Observation of Competition between Drift Instability and Flute Instability in a Bounded Linear ECR Plasma

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Competition behavior between the drift instability and the flute instability has been investigated experimentally in a bounded linear electron cyclotron resonance (ECR) plasma. Time evolutions of the fluctuation in ion saturation currents clearly show the successive appearance of the two instabilities. The drift instability is excited first, then the flute instability appears along with the suppression of the drift instability, and finally, both fluctuations are stabilized. The cyclic competition process in these instabilities continues periodically, and is closely related to the radial density profile.

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It has been considered that drift waves and their associated turbulence induce ‘anomalous transport’ in magnetic confinement devices such as tokamaks and stellarators [1]. Recently, the interaction between drift wave and meso-scale structures, e.g., zonal flows, has also been observed [2]. The nonlinear interaction of drift waves and their associated turbulence plays an important role in the structural formation [3]. In addition, the multi-scale interaction between dissipative instabilities, such as the collisional drift instability and the dissipative trapped electron instability, and reactive instabilities, such as the flute instability or the ion-temperature-gradient (ITG) mode instability, has attracted attention in terms of the magnetic confinement devices. Understanding the mechanism of the drift wave turbulence, therefore, is now one of the most important issues in plasma confinement studies.

We have already observed the coexistence of the collisional drift instability and the flute instability in a bounded linear ECR plasma device [4]. Study of this coexistence phenomenon is expected to clarify the interaction between dissipative and reactive instabilities, and to comprehensively clarify the multi-scale turbulence. In the preceding work [4] only an auto power spectrum was treated, and we found typical behaviors of time-averaged phenomena. In this article we investigate temporal evolutions of the fluctuations in detail and report the first observation of competitive behavior between the two instabilities.

The experiments were performed in a bounded linear ECR plasma device. The cylindrical vacuum chamber had an inner diameter of 400 mm and axial length of 1200 mm. The magnetic coil assembly consisted of eight coils (64 mm in z axial-width, 715 mm in inner diameter) forming a mirror magnetic field, with a mirror ratio of 1.5. The fluctuations of the ion saturation current I_{is} were measured with a Langmuir probe. The tungsten probe tip was 1 mm in diameter and 2 mm in length. Experiments were performed under the following conditions: the magnetic field strength $B = 685$ Gauss, the microwave input power $P_{\mu} = 300$ W, the neutral pressure $p_{(\mathrm{Ar})} = 10^{-3}$ Torr, the electron density $n_{\mathrm{e}} \sim 2 \times 10^{11}\ \mathrm{cm}^{-3}$ and the electron temperature $T_{\mathrm{e}} \sim 2$ eV.

The fluctuations of I_{is} at the radial position $r = 4$ cm were measured and the frequency spectrum is shown in Fig. 1. The evaluated spectrum is an ensemble average of

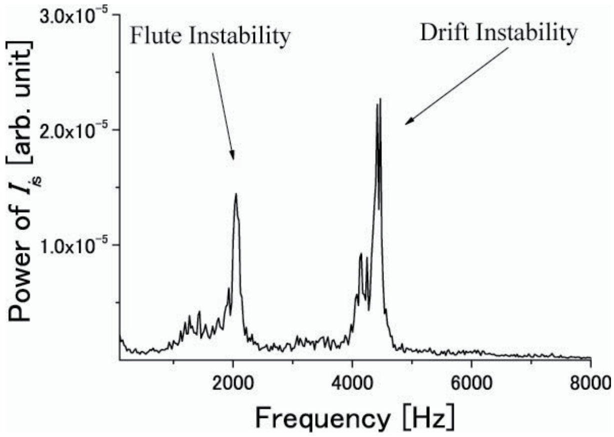

Fig. 1 Frequency spectrum of I_{is} at $r = 4$ cm.

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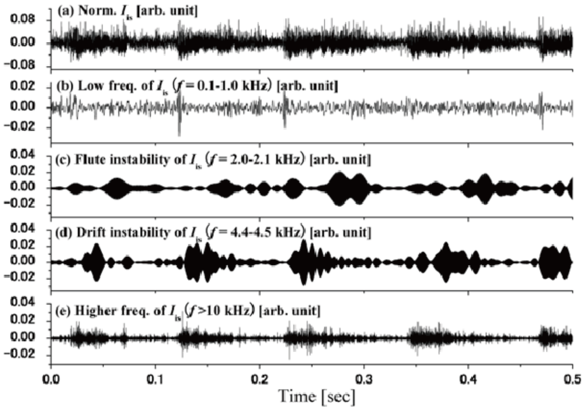

Fig. 2 Time evolutions of (a) normalized I_{is}, (b) low frequency (f = 0.1-1.0 kHz), (c) flute instability (f = 2.0-2.1 kHz), (d) drift instability (f = 4.4-4.5 kHz) and (e) higher frequency ($f \geq 10$ kHz) components.

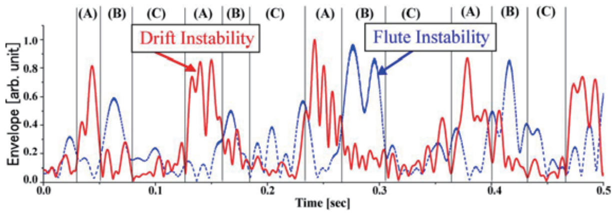

Fig. 3 Time evolutions of envelopes of drift instability and flute instability.

time-varying spectra in a discharge period of 1 sec, where each spectrum was analyzed within a time window containing 4096 data points with a sampling rate of 10 μsec. Two peaks were clearly observed, one corresponding to the flute instability at ∼2.0 kHz ($m/n = 2/0$) and other to the drift instability at ∼4.4 kHz ($m/n = 4/1$).

In order to clarify the time behavior of these instabilities, the fluctuations of I_{is} were measured with band-pass filters of various frequency ranges. Figure 2 (a) shows the time evolution of the fluctuations of normalized I_{is}, and Figs. 2 (b) - (e) show the time evolutions of their various frequency components. The traces (c), (d) and (e) correspond to the flute, drift and high-frequency broad-band components, respectively. These show clear periodical behaviors in each component. We focus here on the relation between the drift and flute instabilities, although a strong correlation between the drift instability and broad-band components was also observed.

To clarify the relation between the two modes, the envelopes of the fluctuation intensity measured with each band-pass filter are shown in Fig. 3. A cyclic process appears, indicated in the figure as (A) - (B) - (C). Here, (A) is the growth of the drift instability in the absence of the flute instability excitation, (B) is the growth of the flute instability with the suppression of the drift instability, and (C) is the stabilization of both instabilities. Competition phenomena between these two instabilities are observed in phases (A) and (B), which indicates the negative correlation between these instabilities. We measured the spatial profiles of plasma density by using multi-channel Langmuir probe arrays simultaneously. The periodic burst shown in Fig. 2 was analyzed by comparison with the modulation of the mean plasma density profile. The excitation and saturation of the fluctuations was correlated with the radial density gradient. When the density gradient becomes high along with the increase of peak density in the radial profile, the drift instability is excited and rapid reduction of the peaked density is observed. The intensity of the drift instability gradually diminishes with the increase of the flute instability excitation. The density gradient increases again, and build-up of the peaked profile occurs after the termination of both fluctuations. The repetition period of around 0.1 sec in the cyclic phenomena is considered to be related to the density build-up time. The analysis of the cyclic dynamics will be discussed in a forthcoming article.

The growth rate of both modes can be evaluated from the logarithmic gradients of the envelopes. The experimental growth rates of the drift instability and the flute instability were obtained by averaging ten sample data, and were $\sim(3 \pm 2) \times 10^2\ \mathrm{s}^{-1}$ and $\sim(1 \pm 0.3) \times 10^2\ \mathrm{s}^{-1}$, respectively. The absolute values of these rates of the drift and the flute instabilities were on the same order of and about a half and one-sixth of the linear numerical growth rates that were given in Ref. [4], respectively. The growth rate of the drift instability was larger than that of the flute instability, which suggesting that the drift instability was previously excited, followed by the flute instability.

In summary, the competition behavior between the drift instability and the flute instability was investigated by envelope analysis. The successive excitation of the drift and flute instabilities formed cyclic competition processes. The growth rate of the two instabilities was closely related with the radial density profile and experimental growth rates of both waves within the same order of the numerical prediction. The modification of the density gradient causes the saturation of the drift instability and works on the flute instability excitation with time delay. This delay is probably related to the density flattening in a localized radial position. A detailed discussion on the density profile modification and dependences on controllable parameters (e.g., a neutral density) will be presented in a forthcoming article. A predator-prey type model should be developed to clarify the whole behavior, which is also left for a future study.

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