DYNAMIC SPECTRAL STUDY OF Pc 3 TO Pc 5 PULSATIONS OBSERVED NEAR $L=6$

Yutaka TONEGAWA*, Hiroshi FUKUNISHI, Takeo HIRASAWA,

National Institute of Polar Research, 9-10, Kaga 1-chome, Itabashi-ku, Tokyo 173

Robert L. MCPHERRON,

Institute of Geophysics and Planetary Physics, University of California, Los Angeles, California 90024, U.S.A.

Tohru SAKURAI and Yoshio KATO

**Department of Aeronautics and Space Science, Tokai University, 1117, Kitakaname, Hiratsuka 259-12*

Abstract: Dynamic spectral characteristics of magnetic pulsations in the frequency range from Pc 3 to Pc 5 are examined on the basis of the magnetic field data observed at the synchronous orbit, ATS 6 and at the high latitude ground stations, Syowa ($L\sim 6$) and Mizuho ($L\sim 7$) in Antarctica, and Husafell (a conjugate station to Syowa) in Iceland. The dynamic spectral power seen at both locations shows generally a similar frequency structure throughout the daylight hours. It contains several dominant frequency trends consisted of a harmonic relation with one another. The satellite location with respect to the magnetic latitude along the field line is very sensitive to the spectral structures seen in the dynamic spectra. When the satellite was located 10° above the magnetic equator, the spectra appeared with two dominant spectral trends. One of them was the lowest frequency trend corresponding to the Pc 4-5 frequency range (3-10 mHz) and another trend was seen in the Pc 3 frequency range (20-80 mHz). They exhibited a harmonic relation with each other. When the satellite was located near the magnetic equator, the lowest frequency trend did not appear and its second harmonics became visible. In the dynamic spectra of the ground station, the spectral trends in the Pc 3 and Pc 4-5 are also in a harmonic relation with each other, seen similarly at the satellite location only except for many dotted structures with an interval of a few tens of minutes.

1. Introduction

One of important aspects of recent studies on magnetic pulsations is believed to clarify their generation and propagation mechanisms in the magnetosphere. The magnetic pulsations in the period range from Pc 3 to Pc 5 have been experimentally evidenced with the ground data and theoretically interpreted as standing resonance oscillations along the magnetic field line (SAMSON *et al.*, 1971 ; SAMSON and ROSTOKER, 1972; LANZEROTTI *et al.*, 1974; FUKUNISHI and LANZEROTTI, 1974a, b; SOUTHWOOD, 1974; CHEN and HASEGAWA, 1974).

Combined with satellite data more detailed characteristics of oscillation mode have been eagerly investigated in recent years. To have clear characteristics for the oscillation modes the location of satellite in space is essential. Although it is difficult to discriminate space/time effects in case of a single moving satellite, satellites located on or near the magnetic equator will detect many different amplitude waves depending upon the mode of the standing oscillation, and can distinguish the definite mode of wave (CUMMINGS *et al.*, 1969; LANZEROTTI and FUKUNISHI, 1974). The geosynchronous satellite set near the magnetic equator can survey vastly different kinds of the waves at a fixed radial distance throughout the day and have provided many fruitful evidences with respect to the oscillation modes for Pc 3 to Pc 5 magnetic pulsations (CUMMINGS *et al.*, 1972, 1975, 1978; ARTHUR and MCPHERRON, 1975, 1977a, b, 1981; ARTHUR *et al.*, 1977; HUGHES *et al.*, 1978, 1979; TAKAHASHI *et al.*, 1981; TAKAHASHI and MCPHERRON, 1982; SAKURAI *et al.*, 1981; TONEGAWA *et al.*, 1980; TONEGAWA, 1982).

Especially, a recent investigation for Pc 3 and Pc 4 frequency range magnetic pulsations obtained from an analysis of the ATS 6 satellite data made by TAKAHASHI and MCPHERRON (1982) has given a strong evidence for frequency structures of harmonic relations in the spectra, which suggests that the Pc 3 and Pc 4 magnetic pulsations oscillate as higher harmonics of standing resonant oscillation of the magnetic field line passing through the satellite. Another evidence supporting such harmonic relations in the frequency range from Pc 3 to Pc 4 has been already shown and suggested by FUKUNISHI and LANZEROTTI (1974a) using the ground data obtained near the plasmapause latitude.

The purpose of the present paper is to clarify detailed characteristics of frequency structures seen in the dynamic spectra which covered the frequency range from Pc 3 to Pc 5 by the use of the magnetic data obtained at the satellite orbit, and at the conjugate ground stations in high latitude. The high latitude ground stations used in this analysis are Syowa (geomagnetic latitude $\Phi=-66.1°$, longitude $\Lambda=70.6°$, L-value $L=6.10$) and Mizuho ($\Phi=-68.0°$, $\Lambda=70.7°$, $L=7.11$) in Antarctica and the conjugate northern hemisphere station, Husafell in Iceland ($\Phi=66.5°$, $\Lambda=70.3°$, $L=6.12$). The satellite data are used for the periods corresponding to the two different locations of the satellite; one is at $\Phi=10°$N during August 1974 and another at $\Phi=3°$S during August 1975, respectively. The combined magnetic data of the satellite and the ground conjugate stations will give fruitful results for the oscillation modes of the waves occurring in the magnetosphere.

2. The Data and Analysis

The satellite data used in the present study are 5-s averages of the vector magnetic field measured by UCLA flux gate magnetometer on board ATS 6, and the magnetic field is analyzed with the dipole coordinate system denoted by V, D and H. The component antiparallel to the dipole axis is given by H. The V component is perpendicular to H, radially outward and the D is the cross product of H and V, *i. e.* $\boldsymbol{H}\times\boldsymbol{V}$, toward the east. The original ground data were measured by induction magnetometers and were recorded on the analogue magnetic tape. The analogue data have been converted to the digital data with 4.8-s sampling.

The power spectra are calculated using the maximum entropy method (MEM) with the thirtieth order prediction error filter in the frequency range from 1 mHz to 100 mHz with logarithmically equal intervals. The dynamic spectra are calculated for a time window of 20 min which is successively shifted by 8 min. In order to emphasize spectral peaks in the dynamic spectrum, we remove a background power spectrum by fitting a second-order polynomial to the average slope of the power spectrum, and then the dynamic spectra are displayed on an electro-static plotter with a 24-step gray code corresponding to the relative power to the background level. In this display the white area corresponds to the power density lower than the background level, and the darkest area corresponds to at least 10 dB greater than the background level.

3. Experimental Results

Figure 1 shows the dynamic spectra obtained at the satellite on August 22, 1974. The dominant spectral trends are clearly seen only in the D component and not in the V and H components of the magnetic field. These trends appear with a narrow fre-

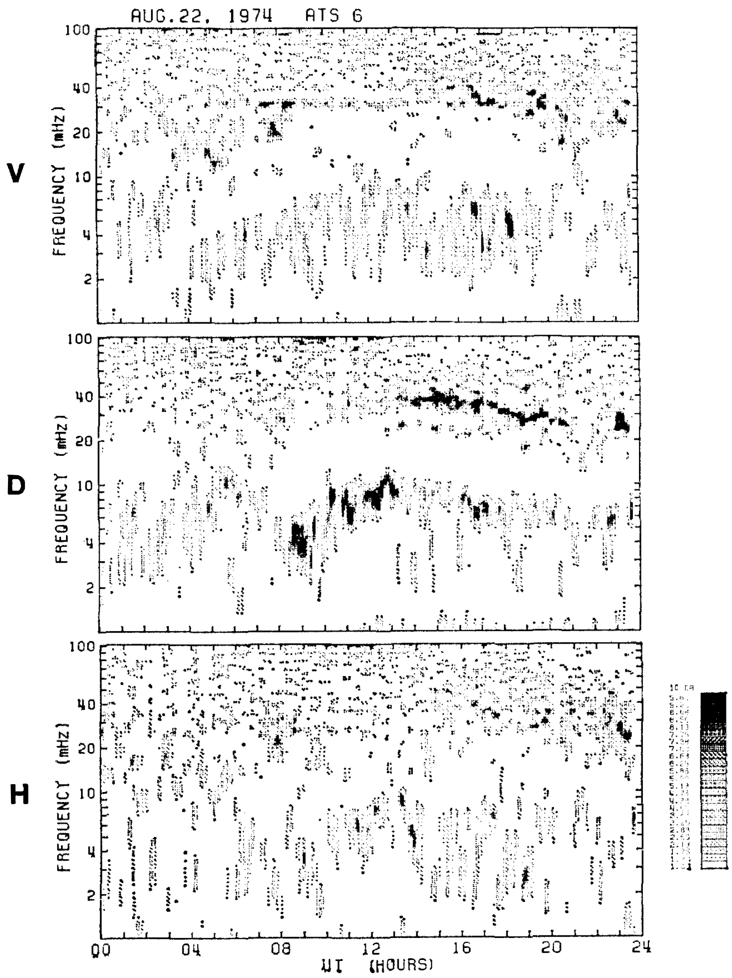

Fig. 1. Dynamic spectra of magnetic pulsations observed by the ATS 6 satellite on August 22, 1974. From the top to the bottom panels show the V, D and H components of magnetic fields. The harmonic spectral trends in frequency from Pc 3 to Pc 5 are clearly seen in the D component field.

quency band in the period range from Pc 3 to Pc 5 and are manifested during the daylight hours. The lowest frequency trend begins at 4 mHz near 09 UT (03 LT) with a rapid increase and continues with successive decrease in frequency to 6 mHz at 22 UT (16 LT). The second trend begins at 25 mHz at 13 UT (7 LT) lasting to 15 mHz at 21 UT (15 LT). This trend appears intermittently with a gradual decrease in frequency. The third showing a dominant spectral trend is clear at a slightly higher frequency, which begins at 40 mHz at 13 UT (7 LT) and continues with a little decrease in frequency to 25 mHz until 21 UT (15 LT). The other two trends can be identified in a much higher frequency range. In this dynamic spectrum the lowest and the third spectral trends are exhibited rather clearly among the trends.

It is noteworthy that the spectral trends are exhibited well in the azimuthal component rather than the others. The spectral trends in the azimuthal component seem to be in a harmonic relation with one another. This kind of spectral character has been reported as 'harmonic structure of Pc 3–4' by TAKAHASHI and MCPHERRON (1982). Although they established that the spectral peaks seen in the Pc 3–4 frequency range correspond to the second or the higher harmonics, they did not give a clear evidence for the spectral peak at the lowest frequency trend. However, in the present analysis,

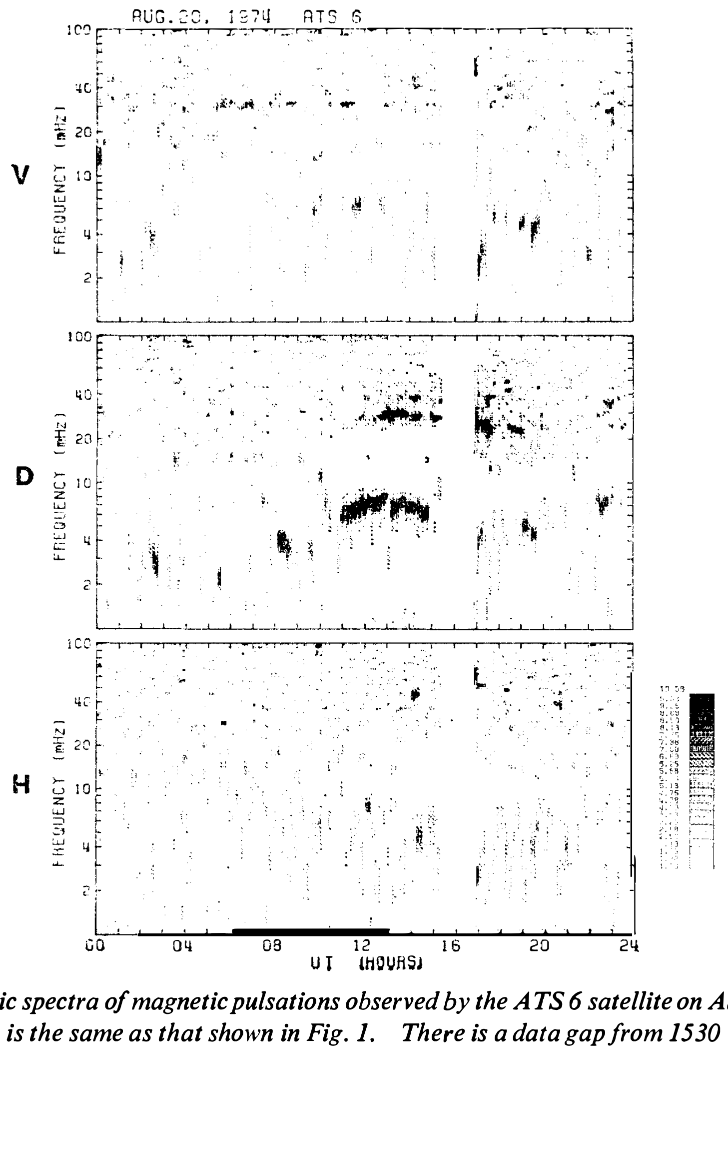

Fig. 2. Dynamic spectra of magnetic pulsations observed by the ATS 6 satellite on August 20, 1974. Format is the same as that shown in Fig. 1. There is a data gap from 1530 to 1700 UT.

the dominant spectral trend is clearly seen in the Pc 4–5 range and it seems to be fundamental one. The similar spectral characters of harmonic trends are seen in the dynamic spectra of the other days, August 20 and 21, 1974, which are shown in Figs. 2 and 3.

During August 1975 the satellite was located near the magnetic equator. The dynamic spectra at such a location of the satellite show very different characters from those at off-magnetic equator. The dynamic spectra of two days, August 8 and 11, 1975, are given in Figs. 4 and 5. At this location of the satellite the magnetic pulsations are clearly seen to oscillate in the radial component of the field in the frequency range of Pc 4 and are exhibited as the second harmonic mode with a distinct diurnal variation in frequency.

In Fig. 4 a clear spectral component with a narrow frequency band centered at 10 mHz appears throughout afternoon hours from 12 UT (14 LT) to 17 UT (19 LT). The higher harmonic spectral trends do not appear in the V component of the field. However, those harmonics are rather clearly seen in the D component, especially in the

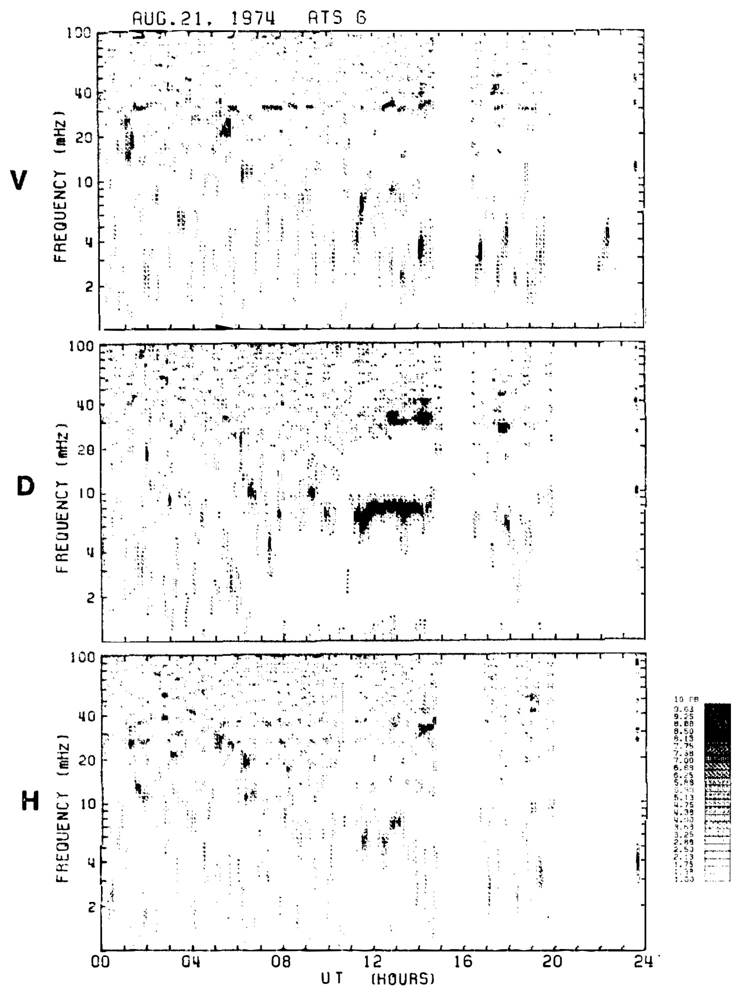

Fig. 3. Dynamic spectra of magnetic pulsations observed by the ATS 6 satellite on August 21, 1974. Format is the same as that shown in Fig. 1. There are two data gaps from 1500 to 1630 UT and from 2000 to 2330 UT.

morning hours. The spectral trend begins at about 20 mHz at 06 UT (08 LT) and continues with a rather monotonous decrease in frequency to 10 mHz at 17 UT (19 LT). The other trends in the higher frequency range can be seen only in the morning hours from 30 to 60 mHz in Pc 3.

The other example of a Pc 4 wave oscillating dominantly in the radial component is indicated in Fig. 5. A clear spectral trend at 20 mHz is shown in both V and D components. However, higher harmonics at 30 mHz and 40 mHz are seen only in the D component. Since the separation of the frequency between the spectral peaks is about 10 mHz, each peak may correspond to the second, third and fourth harmonics, respectively. Therefore, two important characters regarding magnetic pulsations seen near the magnetic equator should be pointed out here. One is that the second harmonic appears only in the radial component without any other harmonics, and the other is the absence of fundamental harmonic in any component.

Next, we will examine the spectral characteristics of Pc 3 to Pc 5 pulsations observed at the ground stations. The ground data used here were observed at the high latitude stations, Syowa and Mizuho in Antarctica, and Husafell in Iceland. Syowa

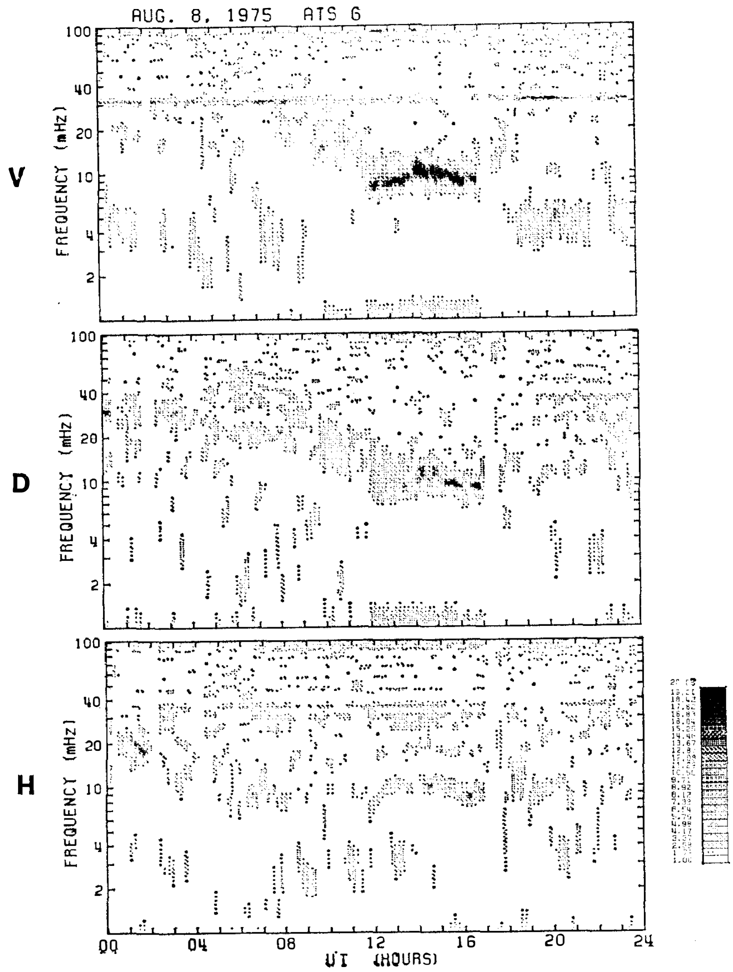

Fig. 4. Dynamic spectra of magnetic pulsations observed by the ATS 6 satellite on August 8, 1975. Format is the same as that shown in Fig. 1. Note that the satellite was located at the magnetic latitude of 3° S during this period.

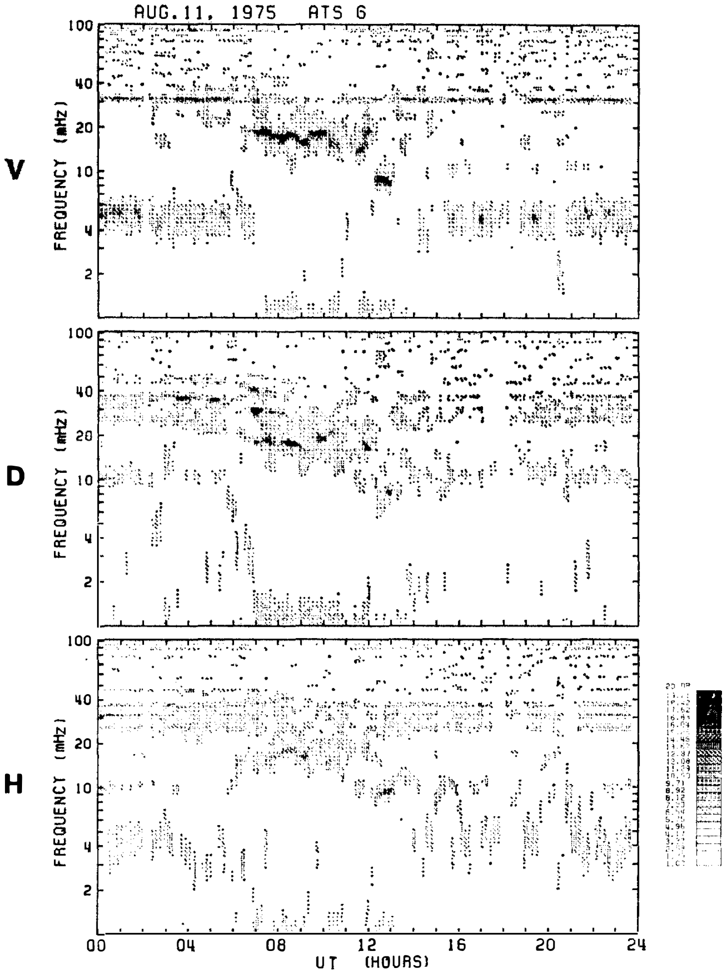

Fig. 5. Dynamic spectra of magnetic pulsations observed by the ATS 6 satellite on August 11, 1975. Format is the same as that shown in Fig. 1.

and Husafell are a good pair of the conjugate stations. The dynamic spectra of H and D components of magnetic field of these ground stations are displayed in Fig. 6. The spectra of H and D components show similar spectral features with each other. Two dominant spectral bands exist in the daylight hours (MLT $\sim$ UT); one is Pc 4–5 band in the frequency range from 3 mHz to 10 mHz, and the other is the Pc 3 band in the frequency range from 20 to 80 mHz. The Pc 4–5 band appears similarly to the lowest trend which was observed when ATS 6 was located off the magnetic equator. On the other hand, Pc 3 band is composed of several spectral peaks of rather clustered structure. The clustered structure of Pc 3 pulsations is clearly seen in the H component rather than in the D at every station. Although this structure may correspond to the harmonic structure seen frequently in the azimuthal component observed at ATS 6, the structures are complicated rather than those seen in the satellite data.

The reasons may be partly due to the effect of an accumulation of the signals propagating through the different paths in the magnetosphere and partly due to the screening effect of the ionosphere. These effects may be superposed on the signals and result the unclear structures of the magnetic pulsations. These effects need to be examined in more detail.

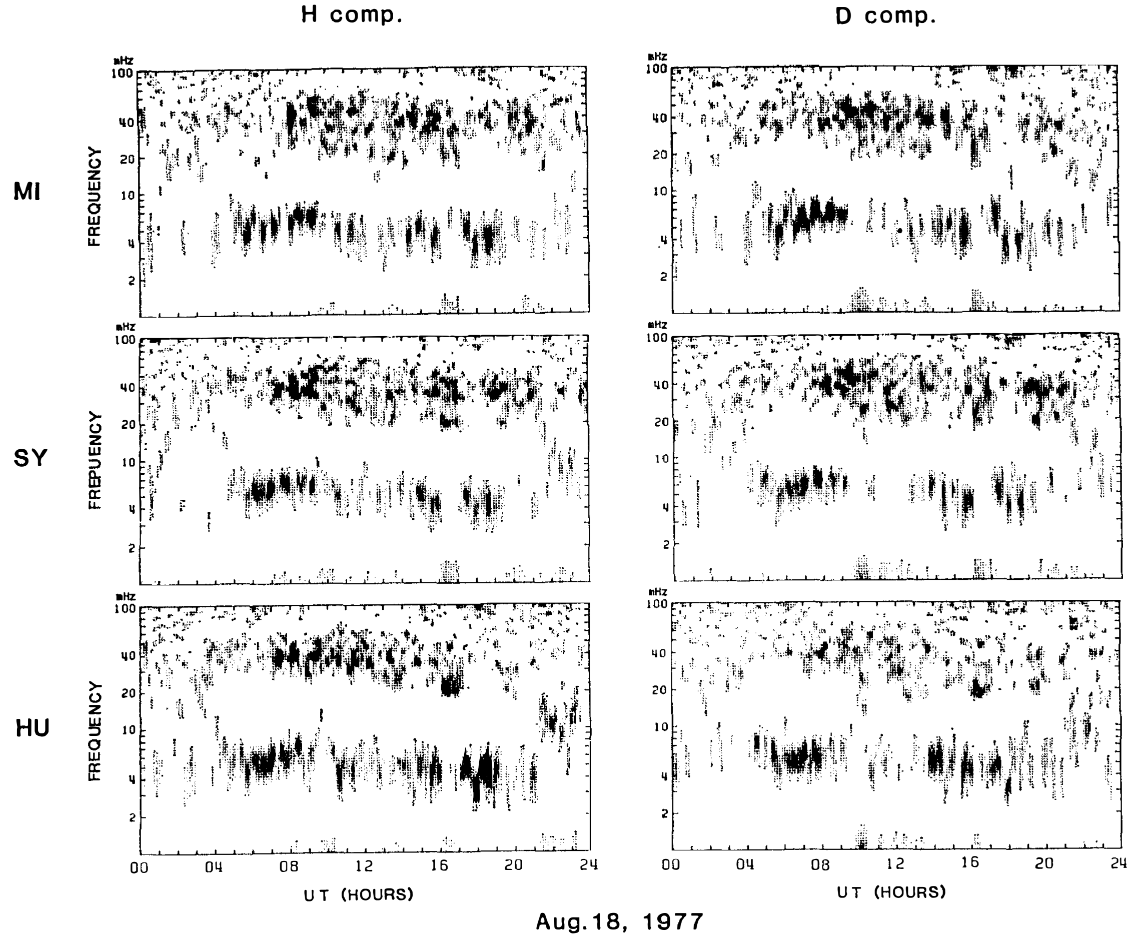

Fig. 6. The dynamic spectra of magnetic pulsations observed at the high latitude ground stations, Mizuho (MI), Syowa (SY) and Husafell (HU) on August 18, 1977. At these stations, the magnetic local time is almost equal to the universal time.

4. Summary and Conclusions

Comparing with dynamic spectra of magnetic pulsations observed at the satellite and at the high latitude ground stations, it was found that the Pc 3, 4, and 5 magnetic pulsations generally show similar spectral characteristics both at the satellite and at the ground. The important characteristics seen in the dynamic spectra are summarized as follows:

(1) Several dominant spectral trends are seen in the azimuthal component of the magnetic field at the satellite location.

(2) These trends are composed of harmonic structures.

(3) The spectral structures seen at the satellite are very sensitive to the satellite location with respect to the magnetic latitude along the magnetic field line. When the satellite was located 10° above the magnetic equator, two dominant spectral trends are clearly seen; *i. e.* one of them is the lowest frequency trend in the frequency range of Pc 4 and Pc 5 (3–10 mHz) and the other trend is in the Pc 3 frequency range (20–80 mHz).

(4) On the other hand, when the satellite was located near the magnetic equator, the lowest frequency trend was not recognized in any component of the magnetic field. The spectral trend of Pc 4 appeared dominantly in the radial (V) component of the magnetic field and not in the azimuthal (D) component. However, the harmonic structures in frequency can be clearly recognized in the D component rather than in the V component.

(5) The spectral trend in the Pc 4–5 frequency range is also seen in the dynamic spectra obtained at all the ground stations. The fine structures in the trends of Pc 3 are not so clear as those seen at the satellite and become complicated structures appearing as a cluster.

Therefore, the spectral analyses of the magnetic pulsations observed in space and on the ground suggest that the magnetic pulsations in the frequency range from Pc 3 to Pc 5 oscillate with several harmonic modes in space and propagate to the ionosphere as shear Alfvén waves along the resonant field line in the magnetosphere. Further detailed harmonic structures of magnetic pulsations will be clarified with the examination of phase relation between the conjugate stations. Fortunately, it will be carried out by using the data at a good conjugate pair stations, Syowa and Husafell.

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