§5. Excitation Characteristics of Nonlinear Electromagnetic and Electrostatic Waves Due to High Power Plug ECRH

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Electron cyclotron waves are important plasma waves relating to an efficient electron heating and a formation of local confining-potential structure in tandem-mirror fusion devices. The GAMMA10 tandem-mirror device at the University of Tsukuba has made a new record of confining-potential height with the introduction of high-power gyrotrons for electron cyclotron resonance heating (ECRH) in the plug/barrier cells. However, it is likely that the high-power wave injection enhances nonlinear effects leading to a degradation of the heating and potential-formation efficiencies.

Based on the above-mentioned backgrounds, the purpose of this work is to investigate the nonlinear effects relating to high-power microwave of several hundred kW in GAMMA10, such as parametric wave-wave interactions between injected electromagnetic and electrostatic waves.[1)]

Experiments are carried out with a plasma in the west plug/barrier cell of the GAMMA10 tandem mirror. The plasma is produced in the central solenoid region by radio-frequency (RF) wave heating, and a potential barrier created by ECRH in the plug/barrier cells at the machine ends prevents the plasma from flowing out along the field lines. The electron cyclotron waves at 28 GHz are delivered to the fundamental resonance layer of 1 T for the plug and to the second harmonic layer of 0.5 T near the mid-plane for the thermal barrier. We have set up a measurement system for receiving and analyzing electromagnetic radiation in the electron cyclotron range of frequencies, which consists of a movable receiver antenna, a heterodyne circuit with a Gunn oscillator (27.9 GHz, 13 dBm), a balanced mixer, and a spectrum analyzer.

When the plug and barrier ECRH are superimposed, several sharp peaks are observed in the frequency spectra of electromagnetic waves radiated from the plug region, the frequencies of which are around the injected electromagnetic-wave frequencies (28.00 GHz for plug, 28.06 GHz for barrier ECRH) at intervals of about 20 MHz.[1)] It is considered that these electromagnetic components are generated by nonlinear effects related to an increase in the ECRH power, e.g., parametric instability coupling to electrostatic waves in plasmas. Here, the ion cyclotron frequency $\omega_{ci}/2\pi$ of hydrogen atomic ion in the plug region is about 15 MHz and comparable to the observed frequency interval. Thus, there is a possibility that the nonlinear waves are driven by the coupling to a wave in the ion-cyclotron range of frequencies (ICRF).

In order to verify the above-mentioned parametric instability between the injected waves and the ICRF wave, electrostatic fluctuations are measured by the Langmuir probe set in the barrier region (B = 0.49 T). Figure 1 shows a typical frequency spectrum of floating potential ϕ_f of the Langmuir probe for $P_{PECH} = P_{BECH}$ = 0 W, where $\omega/2\pi$ is an electrostatic frequency. It is found that the narrow band electrostatic fluctuations of 9.6 MHz, 18.5 MHz, and 29.3 MHz exist in the barrier region. The waves of 18.5 MHz and 29.3 MHz appear to be the second and third harmonics of the electrostatic wave of 9.6 MHz. Here, the theoretical ion cyclotron frequency at this point is about 7.5 MHz and comparable to the fundamental frequency shown in Fig. 1.

Thus, we are guessing that the observed electrostatic fluctuations in ICRF are derived from the electrostatic ion-cyclotron wave instability, whose frequency difference from $\omega_{ci}/2\pi$ may be due to the term of $C_s k$ in its dispersion relation, where C_s and k are an ion acoustic velocity and a wavenumber. The frequency spectrum of floating potential for P_{PECH} = 300 kW and P_{BECH} = 120 kW is also measured in our experiment; the electrostatic ion-cyclotron wave instability with the same frequencies as Fig. 1 is confirmed to be detected. This fact indicates that the injected electromagnetic waves for plug/barrier ECRH could be coupled to the electrostatic waves which originally exist around the plug/barrier region.

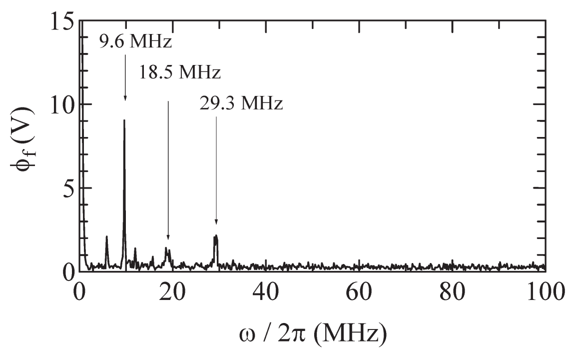

Fig. 1. (a) Frequency spectrum of floating potential ϕ_f of the Langmuir probe set in the barrier region (B = 0.49 T).

Reference

1) Kaneko, T., Takahashi K., Hatakeyama R., Saito T., Tatematsu Y., Nozaki K., Machida N., Kaitsuka T., Itakura A., Yoshikawa M., and Cho T. : Trans. Fusion Sci. Technol. **51** (2007) 154.