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ON THE NATURE OF STEADY SHORT-PERIOD OSCILLATIONS OF THE EARTH'S MAGNETIC FIELD

(Pc3 AND Pc4)

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SUMMARY

The possibility is shown of explaining the generation mechanism of type-Pc3 and Pc4 geomagnetic pulsations by resonance of magnetohydrodynamic waves an the tubes of force, adjacent to radiation belt maximum. The possibility is considered of interpreting the experimental data with the help of the proposed model.

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1. Up until now the authors of works devoted to the solution of problems concerned with the generation of geomagnetic field pulsations were based on the assumption of the presence of minor disturbances in an undistorted Earth's magnetic dipole field. The pulsation themselves were regarded as the consequence of traveling or standing magnetohydrodynamic waves in the Earth's magnetosphere [1 - 3].

However, in reality the data on investigations with the aid of satellites show the presence of significant distortions of the geomagnetic field in the outer parts of the magnetosphere. Besides, a notable depression of the dipole field is observed; it is induced by the field of the ring current flowing in the radiation belt [4, 5].

Considered in the present work is the variation of magnetosphere's resonance properties at the distortion of Earth's geomagnetic dipole by the field of the ring current flowing in the region of trapped radiation. On the basis of the obtained data the possibility is shown of explaining the nature of steady short-period type-Pc3 and Pc4 geomagnetic field oscillations.

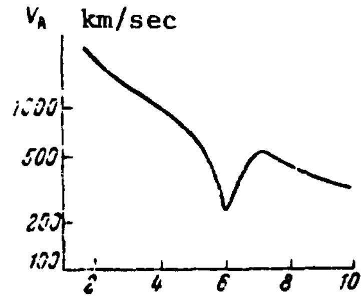
2. We assumed the belt model V_3 with center at 6R_E after Akasofu and Chapman [6 - 8], as the model radiation belt.

Assuming after Parker [9] the polar distribution of charged particle concentration in the magnetosphere and taking for the initial level the averaged latitude profile of particle concentration at 1000 km from "Explorer-22" data

[22], we computed the field ρ of particle concentration, and then also the velocity field of Alfvén waves, $V_A = H/\sqrt{4\pi\rho}$ in the undistorted Earth's magnetic field H. The obtained distribution of Alfvén waves is plotted in Fig.4 of ref.[11] (in km/sec). Its peculiarity is the presence of sharp depression of V_A at the center of the radiation belt. The graph of V_A variation in the equatorial plane is plotted in Fig.1, a. It may be seen that V_A attains minimum values of the order of 230 km/sec at the equatorial distance of $6R_E$. Analysis of peculiarities of V_A distribution along the field lines also shows the presence of a region of sharp minimum of Alfven velocity in the same region (Fig.1, b).

When speaking in terms of variation of resonance properties of the magnetosphere, the occurrence of the sharp minimum of V_A creates favorable conditions for the reflection of magnetohydrodynamic waves propagating along, as well as across the field lines. Therefore, the presence of a radiation belt in the Earth's magnetosphere results in a substantial variation in the propagation of MHD-waves in the near-terrestrial space.

The computation of the transit time of Alfvén waves (T) along distorted field lines (Fig.2) passing through the region of the radiation belt, has made apparent still another interesting peculiarity: outstripping takes place by the Alfvén wave propagating along the more remote field line ($\Phi_m = 66°$) of the Alfvén wave running along the closer field line ($\Phi_m = 65°30'$). The overtaking time is of the order of 120 sec. It should be noted that the indicated peculiarity is observed in a very narrow interval of equatorial distances, of the order of $0.3R_E$, which creates favorable conditions for the formation of beats at propagation of MHD-waves in the magnetosphere.



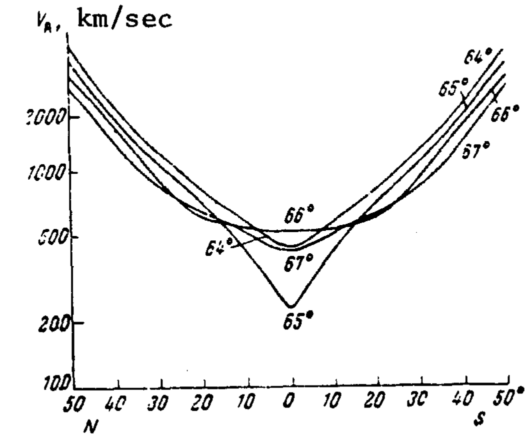


Fig.1

a b

Let us examine now the character of the variation of the magnetic field induced by currents of the radiation belt in the course of any action on the latter's outer boundary. Any perturbation in the form of tightening of the outer boundary of the radiation belt will induce an increase in current density in the radiation belt and, correspondingly an enhancement of its magnetic field. The pattern of vectors of the perturbed field, perpendicular to the magnetic lines of force, is constructed in Fig. 3. Consequently, such kind of action must excite an Alfvén wave propagating along the line of force.

It may be seen from Fig.3 that the perturbation vectors have their greatest value for the lines of force that pass through the V_A region minimum. It is important to underscore that for this group of field lines the maximum values of vectors are disposed along the beam $\sim 20°$ from the equatorial plane. This corresponds to about half the transit time of the MHD-wave from the equatorial plane to the Earth's surface.

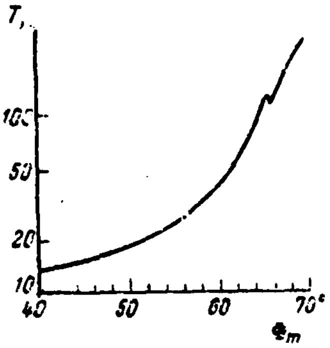


Fig.2

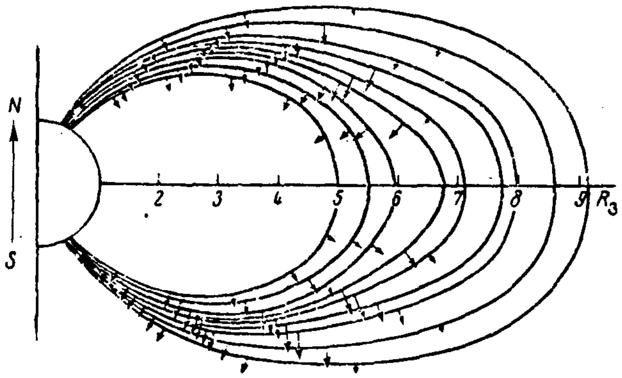


Fig.3

Therefore, the perturbation in the form of sharp tightening of the outer boundary of the radiation belt must lead to the formation of a train of standing Alfvén waves, whose period will be determined by the transit time of the wave along the line of force (Fig.2). Note that the signs of the perturbation vectors (Fig.3), perpendicular to the lines of force are different in the Northern and Southern hemispheres. As may be seen from the drawing, such an action results in an identical sign of H-component variation during the registration of pulsations in magnetoconjugate points on the ground.

If we further assume that a similar action upon the outer boundary of the radiation belt has a continuous character and includes frequencies near the resonance frequencies of the above considered region of the magnetosphere, this will lead to the appearance of a steady generation conditions of short period geomagnetic field oscillations of the types Pc3 and Pc4.

The Pc3 and Pc4 type pulsations observed on the ground apparently cannot be viewed as a manifestation of resonance of MHD-waves of only one Alfvén type. Perturbation in the form of tightening up the radiation belt must evidently excite also a magnetoacoustic type wave. Moreover, the generation of standing Alfvén waves in the tube of force of the geomagnetic field passing through the radiation belt can not fail to exert a reverse effect upon the latter. This process must result in periodic variations of radial dimensions of the radiation belt, and, consequently, in the excitation of magnetoacoustic type of MHD-waves with period equal to that of standing Alfvén waves.

The physical side of the considered mechanism of MHD-wave generation becomes intelligible if one takes into account that the resonator may emit oscillations with wavelength corresponding to the intrinsic frequencies of its walls. The role of the latter is precisely fulfilled by the tubes of force passing through the region of maximum distortions of the geomagnetic field.

We assumed in the present work the model radiation belt situated at $6R_E$. At the same time, it is well known that the topology of the magnetosphere has a complex character. A series of regions of increased radiation are observed in it; they are disposed at different equatorial distances [12]. The position of radiation belts may also vary in different periods of solar activity. This is why analysis of a concrete model radiation belt pursued the aim of illustrating the physical substance of the proposed mechanism of Pc3 and Pc4 pulsations of the geomagnetic field. The location of the region, responsible for the excitation of pulsations at some specific moments of time, will, however, unconditionally depend on physical conditions existing at the given time in the magnetosphere.

3. Let us now consider whether or not the consequences stemming from the given model generation mechanism of Pc3 and Pc4 pulsations are experimentally corroborated.

It follows directly from the model assumed that the period of pulsations must be linked with the position of the radiation belt. Similar connections was experimentally revealed when comparing simultaneous observations of Pc-pulsations of the geomagnetic field with the variations of parameters of radiation belts determined from the data of satellites "Elektron-1, -2 and -4" [13]. A good correlation was obtained between the Pc-period variation and the position of the point $\Delta T = 0$, where ΔT is the deflection of the geomagnetic field from the dipole. By the same token the Pc-period keeps track of the position of the region of Earth's magnetic field distortion by the field of the radiation belt.

The daily course of Pc-oscillation periods may be explained from the same viewpoint. The oscillation periods of these pulsations reach their minimal value in the pre-midday hours. In the morning and in the evening this period increases [14, 15]. A similar course of periods may be the consequence of variation of magnetosphere parameters when it is subject to solar wind flow past it. In daytime, the tightening of the magnetosphere by solar wind is strongest and, consequently, the radiation belts are also found to be closer to Earth.

In magnetodisturbed days radiation belts are disposed at closer equatorial distances from Earth. According to the proposed model, this must result in a decrease of pulsation period. Similar phenomenon is revealed experimentally.: O. V. Bol'shakova [16] has shown the existence of inverse proportionality between the period of oscillations and the magnetic activity.

It was shown above (Fig.3) that the character of disturbance, induced by the radiation belt, is symmetrical relative to the equatorial plane. This is why in magnetoconjugate points a good agreement must observed between the conditions of excitation of oscillations, their form, amplitude and period, and also the coincidence in the polarity of H-components. These peculiarities were indeed observed by us during the processing of Pc-pulsations in magnetoconjugate points [17]. Fig.4 offers an example of Pc-pulsation recording at magnetoconjugate points of Sogra (Arkhangl'sk region USSR) and Kerguelen (in the Soutehrn part of the Indian Ocean).

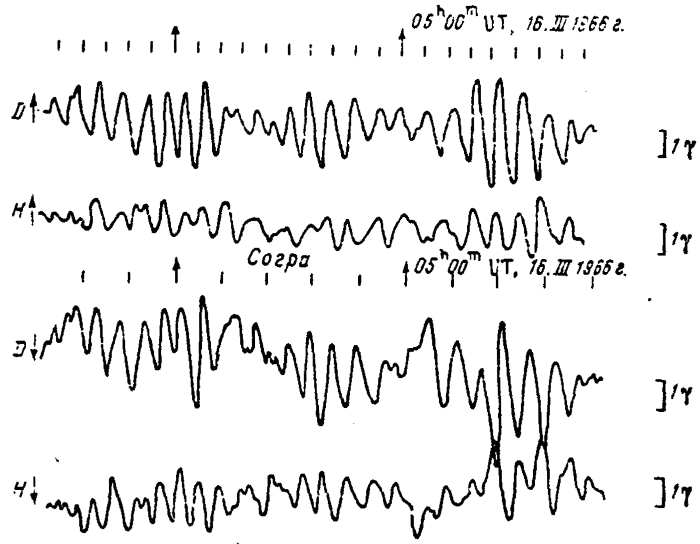


Fig.4

According to the proposed model the region of pulsation amplitude maximum coincides with the projection on Earth of the tubes of force of the geomagnetic field passing through the central part of the radiation belt. Under conditions of moderate magnetic activity the outer radiation belt maximum is located at equatorial distances of about $4.5R_E$ [12], which corresponds to the magnetic line of force crossing the Earth's surface at 62° latitude. The processing of synchronous registrations of geomagnetic field pulsations by the profiles of Borok (Φ_m = 53°, Sogra, Suysar' (Φ_m = 56°) and Lovozero (Φ_m = 63°) has yielded evidence that the amplitude maximum of Pc3 pulsations is located, as a rule, between the stations of Lovozero and Sogra (Suysar'), i. e. it is about confined to th 60° latitude [18]. Unfortunately, the exact location of amplitude maximum of Pc4 pulsations was not determined in [18], as the station net of Borok - Sogra - Suysar' - Lovozero was insufficient for answering that question. Only a tendency was noted to amplitude increase of Pc4 with the increase of observation point's latitude.

The approximate location of these pulsations' amplitude maximum may be estimated by an indirect method. According to [15], the responsibility for Pc4 pulsations lies also with the same resonator, as that for Pi2 excitation. The amplitude maximum of the latter is confined to the southern boundary of the aurora zone, i.e., to 63° - 65° latitudes [19]. If the assertion made in [15] is correct, one should anticipate that Pc4 pulsations have maximum amplitudes on the same latitudes.

The Pc-pulsations usually have the shape of beats (Fig.4). This also confirms the conclusions stemming from the considered model of pulsation generation. We have to concede, however, that the experimentally observed difference in the oscillation periods forming beats is greater by a factor of 2 - 3 than that obtained in the current work by way of theoretical calculations.

4. It may be seen from the above reasonings that the proposed generation mechanism of Pc3 and Pc4 pulsations satisfies sufficiently well the experimental data and provides a physical interpretation to the earlier obtained empirical relations [13, 16], linking the characteristics of Pc3 and Pc4 with parameters of the radiation belts and of the Earth's magnetosphere. As an example we may mention the relationship of the Pc-period with the position of the outer boundary of the magnetosphere, which now becomes logical, as this relationship defines in many ways the position of the point $\Delta T = 0$. The utilization of Pc-pulsations as an indicator of physical processes taking place in the near-terrestrial space also becomes substantiated.

The erection of a sufficiently compact network of stations disposed along the meridian profile will allow us to track the dynamics of the region where optimum distortions of the geomagnetic field by field of currents in the radiation belts take place, by the variation in the position of pulsations' amplitude maximum. In its turn, the magnitude of pulsation period for a known position of their amplitude maximum will provide the possibility of estimating with greater precision the concentration of plasma in the magnetosphere.

The different location of amplitude maximum of Pc3 and Pc4, alongside with the observed cases of simultaneous generation of both types of oscillations [15] point to the fact that there are two resonators in the magnetosphere, responsible for the generation of steady short-period oscillations of the geomagnetic field. The first of them, inducing the excitation of Pc3 pulsations, is confined to outer radiation belt maximum, and the other, responsible for the generation of Pc4, apparently coincides with the region where a jump takes place in the transit time of the Alfvén wave along the magnetic field lines, i. e., in the region of the point $\Delta T = 0$. The authors of ref.[15] reach practically the same conclusions as regards the generator responsible for Pc4. Without indulging into the consideration of the generation mechanism of the oscillations, these authors consider that the resonator is confined to the Carpenter's "knee" region [21]. At the same time, according to the opinion of Nishida [22], the very "knee" of Carpenter is caused Axford's and Hines' vortex flows past the inner parts of the magnetosphere [20].

It is unquestionable that the viewpoint presented in the present paper about the presence of two resonators in the magnetosphere requires further corroboration. However, if the validity of this viewpoint is confirmed, new possibilities will be opened for a more detailed study of magntosphere structure by ground observations of short-period oscillations of the geomagnetic field.

The opinion was expressed in the already mentioned reference [15, as well as in [23] that a magnetoacou ic type MHD-wave generator is responsible for Pc3 pulsations; this generator is formed by the "knee" region and that of the Dessler maximum of Alfvén velocity in the magnetosphere. As was already shown above, without denying the possibility of prevalence of magnetoacoustic type of waves during the formation of the field of Pc3 pulsations, we can not agree with the conclusions of [15, 23]. During the generation of MHD-waves by a resonator of the indicated type, the amplitude maximum of pulsations should be confined to equatorial regions, which in reality is not observed [24].

5. As we end the consideration of the physical model explaining the generation of short-period oscillations of the geomagnetic field, the following conclusions can be derived.

a) The presence in the Earth's magnetosphere of ring currents confined to radiation belts and distorting the dipole geomagnetic field, modifies noticeably the resonance properties of the magnetosphere. There appear in the latter,regions of sharp Alfvén velocity minimum, coinciding with the location of region of maximum geomagnetic field depressions. In these regions, the reflection is possible of MHD-waves propagating along, as well as across the geomagnetic field lines.

b) The continuous action on the outer boundary of the radiation belt results in a steady generation of MHD-waves, of Alfvén, as well as of the magnetoacoustic type, with period determined by the distribution of Alfvén velocity along the magnetic line of force. At the same time, because of the sharp minimum of Alfven velocity , the generation of pulsations is possible in the equatorial region with a period equal to the doubled path time of the wave along the field line from the Earth's surface to the equatorial region.

c) There apparently exist in the magnetosphere two regions that may play the role of resonators during the generation of steady short-period oscillations of the geomagnegic field. The first of them coincides with the radiation belt maximum and is responsible for the type-Pc3 pulsations, while the second is confined to the region of variation of the running time of MHD-waves along the field lines, that is, in the region of the point $\Delta T = 0$. In this region generation of Pc4-type pulsations takes place.

d) The proposed generation model of Pc3 and Pc4 pulsations allows us to interpret from the physical viewpoint the earlier obtained empirical dependences, linking the paramteres of the magnetosphere and of radiation belts with those of pulsations. It opens the possibility of a more substantiated utilization of short-period oscillations of the geomagnetic field as the indicator of physical processes taking place in the Earth's magnetosphere.

e) The experimental data satisfy well the corollarires, stemming from the considered generation mechanism of short-period oscillations of the geomagnetic field.

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