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OSCILLATION CHARACTERISTICS OF Pi 2 IN AURORAL ZONE: SYOWA-ICELAND CONJUGATE STUDY

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Abstract: Oscillation characteristics of Pi 2 magnetic pulsations observed in auroral region have been statistically examined on the basis of the magnetic field data obtained at the conjugate stations, Syowa Station in Antarctica and Husafell, Isafjördur and Tjörnes in Iceland. The examination reveals that the characteristics are quite different between the H and D components of Pi 2 magnetic pulsations. The pulsations in H component show larger amplitude than in the D component. The orientation of the principal axis, ellipticity and phase relations of Pi 2 oscillations are also statistically investigated. The important characteristics of Pi 2 as hydromagnetic waves (HM waves) generated in the magnetosphere are believed to be exhibited well in the H component. All of the characteristics show that oscillations of Pi 2 in auroral region are found to be resonant oscillations of magnetic field-line. Regarding the conjugacy of Pi 2 oscillations, Syowa and Husafell is also found to be the best conjugate station-pair in comparison with other station-pairs of Syowa-Isafjördur, and Syowa-Tjörnes.

1. Introduction

From our recent study (SAKURAI *et al.*, 1986) on Pi 2 observed at the conjugate stations, Syowa in Antarctica and the three stations, Husafell, Isafjördur and Tjörnes in Iceland, the auroal activity is found to affect severely the phase relations of Pi 2's, especially for the D component. The odd mode phase relation becomes unsystematic with auroral activities. The Pi 2 occurs in association with auroral brightening at the breakup, not during the subsequent auroral activities. The subsequent auroral brightenings cause rather complicated phase relations of Pi 2 between the fixed conjugate stations. The real conjugate points for the subsequent Pi 2's seem to displace in accordance with the dynamic development of the auroral breakup. The in-phase relation of the H component is clearly exhibited rather than the out-of-phase relation of the D component. Similar results of the phase relation Pi 2 magnetic pulsations between the conjugate stations, Syowa and Husafell had been presented by KUWASHIMA (1981). The present study complements our previous study and presents statistical characteristics of Pi 2's in the vicinity of auroral breakup region by using twenty eight Pi 2's in the premidnight hours during one month of September, 1984 to obtain clear characteristics of Pi 2 oscillations uninfluenced by the ionospheric current due to severe auroral activity.

Another purpose of the present study is to find which is the best conjugate station-pair for Pi 2 oscillations among the three station-pairs, Syowa-Husafell, Syowa-

Isafjördur, and Syowa–Tjörnes. The conjugate point varies its position due to the secular, seasonal and daily variations of the magnetic field. At the epoch 1985.0 the conjugate point of Syowa Station in Iceland situated just at a middle point between Husafell and Tjörnes (ONO, 1987). Therefore, it is very interesting to know the real conjugate point of Syowa in Iceland by examining the phase relations of Pi 2 observed at the above three pairs of stations in Antarctica and in Iceland.

1. Data Acquisition and Method of Analysis

The magnetic pulsation data used in the present analysis were obtained by an induction magnetometer at four stations, Syowa in Antarctica, Husafell, Isafjördur and Tjörnes in Iceland, in the vicinity of auroral breakup region. The locations of the three stations in Iceland and the conjugate point of Syowa in 1985 has been presented in Fig. 1. The calculated conjugate point of Syowa is located almost at a middle point between Husafell and Tjörnes, about 110 km from Husafell and about 120 km from Tjörnes. The spatial relation between the three stations in Iceland as follows; Isafjördur is located in the almost same magnetic meridian of Husafell, and about 180 km northward from Husafell. Detailed descriptions about the stations and magnetic field data used in the conjugate-campaign have already been reported by SATO *et al.* (1984).

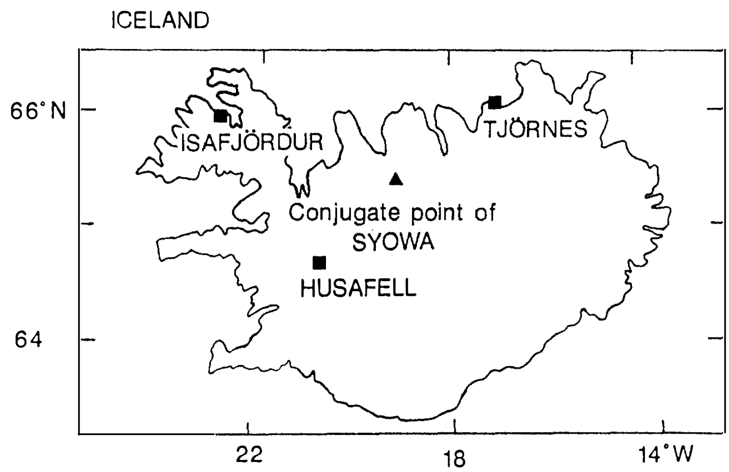

Fig. 1. Locations of Husafell, Isafjördur and Tjörnes, and the conjugate point of Syowa Station in Iceland.

3. Results

Following characteristics of Pi 2's are obtained at the four stations in the vicinity of auroral breakup region and will reveal the important statistical characteristics in close relation to auroral activities. Figure 2 shows the amplitude ratio of the H component to the D component Pi 2 magnetic perturbations observed at Syowa, Husafell, Isafjördur and Tjörnes. The dominant peak appears at the ratio of $\delta H/\delta D = 1$–2. The subsidiary peaks can be seen at the ratio from 2 to 5, and they appear almost similarly but with a slight difference at each station. These results reveal that

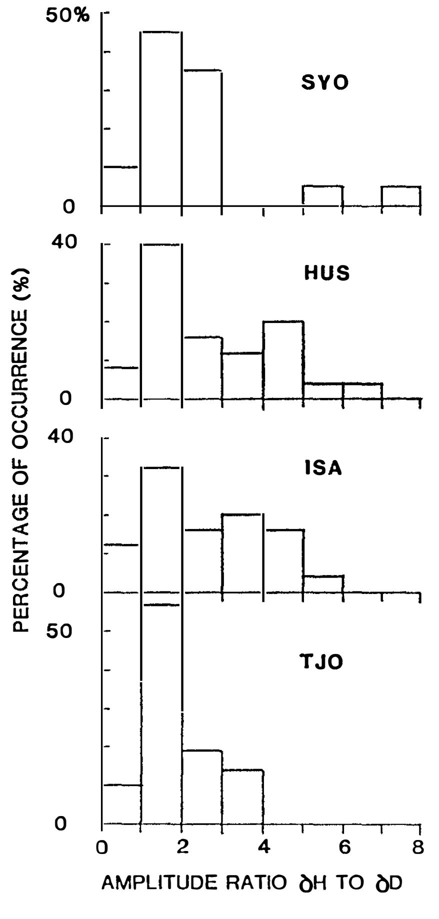

Fig. 2. Percentage occurrence of amplitude ratio of δH to δD component magnetic field perturbations of Pi 2 at four stations, Syowa in Antarctica, Husafell, Isafjördur and Tjörnes in Iceland.

the amplitudes of Pi 2's in the vicinity of the auroral breakup region are almost always larger in the *H* component than in the *D* component.

The coherency of Pi 2 oscillations is examined in the both components of the magnetic field at the three station-pairs, Syowa–Husafell, Syowa–Isafjördur, and Syowa–Tjörnes, and also at the three station-pairs in Iceland, Husafell–Isafjördur, Husafell–Tjörnes, and Isafjördur–Tjörnes. These are illustrated in the left and right diagrams of Fig. 3. At all of the station-pair the high degree of coherency (0.9–1.0) is obtained in the *H* component at all of the station-pair with the occurrence percentage over 50%. On the other hand, the degree of the coherency in the *D* component is lower at all of the station-pair, except at the station-pair of Husafell–Isafjördur, where the peak coherency is almost similar in the *H* and *D* components. These results reveal that the *H* component oscillates coherently at all of the stations, while the *D* component oscillates rather independently in general at each station. The *D* component seems to be much more influenced by a localized condition of the ionosphere. This is clearly seen in the *D* component magnetic field variations as observed at the nearest station-pair, Husafell–Tjörnes.

Orientation of the principal axis of Pi 2 polarization ellipses is given in the left diagrams of Fig. 4. The results show that the principal axis directs toward the north-west at Syowa and the north-east at the stations in Iceland. Mirror image can be most clearly seen at the Syowa–Husafell station-pair. Orientation angle of the prin-

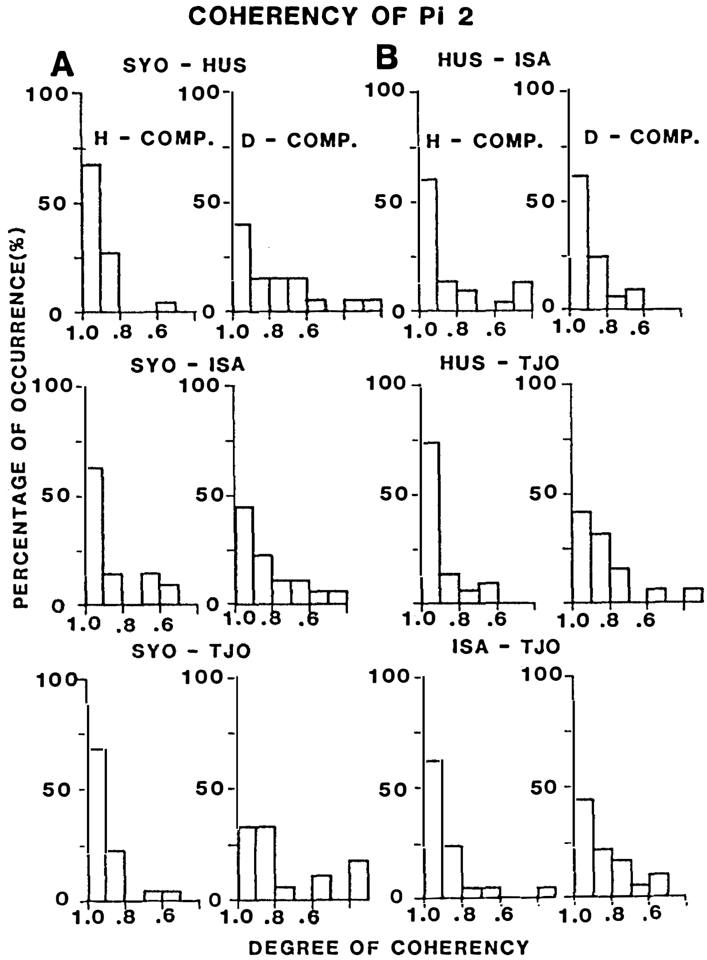

Fig. 3. Percentage occurrence of Pi 2 coherency between Syowa Station in Antarctica and the three stations in Iceland, Syowa-Husafell, Syowa-Isafjördur, and Syowa-Tjörnes and between the two stations in Iceland, Husafell-Isafjördur, Husafell-Tjörnes and Isafjördur-Tjörnes.

cipal axis concentrates within an angle of less than 50°. Ellipticity in the right diagram of Fig. 4 shows very small values at all of the stations, indicating that Pi 2's observed at these stations are almost linearly polarized. This is able to understand as a natural consequence of the fact that the amplitude of the *H* component is larger than that of the *D* component at all of the stations. Almost linear polarization of Pi 2's ellipticity in the vicinity of the auroral breakups is found in the present study, which is also consistent with the results obtained near the center of the substorm current wedge under the large-scale studies of Pi 2's in the auoral zone reported by Samson and Harrold (1985).

Phase relations of Pi 2 magnetic pulsations between the conjugate-pair stations of Syowa–Husafell, Syowa–Isafjördur, and Syowa–Tjörnes are summarized in Fig. 5. The in-phase relation of the *H* component appears more clearly than the out-of-phase relation of the *D* component at all of the station-pairs. The phase relations at the three station-pairs show almost similar characteristics in the *H* component but not in the *D* component; with a sharp maximum distribution around 0° in the *H* component

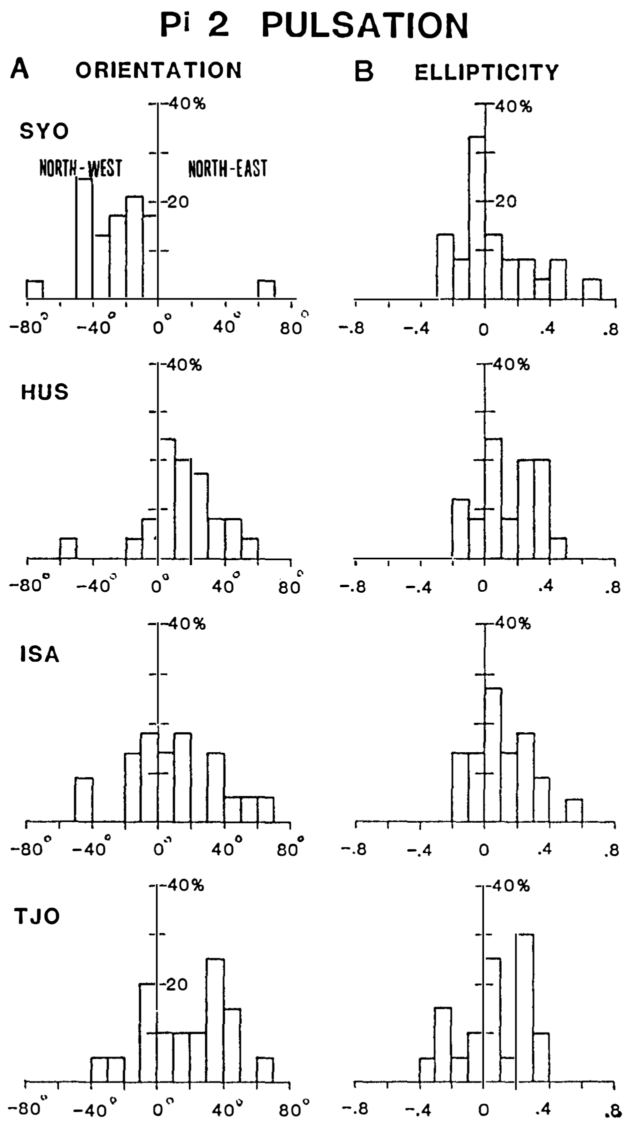

Fig. 4. Orientation and ellipticity of Pi 2 polarization in the horizontal plane.

at all of the station-pairs but with rather broader distribution around 180° in the *D* component. The most clear distribution of the *D* component appears at the station-pair of Syowa and Husafell, while the distribution at the station-pair of Syowa and Tjörnes is less distinct. The results at the conjugate-pair station, Syowa and Husafell, are consistent with those obtained by KUWASHIMA (1981). Even if the calculated conjugate point of Syowa in Iceland situated at a middle point between Husafell and Tjörnes in September 1984 (ONO, 1987), the present study shows that the odd mode phase relation can be most clearly seen at the station-pair of Syowa and Husafell rather than at the station-pair of Syowa and Tjörnes.

The phase relations of Pi 2 magnetic pulsations between the station-pairs in Iceland are also shown in Fig. 6. The high degree of the concentration on 0° of the *H* component appears at every station-pair. While the *D* component distributes differently from the *H* component with rather broad distributions. From the distributions of the *H* component the phase lags larger than about 80° or more are observed

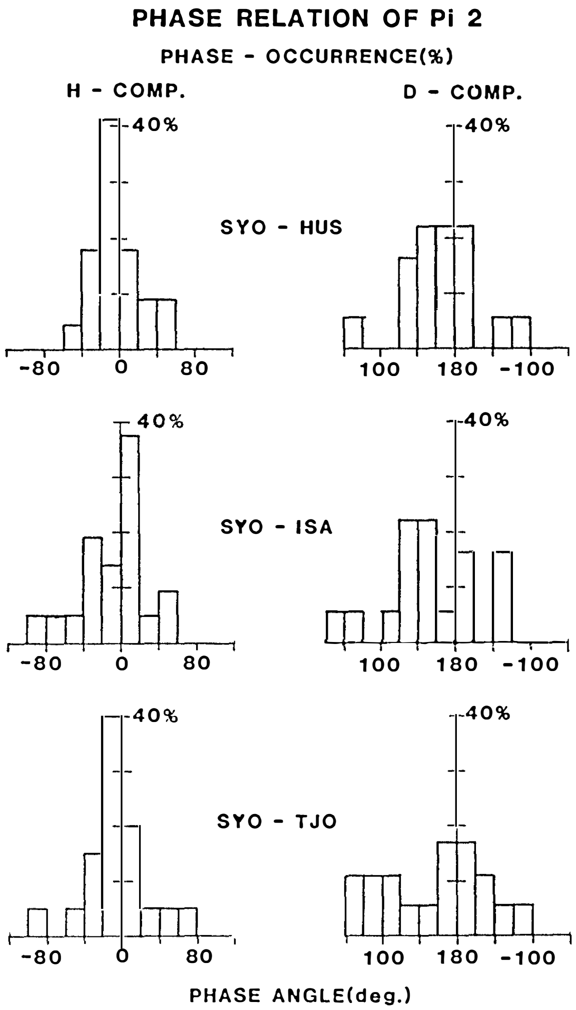

Fig. 5. The phase relations of Pi 2's between the conjugate station-pairs of Syowa-Husafell, Syowa-Isafjördur, and Syowa-Tjörnes, respectively.

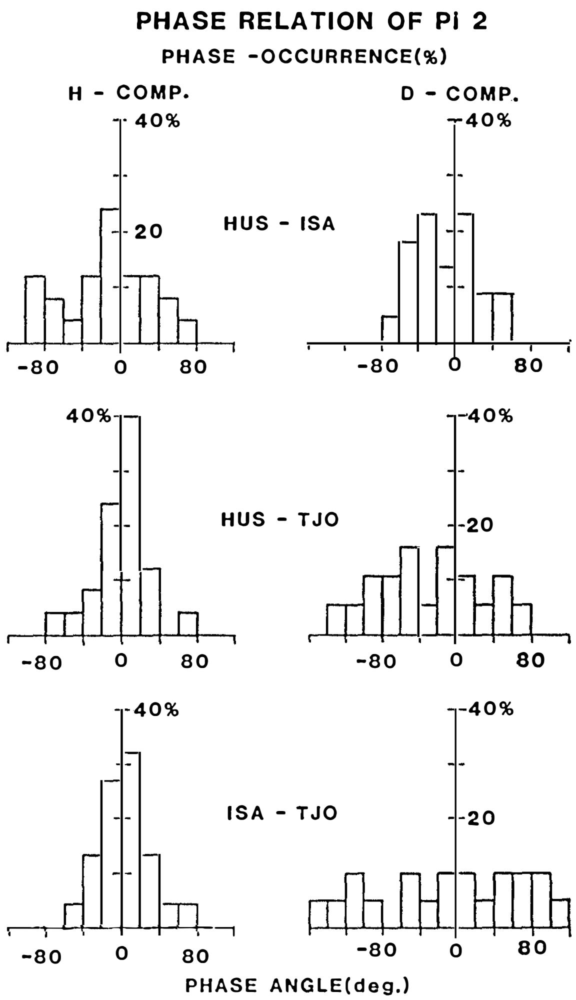

Fig. 6. The phase relations of Pi 2's between the station-pair of Husafell-Isafjördur, Husafell-Tjörnes, and Isafjördur-Tjörnes in Iceland.

only for the pair of Husafell and Isafjördur but with an infrequent occurrence less than 30%. This larger phase lag is not seen in the other station-pairs, Husafell-Tjörnes, and Isafjördur-Tjörnes. One of the candidates for the interpretation of the larger phase lag is that such large phase lag might be an evidence of a hydromagnetic resonance oscillation of Pi 2 occurring between the two stations, where the auroral breakup frequently takes place. This will be discussed in more detail in the last section.

On the other hand, the distributions of the D component are different from those of the H component and are also different at each station-pair; a rather sharp maximum appears around 0° at the pair, Husafell-Isafjördur pair and an almost uniform distribution is seen for Isafjördur-Tjörnes pair. The different behaviors of the phase relation between the H and D components would indicate the complexity of the ground manifestation of magnetic signals of Pi 2 oscillations in the vicinity of the auroral breakup region. The H component is dominant and well-regulated at all of the station-pairs.

Thus, it seems to manifest more essential character of HM waves generated in the magnetosphere. While the D component could be the induced magnetic field influenced by a localized condition of the auroral electrojets.

4. Discussion and Summaries

Important characteristics of Pi 2 oscillations in the vicinity of auroral breakup region have been statistically invetigated in the present study. The most distinct characteristic is that the H component exhibits well-regulated characteristics rather than the D component. This characteristic of the H component is consistent with that obtained in the previous case study by SAKURAI *et al.* (1986) and with that in the statistical study by KUWASHIMA (1981), indicating that the H component observed on the ground tends to manifest the essential character of shear Alfvén waves associated with a field-aligned current-pair, propagating from the magnetosphere to the ionosphere. This observational evidence could be supported by the theoretical prediction by TAMAO (1986), that shows the importance of direct contribution of oblique field-aligned currents accompanying the Alfvén wave to the ground magnetic field perturbations in the auroral zone.

The well-regulated characteristic of the H component rather than that of the D component has been also verified by SAMSON and HARROLD (1985) in the phase velocity distribution of Pi 2's in the auroral zone with rather larger longitudinal extent covering about 75°. The distributions of phase velocity for the H and D components are quite different between them. The H component has predominant phase velocity rather than the D component. Thus, the different behaviors between the H and D components of the phase velocity of Pi 2's in the auroral zone are consistent with our present statistical characteristics of Pi 2's. These results suggest that the H component characteristics observed on the ground are more essential as a ground manifestation of HM waves generated in the magnetosphere.

Another important point to be noticed here is that the odd mode Pi 2 oscillation is best exhibited at the pair of Syowa–Husafell in comparison with other two station-pairs, Syowa–Isafjördur, and Syowa–Tjörnes. This result indicates that a resonant standing oscillation is well exhibited along the magnetic field-line connected between the conjugate stations, Syowa and Husafell and thus, Syowa and Husafell is the best and real conjugate station-pair in comparison with other two station-pairs, even if the calculated conjugate point of Syowa in Iceland situates at a middle point between Husafell and Tjörnes. In the present analysis the degree of the conjugacy, which is dependent on the phase relations of the D component at each station-pair as shown in Fig. 5, is less distinct at the station-pair of Syowa and Isafjördur and much less at the station-pair of Syowa and Tjörnes. Thus, the D component perturbations behave rather independently at each station. This result is consistent with our previous study of Pi 2's (SAKURAI *et al.*, 1986), in which it is described that the effect of the auroral activities on the phase relation of Pi 2 and especially on that of the D component is very severe.

The ellipticities at these stations are almost linear, less than 0.4. This linear characteristic of the ellipticity of Pi 2's is consistent with that of the resonant theory predicted by HUGHES and SOUTHWOOD (1976), suggesting that Pi 2's are also resonant oscillations of magnetic field line. Similar result of ellipticity for Pi 2 oscillations at high latitudes has been shown by SAMSON and HARROLD (1983) and SAMSON (1985) near the center of substorm current wedge. Their results are consistent with our results from the present study of Pi 2's, which are limited to the Pi 2's occurred in the vicinity of auroral breakup region.

One more interesting result to be pointed out here concerns the phase relation between the station-pairs in Iceland. If we attribute Pi 2 pulsations to a resonant standing field-line oscillation, a phase reversal or larger phase lag could be expected to occur across the resonant point (HUGHES and SOUTHWOOD, 1976). In so far as present study is concerned, the phase lag of the H component is small and maximizes around zero degree at every station-pair. The larger phase lags are observed with an infrequent occurrence percentage only at the station-pair of Husafell and Isafjördur. These larger phase lags might indicate a clear evidence for the resonant oscillation of Pi 2 occurred between the two stations, though the small phase lags might be due to a small distance between the two stations dealt in the present study, where each station locates within the region less than about 200 km. However, there is another interpretation of these small phase lags. According to HUGHES and SOUTHWOOD (1976) the phase lag depends sensitively on a resonant scale length across a resonant point. Their calculation showed that the thicker the resonant scale length, the smaller the phase lag across the resonant point. Thus, our results seem to correspond to the scale length thicker than 100 km. This is consistent with our previous case study of Pi 2 (SAKURAI *et al.*, 1986).

In addition, by considering that almost of the auroral breakups occurred between Husafell and Tjörnes as for the Pi 2's dealt in the present study, it may be reasonable that the phase lag observed at Husafell was very small values negative and/or positive with respect to Isafjördur and Tjörnes, except the large phase lags. Thus, this estimation of a resonant scale length is a maximum value for the Pi 2's with small phase lags dealt in the present study, suggesting that the resonant scale length becomes thicker and/or thinner corresponding to the auroral activities and the location of auroral breakup severely affects a phase relation of Pi 2.

However there may be another reason causing the large phase lag between the stations. In a more detailed examination of the phase relation of the corresponding Pi 2 the larger phase lag results from a slight difference of spectral peak frequency between the two stations. One of the typical example showing a large phase lag is illustrated in Fig. 7. The top panel shows auto-power spectra of the H component fields at the two stations, Husafell and Isafjördur (broken curve). The spectral peak occurs at a slightly different frequency at each station, *i.e.*, 12 mHz at Husafell and 15 mHz at Isafjördur. The cross spectrum is shown in the second panel and the spectral peak is at 13 mHz. The corresponding coherency is rather low in the third panel. The cross phase relation at the corresponding frequency is presented in the bottom panel and shows larger phase lag about 120°. It is noteworthy here that the slight difference in the dominant frequencies results in a low coherency and a large phase lag at the common frequency. This result indicates that a large phase lag appeared in this event is caused by a slight difference of spectral peak frequency between

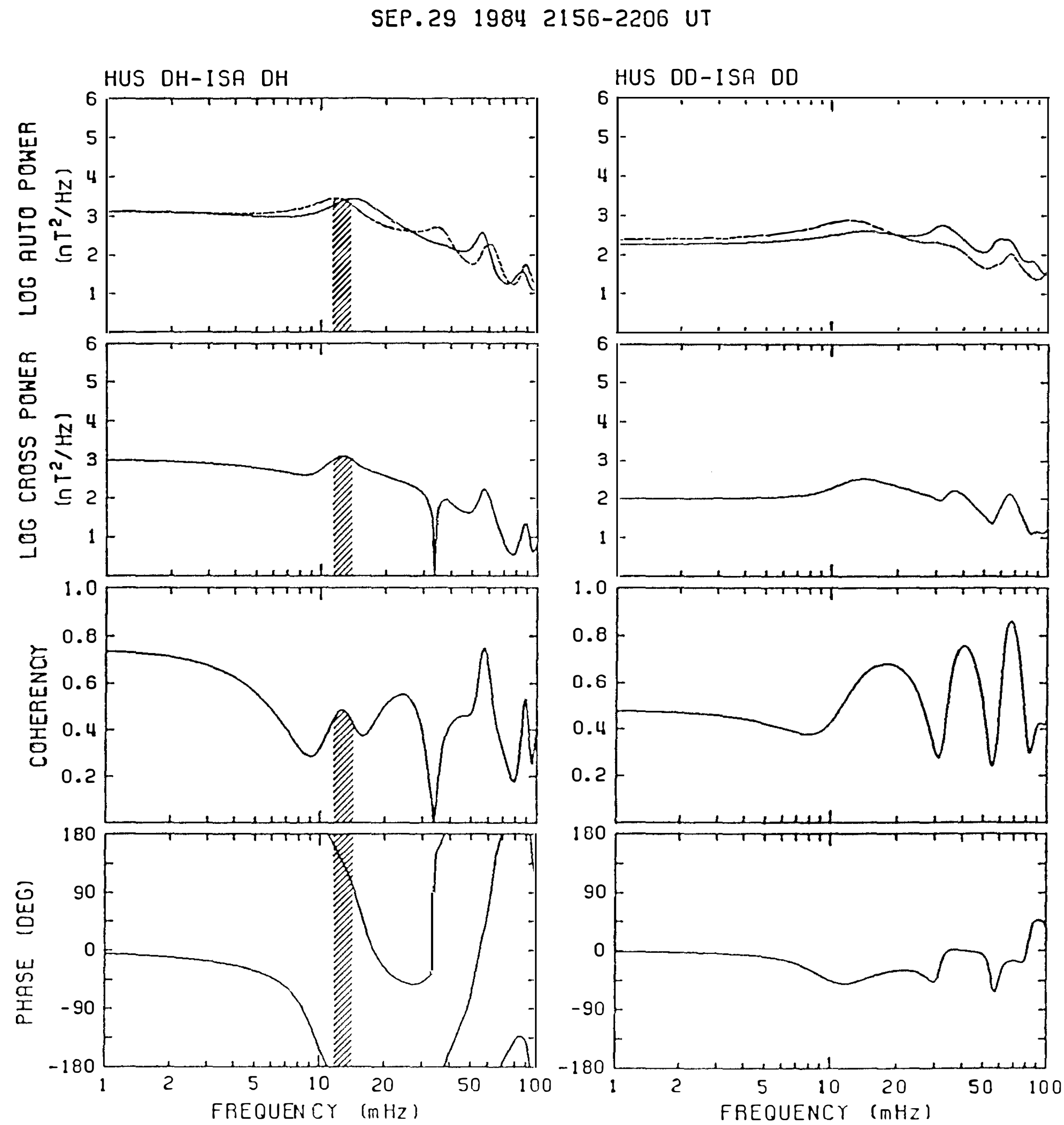

Fig. 7. The auto power spectra at Husafell (solid curve) and Isafjördur (dotted curve), cross power spectrum, coherency and cross phase relation for the Pi 2 occurred at 2156 UT on September 29, 1984, for the H and D components, (left and right panels).

the two stations even in the same component of the field (SAKURAI *et al.*, 1986). This may be due to the non-uniformity of ionospheric conductivity as suggested by GLASSMEIER (1983, 1984).

One more important fact to be noticed here is regard to the phase lag between the *H* and *D* components. It appears to be inconsistent with the result predicted by HUGHES and SOUTHWOOD (1976). Our result shows that the *H* component concentrates on the smaller values than the *D* component. The distributions of the phase lag of the *D* component spreads broader than those of the *H* component. This might be due to another effect, *i.e.*, the localized ionospheric effect due to the auroral activities (SAKURAI *et al.*, 1986), whose effect had not been taken into account of the resonant theory. GLASSMEIER (1983, 1984) has, however, pointed out that HM waves generated in the magnetosphere would be strongly modified in the ionosphere by non-uniform conductivity due to particle precipitations associated with auroral activity. His theory would include the complicated phase relation of the *D* component of the Pi 2 magnetic pulsations observed on the ground. Assuming that the auroral activity is very localized, the resultant non-uniformity of ionospheric conductivity would modify the characteristics of the magnetic perturbations at ground level.

Conclusively, a resonant oscillation of Pi 2 in auroral region is strongly supported by the present results that almost Pi 2's exhibit the small orientation angles, small values of ellipticity and good conjugacy of the phase relations (showing an odd mode oscillation) between the conjugate stations, and large and small phase lags between the station-pairs in Iceland.

The important results of Pi 2 magnetic pulsations observed at the conjugate stations, Syowa Station and the three stations in Iceland, located in the vicinity of auroral breakup region can be summarized as follows;

(1) Amplitude of Pi 2 is larger in the *H* component than in the *D* component.

(2) Coherency of Pi 2 at the three station-pairs is higher in the *H* component than in the *D* component.

(3) Orientation of the principal axis of Pi 2 polarization ellipses is in the direction of north-west at Syowa and north-east at the three stations in Iceland. Mirror image relation of the polarization ellipse can be most clearly seen at the Syowa and Husafell station-pair.

(4) Ellipticity of Pi 2 gives very small values at all stations dealt in the present analysis, indicating that Pi 2's occurred in the vicinity of auroral breakup region show a resonant oscillation of magnetic field line.

(5) In-phase relation of the *H* component appears more clearly than out-of-phase relation of the *D* component at all conjugate station-pairs. This feature is most clearly seen at the station-pair, Syowa and Husafell, indicating that this station-pair is the best conjugate station-pair in comparison with the other station-pairs. The odd mode resonant oscillation can be seen at the station-pair of Syowa and Husafell.

(6) Phase lag of the *H* component of Pi 2 between the station-pairs in Iceland is well-regulated at every station-pair. A very few cases of Pi 2's shows a larger phase lag indicating a clear a resonant oscillation of magnetic field-line, while the remaining Pi 2's exhibit small phase lag, in which the resonant scale length is thicker than that of the Pi 2's showing a large phase lag.

(7) From the observational characteristics summarized above it is concluded that almost Pi 2's are due to the resonant oscillation of magnetic field line, exhibiting a good conjugacy at the conjugate stations.

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