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POLARIZATION OF HYDROMAGNETIC OSCILLATIONS OF THE *Pc*-1 TYPE (PEARLS) AT THE MAGNETICALLY CONJUGATE POINTS SORG (USSR)–KERGUELEN (FRANCE)

(Presented by Academician M. A. Sadovskii, 13 VII 1966)

In recent years, the properties of magnetic-field oscillations of the *Pc*-1 type ($f \approx 0.2$—5 Hz), which appear periodically at magnetically conjugate points with a phase shift close to 180°, have aroused great interest. The totality of properties of series of such oscillations is at present explained by the generation of packets of hydromagnetic waves in distant regions ($L \geqslant 4$) of the Earth' s magnetosphere by streams of charged particles ([1–4]).

In the theory of propagation of hydromagnetic waves it is noted that the propagation of these waves along field lines from one hemisphere into the other is possible predominantly for waves of left-hand polarization (in the Northern Hemisphere), i.e., those in which the electric-field vector of the wave rotates in the same direction as positive ions around the field lines of the Earth' s magnetic field ([5,6]). On the other hand, the proposed mechanisms for the generation of these wave packets allow for the existence of two modes of hydromagnetic waves ([7–10]). Therefore, in order to test the proposed mechanisms of generation and propagation of hydromagnetic waves in the magnetosphere, the study of the polarization of *Pc*-1 oscillations recorded at conjugate points was of fundamental importance. The organization of observations of rapid variations at the magnetically conjugate points Sorga–Kerguelen and the holding of sessions of simultaneous recordings at a high sweep speed (1 cm/sec), with high accuracy of the time service, made it possible to study the character of the polarization of oscillations of the *Pc*-1 type. The study of polarization at magnetically conjugate points for oscillations in the range 0.2—2 Hz was carried out for the first time.

The results presented below are based on an analysis of series of *Pc*-1 recorded from 18 II to 9 III 1965 along two mutually perpendicular horizontal components of the Earth' s magnetic field. In analyzing the polarization, the spectral characteristics of the signal from the sonogram and the polarization of oscillations were studied jointly for "simple" and "complex" series. A simple case was considered to be the case (Table 1, I) when the *Pc*-1 oscillations occurred in one narrow frequency band and were not accompanied by the superposition of simultaneously passing series at higher and lower central frequencies. This spectral structure of a *Pc*-1 series on an analog recording (amplitude—time) is, as a rule, difficult to determine, and for its detection a sonogram (frequency—time dependence) is necessary. It should be emphasized that only with such a differentiated approach to the analyzed materials can one reveal clear regularities in the character of the polarization, which is substantially complicated when several series of *Pc*-1 oscillations are superposed (Fig. 1).

We shall regard the direction of rotation of the horizontal component of the magnetic vector as positive (+) if the vector rotates counterclockwise for an observer looking along the field line toward the Earth. For the Northern Hemisphere this direction of rotation determines

a left-polarized wave, whereas this same wave for an observer in the Southern Hemisphere will be defined as a wave in which the vector rotates clockwise, i.e., as a wave of right polarization. Thus, if the propagation of the hydromagnetic wave along the entire length of the field line occurs in one and the same definite mode, then opposite polarization will be observed at magnetically conjugate points.

Table 1

Direction of rotation for Pc-1 oscillations recorded at conjugate points

	Date	Time intervals, GMT	Frequency band of the series, Hz	Packet swing period, s	Direction of rotation at Kerguelen	Direction of rotation at Sogra
I	18 II 1965	11 h 00 m—11 h 03 m	0.2—0.35		−	+
I	18 II 1965	11 02—11 04	0.2—0.35			
I	4 III 1965	14 00—14 03	0.2—0.7	150	+	−
I	4 III 1965, A	15 00—15 03	0.4—0.9	110	−	+
I	4 III 1965, E	16 15—16 17	0.35—0.7	125	+	−

Fig. 1. Stylized sonogram of a series. Schematic representation of simple and complex segments according to the structure of Pc-1-series cases and the corresponding, for individual segments, directions of rotation in the polarization ellipses

Figure 1: Fig. 1. Stylized sonogram of a series. Schematic representation of simple and complex segments according to the structure of Pc-1-series cases and the corresponding, for individual segments, directions of rotation in the polarization ellipses

	Date	Time intervals, GMT	Frequency band of the series, Hz	Packet swing period, s	Direction of rotation at Kerguelen	Direction of rotation at Sogra
I	8 III 1965	07 00–07 03	0.55–1.05	130	+	−
I	8 III 1965	07 15–07 18	0.75–0.85	130	+	−
II	19 II 1965	02 59–03 01	0.65–0.85	175		+ (100%)
II	19 II 1965	03 00–03 02	0.6–1		−(71%)	
II	4 II 1965, B	15 15–15 18	0.3–0.9		−(67%)	+ (81%)
II	4 II 1965, C	15 45–15 48	0.4–0.75		−(52%)	+ (85%)
II	4 II 1965, D	16 00–16 03	0.4–0.7		+ (89%)	−(93%)
II	5 III 1965	10 45–10 48	0.25–0.5		−(86%)	+ (86%)
II	9 III 1965	06 00–06 03	0.55–1	120	+ (85%)	−(77%)

Analysis of the simple cases shows that the direction of rotation is stably preserved during a Pc-1 series and is opposite at conjugate points. This fact is evidence that the wave, as was indicated above, propagates in one definite mode. However, contrary to the predictions of theory, cases of simple series have been found with different directions of rotation at the given point, i.e., both left and right polarizations are observed (Fig. 2) for hydromagnetic waves propagating from one hemisphere to the other. This fact is in contradiction with the data of work ([11]), obtained for one station, and indi-

Fig. 1. Stylized sonogram of a series. Schematic representation of simple and complex, according to the structure, segments of a Pc-1 series and the directions

Fig. 2

Figure 2: Fig. 2

of rotation in the polarization ellipses corresponding to individual segments.

indicating that in the Northern Hemisphere a wave of left-hand polarization is always observed.

For the complex structure of a series, a frequent change in the direction of polarization is possible for neighboring oscillations, as was theoretically predicted [12]. However, such series are characterized by the fact that the maximum number of cases of rotation in one direction for a given hemisphere corresponds to the maximum number of cases of rotation in the opposite direction in the other hemisphere (see Table 1). Whereas in [12] the change in the direction of rotation is explained by a purely algebraic addition of oscillations with one rotation, Table 1 and Fig. 1 show that, in addition to this, simultaneous propagation of waves of different polarization between conjugate points takes place. From Fig. 1 it is clearly seen that in the Northern Hemisphere the series with the higher central frequency has left-hand rotation (+), while the series with the lower frequency has right-hand (−) rotation. In the Southern Hemisphere the pattern is the reverse.

Fig. 2. Opposite directions of rotation. Recording of Pc-1 oscillations at Sogra and Kerguelen and the corresponding polarization ellipses: a—positive rotation at Sogra; b—negative rotation at Sogra. Portions of the records from the Sogra and Kerguelen stations are taken that are shifted in time by about 1 min, which is required for the "pearl" to propagate from one point to the other.

In addition to analysis of the direction of rotation of Pc-1 oscillations, the change in the directions of the major axis of the polarization ellipse for individual oscillations was studied.

···observations. Mainly the materials of the Sogra station were used, since a larger number of records with both components were available for it (the records from Kerguelen Island had not yet been delivered). Despite the fact that the direction of the major axis may change by about 20° even within a single burst (one "pearl") of Pc-1, the predominant direction is the N-S direction (in agreement with work [11]).

Thus, the results obtained show that:

1. Hydromagnetic oscillations Pc-1 propagate from one hemisphere into the other while preserving a definite polarization characteristic of the given series. In this case both right-hand and left-hand polarization may be observed.
2. In cases where several close but frequency-different series are superposed, both identical and opposite polarizations may be observed at conjugate

points. This fact indicates the possibility of the simultaneous propagation, along field lines, of waves of both left-hand and right-hand polarization.

3. Contrary to the requirements of theory, the oscillations exhibit elliptical, not circular, polarization; moreover, the major axes of the polarization ellipses are elongated in the N–S direction.

The experimental results obtained indicate the need to revise a number of established ideas, namely: at frequencies substantially lower than the ion gyrofrequencies, only the wave of left-hand polarization (as defined for the Northern Hemisphere) propagates along the magnetic-field lines in accordance with theory.

It is precisely for this reason that this wave is called anisotropic, in contrast to the right-hand polarized wave, which can propagate independently of the direction of the magnetic field (an isotropic wave). Since, according to the data obtained, waves of right-hand polarization propagate from one conjugate point to the other, it is necessary to develop a mechanism for this propagation (for example, by invoking the fact of the existence of additional ionization along the field lines, etc.).

The observation of elliptical polarization of the oscillations and the absence of circularly polarized waves also require explanation. It is unlikely that this transformation can be explained solely by the influence of the Earth, especially since elongation in the N–S direction for the major axes of the ellipses is observed at many stations.

The mechanism of simultaneous generation, by particle streams in the magnetosphere, of hydromagnetic oscillations of opposite polarization also requires special consideration.

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Note: Figure translations are in progress. See original paper for figures.