Drift Wave Antenna Excitation in TORPEX Low-field Side

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Introduction

In magnetically confined plasmas, drift wave turbulence is generally believed to be responsible for anomalous cross-field transport, reducing the energy confinement. Improvements in such confinement, down to level determined purely by collisional transport, may be achieved through an active control of drift wave and further understanding of its dynamics. In this contribution, we report, as a first step toward potential control scenarios, drift wave linear excitation in a toroidal plasma using an electrostatic tunable antenna.

Antenna Excitation and Results

The experimental results are obtained in the simple magnetized toroidal plasma device TORPEX [1]. Hydrogen plasmas are produced using a microwave power of 400 W injected during 1200 ms in the low B-field side under a neutral pressure of 6×10^{-5} mbar. The helical magnetic field encompasses a vertical component $B_z \sim 1.2$mT and a toroidal component $B_\phi = 76$ mT. The electron density is of the order of 10^{16} m^{-3}. The electron and ion temperatures are 5 eV and 0.1 eV , respectively. Figure 1(a)-(c) shows the 2D profiles of density, plasma potential, and $\mathbf{E}\times\mathbf{B}$ velocity.

The low frequency oscillations are generated using an antenna that consists of four identical rectangular metallic electrodes ($d_1 = 30$ mm along B_ϕ, $d_2 = 8$ mm along B_z, and thickness 0.9 mm) distributed along the vertical direction. The vertical separation between adjacent electrodes is D = 20 mm (see Fig. 1(d)). These electrodes are driven with a sinusoidal potential with frequency in the drift wave range. Their relative phase shift allows a selection of the vertical wave number k_z.

The plasma response is detected using the various arrays of Langmuir probes in TORPEX [4]. To overcome the large background fluctuations level, a coherent detection technique [2] is applied to density measurements from Langmuir probes yielding a signal-to-noise ratio of 10dB.

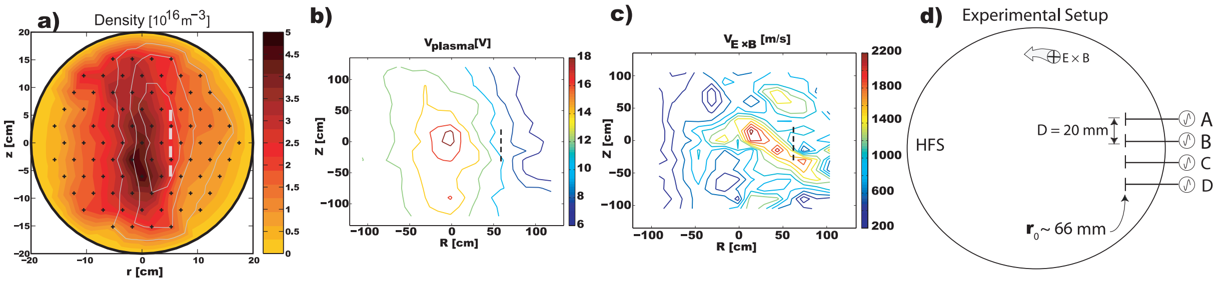

Figure 1: Experimental 2-D profiles and experimental setup. a) Typical time-averaged density profile (T_e = 5 eV) measured (when the antenna is immersed in the plasma) using the HEXTIP array of probes covering the whole cross-section. In addition, the antenna plates position is indicated in dashed lines. The gray contour lines represent contours at 25% (outermost), 50% and 75% of the maximum root-mean-square density fluctuation. b) Plasma potential profile. c) Measured $V_{E\times B}$ profile. In a)-c) the antenna plates are illustrated in dashed lines. d) Experimental setup. A driving signal $\cos(\omega t + \varphi)$ is applied simultaneously on A, B, C, and D. HFS is the high field side.

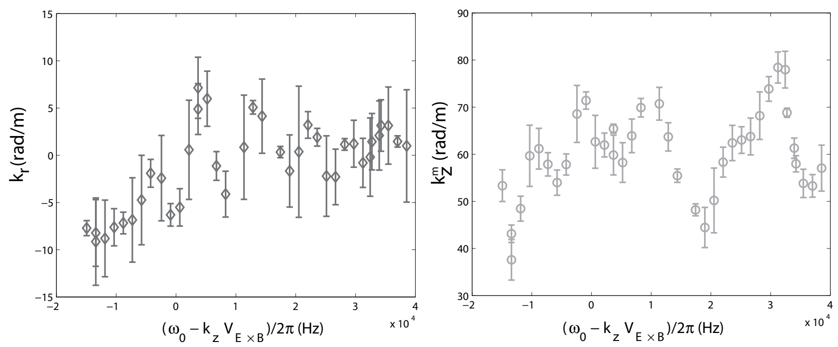

Figure 2: Perpendicular wave number measurements. The left panel shows the measured radial wave number and the right panel the measured vertical wave number as a function of the Doppler-shifted frequency $(\omega - k_z V_{\mathbf{E}\times\mathbf{B}})/(2\pi)$. The velocity $\mathbf{E} \times \mathbf{B}$ is determined from Fig.1(c).

The detected signal represents the density response induced by the antenna excitations and contains a real and an imaginary part. This density response is resolved in both frequency and vertical wave number.

From the $\mathbf{E} \times \mathbf{B}$ velocity profile (see Fig. 1(b)), the density response can be reconstructed in the plasma frame from measurements in the laboratory frame. In addition to this density response, the wave vector induced by the excitation is determined using spatially resolved measurements of the phase of density response. For instance, using Langmuir probes that sample a vertical line in the cross-section, one can determine the antenna-induced vertical wave number. This method is then generalized for both the toroidal and radial directions, which results in a full determination of the wave vector. Figure 2 shows the measured radial and vertical wave numbers as a function of the imposed frequency in plasma frame. The parallel wavenumber remains unchanged over the tuning range and its value is $< k_{\parallel} > \sim 0.4\ \mathrm{m}^{-1}$, consistent with the connection length of 30 m, set by the chosen value B_z/B_ϕ.

Theory-Model and Comparison

A generalized Hasegawa-Wakatani [3] fluid model, with $T_e \gg T_i$, is used to predict the plasma density response induced by the antenna excitation in a toroidal plasma. The equilibrium density is provided by the 2D experimental profiles with dependence in only the radial direction. Since the fluctuations induced by the antenna are small in amplitude compared to the background fluctuations, we can linearize the equations. These are then written in the plasma frame as:

$$\left(i\omega - 2i\omega_d + \frac{c_s^2}{\nu_{||}}k_{||}^2\right)\frac{n}{n_0} + \frac{e}{T_e}\left(2i\omega_d + i\omega_*(r) - \frac{c_s^2}{\nu_{||}}k_{||}^2\right)\phi = S_n$$

$$(-2i\omega_d + c_s^2 k_{||}^2/\nu_{||})\frac{n}{n_0} + \frac{e}{T_e}\left[i\omega\rho_s^2\left(\frac{\partial^2}{\partial r^2} - k_z^2\right) - \frac{c_s^2}{\nu_{||}}k_{||}^2\right]\phi = S_{\nabla_\perp^2\phi}.$$

Here $\nu_{||} = \eta n e^2/m_i$ (η is the parallel resistivity). The density and the potential perturbations due to the antenna are n and ϕ; $\omega_d = k_z\rho_e v_{th,e}/R$ and $\omega^* = k_z\rho_e v_{th,e}/L_n$ are the curvature and the drift frequencies; S_n and $S_{\nabla_\perp^2\phi}$ are the density and vorticity sources driven by the antenna. It is assumed that all the quantities are proportional to $\exp\left[i(\omega t + k_{||}\mu + k_z z + k_r r)\right]$ (μ denotes the toroidal direction). In the limit $c_s^2 < k_{||} >^2 /\nu_{||}$ (~ 100 kHz) greater than all the frequencies in the system, the density response is then given by: $n = i(S_n - S_{\nabla_\perp^2\phi})/\mathscr{D}_w(\omega,\mathbf{k})$, where $\mathscr{D}_w(\omega,\mathbf{k}) = \left(1 + k_\perp^2\rho_s^2\right)\omega + (2\omega_d + \omega^*)$ is the dispersion function whose zero, $\omega_r = -(2\omega_d + \omega^*)/(1 + k_\perp^2\rho_s^2)$, corresponds to the eigenfrequency of of the system. This zero matches the real frequency of the drift wave.

Figure 3 (Left panel) shows the density response from both measurements and theoretical predictions. The calculated density response is given by $n = \left|\mathscr{A}(k_z^m)/\mathscr{D}_w(\omega,\mathbf{k})\right|$, where $\mathbf{k} = (k_r, k_z^m, < k_{||} >)$ is the measured wave vector, and

$$\mathscr{A}(k) = sinc\,(k_z d_2/2)\left[\cos\left(3(k - k_z)D/2\right) + \cos\left((k - k_z)D/2\right)\right]$$

represents the excited antenna k-spectrum. One clearly identifies a resonant mode corresponding to a drift wave with frequency $(\omega - k_z V_{\mathbf{E}\times\mathbf{B}})/(2\pi) \sim 7.8$ kHz in the plasma frame. Furthermore, this mode amplitude varies linearly with the driver amplitude up to 25V (see in the right panel of Fig. 3), which suggests that the mode is linearly driven.

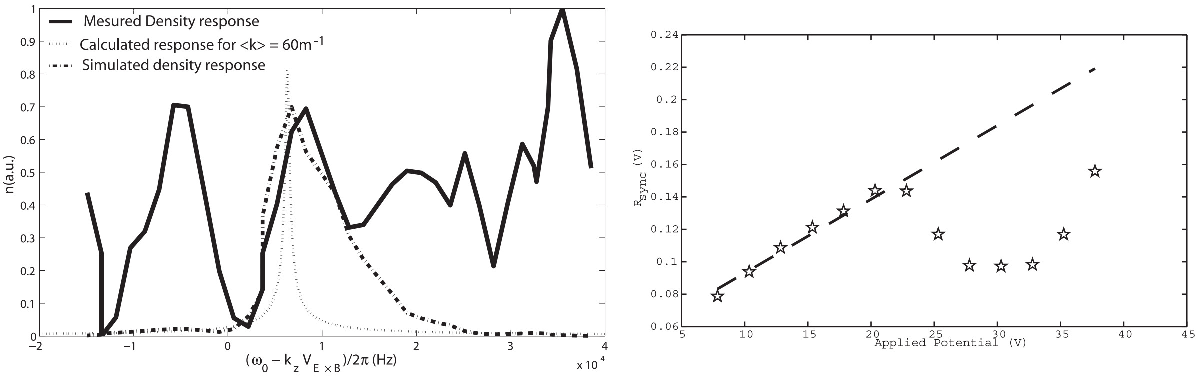

Figure 3: [Left] Measured and calculated density responses. The solid line represents the measured density response at z =0 and r_0 = 66 mm. The horizontal axis is the frequency in the plasma frame. The dotted line is the computed response when the average value of the measured wave number is assumed. The dash-dot line represents the response when both the antenna k-spectrum and the measured wave vector are included in the simulation. [Right]. Amplitude variation of the response function when the antenna is tuned at $(\omega - k_z V_{\mathbf{E}\times\mathbf{B}})/(2\pi) = 7.8$kHz as a function of the driver's amplitude.

Summary

In this contribution, we present a tool for the generation of waves in the drift frequency range. We have demonstrated that electrostatic disturbances can be linearly excited, and detected for different values of the drive frequency and the imposed vertical wave number. The drive frequency is adjusted to match the induced $\mathbf{E}\times\mathbf{B}$ frequency.

Direct measurements of the plasma response and of the wave vector **k** necessary for the identification of the antenna excited mode are obtained using a coherent detection technique. Comparisons of the measured response with the theoretical predictions of the Hasegawa-Wakatani model on the basis of the launched antenna k-spectrum and experimentally measured wave vector are performed. The predicted density response shows agreement for one peak of experimentally measured density response corresponding to a resonant peak that matches a drift mode. The non-resonant peaks, on the other hand, remain unexplained with the current linear model. A linear excitation of drift waves is thus shown in a toroidal plasma using a tunable antenna positioned in the region of maximum density gradient. Finally, in this paper, we have ignored potential wave-wave nonlinear coupling. Such analysis will be subject of future investigations.

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