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Effects of Radial Potential-Profile Control on Low-Frequency Fluctuations in an ECR-Produced Plasma

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Abstract

Low-frequency fluctuations related to a radial electric field are investigated in a magnetized plasma produced by electron cyclotron resonance. Both flute mode and drift mode fluctuations are observed when the radial potential profile is controlled by biasing a segmented end plate. The flute mode fluctuations, rotating azimuthally with $\boldsymbol{E} \times \boldsymbol{B}$ drift frequency, are predominantly excited in a range of positive electric fields, and destabilized when the $\boldsymbol{E} \times \boldsymbol{B}$ drift shear is increased. The drift mode ones persist when the electric field is nearly zero. The $\boldsymbol{E} \times \boldsymbol{B}$ drift shear appears to affect the stabilization of the drift mode fluctuations.

Keywords:

ECR-produced plasma, potential-profile control, radial electric field, $\boldsymbol{E} \times \boldsymbol{B}$ drift shear, drift mode instability, flute mode instability

1. Introduction

Recently, L-H transitions have been observed in tokamaks [1], stellarators [2], and a mirror machine [3]. It is considered that potential profiles perpendicular to magnetic-field lines and related edge-plasma fluctuations play a crucial role in the plasma transport. Although experimental efforts have been made to investigate effects of radial electric field [4] or radial electric field shear [5] on fluctuations and anomalous transport, much yet remains to be clarified. Thus it is one of the most urgent needs to carry out controlled experiments on this issue by using compact devices, where it is much easier to measure and to control spatial profiles of density, temperature, space potential and fluctuations. The goal of our experiment is to investigate detailed behaviors of low-frequency fluctuations and their relations to the radial electric field or its shear.

2. Experiment Setup

Experiments are performed in the Q_T-Upgrade machine as shown in Fig. 1, which has a cylindrical vacuum chamber with about 4.5 m in length and 0.2 m in diameter. When a 6 GHz microwave with a power of 200 W is injected axially at one end of the machine, a plasma with electron density $n_e \simeq 10^{16}$ m^{-6} and electron temperature $T_e \simeq 7$ eV is produced by Electron Cyclotron Resonance (ECR) discharge with Ar gas pressure of 6.7×10^{-3} Pa. The ECR plasma is formed in the source region and diffuses into the experimental region, where the magnetic field is almost uniform ($B \simeq 0.23$ T), through a 0.1-m-diam circular limiter. The limiter determines the plasma diameter ($D \simeq 0.09$ m) and plays a role in making the plasma more detached from the chamber wall. A metal end plate is set at the other end of the plasma to control radial electric field [6]. The end plate consists of five circular concentric

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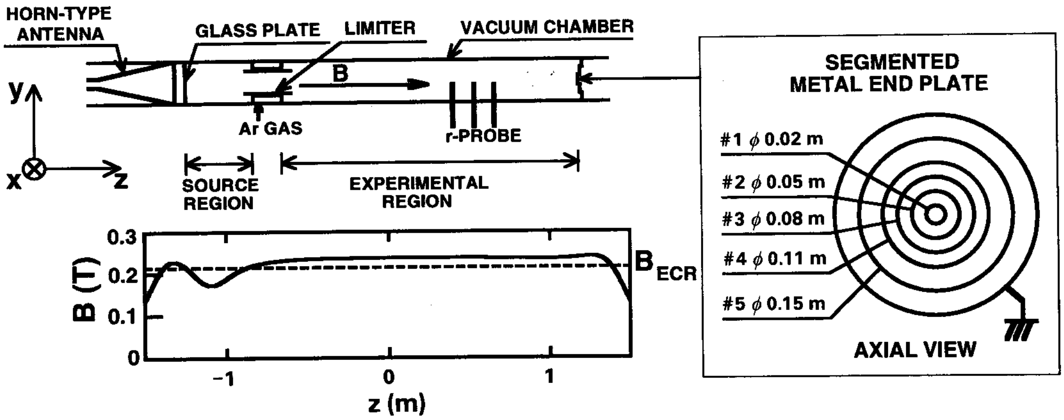

Fig. 1 A schematic view of the Q_T-Upgrade machine and an axial profile of the magnetic field strength.

segmented electrodes. Bias voltages can be applied independently to each segmented electrode and also to the limiter. Hereinafter, the bias voltages of the electrodes set in order from the inside to the outside are called as V_{EP1}, V_{EP2}, V_{EP3}, V_{EP4}, and V_{EP5}, respectively. The bias voltage to the limiter is called as V_L.

Electron density, electron temperature and space potential profiles are measured by Langmuir probes. Fluctuations in the plasma are measured using an electron saturation current J_{es} of the probe and analyzed by an FFT analyzer.

3. Experimental Results

To investigate the effects of the radial electric field on the low-frequency fluctuations, the plasma potential profile is controlled from the hill-type to the well-type by biasing the end plates as shown in Fig. 2 (case 1). In this case, two types of low-frequency fluctuations with the frequency less than a few tens kHz are observed in a region where the density gradient is large ($r \simeq \pm 0.04$ m).

Measurements of azimuthal mode numbers and propagation directions show that some of the fluctuations have the $\boldsymbol{E} \times \boldsymbol{B}$ drift frequency, propagating azimuthally in the $\boldsymbol{E} \times \boldsymbol{B}$ direction. The fluctuation is identified to be a flute mode instability around the ion diamagnetic drift frequency ($\omega_i^*/2\pi \simeq 0$) which is Doppler-shifted by the $\boldsymbol{E} \times \boldsymbol{B}$ drift. The other fluctuations are found to have the frequencies in the region of electron diamagnetic drift and propagate azimuthally in the electron diamagnetic direction. Thus, the fluctuation is identified to be a drift mode instability. It is experimentally confirmed that the former (flute mode) instability is predominantly excited in a range of positive electric fields (hill-type potential profile), while weakly

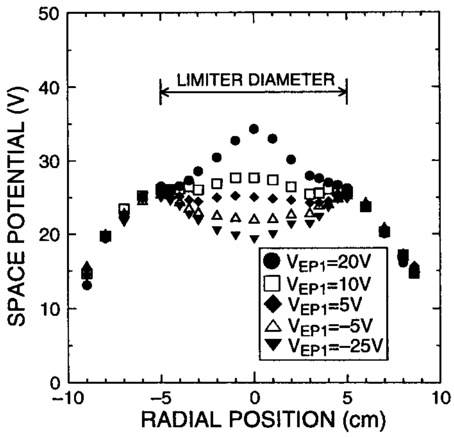

Fig. 2 Radial profiles of the space potential for various V_{EP1} with V_{EP3} = -10 V and V_L = 20 V. Other electrodes are electrically floating.

excited in a range of negative electric fields (well-type potential profile). The latter (drift mode) instability is observed when the electric field is nearly zero and stabilized with an increase in the radial electric field strength.

When the electric field strength is estimated by fitting the potential profile to a parabolic function, the obtained electric field is consistent with the $\boldsymbol{E} \times \boldsymbol{B}$ rotation frequency. The potential profile, however, cannot be precisely approximated by a parabolic function. Thus let us represent the deviation of the potential profile from the fitted parabolic profile by $\overline{\phi}_{dev} = \frac{1}{D}\int_{-D/2}^{D/2} |\phi_{meas} - \phi_{fit}| dr$. Here, ϕ_{meas}, ϕ_{fit} and D are the measured, fitting potentials and the plasma diameter, respectively. This difference of the potential profile from the parabolic one corresponds to the electric-field shear strength. It is gradually enhanced as the radial

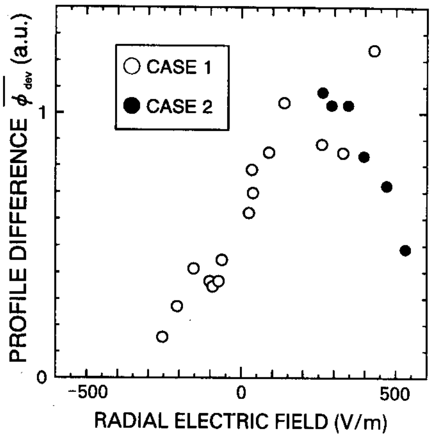

Fig. 3 Difference of the potential profile from the parabolically fitted one versus electric field. The cases 1 and 2 are indicated by open and closed circles, respectively.

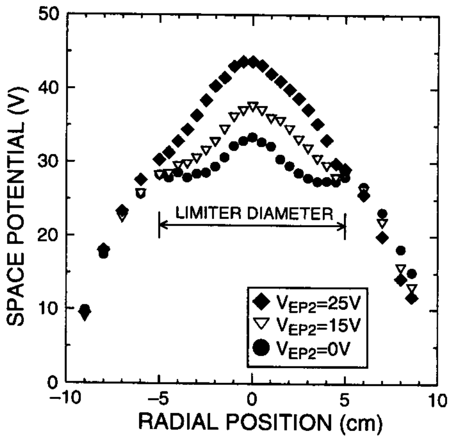

Fig. 4 Radial profiles of the space potential for various V_{EP2} with V_{EP1} = 20 V, V_{EP3} = −10 V and V_L = 20 V. Other electrodes are electrically floating.

electric field is increased from negative to positive, as shown in Fig. 3 (see open circles). Then it is to be emphasized that effects of electric field shear on the instability phenomena have to be taken into account in addition to the effect of electric field strength. In order to clarify the effects of the radial electric field strength and its shear, the potential is more precisely controlled in the vicinity of the typical hill-type profile as shown in Fig. 4 (case 2), where the difference of the potential profile from the fitted parabolic one gradually decreases as the electric field strength is increased (see Fig. 3). Figure 5 shows the fluctuation spectra observed at the position where the density gradient is large. Note that the flute mode strongly depends on the V_{EP2}.

The flute-mode fluctuation amplitude is plotted as a function of the electric field in the case 1 (open circles) and in the case 2 (closed circles) in Fig. 6. The dependence of the flute mode intensity on the radial electric field in the case 2 is clearly different from that in the case 1 especially in the range of E_r = 250 ~ 400 V/m. This means that the difference from the parabolic profile, that is, the shear of $\boldsymbol{E} \times \boldsymbol{B}$ drift rotation strongly affects the flute mode excitation in the positive electric-field region. The flute mode is considered to be the Kelvin-Helmholtz instability which is excited by the $\boldsymbol{E} \times \boldsymbol{B}$ drift shear.

On the other hand the dependence of the drift mode intensity on the electric field is also plotted in Fig. 6. Since the shear of $\boldsymbol{E} \times \boldsymbol{B}$ drift decreases as the electric field strength is increased in the case 2, the drift mode instability appears to be stabilized when the shear of the $\boldsymbol{E} \times \boldsymbol{B}$ drift rotation is increased.

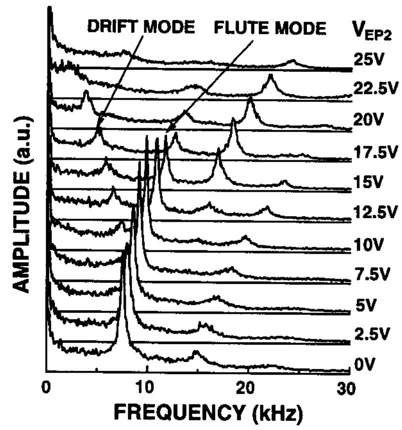

Fig. 5 J_{es} fluctuation spectra for various V_{EP2} in the case 2.

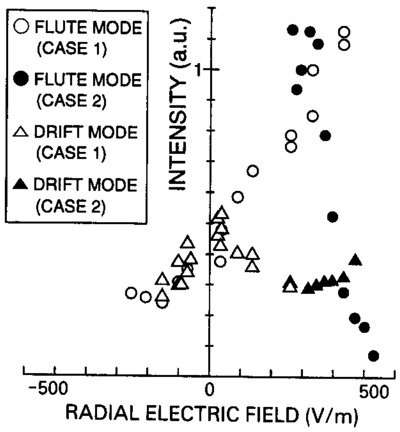

Fig. 6 Dependence of fluctuation amplitudes on the radial electric field. The cases 1 and 2 are indicated by open and closed symbols, and flute and drift mode are indicated by circles and triangles, respectively.

4. Conclusion

In summary, the effect of a radial potential profile on low-frequency fluctuations has been investigated in an ECR-produced plasma, where the radial potential profile is controlled by applying bias voltages to a segmented end plate.

Both drift mode and flute mode fluctuations are observed in the region where the density gradient is large. The flute mode instability which is strongly excited in a range of positive radial electric fields is considered to be the Kelvin-Helmholtz instability. The drift mode instability is stabilized with an increase in the radial electric field regardless of its sign, which also appears to be stabilized by the $\boldsymbol{E} \times \boldsymbol{B}$ drift shear.

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