J. Plasma Fusion Res. SERIES, Vol. 4 (2001) 379–382

# Shear Flow Stabilization of Drift-Wave Fluctuations in an ECR-Produced Linear Plasma

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(Received: 5 December 2000 / Accepted: 27 August 2001)

## Abstract

It is observed that intensity of drift-mode fluctuations destabilized in the range of slightly negative radial electric field are affected by control the ***E***×***B*** rotation frequency shear. When the shear is increased with $E_r$ fixed, the drift-mode fluctuations increase once in a weaker shear region, attain its peak around the shear of ion diamagnetic drift frequency, and then decrease in the stronger shear region. This behavior suggests that the net ion drift shear is effective for stabilizing the drift-mode fluctuation.

## Keywords:

drift mode, flute mode, shear flow, radial electric field, ECR-produced plasma

## 1. Introduction

In confinement-improved modes observed in tokamaks [1], stellarators [2], and a mirror machines [3], a sudden change of radial profile of plasma density and potential is often observed and often correlated with reduction of low-frequency density fluctuations [4].

Radial profile of plasma potential can be controlled by applying bias voltages to a radially-segmented endplate in open-ended $Q_T$-U device [5]. It has been reported that effect of strong ambipolar potentials which stabilize the drift mode are observed experimentally by Mase *et al.* [6]. It is considered that there are effects of radial electric field shear as well as effects of radial electric field in the GAMMA10 results. Furthermore, the dependences of the flute-mode and drift-mode fluctuation intensity on radial electric field are complicated by the effects of radial electric field shear in $Q_T$-U experiment [7]. Therefore, to clarify the effects of radial electric field formation on low-frequency fluctuations, effects of radial electric field and its shear should be separately investigated and it is necessary to carry out more systematically-controlled and precisely-measured experiments on this issue.

The purpose of the present paper is to clarify effects of both radial electric field and its shear on low-frequency fluctuations which are considered to be a main cause of degradation of plasma confinement.

## 2. Experimental Setup

The experiment is performed in the $Q_T$-Upgrade device which has a cylindrical vacuum chamber with about 4.5 m in length and 0.2 m in diameter [7]. The chamber is electrically grounded and the base pressure is kept below $7 \times 10^{-6}$ Torr. A plasma with electron density $n_e \simeq 10^{10}$ cm$^{-3}$ and electron temperature $T_e \simeq 7$ eV is produced by electron cyclotron resonance (ECR) discharge with argon gas pressure of $5 \times 10^{-5}$ Torr. A 6 GHz microwave with a power of 200 W is axially injected through a horn-type antenna located at one end of the device. Surface of the antenna aperture is covered with a glass plate (0.2 m in diameter, 5 mm in width) to insulate the plasma from the antenna which is electrically grounded.

In the plasma-source region a shallow magnetic

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well is formed by depressing the magnetic field strength locally and a plasma is produced in the vicinity of the two ECR surfaces ($B_{\mathrm{ECR}}$ = 2.14 kG). In the experimental region the magnetic field is almost uniform ($B \simeq 2.3$ kG). The plasma produced in the source region diffuses into the experimental region through a 0.1-m-diam metal limiter, the inner surface of which is electrically insulated. The limiter is set between the source and experimental regions and determines the plasma diameter ($D \simeq 9$ cm).

Langmuir probes are inserted radially in the experimental region to measure radial profiles of electron density, electron temperature, and space potential. Fluctuations in the plasma are measured from electron saturation currents $J_{\mathrm{es}}$ of the probes and analyzed by an FFT analyzer.

A metal endplate is set at the other end of the plasma to precisely control both radial electric field and its shear. The endplate consists of ten circular concentric segments. Bias voltages can be applied independently to each segment. Fluctuations are dominantly observed in the region with steep gradient where just inside the limiter edge [8]. The density gradient is very gentle in the core region, therefore it is expected that there is a large shear of ion diamagnetic drift near the limiter edge. To precisely control of the potential profile with and without ***E***×***B*** drift frequency shear, the endplate is divided into narrower segments in the region where fluctuations are strongly observed.

## 3. Experimental Results

### 3.1 Radial Potential Profile Control

In the present experiment, we discuss rotation frequency shear in a cylindrical system instead of the velocity shear in a slab system. To estimate the local value of $E_r$ and its shear, measured profiles of plasma potential are approximated by 6th-order polynomials.

Figure 1 shows various profiles of plasma potential formed by carefully controlling bias voltages applied to the endplate segments. These potential profiles are labeled A to H for convenience' sake as shown in Fig. 1. Figure 1(a) shows potential profiles in the case where radial electric field is mainly varied. Parabolic profiles of plasma potential are formed in the shadowed region where the fluctuations are strongly observed. A parabolic profile of plasma potential causes rigid plasma rotation by ***E***×***B*** drift. The profiles shown in Fig. 1(a) have no shear of ***E***×***B*** drift frequency. On the other hand, potential profiles shown in Fig. 1(b) are more complicated in the shadowed region. It is easily

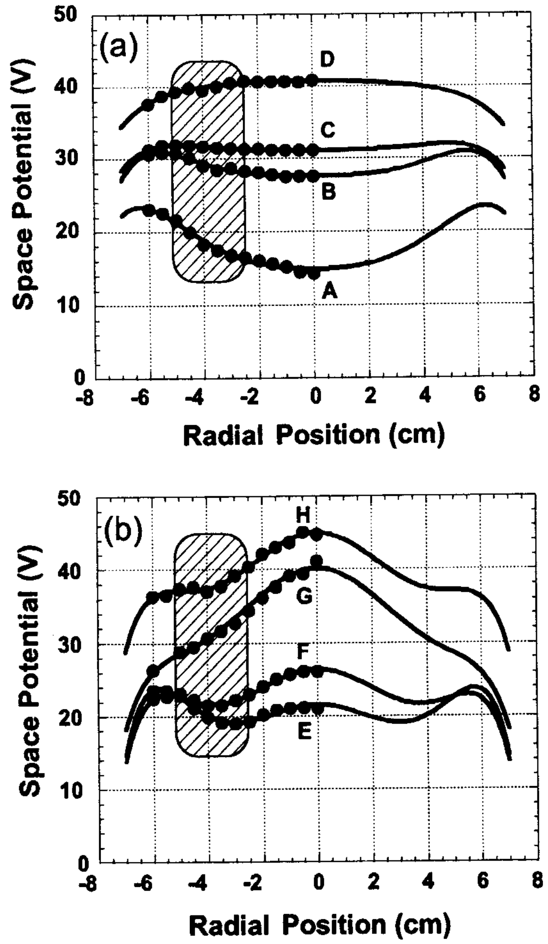


Fig. 1 Radial profiles of plasma potential in cases where (a) the radial electric field is varied without shear and (b) both the radial electric field and the shear are varied.

expected that direction of ***E***×***B*** drift should be reversed in the shadowed region for the profile labeled by F in Fig. 1(b). These profiles have finite shear of the ***E***×***B*** drift frequency. The radial electric field and rotation frequency shear are varied in the range of –400 V/m to 300 V/m and 0 to 400 kHz/m, respectively, while there are no significant change of density gradient.

### 3.2 Observations of Fluctuations

Drift-mode and flute-mode fluctuations with frequencies of a few tens kHz which are much lower than the ion cyclotron frequency are observed in a radial region where the density gradient is steep. We can clearly identify these fluctuations, from the fact that dependence of the drift-mode frequencies on electron temperature is clearly different from that of the flute mode. The drift-mode frequencies changes almost proportionally to the electron temperature. On the other hand, the flute mode frequencies are independent of the electron temperature.

Figure 2(a) and (b) shows fluctuation spectra in case of dominant control of the electric filed and the shear, respectively. Frequencies and intensities of the fluctuations vary complicatedly, depending on either radial electric field or its shear. When the radial electric field is varied from negative to positive with the shear being mostly fixed, frequencies of the drift mode and the flute mode are shifted to lower and higher, respectively as shown Fig. 2(a). Those are caused by Doppler shifts due to the ***E*×*B*** drift. When only the shear increases with the radial electric field being almost fixed, there are no significant variation in the observed frequencies by a Doppler shift as shown in Fig. 2(b). It is note that the flute-mode fluctuations are strongly excited only in the strong shear region. The flute-mode is considered to be a Kelvin-Helmholtz type instability which is destabilized by strong ***E*×*B*** flow shear, details of which will not be described in this paper.

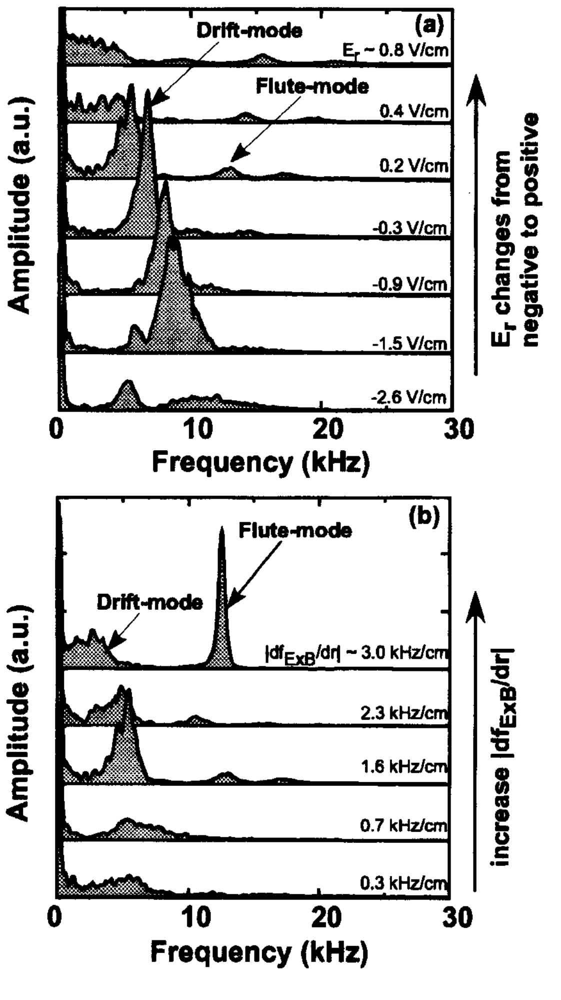


Fig. 2 Fluctuation spectra with potential profile control. The profiles are mainly controlled (a) radial electric field with the shear being mostly fixed ($|df_{E\times B}/dr| \simeq 1.4 \sim 2.3$ kHz) and (b) radial electric field shear with the radial electric field being almost fixed ($E_r \simeq 0.5$ V/cm).

Figure 3 shows the observed frequency plotted as a function of radial electric field. The observed frequencies are varied by a Doppler shift of ***E*×*B*** drift rotation. The radial electric fields are estimated by using local value obtained by fitting the measured potential profile to 6th order polynomial. According to the phase difference measured by using two probes which are set at the same radial but different azimuthal positions, the drift mode has azimuthal mode number $m$ = 2. Namely, the change of the $m$ = 2 drift-mode frequencies corresponds to that of $m$ = 2 ***E*×*B*** drift frequencies. This result well explains the observed frequencies of the drift-mode fluctuations. Therefore, the frequencies of the drift mode are Doppler shifted by locally estimated ***E*×*B*** drift. The flute-mode frequencies are Doppler shifted by ***E*×*B*** drift which is not a locally estimated but a globally estimated.

These behaviors are well correlated with radial distribution of the fluctuations. Figure 4 shows the radial distribution of fluctuation spectra displayed as a contour map. The fluctuations which should be noticed are

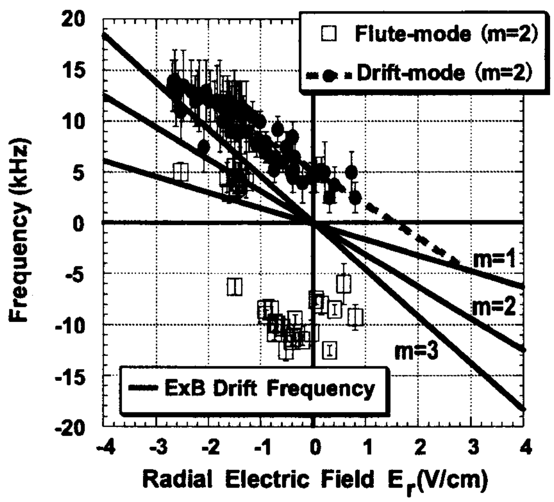


Fig. 3 Observed frequency of fluctuations plotted as a function of radial electric field. $E_r$ is estimated from local data of potential profile.

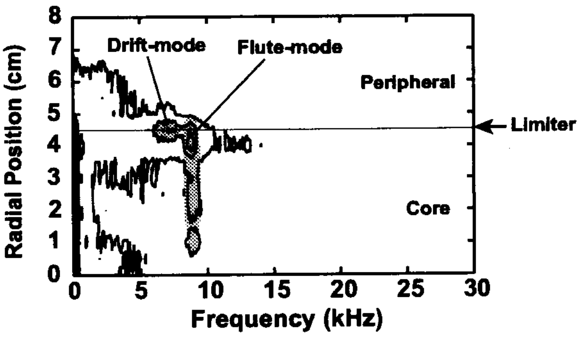


Fig. 4 Radial distribution of fluctuation spectra displayed as a contour map.

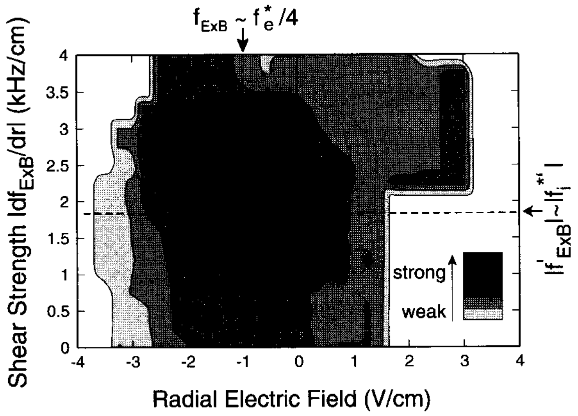


Fig. 5 Intensities of drift-mode fluctuations contour-plotted as functions of radial electric field and its shear.

indicated by shadow. The drift mode has a broad band spectra and is locally distributed near the plasma edge. The flute mode has coherent spectra and is globally distributed over a wide range of radial position.

Figure 5 shows intensities of drift-mode fluctuations contour-plotted as functions of radial electric field and its shear. The drift mode destabilized in the region of weakly negative electric field, where the direction of ***E***×***B*** drift equals to that of electron diamagnetic drift. Furthermore, when the ***E***×***B*** rotation frequency shear is increased with $E_r$ fixed, the drift-mode fluctuations increase once in a weaker shear region, attain its peak around the shear of ion diamagnetic drift frequency, and then decrease in the strong shear region.

## 4. Conclusions

Effects of both radial electric field and its shear on low-frequency fluctuations have been investigated in an ECR-produced plasma, where the radial potential profile is precisely controlled by applying bias voltages to a 10-segmented endplate.

Both drift-mode and flute-mode fluctuations are observed in a region where the density gradient is steep. The drift mode is destabilized in the region of weakly negative electric field, where the direction of ***E***×***B*** drift equal to that of electron diamagnetic drift. When the ***E***×***B*** rotation frequency shear is increased with the $E_r$ being fixed, the drift-mode fluctuations increase once in a weaker shear region, attain its peak around the shear of ion diamagnetic drift frequency, and then decrease in the stronger shear region. This behavior suggests that the net ion drift shear is effective for stabilizing the drift-mode fluctuation.


## Acknowledgements

This work was supported in part by the LHD Joint Planning Research program at National Institute for Fusion Science.


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