THE SPECTRUM OF LOW-FREQUENCY OSCILLATIONS OF THE MAGNETIC FIELD OF SUNSPOTS, AND LOW-FREQUENCY MODULATION OF THE RADIOEMISSION FROM THE ACTIVE REGIONS OF THE SUN

É. I. Moglevskii, V. N. Obridko, and B. D. Shel'ting

UDC 523.164.32

During the past 10 years of heliophysics research investigations of low-frequency oscillations of the radial velocities and brightnesses in the unperturbed regions of the Sun have been performed by various methods [1-5]. It has been possible to reveal 5-min oscillations in the photosphere which have been related to resonance oscillations in a specified layer. The propagation of such longitudinal density waves into the chromosphere and corona has led, according to computations (due to the transition of these waves into shock-waves) to heating of the corona. With the appearance of solar magnetographs it was possible to show [6] that oscillations of the magnetic field having the same period are also observed in the unperturbed regions. In [6] it was indicated that besides 5-min oscillations of the field, oscillations with a period of ≈ 7 min are observed. In a series of papers published by the Scientific-Research Radiophysics Institute [7-9] modulation of the solar radioemission at $\lambda \sim 3$ cm not only with a period of ≈ 5 min but also with other discrete periods was revealed for the first time, the power spectrum of the oscillations from active regions differing from the spectrum of the unperturbed Sun.

Later the modulation of radioemission was successfully revealed at other centimeter wavelengths as well, and even in the modulation of the continuum of radionoise storms in the meter range [10].

The fact that the spectrum of the modulation of the radioemission of the upper chromosphere and the corona corresponds to the spectrum of the oscillations of the velocities, brightness and magnetic field in the photosphere makes the clarification of the nature of these oscillations and the modes of their propagation urgent. This problem becomes all the more urgent if one takes into account the fact that for oscillations of the photospheric parameters having $T \sim 300$ sec it has been possible to establish a relationship with the discrete supergranulation structure [11]. Investigations of the time oscillations of the field have not been performed in active regions having magnetic fields above 100 G. In the present communication preliminary data are presented on the revelation of field oscillations in the nuclei of relatively large "quiet" sunspots. The observations were performed in 1968, on the double vector-magnetograph of the solar tower installation of the Institute of Terrestrial Magnetism and Radiowave Propagation of the Academy of Sciences. Using two independent vector-magnetographs, the magnetic field, velocity and brightness were simultaneously determined in two magnetosensitive spectral lines Fe I λ 5250 Å and Ba II λ 4554 Å. The levels of formation of these lines are separated in altitude by ~700 km (Fe I is a photospheric line, while the nucleus Ba II is associated with the lower chromosphere). The observations were carried out for careful guidance of the nucleus of the spot onto the input slit of the spectrograph with motion-picture recording of the image of the nucleus on the slit. Oscillations of the image on the slit due to atmospheric and equipment effects may lead to the development of fictitious frequencies in the spectrum of the recorded signals. However, the oscillation periods of an atmospheric character amount to 1 to 10 Hz, while the fictitious oscillations of an equipment character must be identical for the two magnetographs. Since the spectra of the oscillations of the magnetic field differ at the two levels, this provides the possibility of assuming that the equipment effects are negligible. Scaling of the Stokes parameters measured by the magnetograph to the parameters of the vector field (the longitudinal components $H_{\parallel}$, the perpendicular

Institute of Terrestrial Magnetism, the Ionosphere, and Radiowave Propagation, Academy of Sciences of the USSR. Translated from Izvestiya Vysshikh Uchebnykh Zavedenii, Radiofizika, Vol. 16, No. 9, pp. 1356-1361, September, 1973. Original article submitted October 23, 1972.

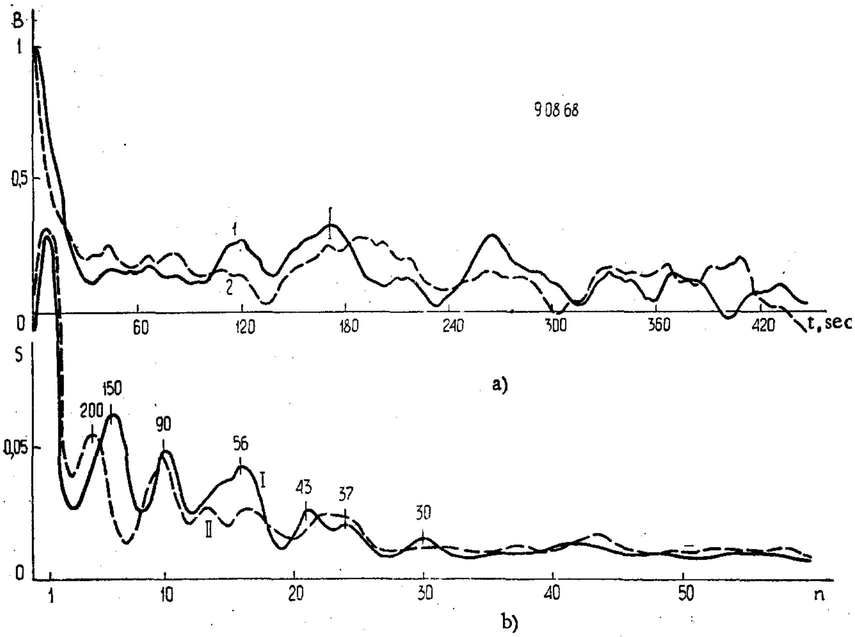

Fig. 1. Figure 1a shows the autocorrelation functions of the oscillations of $H_{\parallel}$ in two lines: Fe I λ 5250 Å (curve 1) and Ba II λ 4554 Å (curve 2); Fig. 1b shows their corresponding spectral functions (I and II). The vertical line in Fig. 1a denotes the 70% confidence interval of the errors of the autocorrelation function; the corresponding confidence interval of the spectral functions is less than 0.01.

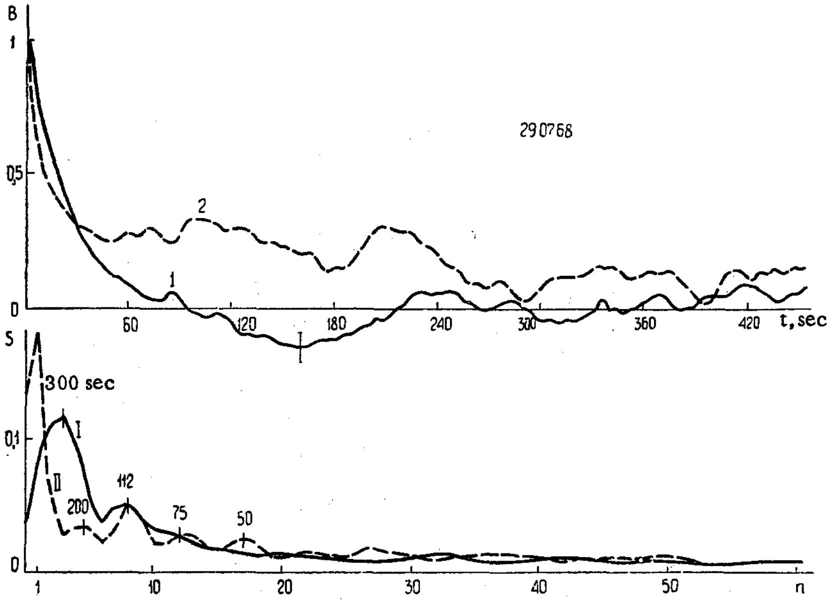

Fig. 2. Autocorrelation and spectral functions of the oscillations of $H_{\perp}$ in the Fe I λ 5250 Å and Ba II λ 4554 Å lines (for the notation see caption of Fig. 1).

components $H_{\perp}$, or $H_x = H_{\perp} \sin \chi$ and $H_y = H_{\perp} \cos \chi$, where the angle χ is the azimuth of the field vector) and the subsequent complete Fourier-analysis were performed on an electronic computer. The runs of observations ("standings") were continued for ~1 h. So far four independent "standings" have been processed (July 29, 1968; August 9, 1968; and August 11, 1968) for two spots near the center of the solar disk. Figures 1 and 2 show the autocorrelation and spectral functions of the longitudinal and transverse fields. We also presented certain results in [12]. The results of the observations lead to the following conclusions.

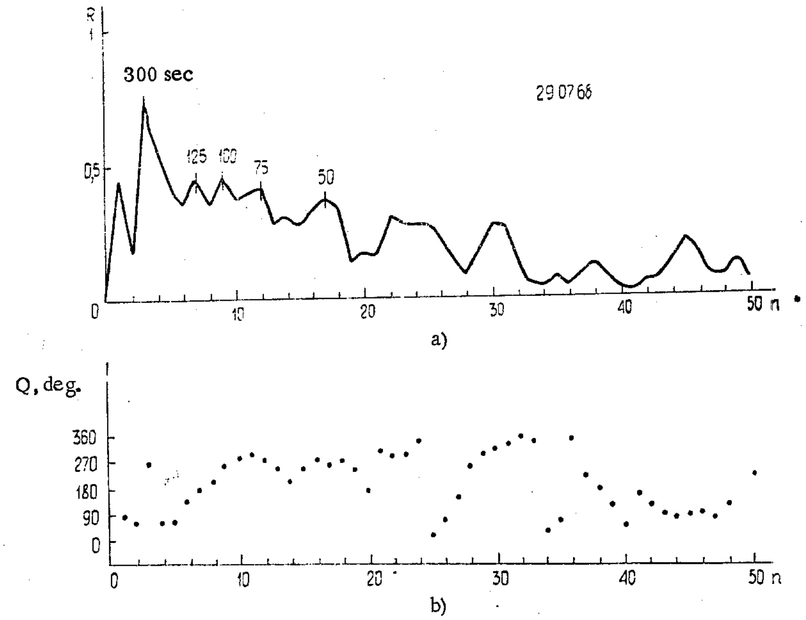

Fig. 3. Figure 3a depicts the coherence R, while Fig. 3b depicts the relative phase shift Θ of the oscillations of $H_{\parallel}$ in the two lines Fe I λ_1 5250 Å and Ba II λ_2 4554 Å; the 70% confidence interval of the coherence errors is less than 0.01.

1. The power spectrum of the field oscillations in the nucleus of the spot has several discrete periods: besides 300-sec oscillations, oscillations having periods of 225 to 125 sec and 110 to 90 sec are revealed. Unlike the unperturbed photosphere, where 300-sec oscillations predominate, they are not always manifested in the spot, while 2-3-min oscillations are observed frequently and revealed more reliably. Note that in the recently received preprint [13], in which an exposition is given of the investigation of oscillations of radial velocity in a sunspot performed on the large solar installation at the Kitt Peak observatory, it is reported that ~170-sec oscillations of the radial velocity have also been detected. The detection of several discrete frequencies of the oscillations of the fields produced by the nucleus even in a "quiet" spot is of interest for the study of the field structure in the photosphere and chromosphere with which the modulation of the radioemission from the chromosphere and corona above the spots is associated.
2. The 5-min oscillations are manifested only in the transverse component of the magnetic field $H_{\perp}$ during two of the four runs of observations, while the 2-3-min oscillations are encountered in all four cases in both the longitudinal and transverse components of the magnetic field. At the photosphere level the oscillations are manifested more frequently in the magnitude of the field, while at the chromosphere level they are manifested more frequently in the direction of the field. The amplitude of the oscillations in the chromosphere exceeds the amplitude of the oscillations of the field in the photosphere. The 5-min oscillations are strongly suppressed in the spot: they are rarely visible in the spectra and are revealed better in the coherence (Fig. 3).
3. The spectra obtained for the field oscillations are quasistationary in character and vary somewhat from realization to realization. It is possible that the spectrum of the oscillations varies with time and differs somewhat at different points of the nucleus. The same conclusion concerning the space and time difference between the spectra of v_D was drawn in the paper [13] mentioned above, where good space resolution was achieved on the large solar instrument using a large amount of data. There is a basis for assuming that in complex and dynamic spots this effect of space and time nonstationarity is manifested considerably more sharply. This allows us to hope to obtain the characteristic of the evolution of a spot and a group from the spectrum of the magnetic-field oscillations.
4. From the measured phase angles of the various parameters at the levels of the photosphere and lower chromosphere it turned out that the propagation velocity of the perturbation at various

discrete frequencies was ~30 km/sec which corresponds to the average Alfven velocity in the considered magnetoplasma above the spot.

5. The character of the 2-3-min oscillations at the two levels provides the possibility of assuming that oscillations of the torsional type are present. The existence of waves of this type of interest not only for a study of the nature of the magnetic-field oscillations but also for a clarification of the mechanism by which the modulation of radioemission above the spots develops. It is well known that sound or magnetosound waves dissipate rapidly during their propagation in a medium (the chromosphere and corona) having an abrupt variation of the density gradient (i.e., they cannot attain the altitudes corresponding to the generation of radioemission). If it turns out that the 2-3-min (and shorter-period) oscillations are actually three-dimensional hydromagnetic waves, then a number of problems involved in the modulation of radioemission is solved naturally. It is well known that three-dimensional hydromagnetic waves of this kind having frequencies considerably lower than the gyrofrequency of the ions are investigated for the Earth's magnetosphere [14, 16]. They are collimated rigorously by the magnetic field and propagate at the Alfven velocity without absorption, decreasing rapidly in amplitude with departure from the "magnetic tube"; standing waves are formed at closed magnetic tubes. Unlike plane Alfven waves, oscillating currents flow along the field in these waves. These properties of three-dimensional hydromagnetic waves may explain the modulation of the radioemission in the centimeter and meter ranges.

LITERATURE CITED

1. B. B. Leighton, R. W. Noyes, and G. W. Simon, Astrophys. J., 135, 474 (1962).
2. G. W. Simon and B. B. Leighton, Astrophys. J., 140, 1120 (1964).
3. B. N. Frazier, Astrophys. J., 152, 557 (1968).
4. R. Howard, Sol. Phys., 2, 3 (1967).
5. A. S. Tanenbaum, Sp. Sci. Lab., Ser., 12, 20, Univ. Calif. Berkeley (1971).
6. A. B. Severnyi, Astron. Zh., 44, 3 (1967).
7. O. I. Yudin, Dokl. Akad. Nauk SSSR, 180, Nos. 4-5, 821 (1968).
8. M. M. Kobrin, in: Collection of Report to the Session of the Scientific Council on the Complex Problem "Radioastronomy," Institute of Terrestrial Magnetism and Radiowave Propagation, Academy of Sciences, October 13-16, 1970 [in Russian], Moscow (1972), p. 27.
9. O. I. Yudin, Izv. VUZ, Radiofiz., 11, No. 4, 617 (1968).
10. A. A. Gnezdilov, in: Collection of Reports to the Session, Astron. Zh., 108 (1972).
11. H. R. Sheely and A. Bhatnagar, Sol. Phys., 18, No. 3, 379 (1971).
12. É. I. Mogilevskii, V. N. Obridko, and B. D. Shel'ting, Astron. Tsirkulyar, 669, 1 (1972).
13. J. M. Beckers and R. B. Schultz, Oscillatory Motions in Sunspots, Sol. Phys. (in press).
14. L. L. Van'yan and V. I. Dmitrieva, Geomagnetizm i Aeronomiya, 7, 887 (1967).
15. L. L. Van'yan and M. V. Gokhberg, Geomagnetizm i Aeronomiya, 8, 157 and 567 (1968).
16. L. L. Van'yan, V. I. Dmitriev, and A. A. Belen'kaya, Geomagnetizm i Aeronomiya, 8, 159 (1968).