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DETERMINATION OF THE SPECTRAL CHARACTERISTICS OF ELECTRON PULSATIONS ACCORDING TO THE INTERCOSMOS — 5 DATA

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The paper describes the computational methods of the spectral and Fourier analysis time series and their application for the research of pulsations of electrons according to the Intercosmos — 5 data.

ОПРЕДЕЛЕНИЕ СПЕКТРАЛЬНЫХ ХАРАКТЕРИСТИК ПУЛЬСАЦИИ ЭЛЕКТРОНОВ ПО ДАННЫМ СПУТНИКА ИНТЕРКОСМОС — 5

В статье приведены вычислительные методы спектрального и Фурье анализов временных рядов. Эти методы применены в исследованиях пульсаций электронов по данным спутника ИНТЕРКОСМОС — 5.

I. INTRODUCTION

For the research of magnetospheric processes it is important to study the dynamic processes which develop pulsations of various kinds. The measurements made on board of satellites point to the existence of electron pulsations in the magnetosphere. Among pulsations occurring in the magnetosphere these pulsations have so far not been understood well. No definite mechanism for thier origin has yet been suggested, except a few remarks in papers [1, 2, 3] and [4]. Their dependence on the occurrence of other geophysical phenomena has not been studied in detail either. Some events of fast irregular changes of electron intensity with energies E_e >4ý keV were observed on boards the satellites Intercosmos — 3 Intercosmos — 5. The first results presenting the amplitude characteristics of precipitating and quasitrapped electrons with energies E_e>40 keV according to the Intercosmos — 5 data are in [4].

In this paper the system of programs for computers is described with the application of the Fourier and the spectral analysis. These programs were used for determining the amplitudes, frequencies and phase characteristics of sections with pulsations of electrons according to the Intercosmos — 5 data. Further, these pulsations were studied in dependence on *L-B* coordinates, local time, geomagnetic activity, and other geophysical parametres.

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II. DESCRIPTION OF THE EXPERIMENT

The Intercosmos — 5 satellite was launched on December 2, 1971 into an elliptic orbit. The fundamental elements of its orbit were: apogee — 1202 km; perigee — 196 km; period of orbit ~98 min. inclination to the equatorial plane ~48.56°. The satellite was magnetically oriented along a geomagnetic line of force. One of the instruments placed on board was the PG-1-A apparatus designed in the Institute of Experimental Physics of the Slovak Academy of Sciences, Košice and made at the Department of Electronics and Vacuum Physics MFF, Charles University, Prague. With the help of this apparatus the intensity of charged particle fluxes within and under the radiation belts was measured. A more detailed description of the apparatus PG-1-A is in papers [5] and [6].

The measured values of the electron intensity were transformed from the analogue form to the digital form using the semiautomatic apparatus NZ 20 and NR 30 and then recorded on a five-track paper tape with step 3 s.

Data prepared in this way were first controlled and completed with identification information (number of the satellite orbit, the starting and ending times of the examined section, etc.) and then the data processing was performed on the computers MINSK-22 and IBM-370 using the computational programs described in the next section.

III. THE SYSTEM OF THE COMPUTATIONAL PROGRAMS OF THE SPECTRAL AND THE FOURIER ANALYSIS OF ELECTRON PULSATIONS

The first step of the spectral analysis is to verify the hypothesis whether the examined time series is or is not a white noise. For this purpose there serve computational programs BIELY SUM and BS-KOLMOGOROV which use the Kolmogorov-Smirnov criterion. In the positive case it is useless to examine this time series by the Fourier and the spectral analyses, since all periods are equally involved in them.

The Fast Fourier Transform is used for the spectral analysis of the time series by computers. This method is quicker than the classic Discrete Fourier Transform and thus it reduces the calculation time. This method is discussed in detail in paper [1]. The computational program GENERAL enables the calculation of the Fourier transform of the examined time series and the determination of frequencies, amplitudes and phases of the individual harmonics, too. This program uses the Fast

Fourier Transform algorithm of base two. This algorithm is described by Cooley and Tukey in [8].

The program SPEKTRUM uses the Fourier transform to compute the linear Fourier spectrum of the examined time series s_t, defined by the equation

$$CZ(k) = 2N(R(k))^2, \quad \text{for } k = 2, \ldots, N-1$$
$$CZ(k) = N(R(k))^2, \quad \text{for } k = 1 \text{ and } N,$$

where $R(k)$ is the amplitude of the *k-th* order harmonic, N is the number of events in the time series s_t.

The subroutine HISTOR draws a histogram of this spectrum. From this histogram it is possible to determine the share of the single harmonic in the resulting time series and its frequency and amplitude, too.

The program SPECTRUM 1 was used for the determination of periods of the time series s_t. This program calculates the spectral function [7]:

$$S_{ss}(f) = 2\Delta t[1 + 2\sum_{k=1}^{L-1} r_{ss}(k)\, w(k) \cos 2\pi k \Delta t],$$

where $r_{ss}(k)$ is the autocorrelation function of the tieo series s_t; L the maximum retardation $L \leq N$; N the number of events in the time series s_t; f the frequency; $t = 1/2F$, where $F \in \langle 2L, 3L \rangle$; w the spectral window.

The plot of this spectral function is printed by means of the subroutine GRAF 1. According to this plot it is possible to determine periods dominant in the examined time series. Further, it is possible to choose spectral windows (e.g. of Bartlet, Tukey or Parzen [8]) and use low-frequency and high-frequency filters, too. The computation programs AUTOCOR and MULTICOR compute covariance and correlation functions of the examined time series. We can use them to determine the mutual continuity of two or more time series.

Originally, the programs were written in FEL-FORTRAN and ran on the computer MINSK-22. Later, they were transformed to the language IBM-FORTRAN and run on the computer IBM-370. The use of this computer enabled to speed up the calculation and to increase the number of the examined data considerably. The detailed description of all programs and instructions as to their use are in paper [1].

IV. THE OBTAINED RESULTS

The pulsations of the energetic electrons on board the satellite Intercosmos — 5 were registered during thirty orbits of the satellite IK — 5 around the Earth, i.e. during a period of 66 hours. The determination of the pulsations of electrons was carried out for 5 time sections from 6[th] March to 30[th] March 1972. The sections were chosen so as to include periods with various activity levels of the

geomagnetic field. The total length of all sections with electron pulsations was 218 minutes. It is about 5.6 % of the total length of the examined sections. This value is in consistence with the value given in [4].

The linear Fourier spectrum of all sections with pulsations was determined by the SPEKTRUM program. The example of such spectrum is given in Fig. 1. In this figure the linear Fourier spectrum from the section of March 29, 1972, is shown. The pulsations of electrons in this section had periods of 24 sec., 20 sec. and

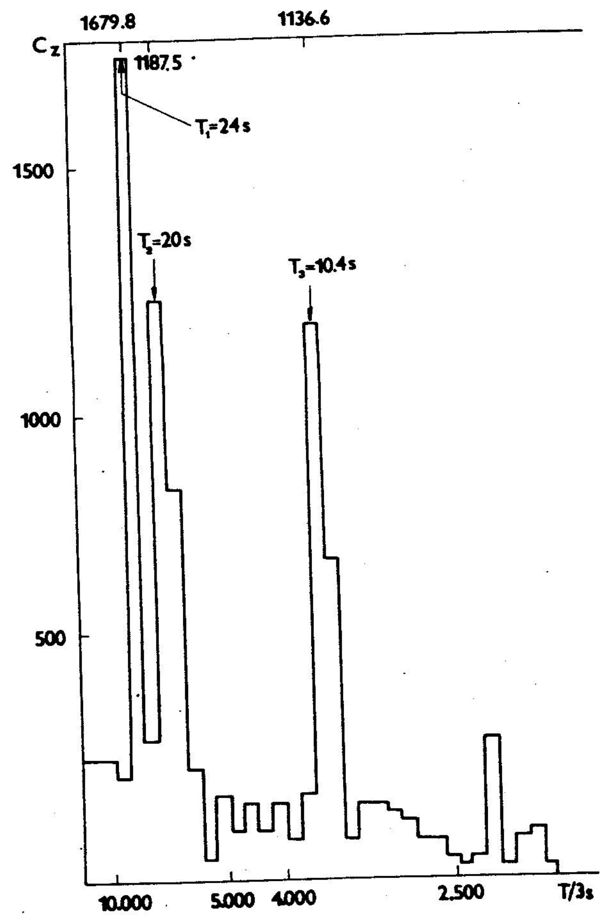


Fig. 1. The linear Fourier spectrum of the section with electron pulsations $E_e > 40$ keV on 29 March, 1972. The periods of the examined signal (divided by 3) are shown on the horizontal axis. On the vertical axis the values of the linear Fourier spectrum are given. These values are printed above this histogram, too.

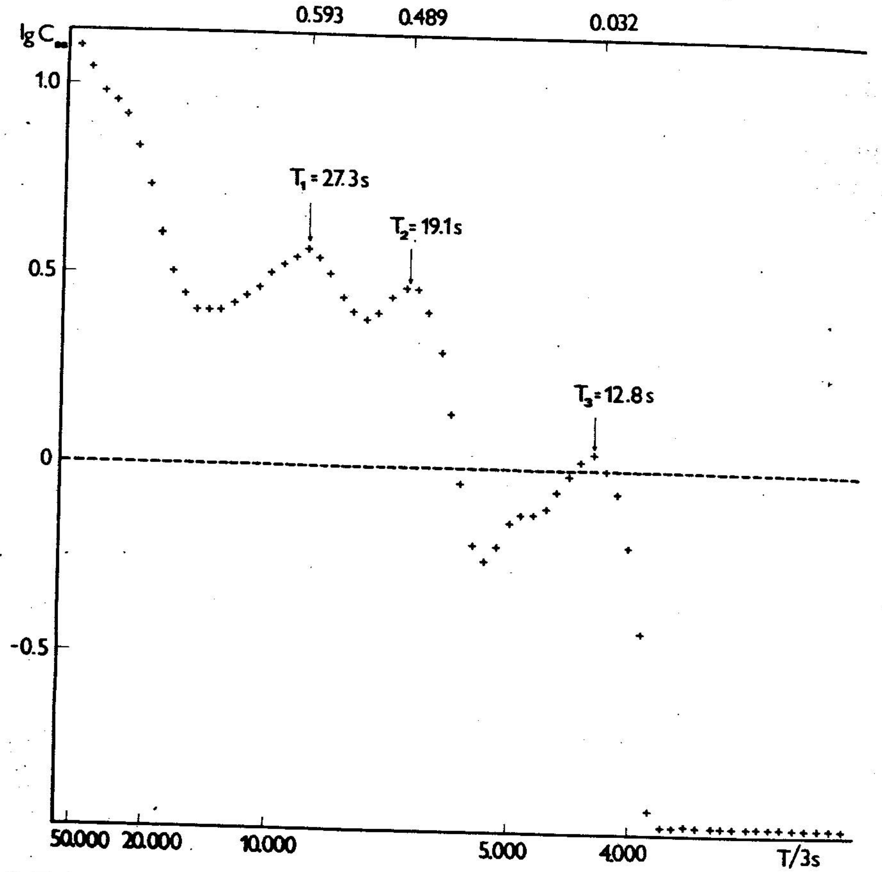


Fig. 2. The spectral function of the section with electron pulsations of $E_e > 40$ keV, registered on 29 March, 1972. The values of periods of the examined signal (reduced by 3) are given on the horizontal axis. On the vertical axis the values of the logarithm of the spectral function of the examined signal are shown. These values are printed above the graph, too.

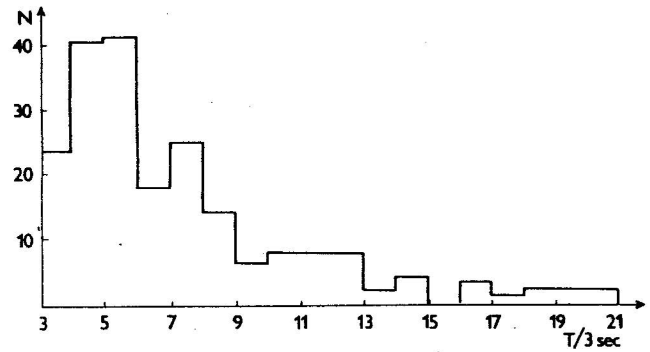
10.4 sec. Mainly the SPEKTRUM 1 program was used to determine the periods of electron pulsations. In Fig. 2 is the spectral function of the section with periods of 27.3 sec. 19.1 sec. and 12.8 sec. In this way altogether 254 sections with pulsations of electrons were determined.

The distribution of the periods of the electron pulsations with energies $E_e > 40$ keV for various K_p-indices is presented in Fig. 3. N is the number of sections with given periods. From this figure we can see that in electrons of $E_e > 40$ keV, oscillations with periods from 9 sec. to 27 sec. predominate. A similar distribution of periods was made for electrons with energies of $E_e > 1$ MeV, too.

Further, the distribution of periods of electron pulsations for regions with $L < 2$, $L > 4$, were obtained, as well as for both the morning and the evening side of the magnetosphere and for various intensities of the magnetic field.

The pulsation of electrons $E_e > 40$ keV and $E_e > 1$ MeV were registered with periods from 9 to 60 sec. Pulsations with greater periods then 60 sec. were registered only in isolated cases.

In Fig. 4 the time distribution of the electron pulsations with energies $E_e > 40$ keV is shown, particularly for events with $L < 2$ and $L > 4$. N is the number of events at the chosen local time T_{LOC}. On the morning side of the magnetosphere ~57.8 % electron pulsations with energies $E_e > 40$ keV were registered for $L < 2$. The ratio of the length of duration of the electron pulsations $E_e > 40$ keV on the morning to that of the evening side is 3 : 1 for the region with $L < 2$ and 1 : 1 for the region where $L > 4$. No correlation was found between the occurrence of the electron pulsations and the magnitude of the K_p-indices.



K_p \ T/3 sec	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12	12–13	13–14	14–15	15–16	16–17	17–18	18–19	19–20	20–21
7	1	1			1			1										
6	2	4	5	3		3	3		1			1			1		1	
5	7	15	15	4	14	3	1	4		5	2	2		2			1	1
4																		
3	4	4	6	4	3	2	1	1	2	1		1		1				
2	4	5	6	1	4	3		1	3									1
1	5	8	8	4	3	1	1	1	2	1						2		
0	1	4	2	2		2				1								

Fig. 3. The distribution of periods of the electron pulsations $E_e > 40$ keV for the various values of the K_p-indices.

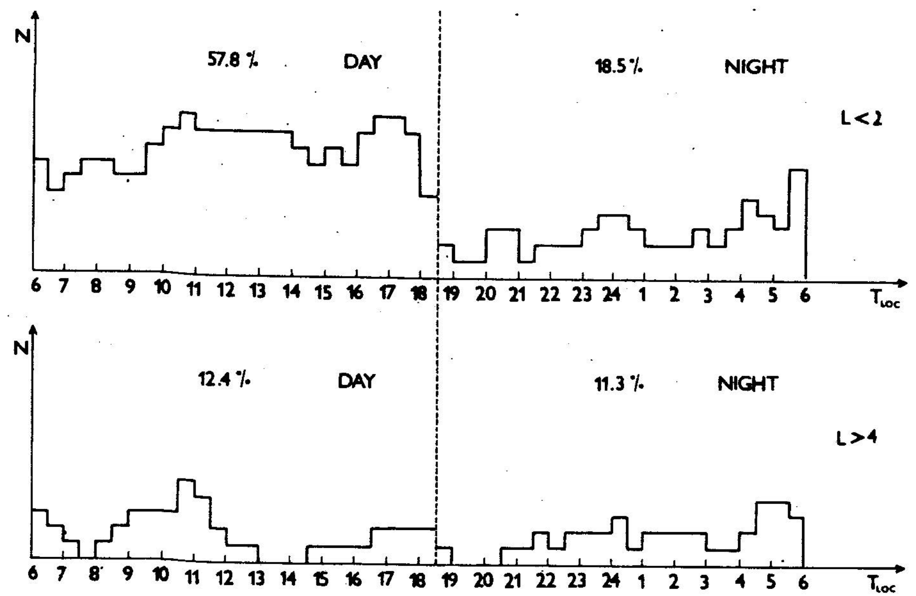


Fig. 4. The time distribution of the electron pulsations $E_e > 40$ keV; a) for $L < 2$; b) for $L > 4$. The percentages designate the shares of the individual groups of pulsations in the total pulsation time.

V. CONCLUSION

The main purpose of this paper is to describe the computation programs for the determination of characteristics of electron pulsations. These programs may be used for the spectral analysis of any time series with equally spaced data. The number of measured sections with electron pulsations does not present a sufficient statistic basis for arriving at any definite conclusions as regards the relation between spectral characteristics of electron pulsations and other geophysical phenomena occurring in the magnetosphere. It is necessary to extend this statistic basis in future and to examine the dependence of electron pulsations on the plasma concentration, the fluctuating electric and magnetic fields in the magnetosphere, especially the level of the electromagnetic VLF emissions, geomagnetic micropulsations. etc.

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