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CONJUGATE RELATIONSHIPS OF MAGNETIC Pi 2 PULSATIONS IN THE AURORAL REGION

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Abstract

Conjugate relationships of magnetic Pi 2 pulsations have been studied based on the data obtained at Syowa Stations in Antarcica and around Reykjavik in Iceland,which are the best conjugate-pair among the many stations in the auroral region. The Pi 2 waves are observed simultaneously at the conjugate-pair with a high coherency. The phase relationships of Pi 2 waves show an in-phase oscillation in the north-south (H) component, while show an anti-phase oscillation in the east-west (D) component. Those observational results strongly suggest that Pi 2 is caused by the odd-mode (fundamental-mode) magnetohydrodynamic (MHD) standing oscillations of the field lines which are anchored at the auroral ovals.

1. Introduction

The magnetic Pi 2 pulsations (Pi 2) are observed almost simultaneously with an onset of the magnetospheric substorm expansion over the wide latitudinal range from the auroral region through low-latitudes (Saito, 1969 ; Saito et al., 1976 ; Kuwashima, 1975, 1978 ; Kuwashima and Saito, 1981). Recently, Sakurai and McPherron (1983) and Kuwashima (1984) found that Pi 2 is also observed in the magnetosphere in association with the substorm expansion. Pi 2 is one of the important manifestations of the magnetospheric substorm expansion (Saito et al., 1976 ; Olson and Rostoker, 1977 ; Rostoker and Samson, 1984). So, it is necessary to clarify the wave characteristics of Pi 2 in a study of the magnetospheric physics. Using the data obtained at the multi-station networks, Pi 2 has been studied in relationships to both the development of the field aligned current and the auroral electrojet in the ionosphere (Rostoker and Samson, 1981 ; Pashin et al., 1982 ; Samson and Rostoker, 1983). On the other hand, we have continued the Pi 2 study based on the data obtained from the concurrent ULF observation at a wide latitudinal range from high-to low-latitudes along almost the same magnetic meridian (Kuwashima, 1975 ; Kuwashima and Saito, 1981). The present paper is a summary of our current works. In the earlier papers, the close relationships of the Pi 2 period to the auroral breakup position were found, namely, the Pi 2 period increases with

increasing the magnetic latitude, where the associated auroral breakup started. Theoretical examination supported that the observed Pi 2 period could be interpreted by the MHD standing oscillations of the fundamental-mode of the field lines localized at the position of the northern and southern auroral ovals. The polarization characteristics near the auroral electrojet were consistent with results-predicted by the MHD standing oscillations of the field lines.

In order to study the MHD oscillation mode more detailed, it is necessary to examine the conjugate relationships. However, the study of the conjugate relationships of Pi 2 in the auroral region has not been sufficiently carried out yet because of the lack of a good conjugate pair in the auroral region. Sakurai (1970) has studied the conjugate relationships of Pi 2 in the sub-auroral region based on the data at College and Macquarie Iseland. According to his results, the odd-mode standing oscillation of the field lines is suggested as a cause of Pi 2. However, the study by Sakurai (1970) was based on the single event, moreover, the conjugacy of the used stations (College and Macquarie Iseland) is not so good. Green and Hamilton (1981) found a clear seasonal dependency with the conjugacy of Pi 2, however, used stations (St. Anthony and Hally Bay) are located in the sub-auroral region, also. In the present paper, the conjugate relationships of Pi 2 will be studied baesd on the good conjugate pair in the auroral region, Syowa Station in Antarctica and stations near Reykjavik in Iceland.

2. Data Analyses

During the period from July 29 to September 18, 1977, concurrent ULF observations have been carried out at Syowa Station and Mizuho Station in Antarctica and Husaffel in Iceland by the 18-th wintering party of the Japanese Antarctic Research Expedition and by the National Institute of Polar Research. Husaffel is located near Reykjavik. The location of those stations are listed in Table 1. The magnetic local time of those stations is almost the same as the universal time.

The data recorded to analogue magnetic tape are converted to the digital data with a sampling interval of 0.6 second. The high-latitude Pi wave has an apparently irregular waveform which could be due to an effect of random fluctuations of ionospheric current caused by the violent precipitations of auroral particles (Samson and Rostoker, 1983; and others). A numerical band-pass filter techniqe is applied to conquer this difficulty. The used filters are both nonrecursive (Gaussian-type) and recursive (Butter-worth and Chebyshev types). An example of band-pass filtered wave trains is illustrated in Fig. 1, where the Pi burst component were removed by the band-pass filter of Chebyshev type with ratios of-3 db at 50 and 200 second, and with ratios of-20db at 10 and 500 second, respectively. The conjugate relationships of Pi 2 will be studied by using those band-pass filtered Pi waves.

TABLE 1 Location of stations used in the present study

Station	Geographic		Geomagnetic	
	Latitude	Longitude	Latitude	Longitude
Husaffel	64.7 N	20.9 W	70.2	74.2
Syowa	69.0 S	39.6 E	-70.0	79.4
Mizuho	70.7 S	44.3 E	-72.3	80.6

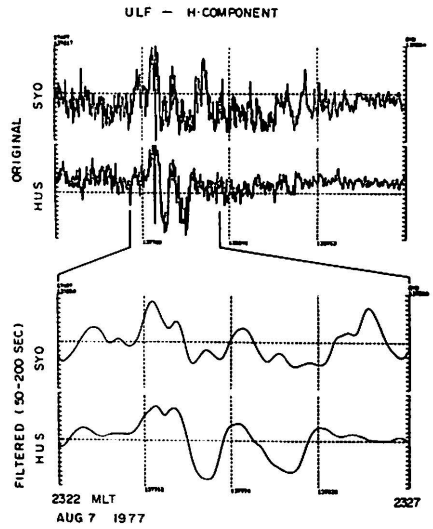

Fig. 1 : Wave trains of original and band-pass filtered Pi pulsations simultaneously observed at a pair of conjugate stations, which are Syowa Station (SYO) in Antarctica and Husaffel (HUS) in Iceland.

3. Conjugate Relationships of Pi 2

During the concurrent ULF observations from July 29 to September 18, 1977, 74 Pi 2 events were identified at the conjugate pair. An example of Pi 2 simultaneously observed at the conjugate pair is illustrated in Fig.2. In the figure, a clearly in-phase relationship of H-component can be found. On the other hand, wave phase relationships are not clear in the D-component because of small wave amplitude.

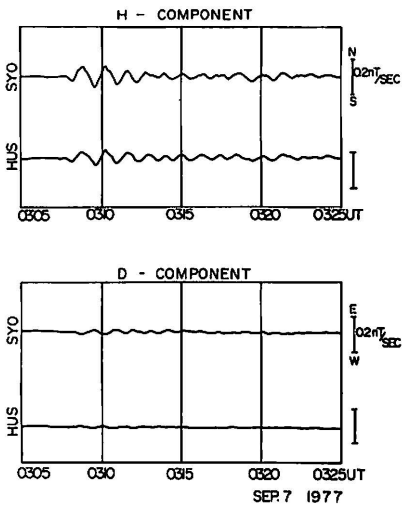

Fig. 2 : Pi 2 pulsations observed simultaneously at a pair of the conjugate stations, Syowa Station (SYO) in Autarctica and Husaffel (HUS) in Iceland. Original Pi wave trains were band-pass filtered to remove both the negative bay and Pi busrt components. The substorm expansion started at about 0308 UT on September 7,1977.

Those relationships will be studied quantitatively by using the cross spectral method. The calculated spectral elements ars,

(1) Auto-power spectra of the H- and D-components,

(2) Cross-power spectra between the two conjugate stations for H- and D-components,

(3) Phase differences and coherencies between the two conjugate stations for the H- and D-components.

The calculated results for Pi 2 event illustrated in Fig, 2 are shown in Fig. 3. In the figure, the cross-power spectra (upper part) show the dominant spectral peak around 11 mHz (90 second) for the H- and D-components. The coherency (bottom part) shows a high value of 0.96 for the H-component, while shows a value of 0.63 for the D-component. A relatively less coherency for the D-component might be related to less wave amplitude of that component as shown in Fig. 2. The cross-power spectral intensities in Fig. 3 show that the wave amplitude of Pi 2 is much larger in the H-component (2.23×10^5 $(nT/sec)^2/Hz$) than in the D-component (1.00 10^4). The wave-phase difference (middle part of Fig. 3) is a little (9°) in the H-component indicating an in-phase oscillation at the conjugate pair, while it is about

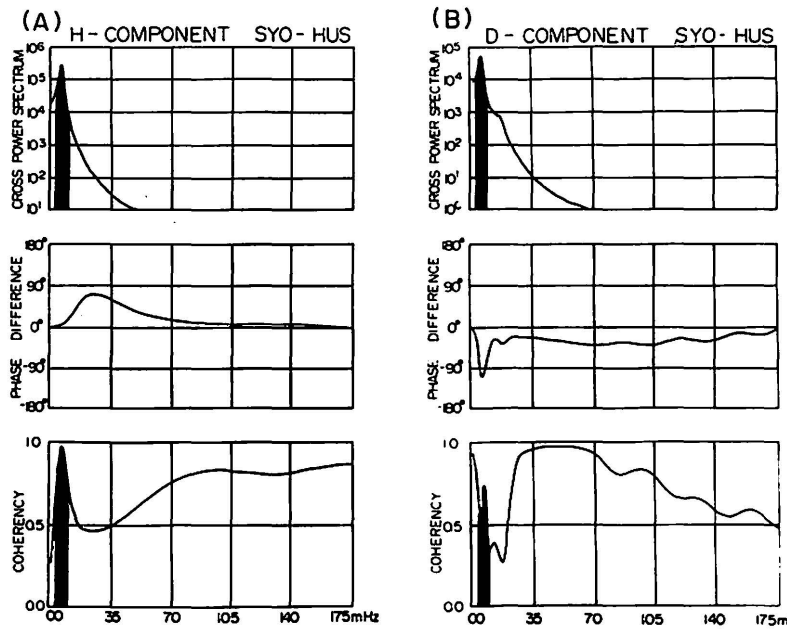

Fig. 3 : Results on conjugate relationships of the Pi 2 event given in Fig. 2 They are cross-power spectrum (upper), phase difference (middle) and coherency (bottom).

$-122°$ for the D-component indicating an anti-phase oscillation at the conjugate pair. Those relationships are further studied statistically using 74 Pi 2 events.

The wave-phase difference of Pi 2 between the conjugate-pair stations, Syowa Station and Husaffel, are summarized in Fig. 4 for the H-component (upper) and for the D-component (bottom). As shown in the figure, the phase-difference of the H-component shows a dominant peak around 0° indicating an in-phase oscillations at the conjugate-pair, while for the D-component the difference ranges around 180° indicating an anti-phase oscillations. The distribution in the D-component was largely scattered comparing with that in the H-component because of less wave amplitude of the D-component as shown in Fig. 2.

The tendecy of less wave amplitude of Pi 2 in the D-component is confirmed statistically as summarized in Fig. 5. In the figure, a ratio of the Pi 2 power intensity in the H-component to that in the D-component is summarized for the data Syowa Station, Mizuho Station and Husaffel. The abcissa in the figure is presented by the common logarithmic method. As shown in the figure, most of Pi 2 events in the auroral region show more dominantly oscillations in the H-component than that in the D-component.

Fig. 6 shows the results for the calculation of the coherency function for both the H-and D-component between Syowa Station and Husaffel. As shown in the figure, nearly 80% of the Pi 2 events have the coherency value higher than 0.70 in the

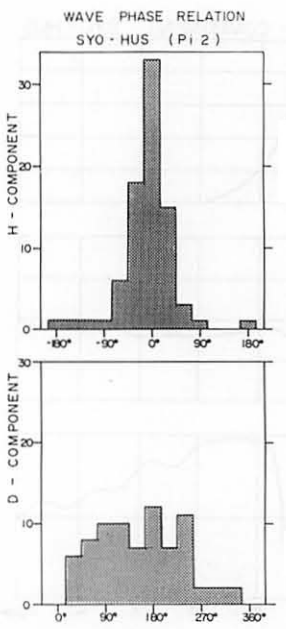

Fig. 4 : Phase differences of Pi 2 at a pair of the conjugate stations, Syowa Station and Husaffel. The north-south (H) component shows an in-phase relationship, while the east-west (D) component shows an anti-phase one.

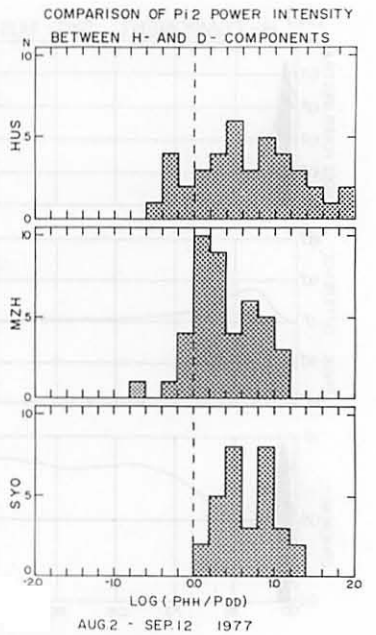

Fig. 5 : Comparisons of the Pi 2 auto-power intensities between the north-south (H) and the east-west (D) components. A ratio of the H-to D-components is represented by means of a common logarithmic function whose posititve value indicates that the amplitude of Pi 2 is larger in the H-component than in the D-components.

H-component ; the value higher thab 0.7 can be understood to indicate a very good conjugate relationship between the two stations. On the other hand, only 35% of the Pi 2 events have the coherency value than 0.70 in the D-component. Those observational results provide very important knowledge that clues for solving of the propagation and generation mechanisms of Pi 2.

The ellipticity of the Pi 2 polarization in the perpendicular plane to the ambient magnetic field direction was summarized in Fig. 7 as a function of occurrence magnetic local time (MLT) for the data at Husaffel and Syowa Station. The ellipticity with a positive value represents a left-handed polarization in the northen hemisphere, wheras a right-handed polarization in the southern hemisphere. The ellipticity that with a value of 0.0 represents a linear polarization. As shown in Fig. 7, most of the Pi 2 events indicate a smaller ellipticity value than 0.5 showing an occurrence peak around 0.0 , indicating that most of the Pi 2 events observed in the auroral region show the linear polarization. The deviation of ellipticity from 0.0

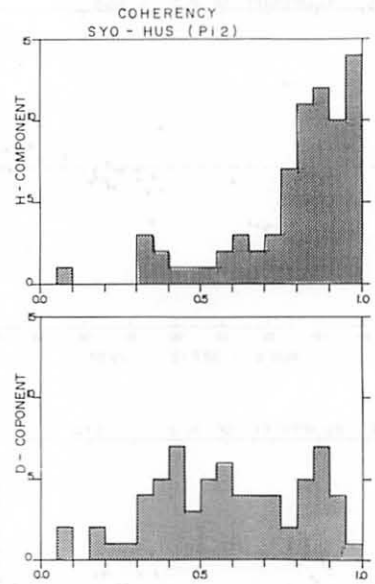

Fig. 6 : Coherencies of Pi 2 at the conjugate-pair stations. For the north-south component (H), nearly 80 % of the Pi 2 events show the value coherency higher than 0.7.

value is opposite between the two stations. That evidence indicates that the rotational sense of the wave polarization in the plane perpendicular to the ambient magnetic field direction is consistent with each other when we consider the propagating Pi 2 pulsation along a magnetic field line anchored at the conjugate-pair stations.

4. Discussion

In earlier papers (Kuwashima, 1975, 1978 ; Kuwashima and Saito, 1981), we have suggested that the main cause of Pi 2 is the MHD standing oscillations of the field lines anchored at the northen and southern auroral ovals based on the results of spectral and polarization characteristics. If Pi 2 is caused due to the MHD standing oscillation of the field lines, the wave-phase relationship at the conjugate pair must obey rules derived from an idealized elastic string model such as the results by Sugiura and Wilson (1964). In order to examine the MHD model, conjugate relationships of Pi 2 in the auroral region have been studied in the present paper based on the semi-statistical basis.

The idealized elastic string model by Sugiura and Wilson (1964) could be adopted to the realistic magnetosphere model in order to examine the observational results presented in Figs. 4-7. Fig. 8 shows calculated results for the distribution of the perturbed magnetic field (b) along the magnetic field line in the dipole coordinate

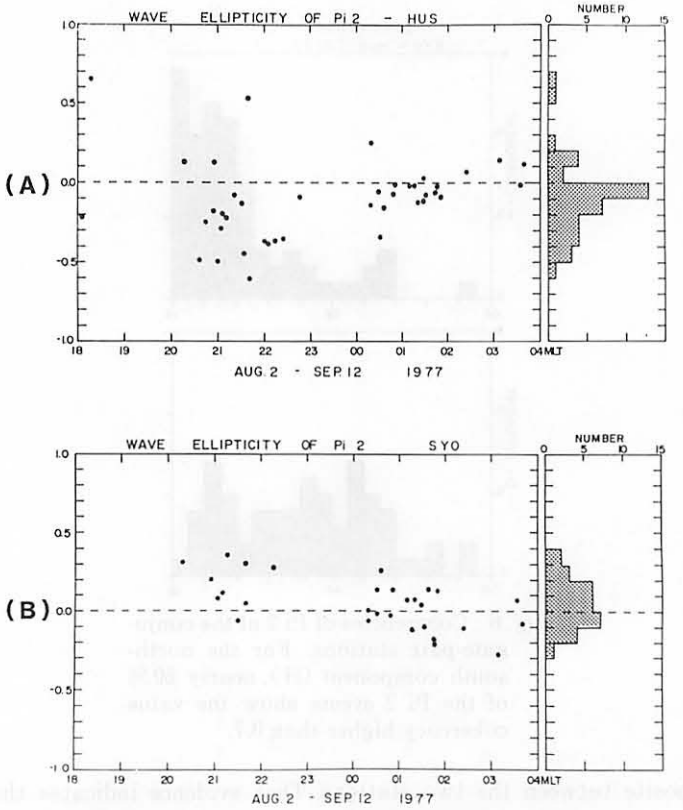

Fig. 7 : Ellipticities of the wave polarization of Pi 2 plotted as a function of occurrence magnetic local time (MLT), at Husaffel (A) and Syowa Station (B).

(Kuwashima, 1984). In the figure, μ, ν and ϕ show directions along the ambient magnetic field, perpendicular to the ambient magnetic field (positive anti-earthward) and azimuthal (positive eastward), respectively. On the earth's surface, ν and ϕ correspond to the H- and D-components. According to the calculation by Kuwashima (1984), the perturbed magnetic field (Pi 2 wave amplitude) becomes the largest at the ionosphere, while it becomes zero at the geomagnetic-equatorial crossing point of the field line in the case of the odd-mode MHD standing oscillation. The phase relationships at the conjugate-pair stations are also shown in Fig. 8. In the case of the fundamental-mode (odd-mode), $b\phi$ at the end of the field lines is anti-phase with $b\phi$ at the other end of the field lines. Similarly, $b\nu$ is also anti-phase at the conjugate point of the field line. Those results indicate that the D-component shows the anti-phase relationship at the conjugate pair, because $b\phi$ corresponds to the D-component at the auroral ovals. On the other hand, $b\nu$ corresponds to $+$H component in the northern hemisphere, while corresponds to $-$H component in the southern hemisphere. Therefoer, the H-component shows an in-phase relationship at the conjugate pair for the case of the fundamental mode of

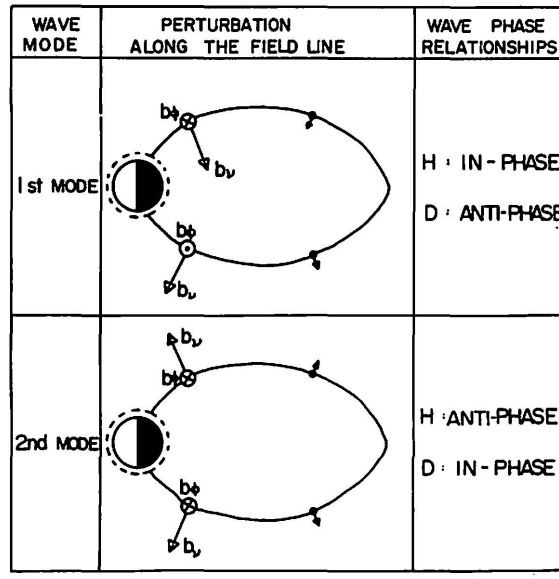

Fig. 8 : Calculated conjugate relationships for the fundamental and the second modes of the hydromagnetic standing oscillation.

the MHD standing oscillation.

For the second mode (even mode) oscillation, both $b\phi$ and $b\nu$ are in an in-phase relationship at the conjugate pair. The results indicate that the H- and D-component are anti-phase and in-phase relationships at the conjugate pair, respectively.

The observational results shown in Fig. 4 indicates that Pi 2 is due to the odd-mode MHD standing oscillalion of the field lines anchored at the northern and southern auroral ovals. As shown in Fig. 5, the wave amplitude of Pi 2 is much larger in the H-component comparing with that in the D-component. Considering the 90° rotation of th major axis of the wave polarization through the ionosphere (Nishida, 1964 ; Tamao, 1964 ; Hughes ana Southwood, 1976), the Pi 2 oscillation is expected to be more dominant in the D-component in the magnetosphere. The dominant oscillation of the D (azimuthal) component corresponds to the shear Alfv'en wave (MHD torsional oscillation). The observational results shown in Figs. 6 and 7 strongly support that Pi 2 is caused by the MHD torsional oscillation of the field lines.

5. Conclusion

Conjugate relationships of Pi 2 have been studied using the data at Syowa Station in Antarctica and Husaffel in Iceland, which are the best conjugate-pair among many stations in the auroral regions.

(1). The Pi 2 waves are observed simultaneously at the conjugate-pair with a high coherency.

(2). The phase relationship of the Pi 2 waves at the conjugate-pair is in-phase in the north-south component, while is anti-phase in the eastwest component, respectively.

(3). The Pi 2 oscillation in the auroral region is much more dominant in the north-south component than in the east-west component suggesting a dominant oscillation in the azimuthal component in the magnetosphere

These observational results strongly support that Pi 2 is due to the hydromagnetic torsional standing oscillation of the field lines anchored at the auroral ovals in association with the substorm expansion.

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極光帯におけるPi 2 型磁気脈動の共役性

桑 島 正 幸

概　　要

極光帯においての良い共役点である，南極昭和基地とアイスランドのレイキャビック周辺での資料を使って，Pi 2 型磁気脈動の共役性についての研究を行った．

その結果，Pi 2 型磁気脈動は共役点において同時に高いコヒーレンシーをもって観測され，波動の位相関係については，南北成分で同位相，東西成分で逆位相であることが明らかになった．これは，Pi 2 型磁気脈動が，基本モードの磁気流体振動によって生じていることを示唆している．