J. Geophys. 42, 257–269, 1976

Journal of Geophysics

Spatial Characteristics of Giant Pulsations

O. Hillebrand

Institut für Geophysik der Universität Göttingen,
Herzberger Landstraße 180, D-3400 Göttingen, Federal Republic of Germany

Abstract. From records of geomagnetic pulsation measurements along a profile in Northern Scandinavia during 1970 and 1971, all events of giant pulsations (pg) Type A have been selected. Data analysis reveals the spatial characteristics of giant pulsations: in particular the pg region normally has the form of a long ellipse with its major axis roughly parallel to a geomagnetic parallel of latitude; distinct phase differences between similar components at adjacent stations can be seen; the vertical component of the giant pulsations commonly is of the same order of magnitude as the horizontal components, in contrast to other types of pulsations; an opposite sense of rotation in the horizontal vectogram is found between stations north and south of the line of maximum pg amplitudes.

Key words: Giant pulsations – pc4 and pc5 pulsations – Time series analysis – Polarization properties.

1. Introduction

Giant pulsations (pg) have been studied for many years by many authors (e.g. Rolf, 1931; Harang, 1936; Sucksdorff, 1939). Because of their large amplitudes and their regular form, they were one of the first types of geomagnetic pulsations to have been described (Birkeland, 1901). In this paper a definition is used given by Sucksdorff (1939) for the type "A" giant pulsations: their periods of oscillation lie between 80 and 600 s (hence pg belong to the pc4 and pc5 pulsations) according to the classification by Jacobs et al. (1964) and their shape is sinusoidal. Their maximum amplitudes frequently reach values up to 35 nT, normally beginning with small amplitudes and rising to this maximum. The decay of amplitudes after that maximum is much faster in most cases. A pg event can be as short as ten oscillations up to several hours of sinusoidal pulsations. The occurrence of giant pulsations is limited to a narrow range in latitude near the auroral belts.

Initial studies of giant pulsations investigated mainly their diurnal distribution (Rolf, 1931). Harang (1936) studied the diurnal and seasonal distribution of giant pulsations using data from Tromsö. He found a maximum of occurrence in the morning hours at about 04:00 UT and maxima in the seasonal distribution around the equinoxes. Sucksdorff (1939), who used magnetic records from Sodankylä, distinguished two types of giant pulsations: the sinusoidal type "A", as defined above and an irregular type "B" with amplitude maxima at around 03:00 and 10:00 LT and a smaller maximum in the afternoon.

Past studies have investigated the possible dependence of the period of pg oscillations on the degree of disturbance or on the location of the pg event. Ol' (1963) found a connection between the latitude of a pg region and the period of the event. Hirasawa (1970) observed a relationship between the degree of magnetic disturbance and the location of the pg region.

The nonuniform distribution of the existing observatories hampered studies on the spatial distribution of amplitudes of pg events. Specifically, there was a lack of pg observations on north-south profiles with closely-spaced stations. The aim of this project was, therefore, the investigation of the latitude dependence of selected pulsation events recorded by a close-spaced north-south profile near the auroral zone.

2. Instrumentation

At 11 European observatories, geomagnetic pulsations are recorded by induction-type pulsation variometers described by Grenet (1949). In addition to these observatories, the Geophysikalische Institut der Universität Göttingen has employed similar but mobile field instrumentation to obtain measurements in more remote areas.

All these variometers use a bar magnet suspended in the centre of an induction coil. Geomagnetic variations cause the magnet to move and hence a voltage is induced in the coil. (Each instrument system has three variometers recording the magnetic components H, D, and Z respectively). At the observatories, the resultant variometer signals are passed through galvanometers and recorded optically on photo-sensitive paper sheets.

In order to improve the sensitivity Steveling (1973) introduced photo-electric amplifiers consisting of galvanometers and differential photo-resistors.

Three further portable systems were built at Göttingen (Hillebrand, 1974), again utilizing the same variometers. However, for these instruments the output voltages (approximately 10 μV/nT) are directly amplified by DC amplifiers. The signals are then recorded by slow-speed (15/320 ips) FM tape recorders which allow 10 days continuous recording.

Typical amplitude and phase response curves for these instruments are illustrated in Figure 1. The amplitude response is normalized to the value 1 at a period of 20 s. The resolution at this period is about 0.05 nT when amplifiers are at maximum sensitivity. The amplitude and phase response of all variometers is similar, each amplitude curve differing from the other by a constant calibration factor only.

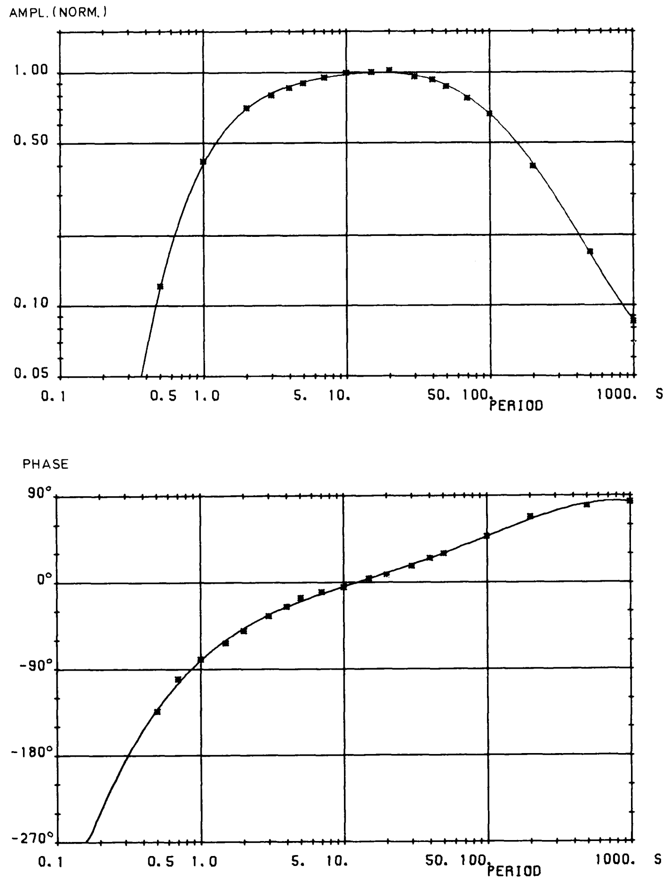

Fig. 1. Amplitude and phase response curves of the pulsation recording equipment

3. Observations in Scandinavia

Studies on the latitude dependence of pc3-4 type pulsations by Voelker (1963) and on the phase reversal of pi2 pulsations between auroral and mid latitudes suggested more finely spaced measurements by mobile field systems in the gap between established observatories in northern Europe. During 6 months in 1970 and 1971 six mobile systems were set up at 16 different sites in northern Scandinavia. Table 1 lists the names, the geographic coordinates, and the geomagnetic latitudes of these sites as well as the observatory stations where similar pulsation instrumentation is used.

The geographic distribution of the stations are shown in Figure 2. At times when the systems covered the entire profile, station spacing was relatively large. However, during some recording periods, station separation was less than 100 km. From the portable systems and from the observatories it was possible to obtain simultaneous data from at most 12 stations.

Table 1. List of observatories (O) and recording sites with tape equipment (T) and film equipment (F) during 1970 and 1971 in Scandinavia

Station	Abbrev.	Type	Geograph. Coordin.		Geomagn. Lat. (centered dipole model)
			Lat.	Long.	
Leirvogur	LI	O	64°10′	338°17′	70.2°
Tromsö	TR	O	69°41′	19° 0′	67.1°
Repparfjord	REP	T	70°22′	24°30′	66.8°
Abisko	ABI	T	68°21′	18°48′	66.0°
Kiruna	KI	O	67°48′	20°24′	65.2°
Ålloluokta	ALL	F	67° 5′	19°30′	64.8°
Porjus	POR	F	66°58′	19°51′	64.6°
Messaure	MES	T	66°39′	20°32′	64.2°
Arjeplog	ARJ	F	66° 0′	17°54′	64.1°
Sodankylä	SO	O	67°23′	26°35′	63.8°
Malå	MAL	F	65°13′	18°50′	63.2°
Lycksele	LYC	T(F)	64°37′	18°44′	62.7°
Åsele	ASE	F	64°11′	17°20′	62.6°
Junsele	JUN	F	63°43′	16°52′	62.3°
Hammarstrand	HAM	T(F)	63° 7′	16°27′	61.8°
Fränsta	FRN	F	62°27′	16° 5′	61.3°
Delsbo	DEL	T(F)	61°48′	16°34′	60.6°
Edsbyn	EDS	F	61°22′	15°49′	60.3°
Svärdsjö	SVJ	F	60°48′	15°53′	59.8°
Garpenberg	GAR	T	60°18′	16°13′	59.3°
Enköping	ENK	O	59°30′	17°17′	58.3°
Wingst	WN	O	53°45′	9° 4′	54.6°

4. Data Collection and Analysis

All data collected at the various stations were examined and categorized. Among numerous pc and pi events observed during the recording periods, 26 events of giant pulsations could be determined. The definition of type "A" giant pulsations by Sucksdorff (1939) was chosen as a base for data selection and only pulsations with a duration of at least ten oscillations were selected. Some of these events were clearly recognizable at as many as 8 stations, whereas others were distinct at only one or two sites. Table 2 lists the time of occurrence of these 26 events as well as the principal period of oscillation, the degree of magnetic disturbance (Kp), and the station at which maximum amplitude in the horizontal plane was recorded.

All components of the events listed, were digitized at 3 s increments using a semiautomatic digitizing table. In order to establish the period and amplitude of the dominant pg pulsations, power density spectral analysis (Blackman and Tukey, 1958) was utilized in which both the autocovariance functions and the power spectra were calculated. Cross-spectral estimates were used to determine phase differences between components at the same location as well as between similar components at different stations. The results of the spectral analyses were then used to draw the polarization ellipses in the H-D, D-Z, and H-Z planes as described by Rankin and Kurtz (1970). These ellipses are used to

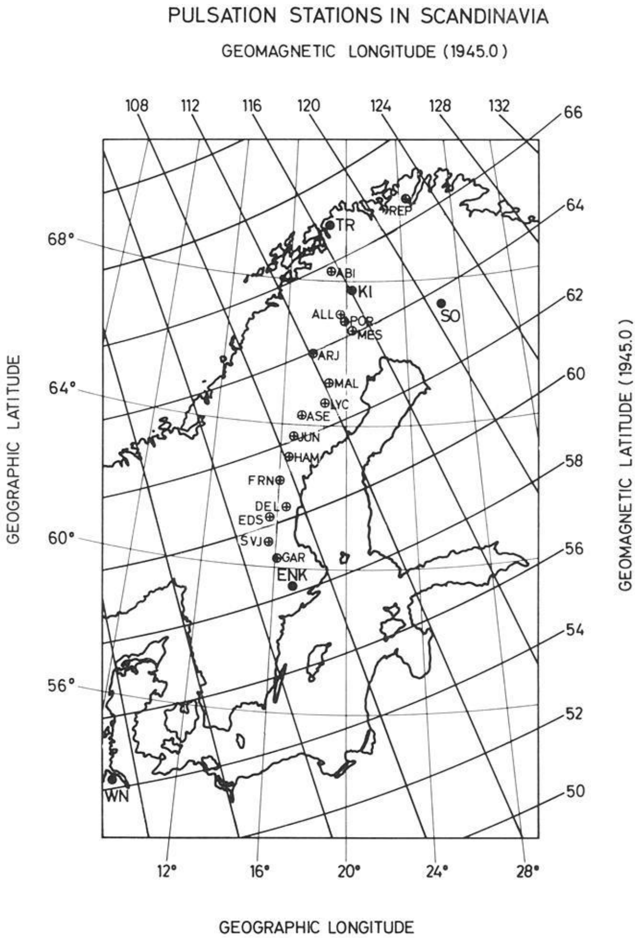

Fig. 2. ⊕ Sites in Scandinavia where the pulsation instruments were set up during 1970 and 1971. ● Observatories in Scandinavia and Northern Germany (WN) with Grenet type pulsation systems whose records were used in data analysis. (Leirvogur (LI) in Iceland is located outside this area)

illustrate the direction of polarization, the rotational sense, as well as the ellipticity and the degree of polarization.

5. Results

An eighteen minute interval of one of the most pronounced events of giant pulsations which occurred during the measurements in Scandinavia is shown in Figure 3. The entire event lasted from about 6:30 to 8:54 UT on June 25, 1971. This event shows the typical sinusoidal oscillations at seven of the eleven recording sites. The pulsations cannot be detected at LI in Iceland which is far away from the other stations. A surprising observation is the attenuation

Table 2. List of giant pulsation events and stations of maximum amplitudes in the horizontal plane

Date	Time (UT) Start	Time (UT) End	Principal period (s)	Kp	Station with max. Ampl.	Number of Stations affected
700810	03:00	05:24	147	2−	TR	5
700811	07:42	08:36	99	2o	TR	3
700811	09:43	11:31	247	2o	SO	1
700812	06:04	06:58	219	2+	TR	3
700812	08:00	11:00	199	2+	SO	4
700813	07:14	08:26	270	2−	MES	3
700816	04:10	04:46	108	1+	TR	4
700822	08:04	08:22	99	1o	LYC	4
700912	03:24	04:00	330	2+	TR	2
710530	03:32	04:26	144	2o	TR	7
710603	10:17	10:53	180	2o	ABI	5
710609	07:47	08:05	219	1−	KI	3
710614	06:50	07:44	114	2−	ABI	7
710618	04:42	05:18	240	2−	SO	8
710625	04:52	05:28	85	3+	KI	6
710625	06:30	08:54	99	4−	SO	7
710627	23:50	00:08	204	1o	REP	3
710628	05:42	06:00	204	1−	REP	3
710708	08:52	09:10	91	2o	REP	2
710718	03:40	04:16	183	2+	ABI	5
710805	06:27	07:21	180	4+	MES	6
710805	10:08	11:02	187	1+	MES	2
710912	09:37	09:55	187	3o	LYC	7
710916	00:27	01:03	103	3−	TR	5
710924	09:31	10:07	225	0o	LYC	3
710929	01:12	01:48	101	3−	TR	4

of pulsation amplitude from ARJ to LYC, which are separated by a distance of approximately 180 km.

During the pg event, the amplitudes of the oscillations rise slowly to a maximum and fall again. The amplitudes of the vertical component are quite large compared to other types of pulsations. Indeed at times the vertical component exceeds the horizontal components. The oscillations of the disturbance seem to be more stable in the D-component than in the H-component: The coherency between H-components of different stations is lower than that of D-components.

The giant pulsations occurring during the time interval illustrated in Figure 3 have a mean period of 99 s. The period varies during the course of the event but is usually the same at different stations and in the three components. The period of this event is initially about 90 s, rises to 99 s during the time of maximum amplitudes, and then returns to its initial value. At the same time coherencies from station to station for this pg approach 1.0, and even records from distant stations often show good coherencies. The phase differences between similar components at different stations can already be seen by visual

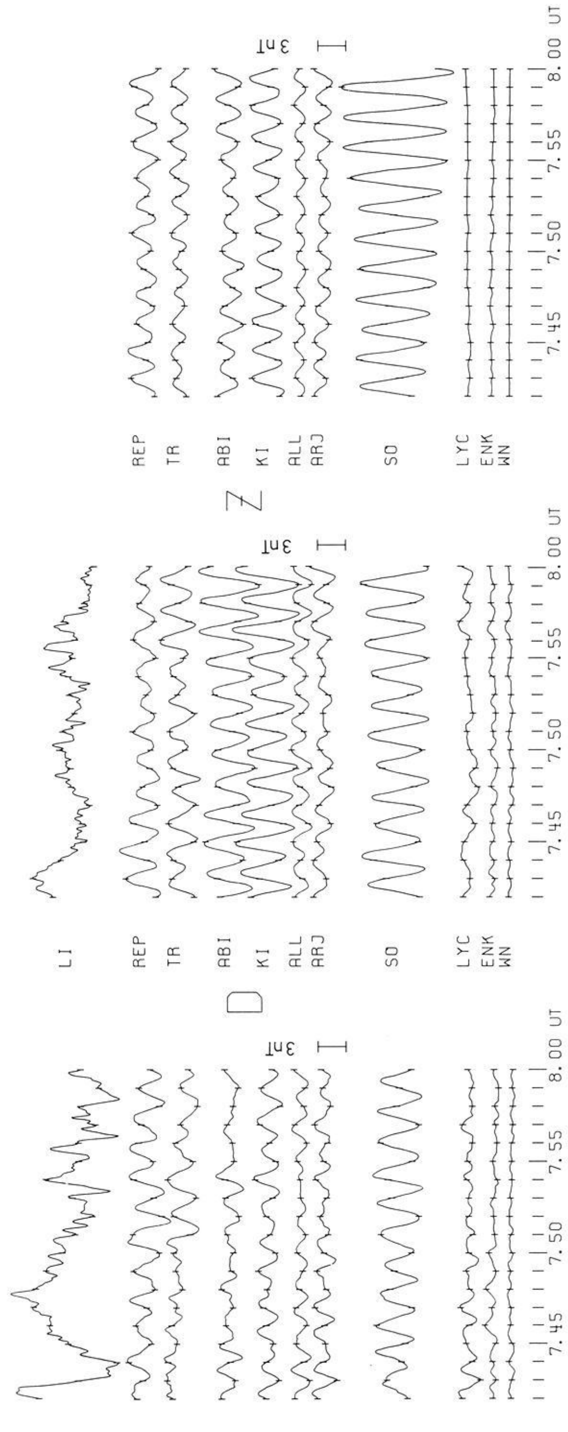

Fig. 3. Example of giant pulsations (pg) on the 25th of June 1971

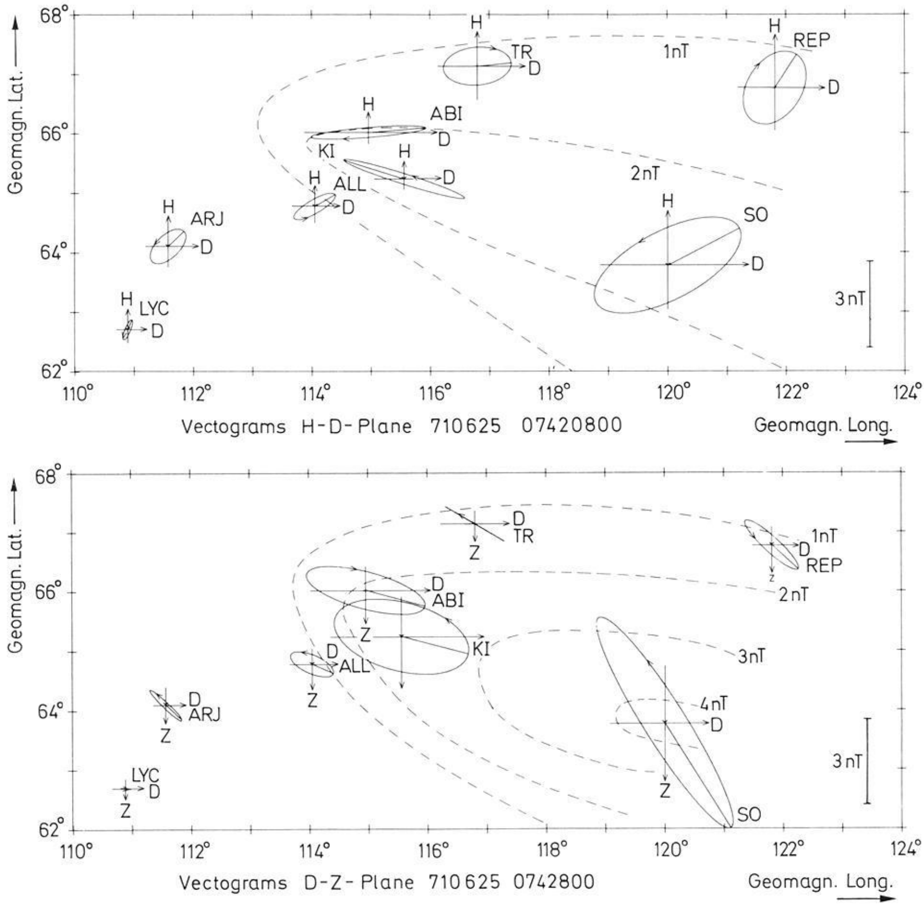

Fig. 4. Polarization ellipses in two planes of the event of giant pulsations on the 25th of June 1971

inspection of the example shown in Figure 3. Even the records of adjacent stations often show distinct phase differences.

With regard to the shape and rotation sense of the polarization ellipse the behaviour of the disturbance vector in the horizontal plane is dependent on the position of the recording site relative to the region where the pg is appearing.

Figure 4 gives an example of the sense of rotation and the shape of the polarization ellipses during an event of giant pulsations. The spatial amplitude distribution of the pg is approximated and marked by dotted lines of equal amplitude. The location of each station is indicated by the position of the centre of the small coordinate system for the polarization ellipses.

From the horizontal vectograms, a relationship between the shape and rotational sense of the polarization ellipses and the position of the observation station relative to the maximum disturbance region is apparent. To the north of this region, oscillations have a clockwise sense of rotation (viewed in the

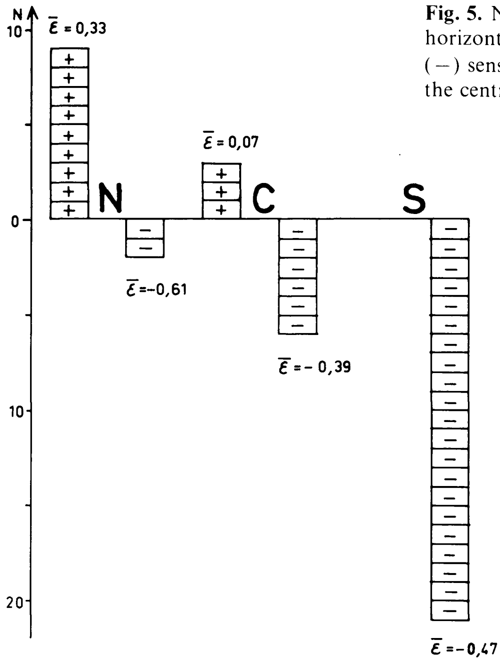

Fig. 5. Number of polarization ellipses in the horizontal plane with clockwise (+) and anticlockwise (−) sense of rotation north (N), south (S) and near the centre (C) of the pg region

horizontal plane in the direction of a fieldline). The opposite sense of rotation is shown at stations to the south of this region. For stations near the line of maximum pg amplitudes, the polarization is almost linear. A similar relationship for the vertical plane vectograms could not be detected.

From the 26 recorded events of giant pulsations nine were selected by criteria which included the number of stations which were affected (at least four), the amplitudes of the oscillations and the coherency of the signal from station to station. The sense of rotation of the polarization ellipse in the horizontal plane for each station was represented by a "+" for clockwise rotation viewed along a line of force, or a "−" for anticlockwise rotation. The stations were then divided into three groups according to their position relative to the region of pg maxima. Group N contains the observations to the north, group S those to the south, and group C those near the centre of the pg region. Furthermore, mean values of the ellipticity were calculated for each group. The results are illustrated in Figure 5. It is clear that an anticlockwise polarization sense is dominant south of the centre of the pg region, whereas to the north clockwise polarization dominates. The relatively small value $\varepsilon = 0.07$ of the ellipticity near the centre of the pg region indicates a prevalence of linear polarization.

6. Discussion

When comparing the results of this study with those obtained by other workers, it should be noted that the duration of the period of observation was much shorter than that examined by Rolf (1931), Harang (1936), and Sucksdorff (1939). The statistical results presented by these authors are based on data recorded over several years. The definition of type "A" giant pulsations and selection criteria should also be kept in mind. Large amplitude pulsations were thus excluded lacking regularity of waveform (for example, those treated by Nagata et al., 1963 or by Ol', 1963). Finally, all giant pulsation events observed during this recording period occurred between midnight and noon. This is in agreement with the statistical investigation of Sucksdorff (1939). His second peak in the occurrence pattern at about 16:00 LT could not be confirmed, possibly due to the relatively limited data.

From this study the shape of the region with simultaneously occurring pg's has the form of a long ellipse with its major axis roughly parallel to a geomagnetic parallel of latitude. A similar elonguated pg region has been reported by Veldkamp (1960) who used a network of 24 stations in recording a rare pg event in middle latitudes. Other authors (e.g. Eleman, 1967), who have analyzed data from a network of stations have also described the region of occurrence of a pg as an ellipse extending in the geomagnetic east-west direction.

The analysis of the periods of the giant pulsations in this study yielded results similar to those of Eleman (1967). During a pg event, the period of oscillation often increases until the occurrence of maximum amplitudes and then decreases again. A period range of 85 s to about 5.5 min was observed in this study for different events.

With regard to the polarization of giant pulsation, this study reveals that the sense of rotation in the horizontal plane is opposite at stations north and south of the line of maximum amplitudes. To the north, the disturbance vector rotates clockwise viewed in the direction of a line of force, while to the south, the opposite sense of rotation is dominant. Samson and Rostoker (1972) obtained similar results in their more general analysis of pc4-pc5 pulsations, which did not specially concern giant pulsations. They observed an opposite rotational sense north and south of a demarcation line characterized by linear polarization and maximum amplitudes. Furthermore, the position of this line was found to change latitude during the day and a reversal of the rotational sense in both the north and south region was observed to occur at about 11:00 LT. This latter feature could not be confirmed in this study due to the lack of pg events in the afternoon hours.

The exact location of the line separating the region of opposite polarization is also significant in the study of horizontal vectograms at geomagnetic conjugate stations. Annexstad and Wilson (1968) found a high degree of correlation in the conservation of rotational sense in the direction of the corresponding line of force. Observed exceptions to this rule may be caused by the position of the recording station relative to the centre of the pg region. Assuming that both stations are not completely conjugate points, normally the centre of the pg is situated poleward or equatorward of both stations and a conservation of the rotational sense can be observed. On the contrary when one of the stations is situated poleward and the other equatorward of the pg centre in each hemisphere no conservation of the rotational sense is found as mentioned for several events in the investigation cited above.

It was tried to find a relationship between the latitude of the pg event and the period of oscillation as Ol' (1963) found and a relationship between the degree of disturbance and the location of the pg region as Hirasawa (1970) investigated. Neither of these effects could be confirmed by this study, probably because of the limited number of observed events.

Comparisons of satellite data to ground-based observations do not as yet allow a complete solution to the problem of the generation and propagation mechanism for magnetohydrodynamic waves in the magnetosphere which are observed as giant pulsations at the Earth's surface. Several events of pc4 and pc5 pulsations have been recorded in the magnetosphere and sometimes correlation analysis has been done with ground observations. Some of these magnetic oscillations at the location of the satellite resemble giant pulsations. Cummings et al. (1969) observed elliptical polarized pulsations in the magnetosphere with the disturbance vector orthogonal to the lines of force.

Lanzerotti and Tartaglia (1972) observed compressional waves in the magnetosphere at times when pc5 pulsations occurred on the ground with elliptically polarized oscillations. A characteristic feature of partly compressional waves in the magnetosphere may be the large vertical amplitudes of giant pulsations which are reported by almost all workers.

Pc5 pulsations with regular waveform have also been observed by Barfield et al. (1972) but these events were correlated to geomagnetic storms, and a relation between these oscillations and the occurrence of pg's or normal pc5's has not been described. An explanation of why giant pulsations have not yet been correlated with magnetic oscillations in the magnetosphere may be the very narrow latitude extension of the pg region, requiring that the observatory and the satellite be situated close to the same line of force.

Simultaneous observations of a pc5 storm time event in the magnetosphere and at different ground based stations together with proton density data have been done by Lanzerotti et al. (1975). The ground magnetometer data showed an opposite sense of rotation of the horizontal vector north and south of $L \approx 5$. The authors concluded that an odd mode shear Alfvén wave was excited by a high β drift instability at a gradient region of the hot plasma distribution. These observations are connected to storm times like in the study of Barfield et al. (1972). Consequently those results cannot be completely compared to pg observations on the ground.

Theoretical work on the excitation and propagation of magnetohydrodynamic waves which are observed as giant pulsations on the ground has been done by several authors. Lehnert (1956) considered oscillations in the conductive layers of the ionosphere as a cause of giant pulsations. Kato and Watanabe (1956) concluded that giant pulsations are harmonics of fundamental oscillations of the magnetosphere. The periods of these oscillations should be in the order of 600 s in the latitudes where giant pulsations are usually observed, and much longer in higher latitudes (3,000 s at 70° geomagnetic latitude). Wilson (1966) explains the correlated polarization characteristics of pg events at conjugate points by a model with circularly polarized standing hydromagnetic waves and induced ionospheric currents.

These theoretical investigations have been unable to explain the polarization characteristics of pg events having an opposite sense of rotation north and south of the amplitude maximum. The theory for pc3 to pc5 by Hasegawa and Chen (1974) explains the polarization characteristics found by Samson and Rostoker (1972). The observed polarization characteristics of giant pulsations are also sufficiently explained by the above theory; i.e., the maximum amplitude and linear polarization at the location of the resonant field line and the opposite rotational sense of the polarization ellipse in the horizontal plane north and south of this region are interpreted. One of the observed characteristics of giant pulsations, the relatively large amplitudes of the vertical component is not explained by this theory.

Acknowledgements. The author acknowledges the cooperative assistance of the Scandinavian observatories and of many individuals during the field work in Scandinavia. This work is part of a project sponsored by the "Deutsche Forschungsgemeinschaft".

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Received January 12, 1976; Revised version April 5, 1976