CHAPTER II

NATURAL LOW-FREQUENCY MAGNETIC VARIATION

II.1 Types and Origins of Some Natural Low-Frequency Magnetic Variation

Studies made of the natural low frequency electromagnetic field fluctuations observed at the earth's surface indicate that there is a number of independent geophysical sources. The generation and propagation of some types of oscillations are now thought to be understood, but little is understood of other types. Helliwell[1] (1969) concluded that oscillations in the range 100 Hz to 100 KHz are caused by lightning discharges, having for a source a transmitter located below the ionosphere. The disturbances propagate within the magnetosphere in one of two modes, "ducted" or "nonducted". Only waves propagating in the ducted mode can be observed at the ground. Below the frequency range associated with these so called "sferic" oscillations are the unique geomagnetic field oscillations of rather sinusoidal form with peak energies in the 1 second, 20 second, 1.5 minute, and 5 minute period regions and with average amplitudes increasing with period. These are believed to be due to the solar wind interaction with the earth's magnetic field. Disturbances originating in the zone between the shock front of the wind and the magnetopause are thought to arise and propogate earthward partially as hydromagnetic waves, guided by the field lines. At the earth surface the disturbances are often observed as regular oscillation and are called micropulsations. In this section we review the main characteristics of sferics and micropulsation disturbances.

II.2 ELF Oscillations, Sferics

Although our primary concern here are the signals in the ultra-low-frequency region (below 5 Hz), we briefly review the natural signal characteristics in the bordering ELF (extra low frequency) region from 3 Hz to 3 KHz. The natural electromagnetic

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[1] Helliwell, R.A. 1969. Low-frequency wave in the Magnetosphere. Reviews of Geophysics, 7, No. 1 and 2, Feb.-May.

fields at 1.0 Hz are in the region of transition between atmospheric (sferics) and geomagnetic effects. Campbell[2] (1959) has shown that above 0.2 Hz and extending throughout the audio-frequency range the magnetic field energy is due primarily to atmospheric events such as distance and local lightning discharges. At 1.0 Hz it has been found by Lokken, Shand and Wright[3] (1963) that the natural background is a steady, low-level energy from sferics, occasionally interrupted by high frequency micropulsations. The amplitudes of the magnetic fluctuations at 1.0 Hz are considerably less than 1.0 gamma. However, the observation of Balser and Wagner[4] (1960) show that the amplitude of these variations increases with frequency to a maximum at about 8.0 Hz. This maximum, together with the maxima at the higher harmonics, corresponds to cavity resonance modes predicted by Schumann[5] (1952). These sub-audio resonant modes are the result of ducted sferic energy propagating around the earth, confined within the imperfect cavity formed by the conducting earth and the ionosphere.

II.3 Micropulsations

At frequencies below that of the sferics there appear regular oscillations (micropulsations) in the earth's magnetic field. These oscillations have period range from 0.2 to 600 seconds and are caused by the interaction between particles (plasma) emitted from the sun and the magnetosphere. Micropulsation have been classified into two groups: those of a regular and mainly continuous character (Pc), and those with an irregular pattern (Pi). In an attempt to standardize the nomenclature Jacobs, Kato,

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[2] Campbell, W.H. 1959. "A study of Micropulsations in the earth's magnetic field". Unpublished Doctorial's Thesis, Institute of Geophysics, University of California, Los Angeles.

[3] Lokken, J.E., Shand, J.A., and Wright, C.S. 1963. Some Characteristic of Electromagnetic background signales in the vicinity of one cycle per second. Journal of Geophysical Research, 60: 789-794.

[4] Balser, M., and Wagner, C.A. 1960. Observations of Earth-Ionosphere cavity resonances. Nature, 188: 638-640.

[5] Schumann, W.O. 1952. Uber die Ausbreit sehr Langer elektrischer Wellenund der Blitzentlandung um die Erede. Zeits. fur Ange. Phys., 4: 474-480.

Matsushita, and Troitskaya[6] (1964) had adopted the breakdown shown in Tables II-1 and 2, at the International Association of Geomagnetism and Aeronomy, XIII General Assembly of the International Union of Geodesy and Geophysics in Berkely, California.

The first class, for which the name Pc is retained, covers the whole range of pulsations (0.2 - 600 sec.). This class is divided into five subgroups, as shown in Table II-1.

TABLE II-1

Classification of Pc Type Micropulsations

Type	Period Range (seconds)
Pc 1	0.2 - 5
Pc 2	5 - 10
Pc 3	10 - 45
Pc 4	45 - 150
Pc 5	150 - 600

The second class of pulsations is characterized by their irregular form. They have a close connection with disturbances of the magnetic field, with upper atmospheric phenomena. This class is divided into two subgroups covering two frequency ranges as shown in Table II-2.

TABLE II-2

Classification of Pi Type Micropulsations

Type	Period Range (seconds)
Pi 1	1 - 40
Pi 2	40 - 150

[6] Jacobs, J.A., Kato, Y., Matsushita, S., and Troitskaya, V.A. 1964. Classification of Geomagnetic Micropulsations. Journal of Geophysical Research, 69: 180-183.

Figures 1 and 2 are examples of Pc and Pi and the micropulsation which we want to study is micropulsation type Pc 1.

II.4 Activity of Pc Type Micropulsations

In the study of micropulsations, the details most thoroughly studied have been in connection with their morphology, e.g. amplitudes, durations and most probable times of occurrence. These factors are usually included in a single descriptive word "activity". The study of micropulsation amplitudes has been made by Holmberg[7] (1953), Angenheister[8] (1954), Campbell[9] (1959) and others. Duffus and Shand[10] (1958) studies the amplitude of micropulsations and found general positive correlation between average micropulsation amplitude and period. Campbell (1959) found and described this also.

The Pc 1 micropulsations have a rather regular sinusoidal form and often show a beating character which has the form of a "string of beads" when seen on a magnetogram; hence the name "pearls" has been applied to this type of Pc 1 oscillation. These electromagnetic field variations range in frequency from 0.15 to 5.0 Hz. The Pc 1 amplitudes are about 0.1 gamma but tend to be smaller, on the average, at shorter periods. Bursts of Pc 1 activity usually last about one-half hour, but may persist, on rare occasions, as long as 12 hours. The Pc 1 and "pearls" have a local time depend-

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[7] Holmberg, E.R.R. 1953. Rapid periodic fluctuations of the Geomagnetic field. Geophysical Supplement, Monthly Notices of the Royal Astronomical Society, 6: 467-481.

[8] Angenheister, G. 1954. Registrierungen erdmagnetischer pulsationen, Goettingen 1952/53. Gerlands Beitr. ur Geophs., 64: 108-132.

[9] Campbell, op. cit., p. 7.

[10] Duffus, H.J., and Shand, J.A. 1958. Some observations of Geomagnetic Micropulsations. Canadian Journal of Physics, 36: 508-526.

ence. Heacock and Hessler[11] (1962) and Heacock[12] (1966) found that at College, Alaska, pearl-type oscillation occurred during the local daytime whereas regular Pc 1 oscillation appeared at night. At middle and low latitudes stations Troitskaya[13] (1961), Kato and Saito[14] (1959), and Hirasawa and Nagata[15] (1966) noted that both pearl and regular Pc 1 appear mainly at night. Little seasonal or 27-day (solar controlled) periodicity is observed and no latitude dependence has been found on Pc 1 frequency and amplitude between 40° and 68° North.

Tepley[16] (1964), Gendrin and Troitskaya[17] (1965) and others found that Pc 1 are conjugate events. Signals are generally not simultaneous at most latitude stations, but a world-wide level of high activity usually persists for several days.

No relationships have been noted between Pc 1 and K indices or visible aurora, but Pc 1's are more likely to occur during high solar activity in the week following large, major magnetic disturbance, and pearls are likely to follow magnetic storm sudden commencements. Attenuation of Pc 1 by the ionosphere is relatively small but increases with frequency and with K_p index.

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[11] Heacock, R.R., and Hessler, V.P. 1962. Pearl-type telluric current Micropulsations at College. Journal of Geophysical Research, 67: 3985-3995.

[12] Heacock, R.R. 1966. The 4-second summertime Micropulsation band at College. Journal of Geophysical Research, 71: 2763-2775.

[13] Troitskaya, V.A. 1961. Pulsation of the earth's Electromagnetic field with periods of 1 to 15 seconds and their connection with Phenomena at the High Atmosphere. Journal of Geophysical Research, 66: 5-18.

[14] Kato, Y., and Saito, T. 1959. Preliminary studies on the daily behavior of Rapid Pulsation. J. Geomag. Geoelektr., 20: 220-221.

[15] Hirasawa, T., and Nagata, T. 1966. Spectral analysis of Geomagnetic Pulsations from 0.5 to 100 seconds in period for the quiet sun condition. PAGEPM., 65: 102-124.

[16] Tepley, L. 1964. Low latitude observations of fine structured Hydromagnetic Emissions. Journal of Geophysical Research, 69: 2273-2290.

[17] Gendrin, R.E., and Troitskaya V.A. 1965. Preliminary results of a Micropulsation experiment at Conjugate points. Radio Sci., 69D: 1107-1116.

The regular sinusoidal oscillations Pc 2 have amplitudes of 0.5 γ and occur in the period range from 5 to 15 seconds. Sometimes there is a beating form. Holmberg[18] (1953) reported that there are slight seasonal variations in Pc 2 activity. The amplitudes of Pc 2 depend on geomagnetic latitude; they are a maximum in the auroral zone (Kato, 1962),[19] and seldom exceed one gamma in middle latitudes. They often occur at night in middle latitude observations. At equatorial sites (less than 7^{o} latitude), Hutton[20] (1965) reported that the Pc 2 is dominant in the daytime.

Jacobs and Wright (1965)[21] found that there is similar activity of Pc 2 at high latitude station that are nearly conjugate. Simultaneous signals have been recorded in Alaska, Colorado, Hawaii and Macquarie Island (south of New Zealand), but there is no evidence for world-wide simultaneous activity.

There are correlations between Pc 2 and K_p index; the characteristic frequency of Pc 2 increases with K_p and enhancement lags behind an increasing of K_p. The 5577°A auroral luminosity fluctuations in concurrent with Pc 2 activity. Pc 2's with a damped-type form appear mostly with the sudden commencement magnetic storms and substorms. The amplitudes of Pc 2 increase during the initial phase of magnetic substorms. The daytime amplitudes chenges of Pc 2 related with electron density variations in F-region. Pc 2 also appears to be attenuated by ionosphere.

The Pc 3 pulsations are sinusoidal regular oscillation in the period range 15 to 45 seconds. All of their activity characteristics are similar to those of Pc 2, but at middle latitudes station Pc 3's are most pronounced at midday.

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18 Holmberg., op. cit., p. 9.

19 Kato, Y. 1962. Geomagnetic Pulsations. Sci. Rept. Tohoku Univ., 13: 141-163.

20 Hutton, R.M.S. 1965. Equatorial Effects. J. Res. NBS, Radio Sci., 68: 1169-1177.

21 Jacobs, J.A., and Wright, C.S. 1965. Geomagnetic Micropulsation results from Byrd station and Great Whale River. Canadian Journal of Physics, 43: 2099-2122.

The Pc 4 pulsations are oscillations with periods between 45 to 150 seconds. Amplitudes at high latitudes may reach 5 to 20 gammas. The signals have a duration from 10 minutes to several hours, and a beating form and damped appearance is regularly observed.

The occurrence of Pc 4 depends on local time and latitude. At middle and equatorial latitudes the maximum daytime occurrence is at midday. In the north auroral zone there are two activity peaks; one near 0300 and the other at 1000 LMT. In Antarctica maxima occur near 0300 and 0600 LMT. Greater amplitudes at auroral latitudes occur after midnight, whereas peak amplitude in middle and equatorial latitudes occur during the daytime.

The occurrence of Pc 4 depends on season. At equatorial and northern auroral latitudes, the signals occur most frequently in summer and much less in winter, but at the middle latitudes only a general decrease of activity in winter is apparent.

Pc 4 oscillations; similar in amplitude and period, have been observed simultaneously at the Byrd, Antarctica and Great Whale River, Canada, conjugate stations.

No special relationships with the geomagnetic K indices or the 27-day solar rotation have been found for Pc 4. At all latitudes, the occurrence seem to be connected with the solar cycles; there is more activity in years of sunspot maximum. In general, the changing of Pc 4 period related with variation of f_oF2 region in ionosphere.

The Pc 5 are pulsations with the longest periods, 150 to 600 seconds. They have extremely large amplitudes, reaching several hundred gammas at high latitudes. Near the northern auroral zone Pc 5's occur most often at 0600 and 1800 LT. The maximum occurrence of Pc 5 appears at middle latitude. The maximum amplitudes of Pc 5 appear in winter and summer seasons. At the various latitudes there are diurnal change in amplitudes of Pc 5.

Jacobs and Wright[22] (1965) showed that Pc 5 are congugate events. The occurrence of Pc 5 is independent of K_p index; they tend to occur neither on quiet nor on disturbed days but appear several days after a moderate magnetic disturbance. As with the Pc 4, the period of Pc 5 changes when there is variation of f_oF2. Pc 5 is also attenuated by ionosphere.

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[22] Jacobs, and Wright, op. cit., p. 11.