550·38 : 550·342(47)

On the Polarization Characteristics of middle latitude Geomagnetic Micropulsations

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(*Received 2 February 1967*)

ABSTRACT. Geomagnetic micropulsations of different types are observed on the Soviet stations in the middle latitudes of the Northern hemisphere. Behaviour of the horizontal disturbed vector is analysed.

Micropulsations of $Pc2$–4 and $Pi2$ types are shown to have statistically dominant counter-clockwise sense of rotation in the morning hours but clockwise sense of rotation in the evening hours. Both the rotational character of polarization and the diurnal variation of the sense of rotation suggest the Alfven (transverse) hydromagnetic mode is an important part of the micropulsation mechanism, although it is difficult to explain the micropulsation occurrence in middle and low latitudes ignoring the magneto-acoustic (longitudinal) mode of propagation.

All the micropulsation types appear to have the preferred directions characteristic of the observational point. Diurnal variation of the hourly mean directions are similar at different sites and appear to have the largest departure from the mean around the morning and the evening hours. Directional properties of micropulsations can be explained by the lateral inhomogeneities in the sub-surface geoelectrical structure.

Polarization studies of geomagnetic micropulsations provide additional information on the characteristics of micropulsation nature and mechanism, and answer some questions which cannot be solved by current morphological studies. The sense of rotation and the direction of major axis of polarization in the horizontal plane of micropulsations Pc 2-4 and Pi 2 types have been analysed.

Observed polarisation in general appears to be an elliptical one, the linear and circular cases of polarization occurring rather rarely. It is seen that rotation of the end point of the micropulsation disturbance vector may change sense even between successive oscillations during continuous time intervals but during local morning and evening hours such changes of rotational sense occur rather rarely as compared to day time and night time.

By the analysis of the magnetic records of station Borok ($\phi \sim 53°$N), Kalashnikov and Zybin (1960) have found that in the Northern hemisphere geomagnetic micropulsations of the period range 0·5–20 min ($T_{\mathrm{mean}} = 8$ min) without distinction as to type exhibit dominating (80–90 per cent) counter-clockwise rotations in the morning hours, while during the evening hours the dominant sense of rotation is clockwise (60–70 per cent). Recent analysis of magnetic records from Soviet stations Borok, Petrepavlovsk ($\phi \sim 44°$N) and earth current records from Alma-Ata ($\phi \sim 33°$N) (data for Pc 2–4 and Pi 2 separately) confirmed the above mentioned polarization property, namely both Pc 2–4 and Pi 2 rotate chiefly counter-clockwise in the morning but clockwise in the evening. It may also be noted that the meridional plane separating the two regions with observed opposite senses of rotation, does not coincide with midday—midnight meridian but is somewhat turned to the earlier hours.

The results of extensive analysis of the rotational sense diurnal behaviour of storm sudden commencements and sudden impulses for world-wide stations (Wilson and Sugiura 1961, Bowling and Wilson 1965) and of Pc 5 for polar-zone stations (Kato and Utsumi 1964, Nagata and Kokubun 1965) agree well with our observation. Comparative examination of rotational sense diurnal variations for different types of micropulsations allow us to establish this unique statistical property, namely that all the types of micropulsations with periods longer than tens of seconds appear to have dominating counter-clockwise rotations in the morning hours but clockwise sense of rotation in the evening hours in the Northern hemisphere.

It is necessary to note, that the earlier workers had reported half-diurnal periods of both senses of rotations. This might possibly be explained as due to their having used very low-sensitive records with a small time resolution and, thus getting unreliable measurements of relative phase angle of variation components which determines the polarizations sense of rotation. Reports of Christoffel and Linford (1966) about dominating counter-clockwise rotation of Pc and exceptional clockwise rotation of Pi 2 in Southern hemisphere, and of Mather *et al.* (1964) about the reversed micropulsations behaviour, are based on a small amount of data (a few days of observations). These data appear to be insufficient to obtain general regularities although they show micropulsation peculiarities proper to that short period of observations.

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Rotational polarization and diurnal variation of that sense of rotation established earlier in this paper are certainly indicative of Alfven (transverse) hydromagnetic mode involved in the generation and propagation of micropulsations. Magneto-acoustic (longitudinal) mode has to be linearly polarised. Even if the linear polarization of longitudinal mode has the possibility of being transformed due to anisotropic ionosphere into the elliptical one as suggested by Greifinger and Greifinger (1965), the transformed polarization will have to display only a single sense of rotation. It is reasonable to suppose that the above mentioned transformation of magneto-acoustic mode linear polarization will be able to account for the relative dominance of counter-clockwise rotation occurrence observed by Kalashnikov and Zybin (1960) and other authors (Wilson and Suguira 1961, Santirocco and Parker 1963, Christoffel and Linford 1966).

Mechanisms for explaining rotational regularities of micropulsations suggested by different authors generally include in one form or other the Alfven waves generated by the solar wind interaction with the boundary regions of magnetosphere and their propagation along the magnetic lines of force downwards to the auroral zones. These mechanisms have been invoked to explain the properties of polar-zone *Pc* 5 (Jacobs and Watanbe 1964, Kato and Tamao 1965), *SSC* (Wilson and Suguira 1961) and *SI* (Bowling and Wilson 1965).

In spite of the fact that Alfven waves cannot penetrate to lower latitudes directly from the region of generation due to strong attenuation during the propagation across the lines of force, observed characteristics of middle latitudinal micropulsations, namely rotations and their diurnal variation similar to those of auroral-zone pulsations, indicate the transversal property even at lower latitudes.

Consequently micropulsation mechanism for middle latitudes needs to include both the Alfven and magneto-acoustic types of propagations in an inter-related fashion and can be pictured qualitatively in the following way.

Oscillations excited in the outer magnetosphere by solar wind interaction with the magnetospheric boundary surface occupy most of the magnetospheric shell. These oscillations must have, in general, circular polarization due to relation between the solar wind and the direction of the lines of force. In the equatorial regions of the magnetosphere plane of polarization of the oscillations must coincide with the equatorial plane, *i.e.*, it must be perpendicular to the direction of field lines. Therefore the oscillations are just the Alfven (transverse) ones.

In the morning and evening regions the solar wind has maximal tangential component of velocity relative to the magnetosphere and transverse oscillations must occur in the most "clear" form (Fig. 1a). Disturbance vector of oscillations has different sense of rotation in the equatorial plane in the morning and evening meridian regions. Sense of vector rotation in the evening region is the same as the direction of Earth's rotation but is opposite to that in the morning region. It must be noted that the meridian separating the morning and evening regions should be taken to demarcate the regions with different senses of rotation of pulsation and should refer to the direction of solar wind arrival but not to Sun-Earth direction.

Oscillations which are excited on the boundary of magnetosphere are propagated along the lines of force which are crossing the excitation region and arrive at polar-zones. Their polarization must be counter-clockwise in the morning hours and clockwise in the evening hours in Northern hemisphere. This is also confirmed by observations.

Magneto-acoustic (longitudinal) waves are excited in the boundary region of magnetosphere simultaneously with Alfven waves. Magneto-acoustic waves are propagated downwards without damping and they possibly generate secondary Alfven resonance oscillations as they pass through lines of force closer to the earth which arrive at lower latitudes (Fig. 1b). Both the magneto-acoustic waves and the secondary Alfven waves, whose polarization is the same as that of a primary Alfven wave excited on a distant line of force come to middle and low latitudes as a result of an inter-related hydromagnetic propagation as was recently pointed out by the author (1965).

It is assumed that the origin of genetically connected disturbances, among them *Pi* 2 type pulsations, may be due to precipitation of corpuscular particles from the outermost belt of charged particles into the polar ionosphere. Precipitating particles will be turbulised by hydromagnetic disturbances generated in the boundary region of magnetosphere (Obayashi 1964). Direction of turbulence, which is transferred from the exosphere along magnetic lines of force into the ionosphere, must correspond to the direction of turbulence in the exosphere. In Northern hemisphere it must be directed counter-clockwise on the side of morning meridian and clockwise on the side of evening meridian. Observed sense of rotation of *Pi* 2 type micropulsations is seen to obey this rule.

Polarization of types *Pc* 2–4 and *Pi* 2 micropulsations in Southern hemisphere must have the opposite behaviour. This is confirmed for polar *Pc* 5 (Kato and Utsumi 1964, Nagata and Kokubun 1965), *SSC* and *SI* (Wilson and Suguira 1961, Bowling and Wilson 1965) from conjugate point observations involving high latitudes. Unfortunately it has

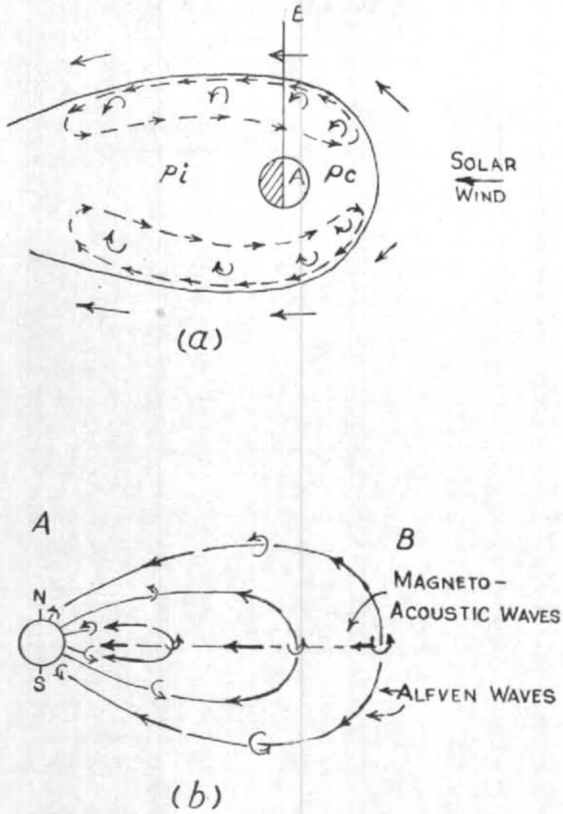


Fig. 1. Schematic diagram showing possible mechanism of excitation and propagation of micropulsations

(a) Equatorial section as viewed from above North Pole

(b) Meridional section showing evening region as viewed from Sun (morning region will be a mirror image)

not been confirmed for low latitude conjugate points due to lack of such stations.

The longer axis of the horizontal polarization diagrams of micropulsation disturbance vector is referred to as the polarization direction. In the case of *Pc* type micropulsations polarization directions may be very variable from oscillation to oscillation. *Pi* 2 type micropulsations generally show the same polarization direction of oscillations during one burst of pulsations but it may show large variability from burst to burst.

Despite that wide range of scatter in azimuths of directions the largest probability of occurrence is confined to a narrow belt of azimuth. At each station a preferred direction is observed, characteristic of the given point of observation but independent of micropulsation type.

The peculiarities of polarization direction discussed above was observed by analysis of magnetic records from stations Borok, Petropavlovsk and Lovozero ($\phi \sim 63°N$). Essential scatter of observed polarization directions and existence of preferred polarization directions are reported by several observers. Data on polarization directions according to different authors are shown in Table 1.

TABLE 1

Preferred polarization directions observed at different stations

Station	Azimuth of preferred direction	Observer
Aburatsubo	16°NW	Hatakeyama (1938)
Bermudas	13°NE	Santirocco and Parker (1963)
Borok	38°NW	Kalashnikov and Zybin (1960), Zybin (1966)
Gottingen	65°NW	Untiedt (1961)
Kiruna	58°NW	Paulson *et al*. (1965)
Lovozero	32°NE	Barsoukov and Zybin (1961)
Petropavlovsk	03°NW	Zybin (1966)
Victoria	32°NW	Duffus and Shand (1958)

Azimuths shown in Table 1 are either reported by authors or computed according to reported tables and graphs. Mean square deviations of observed azimuths range from 24° to 56°.

It is remarkable that among the stations listed in Table 1 those located near regional extended geoelectric structures and shorelines (Aburatsubo, Borok, Gottingen, Kiruna and Lovozero) appear to show a preferred polarization direction perpendicular to the strike of the structures. Preferred polarization direction observed at stations situated above more complex conditions, including island locations and complicated shorelines (Bermudas, Petropavlovsk and Victoria), are more difficult to interpret due to the integrated regional effect of complicated geoelectrical conditions.

Analysis of Borok, Petropavlovsk and Alma-Ata data have shown that hourly mean values of polarization direction azimuth exhibit clear diurnal variation relative to a preferred direction. Both the *Pc* 2–4 and *Pi* 2 hourly mean azimuth of polarization direction swing by some tens of degrees counter-clockwise in the morning, and clockwise during evening relative to the characteristic preferred direction. Around midday and midnight hourly mean azimuths are close to the preferred polarization direction.

Polarization directions of micropulsations without distinction as to types exhibit the same diurnal variation, permitting to trace it without interruptions during complete 24 hours (Kalashnikov and Zybin 1960). During the time interval from morning to evening hourly mean azimuths are gradually turning clockwise, while from evening to

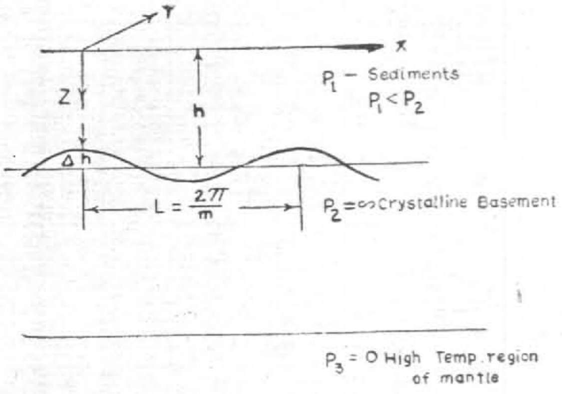


Fig. 2. Two-dimensional geoelectric structure used for estimating the geological correction for horizontal component of magnetic field

morning, they turn counter-clockwise. At the morning and evening hours the mean azimuths reach the extremal values relative to preferred polarization direction.

All the reported data dealing with diurnal variations of polarization directions including earth current ones, and also other data from which diurnal variations could be determined establish the existence of diurnal variations of directions similar to the above mentioned pattern for Northern hemisphere. It is necessary to note that the only paper for Southern hemisphere (Christoffel and Linford 1966) reported an inverse of the pattern discussed above.

It is evident, that for any given observational point the preferred polarization direction characteristically reflects the geoelectrical properties of observational region, but scattering of directions and existence of polarization direction diurnal variation are due to the nature of micropulsation mechanisms.

Accepting the currently adopted view that the Earth acts almost as an ideal conductive screen, the horizontal magnetic micropulsation field observed on the Earth's surface is equal to double the incident field. This result is justified for horizontally uniform sub-surface structures. Effects in the case of horizontally non-uniform conditions are bound to be more complicated.

Estimates attempted by Vanyan and Zybin (1967) showed that even very minor departure from horizontal uniformity in the case of two-dimensional structure may effect the horizontal field of magnetic variations observed on the surface. This effect is due to non-uniform electric currents induced by incident magnetic field in the electrically non-uniform structure.

As a result of the effect of geology the amplitude of magnetic field component, directed perpendicular to the strike of the structure will not be equal to double incident values and the phase angle between that component and the one directed along strike will be changed relative to the incident value. Magnitudes and signs of this "geological effects" are determined by parameters of structure, periods of incident oscillations and location of observational point relative to the structure.

For a typical structure encountered in nature as shown in Fig. 2 ($\rho_1 = 10$ ohms, $\triangle h/h = 0\cdot3$, $mh = 0\cdot1$) and with micropulsation periods of the order of tens of seconds estimated values of "geological corrections" over the extreme of structure is of order ± 10 per cent in amplitude and ± 5° in phase angle. Signs "+" and "—" correspond to the observational point location over troughs and crests of the structure respectively. At the intermediate points on the surface the values of "geological corrections" are modified according to the cosine law.

The component of observed magnetic field directed along strike of the structure is invariable and equal to double the incident values. This circumstance leads to essential differences between the parameters of "incident" and "observed" fields for the general case of elliptically polarized fields, in spite of insignificant values of total field changes.

For example, in the case of circularly polarized incident field, the polarization calculated over the trough of the above structure will become an elliptical one, with an axis ratio of order 1·14 and an angle between major axis and the normal to the strike of order +23° for clockwise and —23° for counter-clockwise incident polarizations.

Natural horizontal micropulsation fields possess in general elliptical polarization with variable polarization directions. Relative changes in polarization properties influenced by the above mentioned geology (observation point situated over a trough of structure) are next considered. Incident field was assumed as characterised by elliptical polarization with polarization directions distributed isotropically relative to any horizontal coordinate system and with axis ratio 1·2 for every direction. Choice of axis ratio 1·2 is of the right order for natural micropulsation fields.

Fig. 3 shows the obtained deviations of computed ellipse directions against directions of incident field ellipses. Fig. 4 illustrates the obtained axis ratio of computed ellipses against directions of major axes of computed ellipses. Dependence for counter-clockwise polarization sense of incident field is represented by solid lines, and that for clockwise ones by dashed lines on both the figures.

A count of occurrence frequency of different values of obtained polarization direction for the direction ranges 0°–10°, 10°–20°, ..., where 0° is

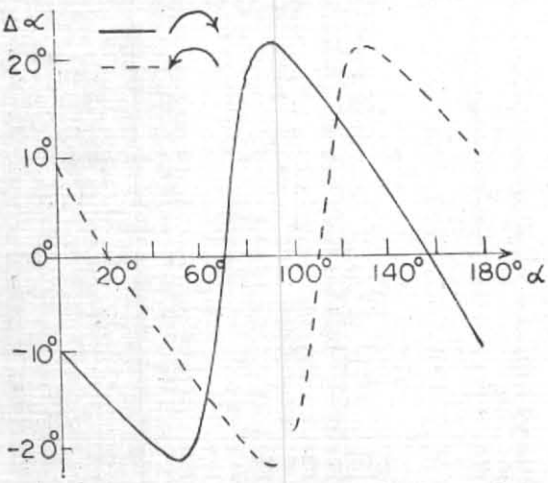


Fig. 3. Deviation of computed ellipse directions against directions of incident ellipses

Horizontal axis gives azimuths of incident ellipses and the vertical axis, the deviation between incident and computed azimuths

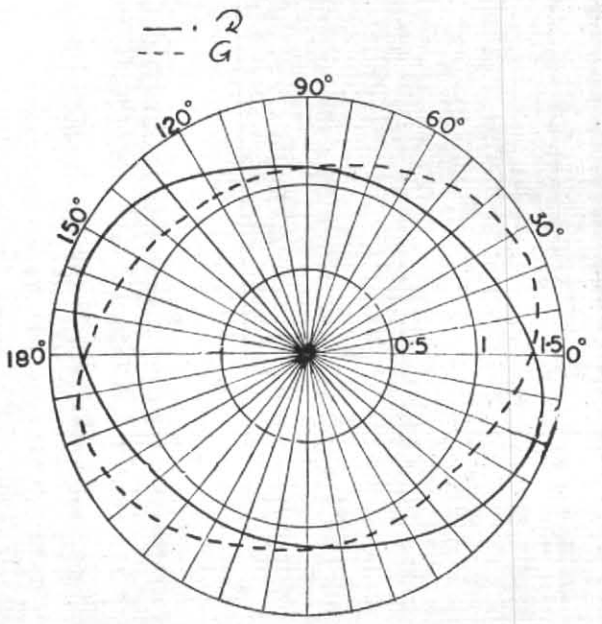
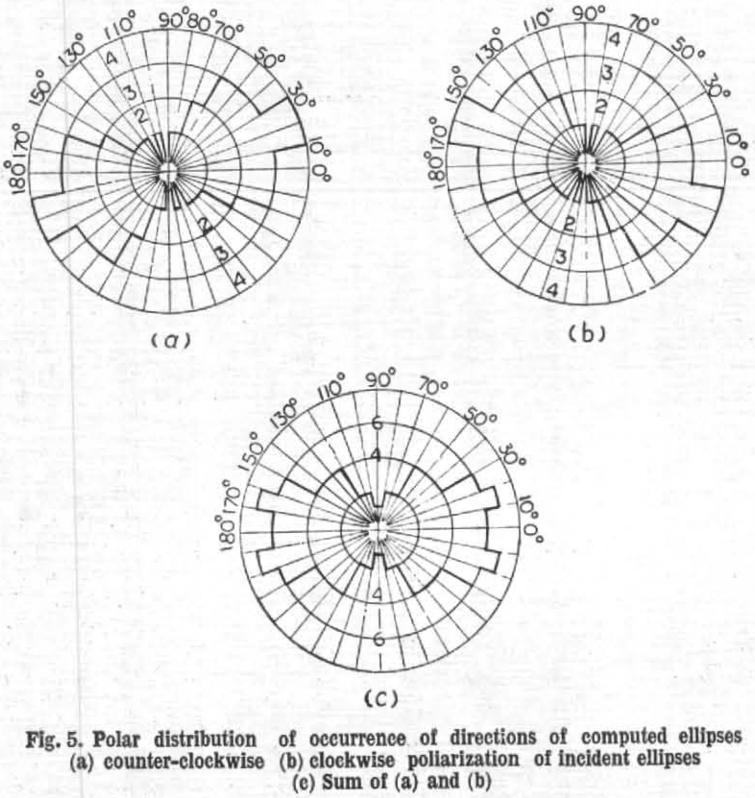


Fig. 4. Polar diagram showing the axis-ratio of computed ellipse on the direction of main axis of computed ellipse

Radials are marked in units of axis-ratio



(a)

(b)

(c)

Fig. 5. Polar distribution of occurrence of directions of computed ellipses (a) counter-clockwise (b) clockwise polarization of incident ellipses (c) Sum of (a) and (b)

Radials are marked in number of occurrences. Incident polarization assumed as having the same occurrence frequency in every direction

the direction normal to strike of the structure, showed non-isotropic distribution of computed ellipse directions having a higher frequency around the preferred direction. Both the direction distributions of computed ellipses and their preferred directions are different for different polarization senses of rotation (Figs. 5a and 5b) although the incident distributions were supposed to be isotropic characterised by equiprobable occurrence of every polarization direction independently of polarization rotational sense.

Preferred mean direction of computed distribution (both clockwise and counter-clockwise rotations together) coincides with the normal to the strike of the structure (Fig. 5c). It is clear from Figs. 5(a) to 5(c) that the preferred directions of computed distribution for counter-clockwise polarizations and clockwise polarizations separately are turned relative to preferred mean direction by angles of order 20° counter-clockwise respectively. Mean square deflection of computed polarization direction is of order $\pm 35°$. Computed axes ratios range from $1 \cdot 40$ in the directions coinciding with preferred direction for respective senses of polarization rotation, to $1 \cdot 05$ in the directions perpendicular to the preferred direction. The average axes ratio of the computed ellipses is equal to $1 \cdot 2$, *i.e.*, it is invariably relative to the incident ellipses and also the sense of polarization rotation remains the same.

One may point out that the properties of computed polarization (obtained by assuming elliptically polarized incident field possessing isotropic distribution of directions) resemble the natural observed properties of micropulsations polarization. The above mentioned analysis shows clearly that preferred polarization direction observed in natural micropulsation field may be explained by the effect of subsurface horizontal inhomogeneity but diurnal variation of polarization direction may be due to the reflection of rotational properties of micropulsations mechanisms. In other words, the diurnal variations of hourly mean direction are due to diurnal variation of rotational sense, which has been pointed out earlier.

It is necessary to note that natural geological structures may have more complicated shapes than the case considered above, as for example, wedgelike and dykelike structures, structures with large dips, three-dimensional structures, etc. It is evident that effect of such complicated structures upon the horizontal component of geomagnetic micropulsation field must be more strong and complicated.

Acknowledgements

In conclusion, the author desires to thank Dr. Sanker Narayan of National Geophysical Research Institute, Hyderabad for his kind help in the preparation of this paper.

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