WAVE CHARACTERISTICS OF MAGNETIC Pi2 PULSATIONS IN THE AURORAL REGION: CONJUGATE RELATIONSHIPS

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Abstract: Conjugate relationships of Pi2 are studied by using data at Syowa Station in Antarctica and Reykjavik (Husafell) in Iceland. The results indicate an odd-mode hydromagnetic standing oscillation as a main cause of Pi2. The generation mechanism of Pi2 is examined theoretically on the basis of the observational results.

1. Introduction

Pi2 is observed almost simultaneously with an onset of substorm expansion over a wide latitudinal range from the auroral region through low latitudes. Many researchers suggested that Pi2 is one of the important manifestations of magnetospheric substorm (AKASOFU, 1968; SAITO, 1969; SAITO *et al.*, 1976; OLSON and ROSTOKER, 1975; PYTTE *et al.*, 1976). It is important to clarify the wave characteristics of Pi2 in a study of the magnetospheric physics. However, most of Pi2 wave characteristics have remained unclear. This is due primarily to the lack of concurrent observations of Pi2 at a wide latitudinal range from high to low latitudes along the same geomagnetic meridian, and to the difficulty in the analysis of Pi pulsations observed during a substorm expansion at high latitudes.

Several models have been proposed for the generation of Pi2. SAITO (1969) proposed the torsional oscillation model which suggests that the main component of Pi2 wave is caused by the odd-mode torsional eigen oscillation of the field lines anchored on the auroral oval. The torsional oscillation model has been supported by SAITO and SAKURAI (1970), RASPOPOV *et al.* (1972) and SAITO *et al.* (1976). On the other hand, FUKUNISHI and HIRASAWA (1970) emphasized that the Pi2 oscillations observed at low latitudes are fairly sinusoidal, while those in the auroral region are irregular. Then they suggested together with SUTCLIFFE (1975) that Pi2, especially at low latitudes, is caused by a transient surface wave on the plasmapause excited by high-latitude irregular disturbances associated with substorm. In addition to the hydromagnetic oscillations of field lines, the fluctuations of magnetospheric and ionospheric current systems might have an effect on the generation of Pi2 pulsations as suggested by OLSON and ROSTOKER (1977) and WILHELM *et al.*

(1977). In order to clarify those contradictions and to construct a systematic Pi2 model, a concurrent observation should be carried out continuously at ground-based stations situated along on the same geomagnetic meridian.

In the previous paper (KUWASHIMA, 1978), spectral and polarization characteristics of Pi2 are studied by using ULF data obtained at Syowa chain stations, namely, Mawson ($L=$ 8.9), Mizuho Station ($L=7.5$), Syowa Station ($L=6.1$), Sanae ($L=4.0$) and Hermanus ($L=1.8$). In the study, the close relationship of the Pi2 period to the auroral breakup position was clarified. Namely, the Pi2 period increases with increase of the geomagnetic latitude where the associated auroral breakup started. Theoretical examination showed that the observed Pi2 period can be interpreted by the fundamental mode of the hydromagnetic torsional oscillations of the field lines localized on the northern and the southern auroral ovals. The polarization behaviors of Pi2 near the auroral electrojet also support the hydromagnetic resonance oscillation of the field line as a cause of Pi2.

It is also necessary to study the Pi2 behavior at conjugate-pair stations in order to clarify the wave characteristics of Pi2 in detail. The conjugate relationships of Pi2 have been studied in detail on the basis of data obtained around the plasmapause (FUKUNISHI, 1975; STUART, 1978). However, the study of Pi2 conjugate relationships in the auroral region is not sufficient because of the lack of good conjugate-pair stations in that region. SAKURAI (1970) has first studied the conjugate relationships of Pi2 in the auroral region on the basis of data at College and Macquarie Island. According to his result, the odd-mode standing oscillation of field lines is suggested as a cause of Pi2. Among many stations in the auroral region, Syowa Station in Antarctica and Reykjavik in Iceland are the best conjugate-pair. In the present paper, the conjugate relationships of Pi2 is studied in detail on the basis of data obtained at the two stations.

In Section 2, data sources and data analyzing method are described. Conjugate relationships are studied by the cross-correlation method and by the cross-spectral method in Sections 3 and 4, respectively. In Section 5, the observational results are theoretically examined. Pi2 generation mechanism is discussed in Section 6.

2. Data Sources and Data Analysis

During the period from August 29 to September 29, 1973 a concurrent ULF observation was carried out at Syowa Station and Mizuho Station in Antarctica by means of induction magnetometer and flux-gate magnetometer by the 14th wintering party of the Japanese Antarctic Research Expedition. In cooperation with that, the ULF observation was also continued at Reykjavik in Iceland by the LaCour type magnetometer. Syowa Station and Reykjavik are the best conjugate-pair stations among many stations in the polar region.

During the period from July 29 to September 18, 1977, observation of ULF by induction magnetometer was carried out at Syowa and Mizuho Stations in Antarctica and at Husafell in Iceland by the 18th wintering party of the Japanese Antarctic Research Expedition and by the National Institute of Polar Research, respectively. Husafell is located nearer to the conjugate point of Syowa Station than Reykjavik. The locations of these stations are shown in Table 1. The magnetic local time (MLT) of these stations is almost equal to universal time (UT).

Rapid-run magnetograms by the flux-gate and LaCour type magnetometers

Table 1. Locations of stations used in the present study.

Station	Geographic		Geomagnetic	
	Latitude	Longitude	Latitude	Longitude
Reykjavik	64.1°N	21.8°W	70.1°	71.4°
Husafell	64.7°N	20.9°W	70.2°	74.2°
Syowa Station	69.0°S	39.6°E	−70.0°	79.4°
Mizuho Station	70.7°S	44.3°E	−72.3°	80.6°

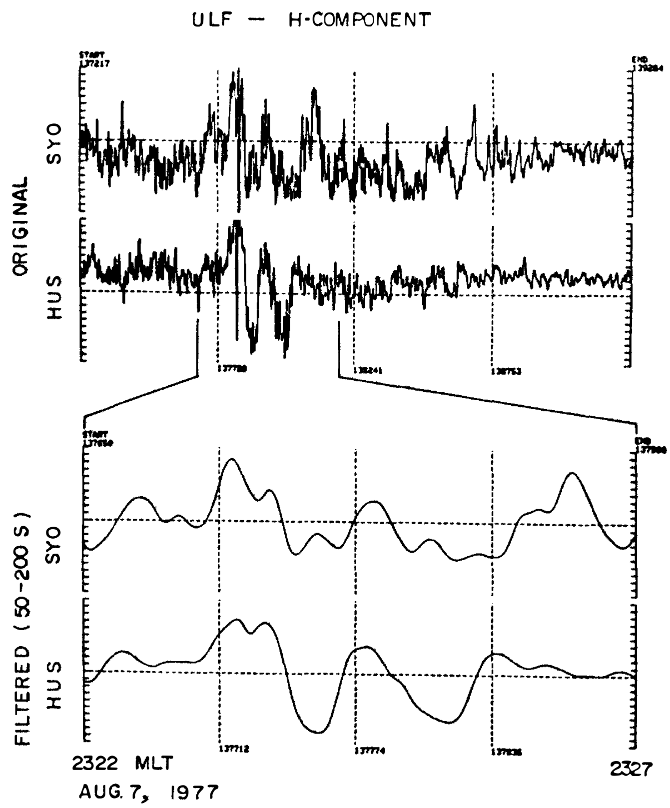

Fig. 1. An example of band-pass filtered Pi wave train using the Chebyshev filter with a bandwidth of 50–200 s.

were converted to digital data in a card format with a sampling interval of 6.0 s using a curve tracer. The ULF data obtained by the induction magnetometers were recorded on magnetic tapes by an analogue data recorder. The tapes in an analogue format were converted to a digital format with a sampling interval of 0.6 s using a minicomputer and its accessories.

The high-latitude Pi has an apparently irregular waveform, which could be due to an effect of random fluctuations of ionospheric current caused by violent precipitation of auroral particles. A numerical band-pass filter techniques is used to conquer this difficulty. The used filters are both nonrecursive (Gaussian-type) and recursive filters (Butter-worth and Chebyshev types). An example of band-pass filtered wave trains is illustrated in Fig. 1. In the figure, the Pi burst components were removed by the band-pass filter with ratios of -3 db at 20 s and 200 s, and with ratios of -20 db at 10 s and 500 s, respectively.

Using the band-pass filtered wave train, conjugate relationships of Pi2 are studied by means of the cross-correlation method and the cross-spectral method. The former examined the wave-phase relation at the conjugate-pair using cross-correlation functions, while the latter examined wave-phase relation, coherency and wave ellipticity of polarization using cross-spectra, respectively.

3. Conjugate Relationship of Pi2 by the Cross-Correlation Method

Wave-phase differences of Pi2 are studied by comparing rapid-run magnetograms obtained at the conjugate stations, Syowa Station and Reykjavik, during the period from August 29 to September 29, 1973. A typical example of simultaneous occurrence of Pi2 waves at the conjugate stations, Syowa Station and Reykjavik, is shown in Fig. 2. The wave trains in the figure have been high-pass filtered with ratios of -3 db at 5 mHz (200 s) and -10 db at 2 mHz (500 s) to remove the background substorm component. The Pi2 event started at about 0017 UT, which is almost coincident with the start of a sharp negative change of the H-component magnetic field which was simultaneously registered at the conjugate stations. According to the change of the Z-component magnetic field, the associated auroral breakup is considered to have occurred on a poleward side of both the stations. As is shown in Fig. 2, the Pi2 waves oscillate with very similar waveforms at the conjugate-pair. However, the phase relation shows a drastic difference between the two. The H-component shows an in-phase oscillation, whereas the D-component shows an out-of-phase one. These relations will be examined more clearly by using the cross-correlation method. For the H-component the cross-correlations function shows a positive correlation with a maximum value of 0.43, whereas for the D-component it shows a negative correlation with a minimum value of -0.65.

Using the cross-correlation functions, the wave-phase difference between the conjugate-pair is calculated for 10 Pi2 events, which were observed simultaneously

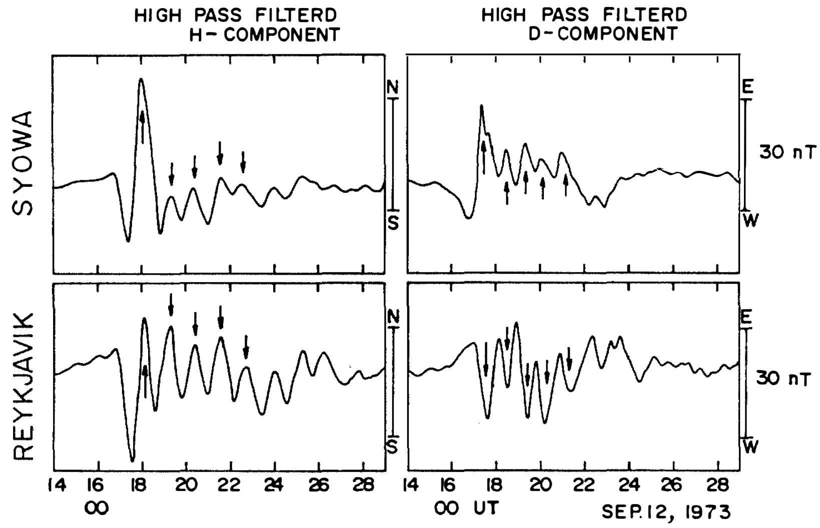

Fig. 2. An example of simultaneous appearance of Pi2 at the conjugate-pair in the auroral region. The H-component shows an in-phase relation, whereas the D-component shows an out-of-phase one.

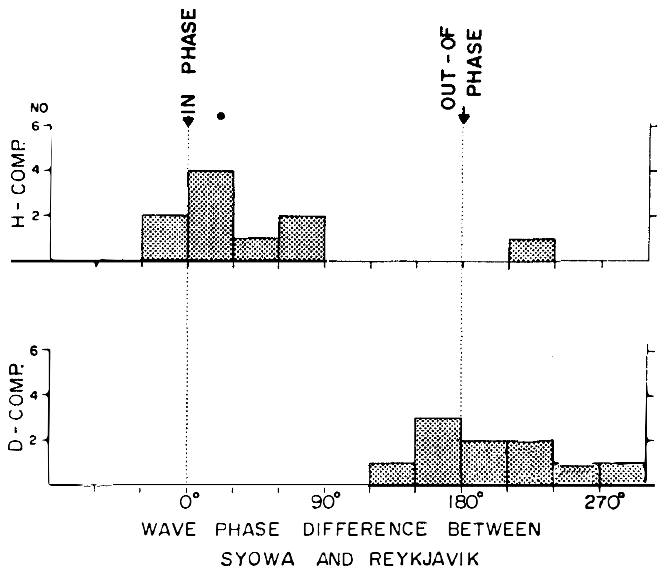

Fig. 3. Wave-phase relations of Pi2 at the conjugate-pair by the cross-correlation method. In the H-component the phase differences range around 0° showing in-phase relations, whereas in the D-component they range around 180° showing out-of-phase ones.

with similar waveforms at the two stations. The filtered wave train at Syowa Station is used as a reference wave. The results are summarized in Fig. 3. For the H-component most of the Pi2 waves range from $-30°$ to $+90°$ with a mean value of $+25°$, whereas for the D-component they range from $+120°$ to $300°$ with a mean value of $+201°$. These results suggest that the H-component oscillates in-phase, whereas the D-component oscillates out-of-phase at the conjugate-pair in the auroral region.

The above-mentioned conjugate relationships are further examined in the next section.

4. Conjugate Relationships of Pi2 by the Cross-Spectral Method

Conjugate relationships of Pi2 are studied by using the induction magnetometer data obtained at the conjugate stations, Syowa, Mizuho Stations and Husafell, during the period from July 29 to September 18, 1977. Seventy-four Pi2 events were registered during the period. An example of simultaneous Pi2 occurrence at those stations is shown in Fig. 4. The wave trains in the figure have been band-pass filtered with a band-width from 40 to 200 s. In Fig. 4, the H-component shows conspicuous in-phase

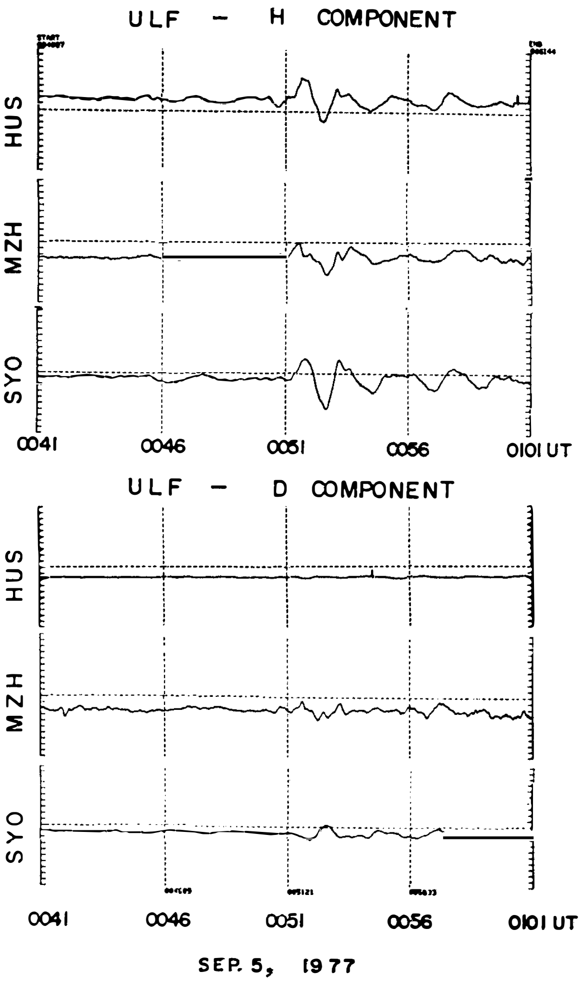

Fig. 4. Simultaneous appearance of Pi2 at the conjugate stations, Syowa and Mizuho Stations in Antarctica and Husafell in Iceland.

oscillations at the conjugate stations. On the other hand, wave amplitudes in the D-component are less than those in the H-component, and the wave-phase relation for the D-component is not clear. The cross-spectral method is used for the detailed study of Pi2 conjugate relationship. The cross-spectra are computed by the Auto-Regressive method or the FFT method. The calculated spectral elements are 1) power spectra of the H- and D-components at the three stations, 2) phase differences of the H- and D-components between Syowa Station and Husafell, and 3) ellipticities in the H-D plane at the three stations.

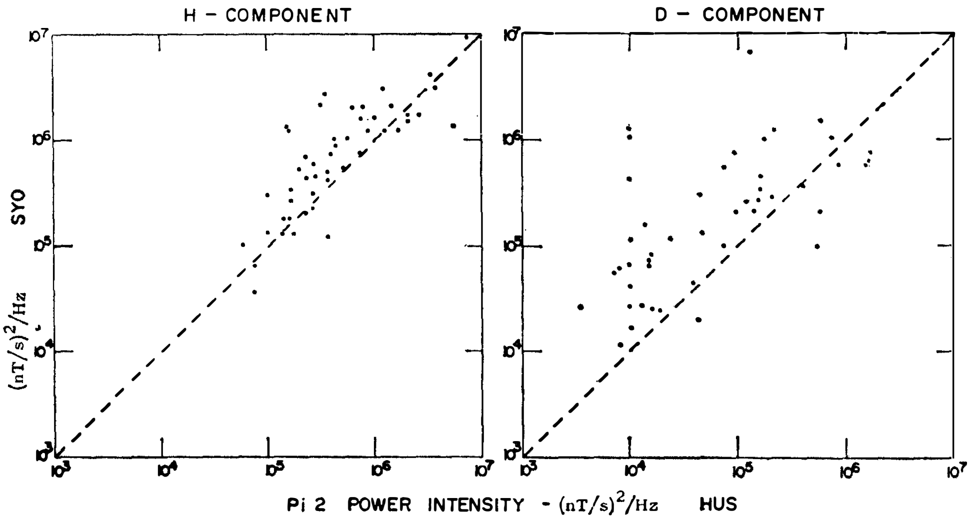

Fig. 5. Comparison of Pi2 power intensity at the conjugate-pair, Syowa Station and Husafell.

Plotted in Fig. 5 are comparisons of Pi2 power intensities between Syowa Station and Husafell for the H- and D-components. For the H-component, the wave amplitude at Syowa Station is nearly equal to that at Husafell. For the D-component, on the other hand, the Pi2 power intensities are largely scattered around the equal amplitude line. In Fig. 5, it seems that the Pi2 wave amplitudes are larger in the H-component than in the D-component at both the stations. This tendency is more clear in Fig. 6.

Histograms in Fig. 6 are comparisons of Pi2 power intensities between the H- and D-components at the three stations. The Pi2 power ratios are presented by means of common logarithms. A positive value means a larger H-component oscillation compared with that of the D-component. As seen in the figure, most of Pi2 events in the auroral region show dominant wave oscillations in the H-component.

Fig. 7 shows statistical results of the Pi2 wave-phase relation between Syowa Station and Husafell for both the components. Generally speaking, the results in the figure are consistent with those in the preceding section (Fig. 3). The H-component shows a dominant peak around 0° indicating in-phase oscillations at the

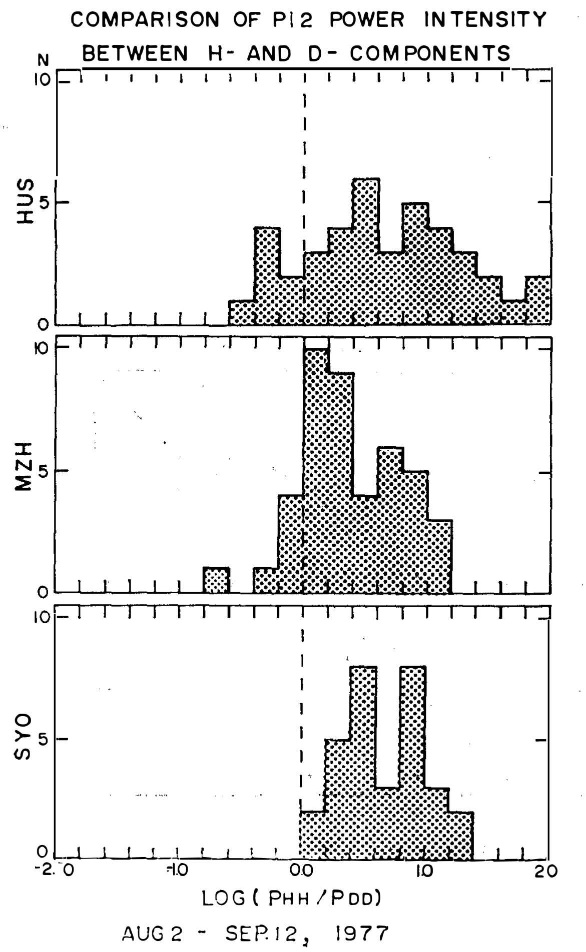

Fig. 6. Comparison of Pi2 power intensity between the H- and the D-components at Husafell (upper), Mizuho Station (middle) and Syowa Station (bottom).

conjugate-pair, whereas the *D*-component is distributed around 180° indicating out-of-phase oscillations. The large scattering of the *D*-component seems to be closely related to the small wave amplitude in that component.

Coherencies of Pi2 between Syowa Station and Husafell are summarized in Fig. 8 for both the components. The coherency is defined as

$$\gamma^2 = \frac{(P_{hs})^2}{P_{ss} \cdot P_{hh}}$$

where P_{ss} and P_{hh} are auto-power spectra at Syowa Station and Husafell, and P_{hs} is cross-power spectrum between the two stations. In the figure, the *H*-component shows higher coherency than the *D*-component. In the *H*-component nearly 80% of Pi2 events show the coherency higher than 0.70, whereas in the *D*-component the events which show the higher coherency than 0.70 are only about 35%. The results of Figs. 6–8 show that Pi2 oscillations are dominant in the *H*-component in the auroral region.

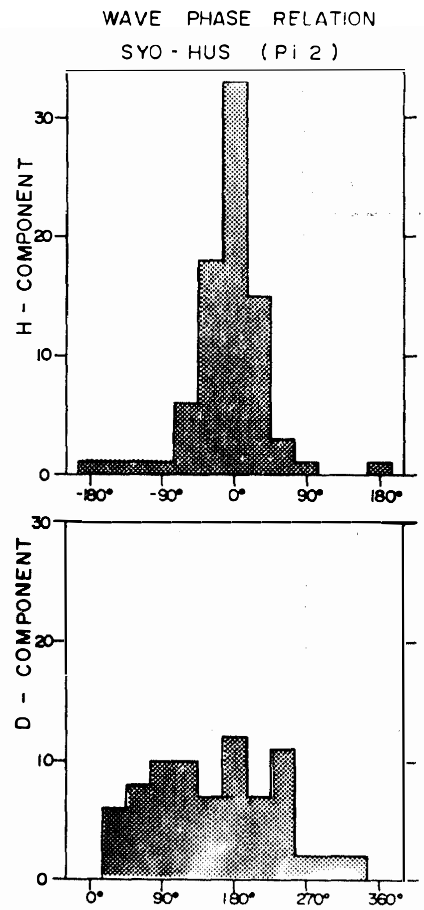

Fig. 7. Wave-phase relations of Pi2 at the conjugate-pair by the cross-spectral method. The H-component shows a dominant peak around 0° showing in-phase relations. The D-component shows a broad maximum around 180° showing out-of-phase relations.

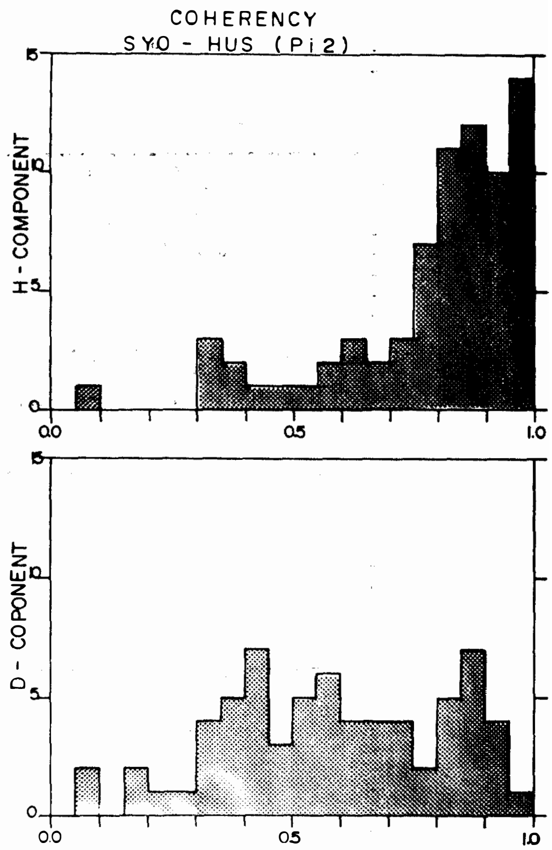

Fig. 8. Coherencies of Pi2 at the conjugate-pair. In the H-component nearly 80% of the Pi2 events show the higher coherency than 0.70, while in the D-component the events which show the higher coherency than 0.70 are only ~35%.

In Figs. 9a, 9b and 9c, ellipticities in the *H-D* plane are plotted as a function of MLT for the three stations. The *H-D* plane wave ellipticity ϵ is defined as

$$\epsilon = \tan \alpha$$

where

$$\sin 2\alpha = \frac{2\mathrm{Im}(P_{\mathrm{DH}})}{P_{\mathrm{HH}} + P_{\mathrm{DD}}}$$

where P_{HH} and P_{DD} are auto-power spectra, and P_{DH} is cross-power spectrum.

(a)

(b)

(c)

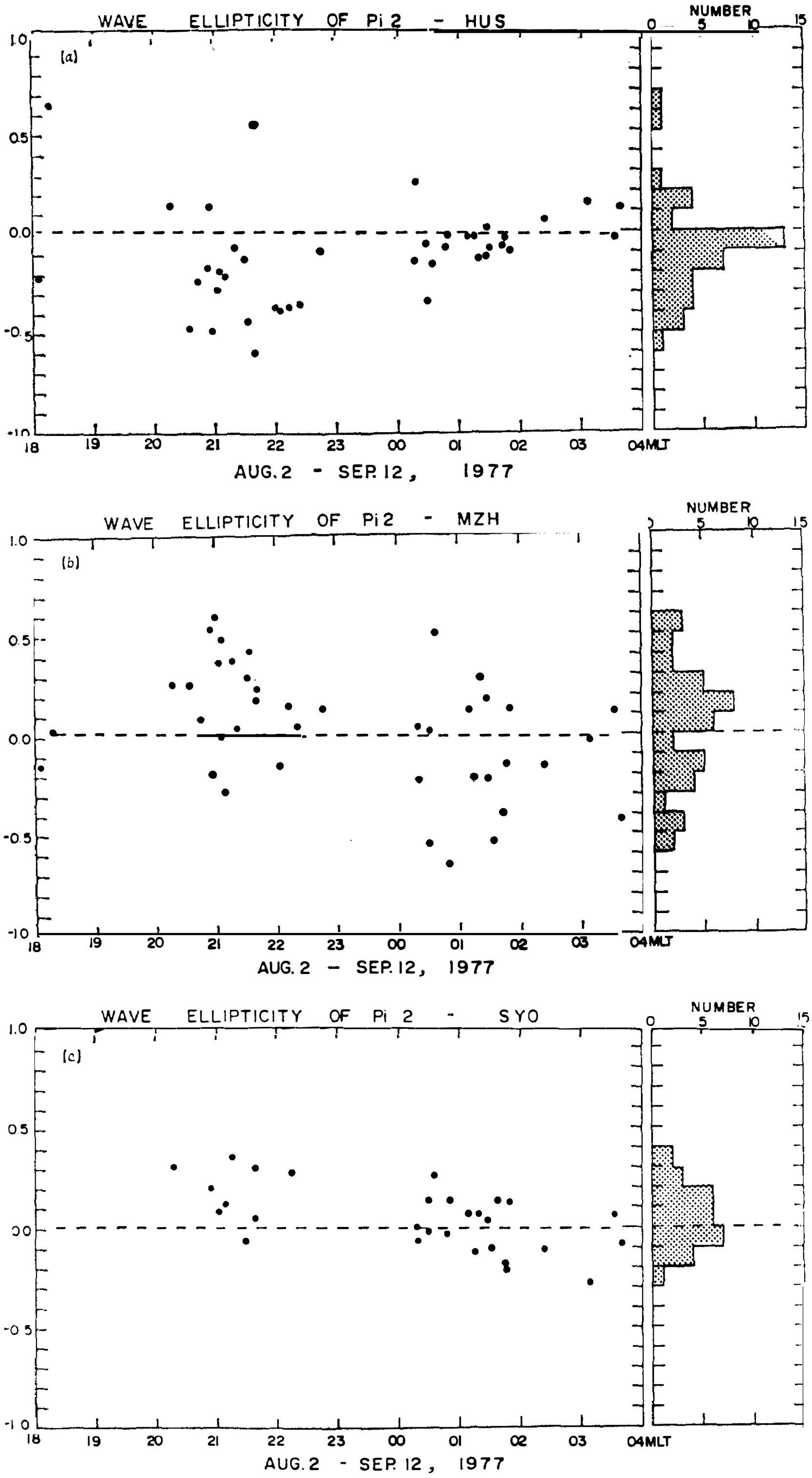

Fig. 9. Wave ellipticities of Pi2 polarization are plotted as a function of magnetic local time for the events obtained at Husafell (a), Mizuho Station (b) and Syowa Station (c).

Positive ϵ represents left-hand polarization in the northern hemisphere and right-hand polarization in the southern hemisphere. $\epsilon = \pm 1.0$ represents circular polarization and $\epsilon = 0.0$ represents linear polarization. In Figs. 9a–9c most of Pi2 events have the smaller wave ellipticities than 0.5 showing an occurrence maximum around 0.0. This result indicates that a linear polarization is dominant in the Pi2 events observed in the auroral region. The figures also show that the sense of polarization along the magnetic field line is equivalent at the conjugate-pair.

5. Theoretical Examinations of the Observational Results

The observational results in the preceding sections are summarized as follows.

(1) The Pi2 wave is observed simultaneously at the conjugate-pair in the auroral region with similar waveforms to each other.

(2) The Pi2 wave shows in-phase oscillations in the H-component and out-of-phase oscillations in the D-component.

(3) The H-component oscillations show a remarkable high coherency at the conjugate-pair compared with the D-component.

(4) The wave amplitude in the H-component is larger than that in the D-component for most of Pi2 events in the auroral region.

(5) Most of Pi2 events show the smaller wave ellipticity than 0.5 suggesting nearly linear polarization.

(6) The rotational sense of polarization in the perpendicular plane to the magnetic field line is equivalent to the Pi2 waves observed at the conjugate-pair.

The wave-phase relations of Pi2 will be interpreted by an idealized elastic string model by SUGIURA and WILSON (1964) as shown in Fig. 10. According to their model, the H-component shows an in-phase relation, whereas the D-component shows an out-of-phase one at a conjugate pair for an odd-mode standing oscillation. The present result (2) indicates that the Pi2 waves observed in the auroral region are due to the odd-mode hydromagnetic standing oscillation of localized field lines. The odd mode concerned is likely to be the fundamental mode, since the observed Pi2 period is very close to the fundamental period of the torsional oscillation of the field lines anchored on the auroral oval (KUWASHIMA, 1978; KUWASHIMA and SAITO, 1981). As regards the ellipticity of Pi2 observed at the conjugate stations, it will be reasonably interpreted with the following theoretical considerations.

As is well known, the two MHD wave modes exist in a low-β plasma (β is defined as the ratio of the plasma particle pressure to the magnetic field pressure). They are the shear Alfvén (anisotropic: $1-K_{\parallel}{}^2V_A{}^2/\omega^2=0$) waves and the fast magnetosonic (isotropic: $1-K^2V_A{}^2/\omega^2=0$), waves, respectively (K is the wave number, V_A is the Alfvén velocity and ω is the wave frequency). In an uncoupled case with an axially symmetry condition, the shear Alfvén wave corresponds to the torsional oscillation. In the magnetosphere, these two modes must be coupled. By

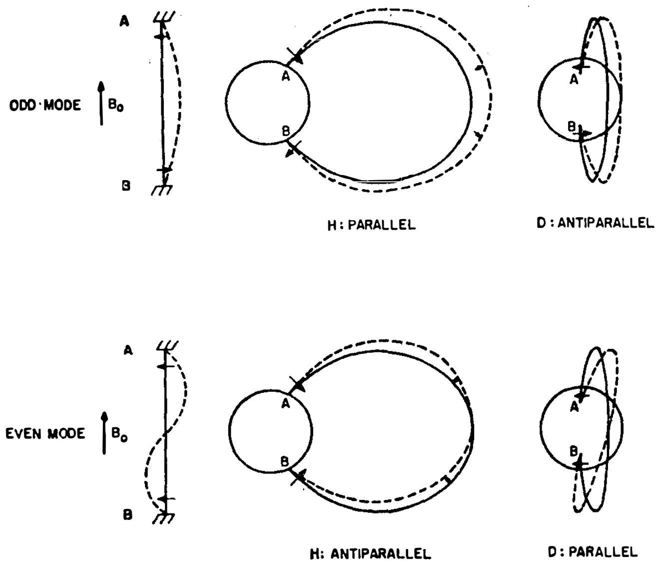

Fig. 10. Symmetry relations at conjugate points of the standing oscillation of the field line (after SUGIURA and WILSON, 1964).

linearizing the standard set of MHD equations, the coupled wave equation can be represented as follows (HASEGAWA and CHEN, 1974; SOUTHWOOD, 1974).

$$\rho\ddot{\boldsymbol{\xi}} = -\nabla\left(\boldsymbol{P}+\frac{\boldsymbol{b}\cdot\boldsymbol{B}}{\mu_0}\right)+\frac{1}{\mu_0}(\boldsymbol{b}\cdot\nabla)\boldsymbol{B}+(\boldsymbol{B}\cdot\nabla)\boldsymbol{b} \tag{1}$$

where $\boldsymbol{\xi}$ is the fluid displacement vector, $(\boldsymbol{P}+\boldsymbol{b}\cdot\boldsymbol{B}/\mu_0)$ is the total perturbed pressure, while $\boldsymbol{b}$ and $\boldsymbol{B}$ are the perturbed and the unperturbed magnetic fields. The perturbed magnetic field, $\boldsymbol{b}$, is in the following relation,

$$\boldsymbol{b} = -\boldsymbol{B}(\nabla\cdot\boldsymbol{\xi})+(\boldsymbol{B}\cdot\nabla)\boldsymbol{\xi}-(\boldsymbol{\xi}\cdot\nabla)\boldsymbol{B}. \tag{2}$$

For simplification, consider a one-dimensional layer model with straight magnetic field $\boldsymbol{B}=B\cdot\boldsymbol{z}$ and the plasma parameters (ρ, P and $\boldsymbol{B}$) vary only in the y direction. In the case of a relatively localized field line resonance in the east-weat direction ($K_\perp \gg K_\parallel$), eq. (1) becomes as follows,

$$\frac{d^2\xi y}{dy^2}+\frac{d\ln\varepsilon}{dy}\frac{d\xi y}{dy}-K_\perp{}^2\xi y=0 \tag{3}$$

where $\varepsilon\ (y)=\omega^2\mu_0\rho(y)-K_\parallel{}^2B(y)$. Away from the resonant field line $\varepsilon\neq 0$, eq. (3) becomes $\nabla^2\ \xi y=0$, which is the wave equation for the isotropic (fast magnetosonic) mode. Around the resonant field line where $\varepsilon\rightarrow 0$, the second term dominates over the third term causing a strong coupling between the fast magnetosonic mode and

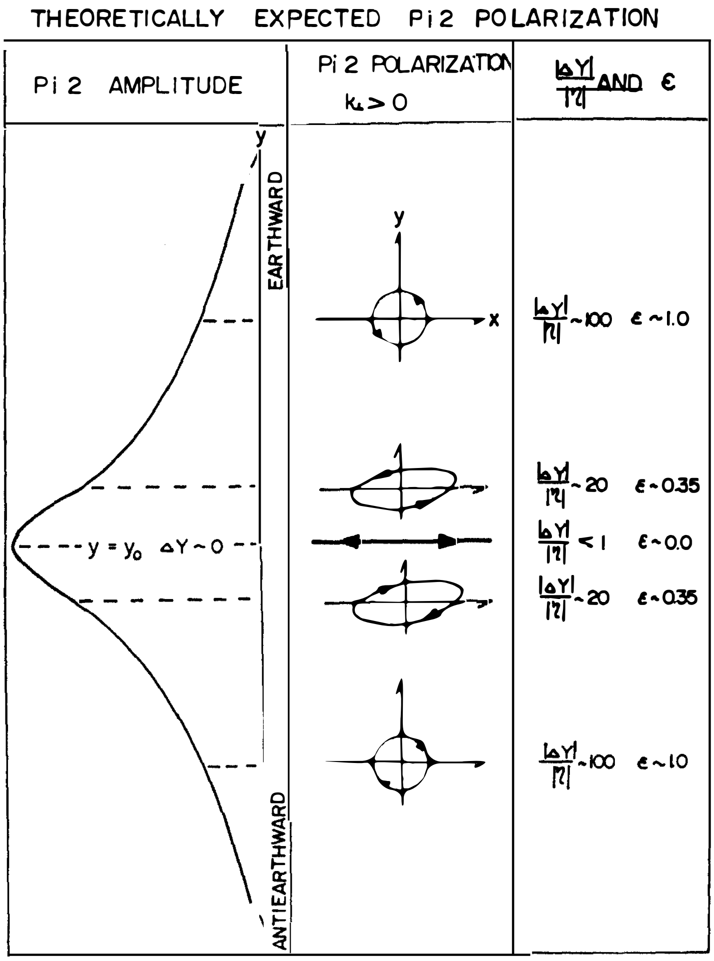

Fig. 11. Schematic profile of the theoretically expected wave polarization around the Pi2 resonant region.

the resonant shear Alfvén mode. At the resonant field line where $\varepsilon = 0$, the decoupled shear Alfvén wave with $\omega^2 = K_{\parallel}{}^2 V_A{}^2$ would be expected.

The above-mentioned relations are shown quantitatively in Fig. 11. In the figure, expected wave polarizations are illustrated for each region. The wave ellipticity (ε) and the orientation angle (θ) of the major polarization ellipse are calculated by the following relation (CHEN and HASEGAWA, 1974),

$$\tan 2\theta = \frac{2g}{1-(g^2+h^2)} \tag{4}$$

$$\begin{aligned} &= (D/E)^{1/2} \quad \text{for the case of} \quad D<E \\ &= (E/D)^{1/2} \quad \text{for the case of} \quad D>E \end{aligned} \tag{5}$$

where $D=(\sin\theta-g\cdot\cos\theta)^2+h^2\cos^2\theta$

$$E=(\cos\theta+g\cdot\sin\theta)^2+h^2\sin^2\theta$$

$$g=K_\perp\, y_0\left[\frac{\eta}{2}\ln(\Delta Y^2+\eta^2)+\Delta Y\tan^{-1}\frac{\eta}{\Delta Y}\right]$$

$$h=K_\perp\, y_0\left[\eta\tan^{-1}\frac{\eta}{\Delta Y}-\frac{\Delta Y}{2}\ \ln(\Delta Y^2+\eta^2)\right]$$

$$\eta=\frac{\delta}{y_0},$$

δ is the radial scale length of the resonant region and 100 km is adopted in the present calculation. In Fig. 11, a linearly polarized longitudinal oscillation is expected at the resonant field line ($y=y_0$). This longitudinal oscillation is thought to correspond to the decoupled shear Alfvén wave (torsional oscillation). Near the resonant field line, the D-component would be dominant compared with the H-component in the magnetosphere.

Before reaching the ground to be detected as magnetic pulsations, hydromagnetic waves generated in the magnetosphere have to pass through the ionosphere and the atmosphere. By the effect of the Hall current in the ionosphere, the axis of the polarization ellipse is rotated through 90° in the counterclockwise direction when viewed toward the ground in the northern hemisphere, while in the southern hemisphere it is rotated through 90° in the clockwise direction (NISHIDA, 1964; TAMAO, 1964; INOUE, 1973; HUGHES and SOUTHWOOD, 1976a, b).

Considering the 90° rotation of the polarization axis through the ionosphere, the large amplitude H-component oscillation is theoretically expected to be observed near the resonant region on the ground. This expectation is really consistent with the observational results eqs. (3)–(5). It is strongly suggested that Pi2 in the auroral is due to the hydromagnetic torsional oscillations of the field lines localized on the region auroral ovals.

6. Generation Mechanism of Pi2

From the study of spectral and polarization characteristics, it was strongly suggested that the main cause of Pi2 is the hydromagnetic torsional oscillation of the field lines anchored on the northern and the southern auroral ovals (KUWASHIMA, 1978). This model is also supported by the observational results of conjugate relationships and their theoretical examinations in the present study. The substorm expansion is generally considered to be closely associated with an occurrence of magnetic field line reconnection in the magnetotail. In a reconnection region, the magnetic field energy is transferred into the particle and wave energies through the plasma instability there. Such the energy transformation would make it possible to excite the Alfvén wave which propagates along the field from the reconnection region to the northern and the southern auroral ovals. When the Alfvén wave arrives at the polar ionosphere simultaneously with the particles, the onset of Pi2 is observed there. The Alfvén wave is then reflected and propagates to the opposite polar ionosphere along the field line that is already contracted to the dipole-like configuration. The propagation along the contracted field line makes a temporally standing oscillation whose period corresponds to the Pi2 period. Actually, the observed Pi2 period is interpreted by the fundamental mode of the hydromagnetic torsional oscillation (KUWASHIMA, 1978; KUWASHIMA and SAITO, 1981). The above-mentioned energy transformation also makes it possible to excite the fast magnetosonic wave. This wave propagates in the magnetosphere toward the earth and is transferred into a surface wave on the plasmapause, where an additional secondary Pi2 amplitude maximum is observed. The above-mentioned relations are illustrated schematically in Fig. 12.

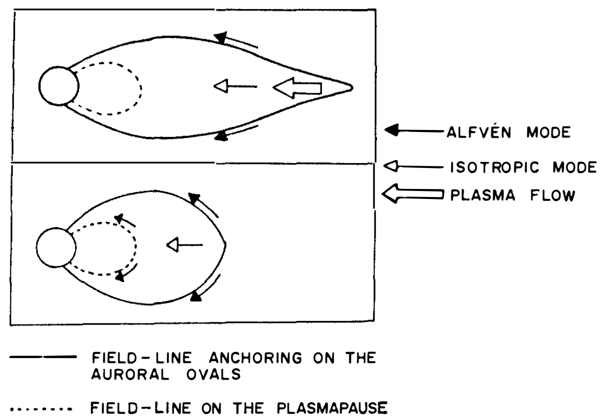

Fig. 12. A model for the Pi2 generation mechanism derived from both the observational and the theoretical results.

Possibilities of the excitation of Alfvén wave along the field line in association with the magnetospheric substorm have been theoretically examined by several research workers. NISHIDA (1979) suggested that the transient electric field generated in the nightside magnetosphere in association with the substorm expansion is a possible cause of Pi2 generation. According to his examination, the transient dusk-to-dawn electric field (AGGSON and HEPPNER, 1977) propagates along the field line to the polar ionosphere with the Alfvén speed. At the ionosphere, the incident electric field is reflected reversing the polarity and the reflected electric field propagates to the opposite polar ionosphere along the field line forming a hydromagnetic standing oscillation. Because of significant dissipation of the wave energy in the nightside ionosphere (HUGHES and SOUTHWOOD, 1976a; NEWTON *et al.*, 1978), the expected oscillation is a damping one. The expected period is equal to the bounce period of the Alfvén wave along the field line.

NISHIDA's idea is further developed by MIURA *et al.* (1979), MIURA and TAMAO, (1980). They examined the possibility of the excitation of Alfvén wave in association with the coupling between the ionosphere and the magnetosphere during the substorm expansion. They suggest that the Alfvén wave is excited when the intensity of the incident electric field to the ionosphere is more than $\sim$10 mV/m. Actually, the electric field with several tens mV/m is observed in the magnetosphere in association with the substorm expansion (AGGSON and HEPPNER, 1977).

On the other hand, MALTSEV *et al.* (1974) suggest an Alfvén impulse originated in the auroral ionosphere associated with a sudden brightening of the aurora as a possible cause of Pi2. The induced electric field will propagate along the field line with the Alfvén velocity forming a hydromagnetic standing oscillation. MALTSEV *et al.* (1974) suggest that the period is not always equal to the bounce period of the Alfvén wave between the opposite polar ionospheres along the field line, and is also dependent on the conductivity of the ionosphere. However, according to the calculation by NEWTON *et al.* (1978), the effect of ionosphere on the wave period is negligible in the Pi2 period range (10$\sim$100 s). The effect is important only for the damping of wave oscillation.

The present results for the conjugate relationships of Pi2 are consistent with those of the spectral and polarization characteristics in the previous paper (KUWASHIMA, 1978). The next research is directed to a study of Pi2 in the magnetosphere. The study is now under way.

Acknowledgments

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