SUPPRESSION AND ENHANCEMENT OF UNSTABLE ION CYCLOTRON HARMONIC WAVES BY RF FIELD IN AN ION BEAM AND INHOMOGENEOUS PLASMA SYSTEM

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Abstract

In an ion beam-inhomogeneous plasma system, when the drift frequency ω^* exceeds the harmonics of the ion cyclotron frequency $n\omega_{ci}$, the electrostatic ion cyclotron harmonic waves are excited by the coupling with drift waves, and are enhanced by an ion beam injection parallel to the magnetic field. Ion cyclotron harmonic waves with frequencies up to $4\omega_{ci}$ are observed experimentally. By the application of externally launched rf field near the lower hybrid frequency (the frequency = 50-65 MHz), the suppression of these unstable waves has been observed. Suppression is due to ponderomotive force, which upshifts the frequency of these waves. For pump rf field of the frequency above 66 MHz, the enhancement of unstable waves has been observed.

1 Introduction

The instability at the multiple ion cyclotron harmonics in the magnetized ion beam–plasma system is of interest, in part, in order to obtain its possible emission mechanism. In the vicinity of polar cusp region of the magnetosphere, the broadband electrostatic emission at the ion cyclotron harmonics has been observed[1,2] but, the mechanism for generating these emission remains uncertain. When the electron drift frequency ω^* exceeds harmonics of the ion cyclotron frequency $n\omega_{ci}$, ion cyclotron harmonic (ICH) waves may be excited by coupling between electron drift waves[3] generated on the inhomogeneity and the ion Bernstein waves[4]. We have observed the strong excitation of ICH waves, when the ion beam is injected parallel to the magnetic field in a cylindrical plasma[5]. By the application of externally launched *rf* field near the lower hybrid frequency (50–65 MHz), the suppression of these unstable ICH waves has been observed. Also, naturally excited drift waves are simultaneously suppressed[3]. When the frequency of applied *rf* field is larger than 66 MHz, the enhancement of unstable ICH waves has been observed by the parametric decay instability of lower hybrid waves.

2 Experimental Apparatus and Procedures

Experiments are performed in the linear vacuum chamber of 10 cm in diameter and 90 cm long[5]. The ion beam source that is generated by an argon gas discharge (via a cold cathode) is set at the end of the chamber in the uniform magnetic field B_0 (B_0=100-700 G). Ion beam with diameter=9 mm is extracted by applying the dc potential (V_a=100–500 V) between the anode electrode of the ion beam source and the mesh accelerating electrode (diameter of mesh =10 mm). Ion beam is continuously injected into the plasma produced by a dc argon gas discharge (via a hot cathode) at the opposite side of the ion beam source. The externally *rf* field is applied to one of accelerating electrodes of the ion beam. The region in a beam–plasma system is maintained at pressure $p \simeq 1$ mTorr. The plasma density and electron temperature are measured by axially and radially movable Langmuir probes, and the wave intensity received with axially and radially movable antennas is detected by the spectrum analyzer.

3 Experimental Results

In an ion beam–plasma system, spontaneously excited waves appear at the frequency $\omega > n\omega_{ci}$ (n is an integer, ω_{ci} is the ion cyclotron frequency). The typical frequency spectra of unstable waves are shown in Fig. 1, where $\omega_{ci}/2\pi$ = 12.4 kHz, and the estimated inhomogeneity $\omega^*/\omega_{ci} \simeq 2.4$ (for the azimuthal mode number of waves $\ell = 1$) and 4.8 (for $\ell = 2$). Then ω^* exceeds $4\omega_{ci}$. It is seen that waves up to 5th mode are at least unstable. We estimate the wave numbers of each unstable wave. We cannot obtain any axially and radially propagating patterns, although we measure by using the interferometer method. These waves are therefore considered to be full standing waves in the cylindrical frame. By measuring the axial and

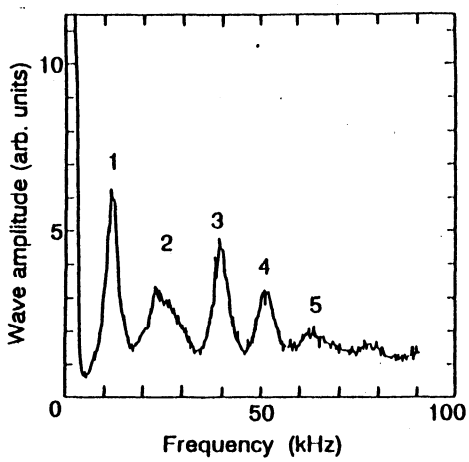

Fig. 1 Frequency spectra of unstable waves.

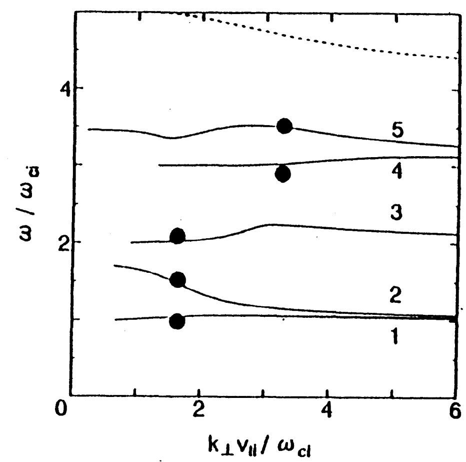

Fig. 2 $k_\perp - \omega$ diagram, where solid circles is plots observed.

radial amplitude profiles of unstable waves, the wave number of each wave is estimated. The parallel wave number of each modes can be taken as $k_\parallel = m\pi/L$, is estimated to $\simeq 0.046$ cm^{-1} (m=1) for modes of 1, 2, and $\simeq 0.092$ cm^{-1} (m=2) for modes of 3–5. Then these modes can satisfy approximately the relation $\omega = k_\parallel v_b$ or $\omega = k_\parallel v_b - \omega_{ci}$. It is considered that all unstable modes therefore interact with the ion beam via Cherenkov and cyclotron coupling[5]. The radial profile of these wave amplitudes can see as that of ℓth Bessel function ($\ell \geq 1$). We therefore take the radial wave number k_r as $3.8/r_p \simeq 1.52$ cm^{-1} for $\ell = 1$ and $5.1/r_p \simeq 2.04$ cm^{-1} for $\ell = 2$, where ℓ becomes the azimuthal mode number. We analyze numerically the dispersion function $\varepsilon(\omega, \mathbf{k})=0$[4,5] in the inhomogeneous ion beam–plasma system. Figure 2 shows numerical dispersion diagram $k_\perp - \omega$ for $k_\parallel$=0.046 cm^{-1} (lower two modes), 0.092 cm^{-1} (higher four modes), and corresponding numerical growth rate versus $k_\perp$ in Fig. 3. We can take values of $k_\perp$ as $\ell = 1$ for 1-3 modes, and as $\ell = 2$ for 4, 5 modes. Thus obtained values of $k_\perp - \omega$ are plotted by solid circles in Fig. 2. It is seen that five unstable waves in the experiment agree with the numerical ICW waves with regard to the frequency and growth rate. Therefore unstable waves are ICH waves excited by the plasma inhomogeneity and the ion beam injection. When the *rf* field near the lower hybrid frequency is externally launched,

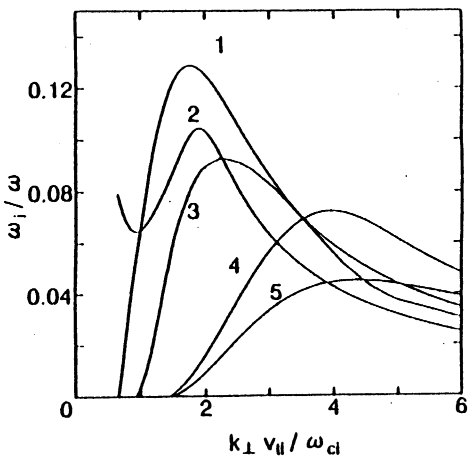

Fig. 3 The growth rate versus $k_\perp$ for modes denoted by 1–5.

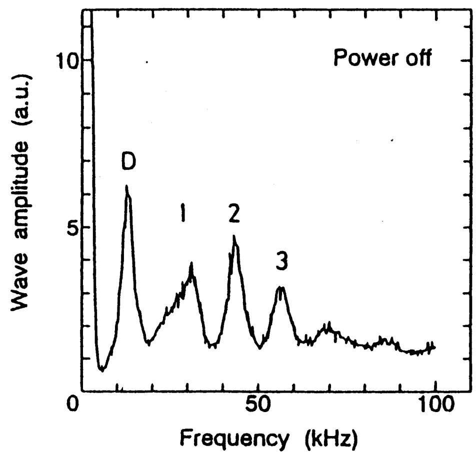

Fig. 4 Frequency spectra of unstable waves for no *rf* field.

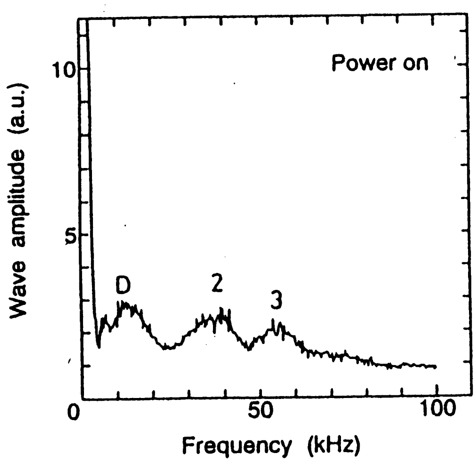

Fig. 5 Frequency spectra of unstable waves for pump *rf* field.

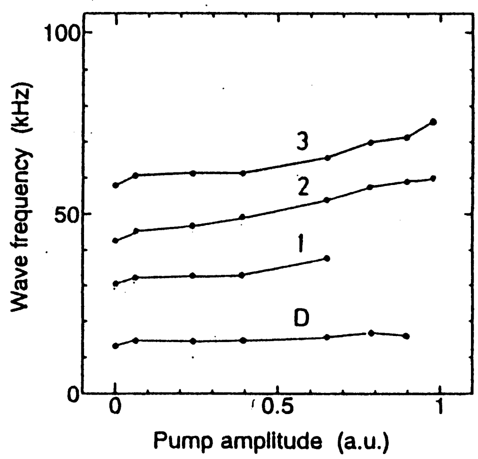

Fig. 6 Frequency of unstable waves versus amplitude of pump *rf* field.

typical frequency spectra of unstable waves are shown in Fig. 4 and Fig. 5 for no pump and the pump of *rf* field (60 MHz), respectively, where the wave with the lowest frequency is the drift wave. The fundamental ICW mode almost disappears, and the amplitude of the drift wave, 2nd and 3rd ICW modes is reduced by *rf* field. Figure 6 shows the frequency of unstable waves versus the amplitude of the pump *rf* field. It is seen that the frequency of each unstable modes increases to a factor $\simeq 1.3$ due to the pump of *rf* field. This results indicate that the ponderamotive force via *rf* field upshifts the frequency of these waves, thus enhances the electron Landau damping, and waves damp. Figure 7 shows frequency spectra of lower and upper sideband waves about the pump frequency 60.65 MHz of pump *rf* field. Each lower and upper sideband waves which corresponds to the frequency of each unstable mode are seen. The ponderamotive force above-mentioned is due to the pump *rf* field and the field of each sideband wave. Figure 8 shows the amplitude of unstable modes versus the frequency

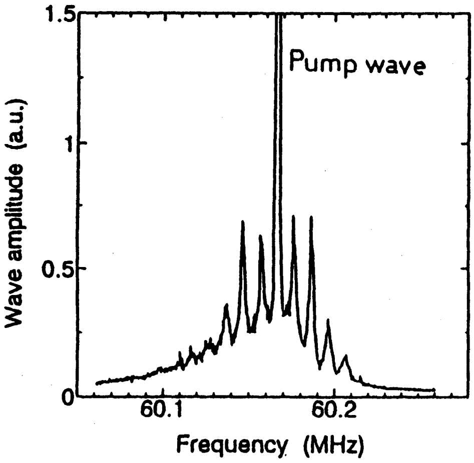

Fig. 7 Lower and upper sideband frequency spectra about pump frequency spectra.

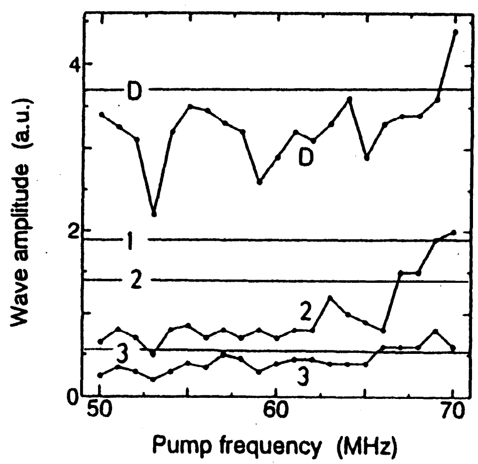

Fig. 8 Amplitude of unstable waves versus frequency of pump *rf* field.

of pump *rf* field, where horizontal bars are the level of the amplitude of each unstable mode for no pump of *rf* field. This shows the suppression of all unstable waves in the range of the pump frequency 50–66 MHz. On the other hand, when the frequency of applied *rf* field is larger than 66 MHz, the enhancement of unstable ICH waves is observed, and the drift wave also enhances for the pump frequency above 70 MHz. Then the amplitude of lower sideband waves becomes much larger than that of upper sideband waves. It is considered that the mechanism of the enhancement attribute to the parametric decay instability of lower hybrid waves.

References

[1] Ashour-Abdalla M. and Thorne R. M. 1977 *Geophys. Res. Lett.* 4, 45.

[2] Benson R. F. 1985 *J. Geophys. Res.* 90, 2753.

[3] Praburam G., Honda H. and Sugawa M. 1993 *J. Phys. Soc. Jpn.* 62, 4262.

[4] Mikhailovskii A. B. 1974 *Theory of Plasma Instabilities Vol. 2 Instabilities of an Inhomogeneous Plasma* (Consultants Bureau, New York-London, 1974) Part 1.

[5] Sugawa M., Iwamoto S., Kondo T., Utsunomiya S., Maehara T. and Sugaya R. *1996 Proceedings of the 1996 International Conference on Plasma Physics*, Nagoya (The Japan Society of Plasma Science and Nuclear Fusion Research, 1996) Vol. 1, p. 82.