The Appearance of Beat Frequencies Caused by AIC Waves in an Analysis of End-Loss Ion Current in the Tandem Mirror

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Alfvén ion-cyclotron (AIC) waves of various frequencies have been measured in the central cell of a tandem mirror, excited due to non-isotropic ion heating. Differential frequencies of the AIC waves were observed by analyzing the fluctuations of the end-loss ion current. From the analysis of both the frequency and intensity of the fluctuations, it was found that the differential frequencies are generated by the beat phenomenon caused by the AIC waves. The AIC waves affect the ion transport in the velocity space, and this phenomenon can be used to investigate the ion transport from the trapped region to the loss region in the tandem mirror.

Keywords:

tandem mirror, end-loss ion, Alfvén ion-cyclotron wave, beat frequency, ion transport

Ion heating in the central cell of the tandem mirror is carried out by injection of the ion-cyclotron range of frequency (ICRF) waves. The Alfvén ion-cyclotron (AIC) waves in the central cell have been excited by the non-isotropic ion heating [1-3]. The trapped ions in the tandem mirror are influenced by the AIC waves on the ion transport in the velocity space [4]. The velocity and energy distribution functions of the end-loss ions have been measured by using an end-loss energy component analyzer (ELECA) having a 20-channel micro-channel plate (MCP) located on the end of the machine [5]. Ion transport from the trapped region to the loss region is one of the important subjects in the investigation of the confinement of the tandem mirror device. Through the observation of various fluctuations in the end-loss ion current, we report the beat phenomenon caused by the AIC waves.

In order to extensively and simultaneously analyze the frequencies of the fluctuations of the end-loss ion current, we prepared two types of analog-to-digital converters (ADC) whose sampling frequencies are 333 kHz and 64 MHz, respectively. The high frequency ADC has a single channel and analyzes the summed signal of the MCP detector. The low frequency ADC has 20 channels. Figures 1 and 2 show the three-dimensional frequency spectra of the AIC waves and time evolution of $\tilde{I}/I$, respectively, where I is the end-loss ion current. Three kinds of AIC waves and two kinds of fluctuations with the differential frequency were observed in the end-loss ion current. The differential frequencies derived from the AIC waves were compared with the frequencies of the fluctuations analyzed through the low frequency ADC as

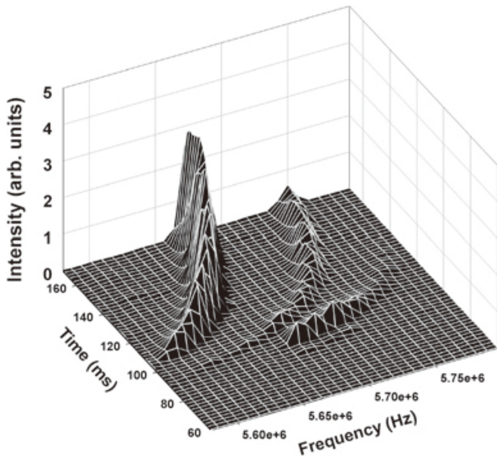

Fig. 1 AIC waves of three kinds of frequencies.

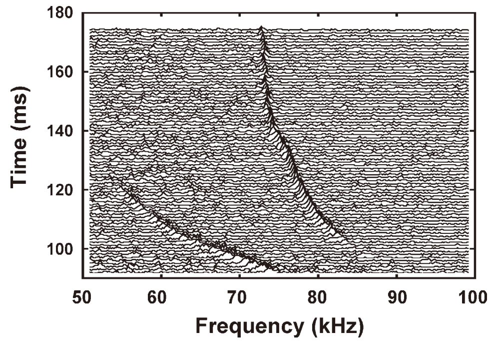

Fig. 2 Two fluctuations of the differential frequency.

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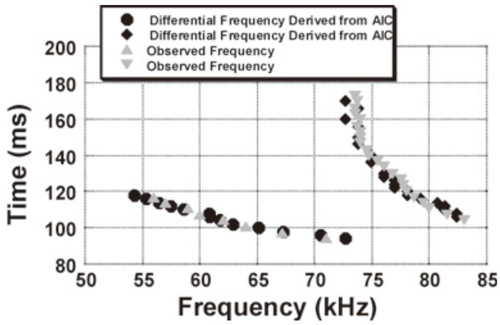

Fig. 3 Comparison of the frequencies.

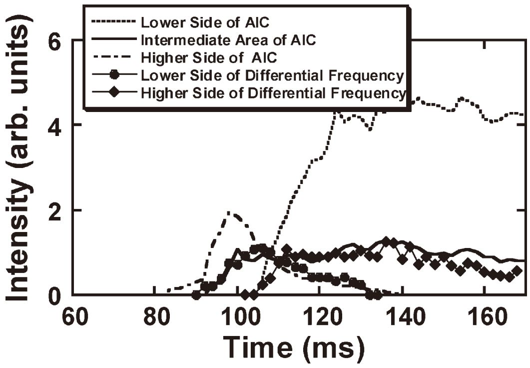

Fig. 4 Intensity's time evolution of the AIC waves and the fluctuations of the differential frequency.

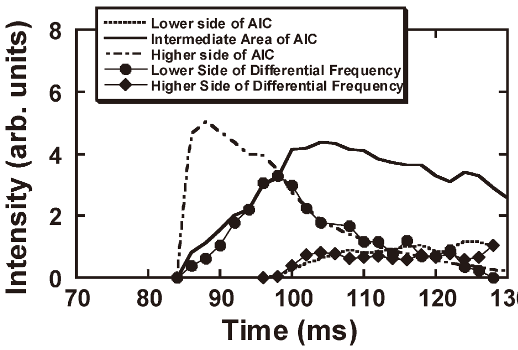

Fig. 5 Intensity's time evolution of the AIC waves and the fluctuations of the differential frequency.

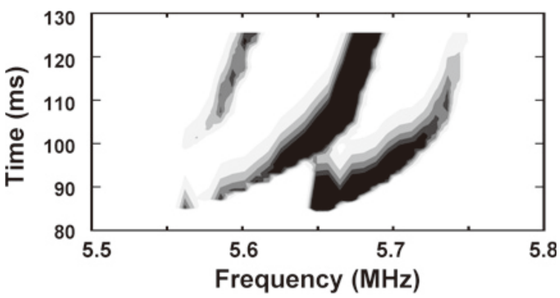

Fig. 6 Logarithmic contour plots of the AIC waves.

shown in Fig. 3. These frequencies agree closely with each other. We paid attention to the relation between the intensity of the AIC waves and that of the fluctuations of the differential frequency. In Fig. 4, the dotted, solid, and dashed-and-dotted lines indicate intensity of the lower side of the AIC wave, the intermediate area of the AIC wave and the higher side of the AIC wave, respectively. The closed circles and diamonds indicate the intensity of the lower side and the higher side of the fluctuations, respectively. The closed circle line is normalized so as to coincide with the solid line at 110 msec.

Figure 5 shows another example of the intensity's time evolution corresponding to the AIC waves shown in Fig. 6. The closed circle line is normalized so as to coincide with the solid line at 98 msec. From the experimental results, it was found that the amplitude of the fluctuation of the differential frequency depends on the smaller amplitude of the neighboring AIC waves.

We estimated the frequency and the amplitude of the beat produced by the following two waves (amplitude: A, phase: θ, angular frequency: $\omega_1 \gg \Delta\omega$),

$$z_1(t) = A_1 e^{i(\omega_1 t + \theta_1)},$$
$$z_2(t) = A_2 e^{i((\omega_1 + \Delta\omega)t + \theta_2)},$$
$$z(t) = z_1(t) + z_2(t) = A(t) e^{i(\omega_1 t + \theta_1 + \phi(t))},$$

$$A(t) = \sqrt{A_1^{\ 2} + A_2^{\ 2} + 2A_1A_2\cos(\Delta\omega t + \theta_2 - \theta_1)},$$
$$\phi(t) = \tan^{-1}\left\{\frac{A_2\sin(\Delta\omega t + \theta_2 - \theta_1)}{A_1 + A_2\cos(\Delta\omega t + \theta_2 - \theta_1)}\right\}.$$

The angular frequency of the beat is $\Delta\omega$, and the fluctuation of $A(t)$ depends on the smaller amplitude of the original two waves. The experimental results indicate the beat phenomenon well. We also observed the beat fluctuations in the core plasma of the central cell by use of a gold neutral beam probe (GNBP). In this paper, we analyzed the beat signal obtained from one channel of the detector. The 20-channel ELECA device gives us information regarding the pitch angle of the end-loss ion. In a previous study we found the dependence of the beat signal on the pitch angle. The appearance of the beat phenomenon in the loss region can provide an important approach to the investigation of ion transport in the velocity space due to the electromagnetic AIC waves. The present paper describes the basic data regarding this phenomenon.

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