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Behavior of the Temperature Anisotropy Driven ICRF Wave in the Inner Region of the GAMMA10 Plasma

温度非等方性が駆動するICRF波動のGAMMA10プラズマ内部領域における挙動

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Behavior of a temperature anisotropy driven ICRF wave, named Alfvén ion cyclotron (AIC) wave, is investigated in GAMMA10 by using a microwave reflectometer and edge magnetic probes. The frequency spectrum of the AIC wave has several discrete peaks in GAMMA10. Simultaneous measurement of the internal density fluctuation and edge magnetic fluctuation shows that AIC waves grow as the same radial eigenmode, and so the separation of peaks arises from some axial boundary condition. To investigate the axial behavior of AIC waves, reflectometer system is being upgraded.

1. Introduction

GAMMA10 is the world's largest tandem mirror machine and characterized with strong temperature anisotropy because of loss corn nature of mirror trap and strong ICRF heating of a few hundred kW. Here, temperature anisotropy is defined as the ratio of component perpendicular to the magnetic field line to that parallel, $T_\perp / T_\parallel$. In the main confinement region named central cell, ion temperature and its anisotropy becomes greater than a few keV and 10, respectively. In such plasma, an electromagnetic wave named Alfvén ion cyclotron (AIC) wave becomes unstable and spontaneously excited. Theoretically predicted driving force of AIC wave is proportional to $\beta(T_\perp / T_\parallel)^2$.

In GAMMA10, AIC waves with several discrete peaks in the frequency spectrum are excited simultaneously and those frequencies and the number of peaks vary with the change of plasma parameters [1]. Previous studies using adjacent edge magnetic probe sets have revealed that the axial wave numbers $k_{//}$ of the AIC waves vary from finite (propagating) to zero (standing) [2]. From these edge measurements, following behaviors have been deduced; the AIC waves are excited in the center region of the central cell where both of β and temperature anisotropy seems to be the highest in GAMMA10 and then propagate to the mirror throats. As the high β and the strong anisotropy region extends, the boundary between standing and propagating waves moves to both in axial and radial directions. The detailed spatial structure and the time evolution of the boundary have remained to be clarified, partly because of the lack of internal measurements.

2. Set-up

To investigate the spatiotemporal behavior of the AIC waves in detail, we have developed the internal measurement using a reflectometer. With the use of a reflectometer, we can observe the density fluctuation arising from AIC waves and/or the magnetic fluctuation in the inner region of the plasma [3,4]. At first, we constructed a simple reflectometer system, where a pyramidal horn is used as both transmitter and receiver, which reduces the number of horn antennas that must be installed inside the vacuum chamber. Reflected wave from plasma is separated from the incident wave by a circulator. We used a frequency-variable yttrium-iron-garnet (YIG) oscillator as the microwave source, which enables us to survey the measuring position in radial direction by appropriately tuning the frequency. In this study, the incident frequency is fixed during a shot so that we can measure a time evolution of the density fluctuation at a fixed cut-off layer, and varied shot-by-shot.

3. Radial Evolution of AIC Wave

We have measured inner density fluctuations and also edge magnetic fluctuations, which are digitized in synchronization and then Fourier transformed. We successfully observed several peaks of AIC waves in the frequency spectra of both signals. The coherence between them is found to be well above the statistical noise level in those frequency ranges. Therefore, we can evaluate the phase difference of those two signals. In Figs. 1(b) and (c), we show the radial variations of the phase differences at two time periods shown on Fig. 1(a), which were obtained by varying the incident frequency of the reflectometer shot-by-shot in a series of plasma discharges with discharge conditions fixed. The horizontal axis can be regarded as radius because the cutoff radius is monotonically related to the incident frequency for the GAMMA10 density profile. Figure 1(b) shows that in the initial excitation phase, when the peak frequencies rise rapidly, the radial profiles of the phase differences differ each other except some peaks. In the later steady phase, shown in Fig. 1(c), the difference is diminished, and those radial profiles approach each other. This behavior indicates that several AIC waves grow as the same structure in radial direction, namely as the same radial eigenmode [5].

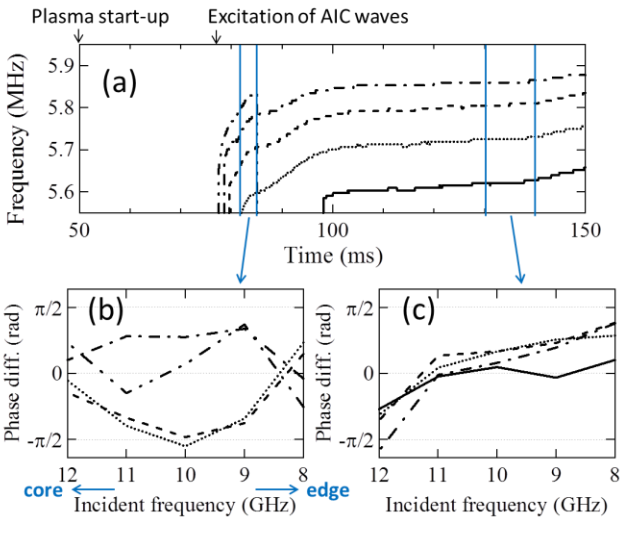

Fig. 1. Frequencies of spontaneously excited AIC waves (a), and phase differences of AIC waves between inner density fluctuation measure with a reflectometer and edge magnetic fluctuation, (b) and (c), which are time averaged over the time periods denoted on (a).

4. Measurement of Axial Correlation

To investigate the axial evolution of the AIC waves in the inner region of GAMMA10 plasma, we have installed new horn antennas at z = 112 and 137 cm with the same azimuthal angle. We have successfully observed density fluctuations simultaneously at these two axial positions by modifying the reflectometer system so as to incident microwaves through two antennas by dividing the power of an oscillator with a 2-way power splitter, and mixes the received reflected waves from two cut-off positions with the reference waves separately. Although, the similar time evolutions of the AIC waves have been obtained, the correlation between them has found to be weak compared with the correlation of signals from a reflectometer and a magnetic probe. Therefore, we couldn’t clearly distinguish the phase difference between them. Reasons for poor correlation may include small gap between magnetic field lines on which the cut-off layers lie, and weak amplitudes of detected signals, and some fluctuations disturbing cut-off layer as to violate clear measurement with a reflectometer.

To carry away the above mentioned causes, we are further upgrading the reflectometer system. The main upgrade is modification of the detecting system from previous homodyne to heterodyne, which enables us to discriminate the phase fluctuation arising from the oscillation of the cut-off layer from the variation of the amplitude of reflected signal, which is neglected on the previous homodyne system. This discrimination might help to improve clarity of density fluctuation from AIC waves. The experiment using this new system is in progress. Furthermore, we plan to use two oscillators so that we can simultaneously measure at two positions which exactly lie on the same field line by appropriately altering the two incident frequencies.

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