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On the Ionospheric Screening or Self-Impedance Effect on Pulsations

By Kazuo Yanagihara

摘　要

脈動の一次原因が電離層外か又は電離層上部にあるとして，脈動の頻度日変化を電離層の遮蔽効果によつて説明しようとする２，３の試み（１），（２）があるが，一次原因の場を一様と仮定する限り中緯度以上の頻度日変化を説明することは困難である。この日変化の緯度による違いを説明するためには，一次原因として高緯度に向つて急激に増大する場を仮定しなければならない。従つてこの観点からすれば一次原因の場が電離層内にあると考えた方が都合がよい，又脈動頻度の年々変化を電離層電気伝導度の年々変化によるとして推算を試みたが一次原因の場の年々変化が明らかでないので現状では困難である。

§ 1. Introduction

Considering the screening effect of the non-uniform ionosphere, Ashour and Price attempted to interpret theoretically the diurnal variation of the frequency of geomagnetic pulsations. They succeeded fairly well to explain the Lubiger's result obtained mainly in the equatorial zone (Ashour and Price, 1948)(1). Recently, Kato and Watanabe have remarked the principal eight observational facts on pt-pulsation, which are mainly based on the dH/dt records at Onagawa, and they showed that almost all of these facts can be interpreted by the theory of extra-ionospheric origin and extending the Ashour and Price's calculation (Kato and Watanabe, 1956)(2).

For higher latitudes, however, these theoretical calculations give the different results from low latitude phenomena on the occurrence of pulsations for the returning (eastward) part of induced currents in the ionosphere, as already mentioned by Ashour and Price. In this paper will be given the discussions on the latitude change of the diurnal variation of frequency of pt-pulsation, together with a brief remark on the year-to-year change of frequency. The pulsation dealt with in this paper means only pt, which is the proposed symbol for one group of pulsations by Romana.

§ 2. Theoretical calculation and observed fact

A model ionosphere dealt with in the theoretical paper of Ashour and Price is a non-uniform isotropic conducting shell, whose resistance is given by,

$$\rho=\rho_0\ (1+\mathcal{E}\cos\theta) \qquad \text{(Fig. 1)}$$

The screening effect of this model ionosphere has been calculated by them for the external uniform field perpendicular to the axis θ. Table 1 gives their numerical results for the inducing field of period 2 min., together with similar data numerically calculated here for the period 20 min.

The simultaneous quick-run records of pulsations at six observatories, Lerwick, Lovö, Eskdalmuir, Rude Skov, Witteveen, Chambon-la-Forêt and Hermunus have been reproduced in the Bulletin of the IATME[(3)]. The latitude change of their amplitudes are shown in Fig. 2, together with the variation of the theoretical

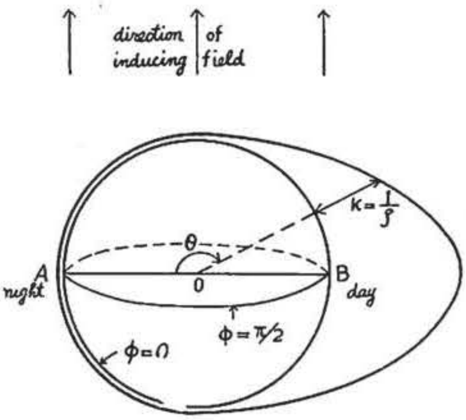

Fig. 1.

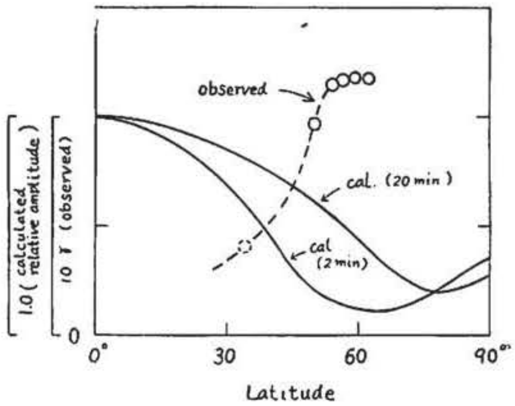

Fig. 2. Latitude changes of amplitudes.

Table 1.
Amplitude of pulsations at various points on the noon and midnight meridian corresponding to pulsations of unit amplitude in the inducing field (Horizontal component).

Latitude	Dark hemisphere		Sunlit hemisphere	
	period 20 min.	period 2 min.	period 20 min.	deriod 2 min.
0°	0.8039	0.1937	0.3718	0.0289
15°	0.7700	0.1772	0.4456	0.0394
30°	0.6768	0.1335	0.5898	0.0647
45°	0.5356	0.0767	0.6356	0.0898
60°	0.3519	0.0235	0.5727	0.1015
75°	0.1722	0.0343	0.4153	0.0943
90°	0.2278	0.0702	0.2278	0.0702

amplitude mentioned above. As a whole the amplitude is pronouncedly increased with higher latitude, though the six observatories are not so well-distributed. This observed fact is contradicted with the theoretical results.

In the present status, nevertheless, it is safe to say that the world-wide distributions of amplitude of pulsation are scarcely known, and the most reliable and widely collectable data on pulsations are the diurnal variations of frequency. The diurnal variations at nine stations, Samoa, Batavia, Zikawei, Kakioka, Central Asia, Toledo, Potsdam, Cheltenham and Sitka, are shown in Fig. 3.

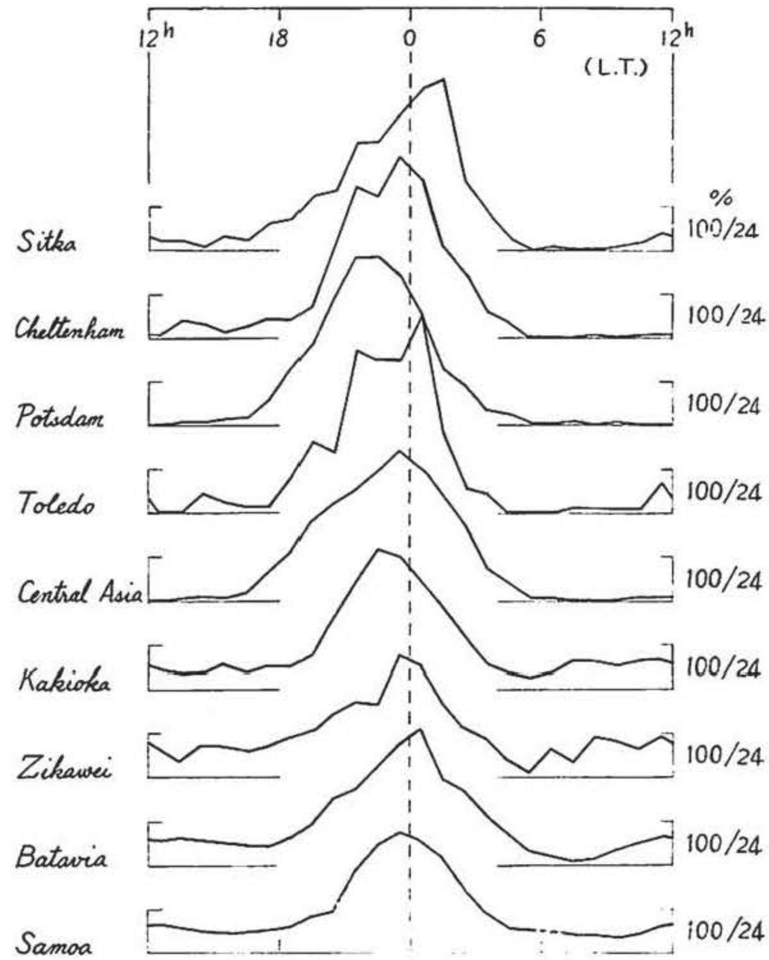

Fig. 3. Diurnal variations of frequencies.

These diurnal variations are based on the same data as used already in the previous paper dealing with their longitude effect (Yanagihara, 1957)(4), except the curves for Toledo and Potsdam. The curve for Potsdam is the result of Lubiger (Lubiger, 1935)(5), and that for Toledo is derived from the frequency of the pulsations (Vibraciones, Bahia con vibraciones and Salto brusco con vibracionnes) tabulated in the annual report of earth-currents (Toledo, 1951 and 1952)(6). To compare these nine curves with the theoretical results, the ratio of the frequency during the four hours centred at midnight to that for the four hours centred at

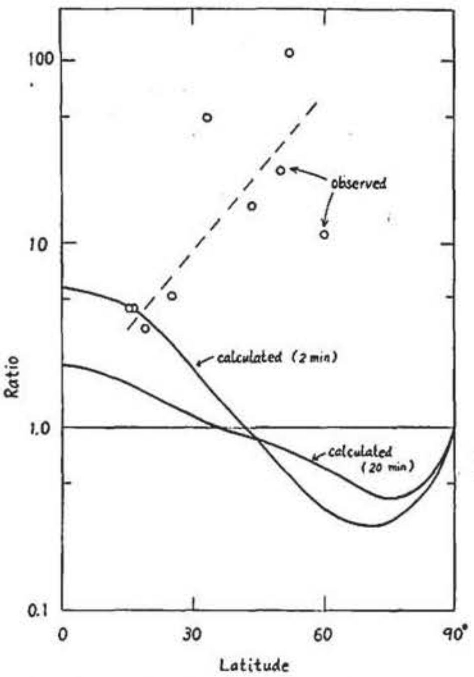

Fig. 4. Latitude changes of ratios.

noon are calculated for each station, and the results are shown in Fig. 4.

§ 3. Discussions

The calculated amplitude of pulsation tends to decrease towards the higher latitude along midnight meridian, whereas observed amplitude tends to increase towards the higher latitude. Even if the increase is not so pronounced as bay-disturbances, at least there is no tendency to decrease so abruptly towards the higher latitude (Fig. 2).

Though it is rather difficult to compare thoroughly the change of the theoretical amplitude to that of observed one by a small sample, the another comparison gives the similar results by using the observed frequency in place of the observed amplitude. Considering that the hourly distribution of frequency is due to the change of amplitude with longitude, the pulsation must be found numerously in daytime in higher latitudes than 45°, because the theoretical amplitude on the sunlit side exceeds that on the dark side in such latitude. The observed pulsations are, however, numerous in night hours, also at higher latitudes extending up to 60°. These circumstances are shown in the Fig. 4 by the ratios of theoretical amplitude at midnight to that at noon and the similar ratios of observed frequency during the four hours centred at midnight to that for the four hours centred at noon.

To approach to the actual state of ionosphere, the high conductivity of the auroral zone and the equatorial region should be taken into consideration together with such a non-uniform conductivity as is assumed by Ashour and Price. Though the theoretical calculations of screening effect for the actual distribution of conductivity are extremely complex and laborious, an alternative is offered by the experimental result, giving the general tendency of the induced current in agreement with the result of rather intuitive consideration (Oguti and Nagata, 1954)[7]. The effect of the high conductivity in the auroral zone and the equatorial region will be estimated intuitively as follows. The high conductivity of the auroral zone increases the induced westward currents both on the dark and sunlit side, and the high conductivity of the equatorial region on sunlit side tends to draw near the returning eastward currents. Therefore, the inconsistency of the above circumstances remains unaltered.

If the external inducing field is not the same as the uniform field assumed by Ashour and Price, the results of screening effect ought to be different. But yet the screening or self-impedance effect of non-uniform ionosphere must remain to affect the amplitude of pulsation in like manner, and hence for the interpretation of the observed latitude effect, it is demanded to assume an original field increasing rapidly towards the higher latitudes. So far as this latitude change is concerned, it is not unnatural to suppose that the seat of original field of pulsation is in the ionosphere.

§ 4. Remarks on the year-to-year change

It is an obvious and interesting fact that the annual mean frequency of pulsation is inversely proportional to the solar activity (Yanagihara, 1956 and 1957)[(8)]. To discuss the year-to-year change of the annual mean frequency, the screening effect of the uniform ionosphere on the uniform external inducing field is taken first into consideration. Such screening effect has been calculated by Sugiura (Sugiura, 1949)[(9)] as follows. Corresponding to the periodic inducing field of unit amplitude, the amplitude of the total field (inducing+induced field) on the earth is given by,

$$A=\frac{3}{4\pi ka\alpha}\Big/\sqrt{1+\left(\frac{3}{4\pi ka\alpha}\right)^2},$$

where k, α and a are the integrated conductivity of the ionosphere, which is assumed to be thin spherical shell, the angular velocity of periodic the field a nd theradius of the shell, respectively. When the period of the field is less than few minutes, the amplitude of the total field is proportional to the reciprocal of the integrated conductivity.

If the integrated conductivity of the ionosphere is proportional to the maximum electron density, being mainly due to the E-layer, the ratio of the integrated conductivity for the sunspot maximum year, to that for the sunspot minimum year is two at most. Disregarding the change of the intensity of inducing field, the ratio of the amplitude of the total field for the sunspot maximum year, e. g. A_{max}, to that for the sunspot minimum year, e. g. A_{min}, is 1/2 at least.

The mean intensity or frequency of the inducing field can not be supposed to be uniform during a solar cycle, but the manner of the change has not been known as yet. Then, considering the close relation of the occurrence of pulsations to the commencement of bay-disturbances, the frequency of bay-disturbances is now assumed temporarily to be substituted for the frequency of the original field of pulsation, whose year-to-year change is not clear. The bimonthly frequency of bay-disturbance is shown in Fig. 5 for the recent seven years, being based upon the

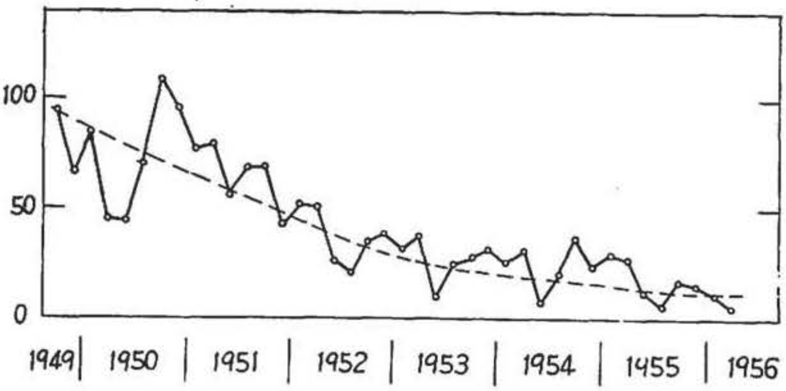

Fig. 5. Bimonthly frequency of bay-disturbances.

provisional report of the Kakioka Magnetic Observatory. This figure shows that the ratio of the mean frequency for the sunspot maximum year, e. g. f_{max}, to that for the sunspot minimum year, e. g. f_{min}, is four at least.

Synthesizing the two ratios, A_{max}/A_{min} and f_{max}/f_{min}, it is said that the mean frequency of the pulsation observed on the earth for the sunspot maximum year is higher than that for the sunspot minimum year in the ratio 2 : 1. This estimation is not in harmony with the observational fact of the year-to-year change of pulsations. But this may arise from the substitution of the frequency of the bay-disturbances for that of the original field of pulsations, the substitution bearing the unreal circumstance that the increase of the original field of pulsation overcomes the increase of the screening effect for the sunspot maximum year.

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