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Interactions of High-Energy Ions with High and Low Frequency Fluctuations in the GAMMA 10 Tandem Mirror

GAMMA 10における高エネルギーイオンの高周波および低周波揺動との相互作用

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In the ion cyclotron range of frequency (ICRF) heating experiments on GAMMA 10, wave-wave and wave-particle interactions are investigated. Fluctuations of which frequencies are lower than 100 kHz have been observed in a typical discharge. These low-frequency modes are detected in the signal of electrostatic probes in the central cell and in both signals of high-energy ion detectors in the central cell and at the east end. Radial transport of high-energy ions owing to drift-type and flute-type fluctuations has been observed in the central cell. Axial transport of high-energy ions owing to the Alfvén-ion-cyclotron (AIC) modes is clearly indicated. The fluctuations, of which frequencies are the differential frequency between each discrete peak of the AIC modes, are observed in the signal of the end-loss high-energy ion detector.

1. Introduction

Ion cyclotron range of frequency (ICRF) wave is one of most promising schemes for heating fusion plasmas. When the ICRF power and consequent wave energy levels increase, it will become important to understand the detailed physics of wave-wave and wave-particle interactions. It is required to consider both linear and nonlinear processes for deposition of ICRF powers, for example, the parametric decay of the heating ICRF waves has been observed in many fusion experiments. Axial and radial transports of high-energy ions owing to these waves are studied in this research.

In the GAMMA 10 tandem mirror, ICRF waves have been used for the plasma production, heating and sustaining MHD stability. In a high power ICRF heating experiment, plasmas with strong temperature anisotropy have been formed because the fundamental cyclotron resonance layer exists near the midplane of the central cell. Alfvén-ion-cyclotron (AIC) modes are spontaneously excited due to the strong temperature anisotropy. The AIC modes have several discrete peaks in the frequency spectrum just below the ion cyclotron frequency. Fluctuations of which frequencies are the differential frequency between each discrete peak of the AIC modes are observed. Radial transport of high-energy ions owing to low-frequency drift-type and flute-type fluctuations has been observed in the central cell.[1]

2. Experimental Setup

For the initial plasma production, an ICRF source (RF1) with so-called Nagoya Type-III antennas on both east and west sides of the central cell is used in combination with the hydrogen gas puffing. Fast Alfvén waves are excited in the central cell and propagate to the anchor cell. The MHD stability of GAMMA 10 is kept by the anchor plasma with averaged minimum-B configuration. Another ICRF source (RF2) with conventional double half-turn (DHT) antennas installed on both sides of type III antenna is applied for the main ion heating in the central cell.

The typical plasma parameters are the density of $2 \times 10^{18}\,\mathrm{m}^{-3}$, the ion temperature of more than 5 keV and the temperature anisotropy of more than 10. The temperature anisotropy is estimated from signals of the diamagnetic loop arrayed in the axial direction. Magnetic fluctuations excited in the plasma are detected by using magnetic probe array both in the axial and azimuthal directions and a microwave reflectometer. [2]

To measure the behavior of high-energy ions, diagnostic tools with a semiconductor detector are installed at the midplane of the central cell (central cell High-Energy-ion Detector; ccHED) and the east end cell (east end HED; eeHED). The ccHED is inserted perpendicularly to the magnetic field line and is positioned just outside of the limiter radius in the midplane of the central cell. By rotating ccHED against to the normal axis of the magnetic field line, a pitch angle profile of high-energy ions can be measured. The eeHED can measure high energy ions escaping along the magnetic field line from the core region of the central cell.

3. Experimental Results

The ICRF waves have been used for the plasma production and heating in the GAMMA 10 tandem mirror. Figure 1 shows the temporal evolution of (a) line density and (b) three diamagnetic signals at different locations along the magnetic field line. As shown in the figure, there are large differences between diamagnetic signals near the midplane (z = -0.33 m) and off-midplane (z = 1.5 m and z = 1.9 m). These differences indicate the pressure anisotropy as shown in Fig.1(c). Plasmas with strong pressure anisotropy of more than 10 are formed in the central cell. The AIC modes are excited spontaneously due to such strong pressure anisotropy. ccHED and eeHED are used for the evaluation of the transport of high-energy ions owing to fluctuations in the perpendicular and along the magnetic field line, respectively. The raw signal of eeHED is shown in Fig.1(d). When the diamagnetic signal near the midplane increases and the temperature anisotropy becomes high, the eeHED signal increases suddenly. Fluctuations are contained in the eeHED signal as shown in the figure. The frequency spectrum of the eeHED signal is analyzed as shown in Fig.1(e). Fluctuations around 100 kHz, of which frequencies are differential frequencies between discrete peaks of the AIC-modes, are clearly observed. These fluctuations are also detected in the signal of magnetic probes installed on the central cell.

On the other hand, radial transport of high-energy ions owing to low-frequency drift-type and flute-type fluctuations has been observed in the central cell. ccHED is located just outside of the limiter radius at the central cell midplane and can detect high-energy ions which escape from the confined region near their turning points in the perpendicular direction.[1]

The pitch angle scattering owing to the spontaneously excited Alfvén waves and the radial transport owing to low-frequency drift-type and flute-type fluctuations are clearly detected experimentally.

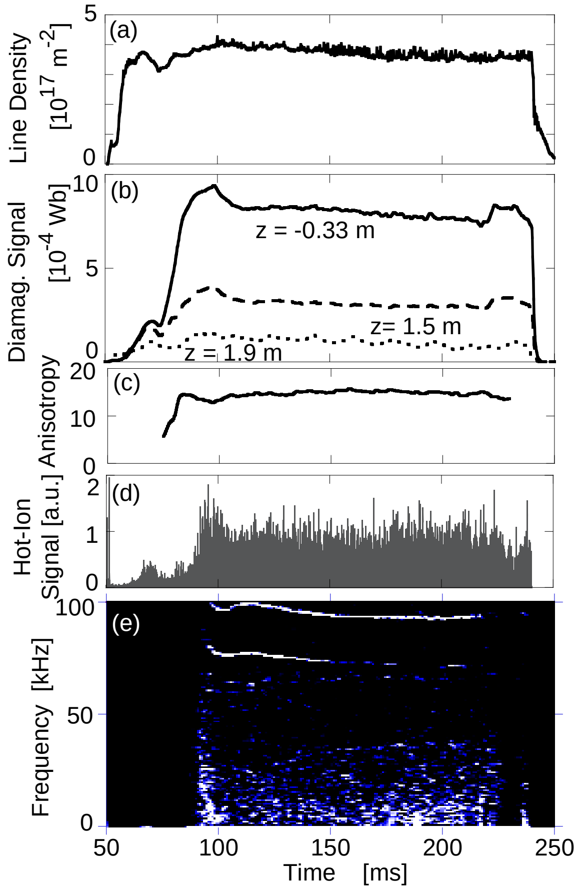

Fig.1 Temporal evolution of (a) line density, (b) diamagnetic signals at z=-0.33 m, 1.5 m and 1.9 m, (c) estimated pressure anisotropy, (d) raw signal of eeHED and (e) an intensity plot of the frequency spectrum of the eeHED signal.

4. Summary

Wave-particle interactions observed in GAMMA 10 are described. The first is the pitch angle scattering of high-energy ions owing to the fluctuations of which frequencies are differential frequencies between discrete peaks of the AIC modes. The second is the radial transport of high-energy ions owing to drift-type and flute type fluctuations near their turning points in the confining mirror field.

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