in Figure 3. The sufficiently long duration of the data (11 hr) has given rise to a composite multicomponent character of the spectrum, where the largest peaks with periods of 5.68 and 4.65 min have amplitudes of 2.6 and 2.3 μT. It is known from observations of global Doppler oscillations of the Sun (Grec, Fossat, and Pomerantz, 1983) that the heights of peaks in corresponding power spectra increase considerably as they approach an almost exactly 5-min period and in Figure 3 such a concentration is absent; this gives rise to doubt that this spectrum does, indeed, reflect the 5-min variations of the solar magnetic field accompanying global oscillations of the Sun. In order to ascertain if such oscillations increase in some shorter time intervals (and such a possibility was pointed out by Ioshpa, Obridko, and Shelting, 1973), the observations for 4 May, 1987 considered here have been divided into 1.5-hr intervals, for which corresponding CPGA spectra were then calculated. However, no one of the spectra showed significant 5-min oscillations. Such oscillations were also absent on the adjacent days of observation: 3 May, 1987 (a record of 10 hr length) and on 5 May, 1987 (a record of 3 hr length).

A common property of the above-mentioned observations is that mean field strengths, upon which the fluctuations occur, are very small, almost of zero value (which agrees with the Sun-as-a-star observations during those days at Sayan and at Stanford). As is known (Dittmer, 1977), characteristics of 5-min velocity oscillations do not depend on the sign of the background magnetic field; hence, in the case of small values of the resulting magnetic flux in the spectrograph aperture when fields of different sign are

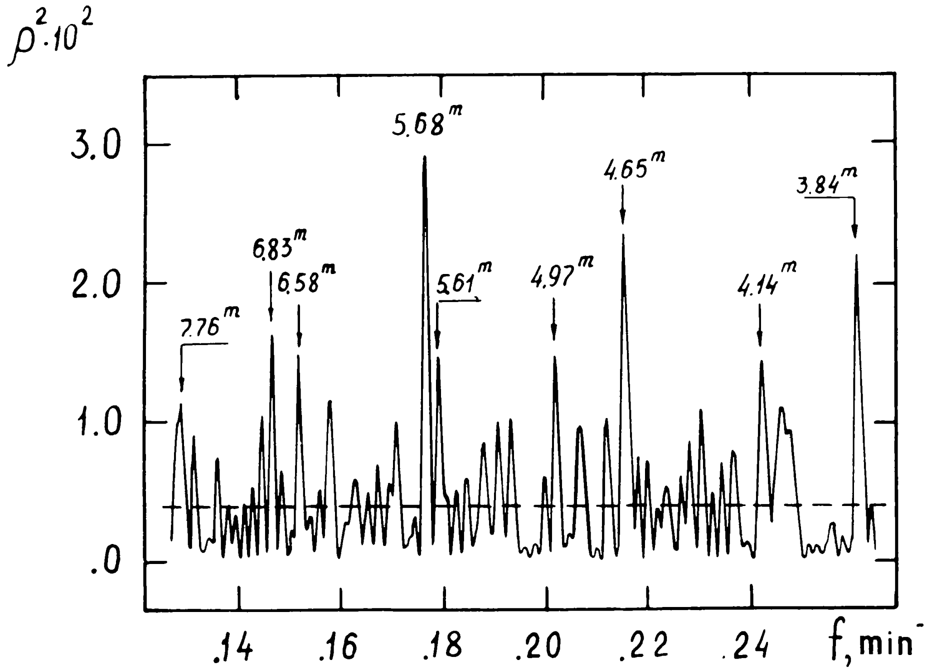

Fig. 3. The CPGA spectrum (correlation periodogram analysis) in the range of 5-min period for the magnetic field observations (of 11 hr duration) with a 0.5 $D_\odot$ aperture as shown in Figure 1. A dashed horizontal line corresponds to the correlation coefficient ρ whose significance in data sets with N measurements (which is determined by the formula $P = 1 - (1 - \rho^2)^{(N-3)/2}$) is 0.90.

compensated for each other, one should, indeed, expect small oscillation amplitudes. On the contrary, if a one-polarity field predominates in the region observed, such oscillations must be more pronounced. The observations we have available have permitted us to test such a variant; it has actually appeared that for the 24 April, 1987

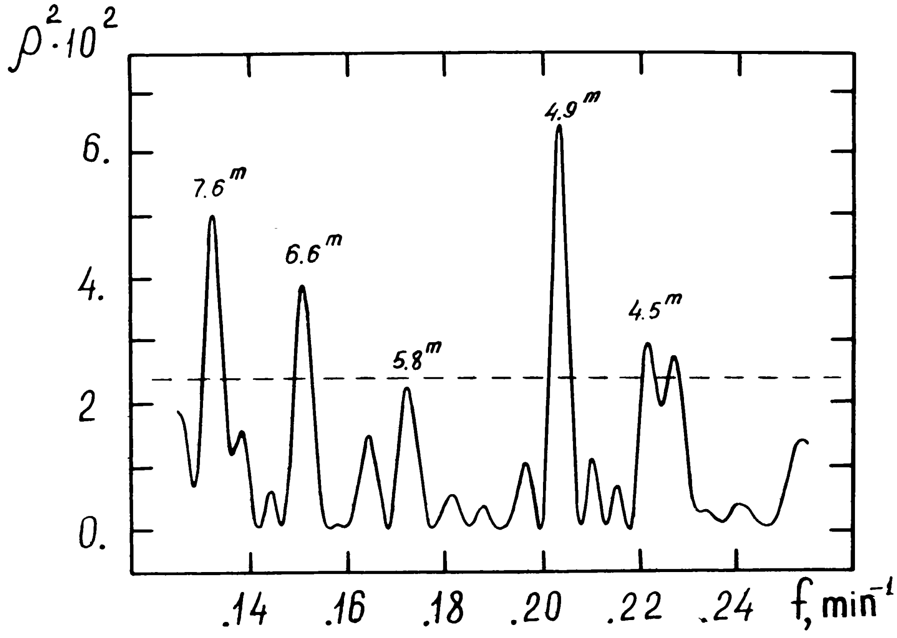

Fig. 4. The same as in Figure 3 but for the observations (of 3 hr duration) of 9 June, 1987 as obtained with a spatial resolution of 0.5 $D_\odot$.

observations (of a duration of 5.2 hr), with the mean signal level of − 40 μT now, 5-min oscillations are identifiable with higher confidence. Maximum peaks in the corresponding spectrum with periods of 5.81, 4.86, and 4.77 min have amplitudes of 3.3, 2.8, and 2.6 μT. For the 9 June, 1987 observations (of a duration of 3 hr), the spectrum is shown in Figure 4 which clearly indicates that the 5-min oscillations (with an amplitude of 4 μT) are dominant in this case. Also, the mean signal level is 60 μT. In the last record analyzed here (for 20 August, 1989, of a length of 5.4 hr), when the mean field strength is about 150 μT, not only did the 5-min oscillations reveal themselves clearly in a corresponding power spectrum, but were even seen visually on individual fragments of the original records. In particular, one of such fragments, with a duration of about 20 min, is shown in Figure 5. One can see that the oscillation amplitude is very high, perhaps, even anomalously high, but we believe that there are no reasons for suspecting that they have some extraneous, for example, instrumental, origin.

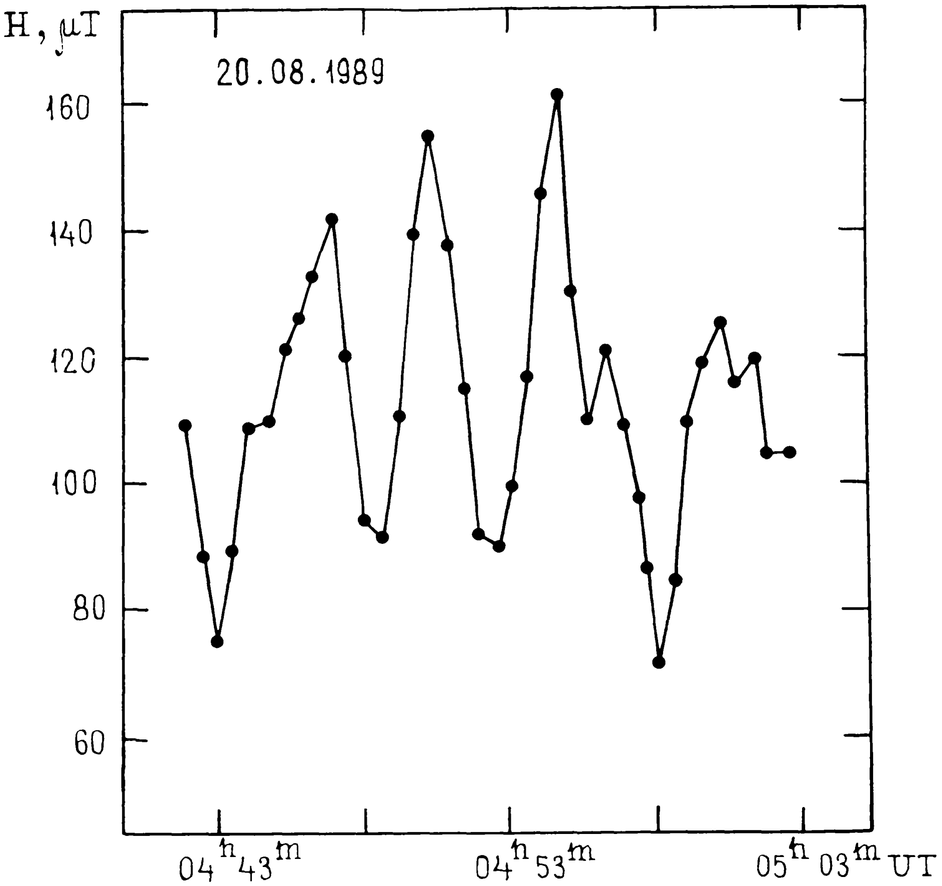

Fig. 5. A fragment of the magnetic field observations with 0.5 $D_\odot$ spatial resolution as obtained on 20 August, 1989, in which 5-min oscillations are observed in raw data. Note that the present case is quite a unique one.

An assessment of the possible effect of small guiding errors can be made on the basis of direct records. Photo-electric guiding is effected along the solar limb to an accuracy of about 1″ and, in the case of long observations,.structural elements of field, due to solar rotation, displace slowly over the 0.5 $D_\odot$ aperture. This gives rise to a trend and permits an estimate of guiding errors to be made. For instance, in the observations of 4 May, 1987 (Figure 2(b)) the signal trend in the second half of the record was not more than 20 μT during 5 hours. With a guiding error of about 1″, the variations in the signal with such a trend will be less than 0.5 μT, and this is significantly less than the observed amplitudes of SMMF variations.

Thus, in summarizing the experimental results presented here, it is necessary to conclude that magnetic oscillation spectra in the range of 5 minutes undergo a significant variability. Five-min variations of the global magnetic field are most reliably identified at sufficiently high values of the mean field strength inside the magnetograph aperture.

3. Conclusions

The question of the physical nature of the oscillations concerned is rather complicated such that only some preliminary suppositions may be made at present. Qualitatively, the influence of the plasma oscillations upon the measured magnetic field strength was considered by Tanenbaum, Wilcox, and Howard (1971). The numerical calculations of the V parameter of the line λ525.0 m of Fe I we have carried out for different models of distribution of magnetic fields and line-of-sight velocities inside the magnetograph aperture have shown a rather complex dependence on the form of the V parameter of the adopted model.

The observed SMMF variations might be attributable both directly to magnetic field strength oscillations and to plasma oscillations and to the influence of these oscillations via variations of the line profile and of the V-parameter in the line upon the mean magnetograph signal. In this case, the magnetic field structure in the aperture can play the role of a spatial filter, which determines the contribution of the plasma oscillations to the measured SMMF signal. This can be responsible for the day-to-day variability of the SMMF variation spectrum.

A detailed account of the results obtained will be the subject of a separate paper so that we shall not consider them here because the main objective of this paper has been only to analyze the possibilities of experimental recordings of weak fluctuations of the global magnetic field.

In general, the results of this study can, we surmise, be regarded as proving the reality of 5-min SMMF variations, although the obtained dependence of oscillation spectra on the mean field strength inside the magnetograph aperture (as one would expect) complicates the comparison of 'magnetic' oscillation frequencies with data, for example, of Doppler observations of solar global oscillations.

Of course, further progress in the study of rapid magnetic variability of the Sun requires further investigations. Simultaneous observations with different instruments and observatories would be extremely useful.

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