

Fig. 2 : Pi 2 pulsations observed simultaneously at a pair of the conjugate stations, Syowa Station (SYO) in Antarctica and Husaffel (HUS) in Iceland. Original Pi wave trains were band-pass filtered to remove both the negative bay and Pi burst 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 are,

- (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

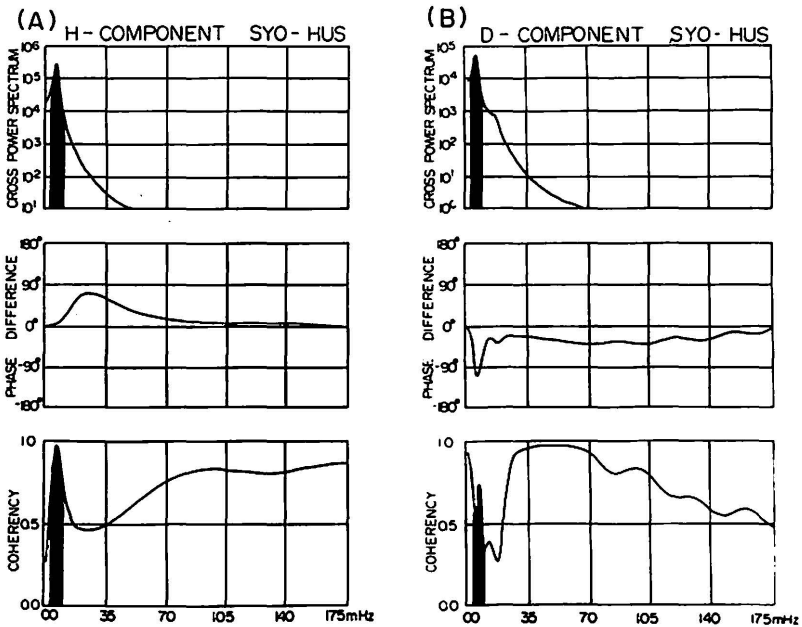


Fig. 3 : Results on conjugate relationships of the Pi 2 event given in Fig.2 They are cross-power spectrum (upper), phase difference (middle) and coherency (bottom).

-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 tendency 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 abscissa 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

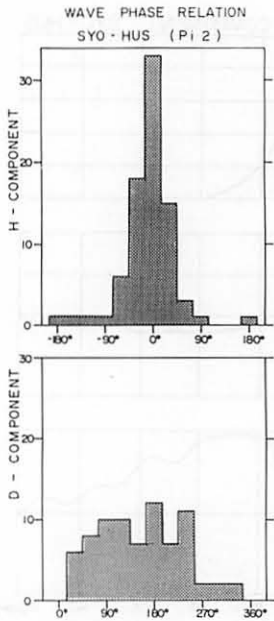


Fig. 4 : Phase differences of Pi 2 at a pair of the conjugate stations, Syowa Station and Husaffel. The north-south (H) component shows an in-phase relationship, while the east-west (D) component shows an anti-phase one.

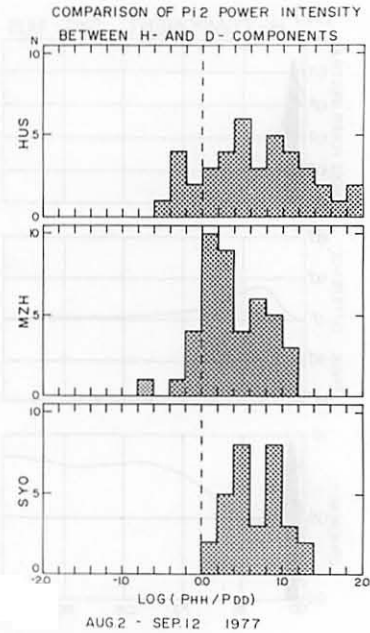


Fig. 5 : Comparisons of the Pi 2 auto-power intensities between the north-south (H) and the east-west (D) components. A ratio of the H-to D-components is represented by means of a common logarithmic function whose positive value indicates that the amplitude of Pi 2 is larger in the H-component than in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

H-component ; the value higher than 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 northern hemisphere, whereas 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

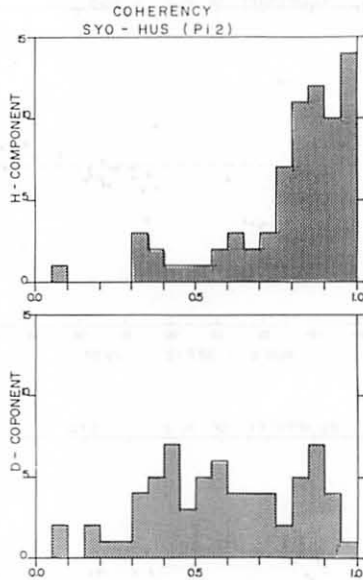


Fig. 6 : Coherencies of Pi 2 at the conjugate-pair stations. For the north-south component (H), nearly 80 % of the Pi 2 events show the value coherency higher than 0.7.

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 northern 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

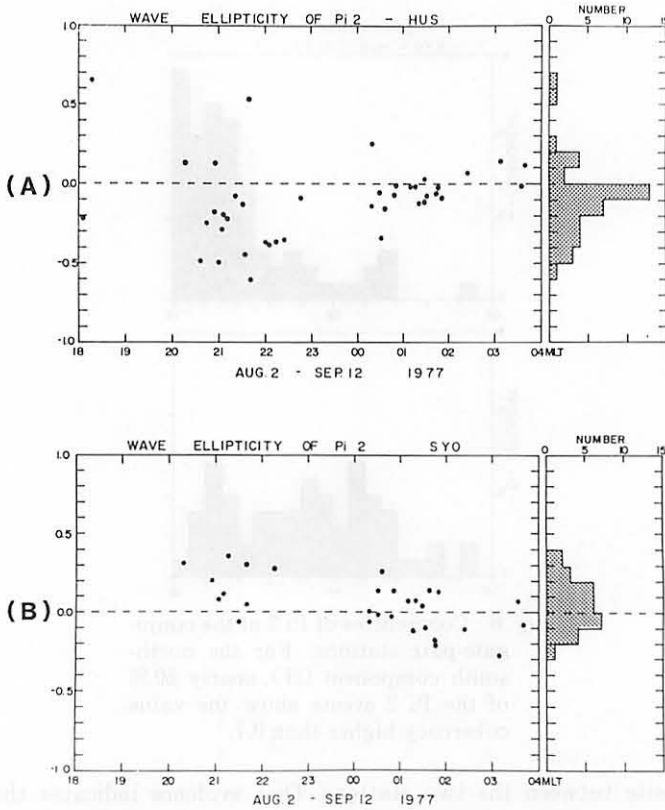


Fig. 7 : Ellipticities of the wave polarization of Pi 2 plotted as a function of occurrence magnetic local time (MLT), at Husafell (A) and Syowa Station (B).

(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. Therefore, the H-component shows an in-phase relationship at the conjugate pair for the case of the fundamental mode of

WAVE MODE	PERTURBATION ALONG THE FIELD LINE	WAVE PHASE RELATIONSHIPS
1st MODE		H : IN-PHASE D : ANTI-PHASE
2nd MODE		H : ANTI-PHASE D : IN-PHASE

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 oscillation 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 the major axis of the wave polarization through the ionosphere (Nishida, 1964 ; Tamao, 1964 ; Hughes and 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 Alfvén 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 east-west 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.

Acknowledgement

The author would like to express his appreciations to Profs. T. Nagata, T. Hirasawa, H. Fukunishi and N. Sato of the National Institute of Polar Research for providing the ULF data obtained in Antarctica and Iceland, and for their supporting to the present study. The author also very thanks to Profs. H. Oya and T. Saito of the Tohoku University for their valuable discussions and comments. The author is grateful to Dr. Murakami, the director of the Kakioka Magnetic Observatory, for his encouragement to the present study.

References

- Aggson, T. L. and Heppner, J. P., (1977) : *J. Geophys. Res.*, 82, 5155.
 Fukunishi, H., (1975) : *J. Geophys. Res.*, 80, 98.
 Hughes, W. J. and Southwood, D. J., (1976) : *J. Geophys. Res.*, 81, 3234.
 Kan, J. R., Longenecker, D. U. and Olson, J. V. (1982) : *J. Geophys. Res.*, 87, 7483.
 Kuwashima, M. (1975) : *Mem. Kakioka Mag. Obs.*, 16, 2.
 Kuwashima, M. (1978) : *Mem. Nat. Inst. Polar Res. Ser. A*, 15, 1.
 Kuwashima, M. and Saito, T. (1981) : *J. Geophys. Res.*, 86, 4686.
 Mallinckrodt, A. J. and Carlson, C. W., (1978) : *J. Geophys. Res.*, 83, 1426.
 Maltsev, Y. P., Leontyev, S. V. and Lyatsky, W. B., (1974) : *Planet. Space Sci.*, 22, 1519.
 Nagata, T., Hirasawa, T., Fukunishi, H., Ayukawa, M., Sato, N., and Fujii, R., (1980) : *Mem. Nat. Inst. Polar Res.*, 16, 25.
 Nishida, A., (1964) : *J. Geophys. Res.*, 69, 1861.
 Nishida, A., (1964) : *J. Geophys. Res.*, 84, 3409.
 Lester, M., Hughes, W. J. and Singer, H. J., (1983) : *J. Geophys. Res.*, 88, 7958.
 Lester, M., Hughes, W. J. and Singer, H. J., (1984) : *J. Geophys. Res.*, 89, 5489.
 Olson, J. V. and Rostoker, G., (1977) : *Planet. Space Sci.*, 25, 663.
 Pashin, A. B., Glassmeier, K. H., Baumjohan, W., Raspopov, O. M., Yahnin, A. G., Opgenoorth, H. J. and Pellinen, R. J., (1982) : *J. Geophys. Res.*, 51, 223.
 Rostoker, G. and Samson, C., (1981) : *Planet. Space Sci.*, 29, 225.
 Saito, T., (1969) : *Space Sci. Rev.*, 10, 319.
 Saito, T., Sakurai, T. and Koyama, Y., (1976) : *J. Atmos. Terr. Phys.* 38, 1265.
 Sakurai, T., (1970) : *Sci. Rep. Tohoku Univ.*, Ser. 5, 20, 107.
 Sakurai, T. and McPherron, R. L., (1983) : *J. Geophys. Res.*, 88, 7015.

- Samson, J. C., (1982): Planet. Space Sci., 30, 1239.
Samson, J. C. and Rostoker, G., (1983): Planet. Space Sci., 31, 435.
Singer, H. J., Hughes, W. J., Fougere, P.F. and Knecht, D., (1983): J. Geophys. Res., 88, 7029.
Sugiura, M. and Wilson, C.R., (1964): J. Geophys. Res., 69, 1211.
Tamao, T., (1964): J. Geomagn. Geoelectr., 16, 89.
- Reference is also made to the following unpublished materil Kuwashima, M., (1984):
Ph. D. Thesis, University of Tohoku, Japan.

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。