Plasma Turbulence in the TCABR Scrape-off Layer

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I. INTRODUCTION

Plasma turbulence is investigated in the scrape-off layer of the TCABR tokamak [1]. Wavelet spectral analysis is applied in order to obtain linear and quadratic spectra as well as the particle transport for plasma potential and density fluctuations [2-5]. We study the turbulence changes introduced by the RF power coupled to the plasma during Alfvén wave excitation pulse. We analyze also the changes of the recurrence of the fluctuations, typical of chaotic low dimensional systems [5, 6].

II. ANALYSIS OF TURBULENCE

The experiment is performed in a hydrogen circular plasma in the TCABR tokamak (major radius $R_o = 0.61$ m and minor radius $a = 0.18$ m). The plasma current I_p is 100 kA, the current duration 100 ms, the toroidal magnetic field B_t is 1.1 T, and the hydrogen filling pressure 3×10^{-4} Pa. In order to study turbulence changes introduced by Alfvén wave injection, we keep the RF power in the range (1 – 60 kW) at 3.6 MHz, for excitation of modes m/n = 1/4. Where m and n are the poloidal and toroidal mode number, respectively. Duration of Alfvén pulse is 10 ms.

The data are collected with a multipin Langmuir probe that measures, the fluctuations on the floating potential and ion saturation current, the mean density, the electron temperature, and the plasma potential [4]. In order to examine the time behavior of the fluctuations, we split the data into consecutive segments of 1024 data points (≈ 1.02 ms) and apply the wavelet analysis to each segment. To detect evidences of phase coupling between wavelet components (f_1, f_2), possibly present in the turbulence, we combine wavelet and bispectral analysis, calculating the summed and the total wavelet-bicoherence.

In the scrape-off layer, the values of density, temperature, and plasma potential without Alfvén injection are $n_e \approx 7.5 \times 10^{17}$ m^{-3}, $T_e \approx 6$ eV, and $V_p \approx 17$ V; with Alfvén wave excitation, those values change to $n_e \approx 8.3 \times 10^{17}$ m^{-3}, $T_e \approx 14$ eV, and $V_p \approx 34$ V. The relative

level of fluctuations are $\tilde{n}_e/\overline{n}_e \approx 0.30$ and $e\tilde{V}/kT_e \approx 0.45$ without and $\tilde{n}/\overline{n}_e \approx 0.50$ and $e\tilde{V}/kT_e \approx 0.70$ with Alfvén wave excitation.

Fig. 1 presents the superposition of wavelet power spectra of the measured potential fluctuations, at a given radial position (r/a = 1.17), for a chosen time interval without and with 50 kW of RF power injection. The frequency spectra are broad and extend up to 120 kHz. The fluctuation level increases with Alfvén injection. The main characteristics of these spectra do not change during a pulse.

Fig.2 (a, b) shows contour plots of the S(k) autopower spectrum in wavenumber, for potential fluctuations, and for discharges without (a) and with 40 kW of injected power (b), at r/a=1.17. With power injection, we observe the transference of maximum power of frequency components from positive to negative wavenumbers. To observe the effect on phase velocity for different values of the injected power, we analyze the data from discharges with same density and plasma current, but with varying levels of injected power from 0 to 50 kW. Fig. 3 shows the dependence of phase velocity with power injection. We see that is necessary a minimum value of the injected power to change the direction of most frequency components. However, we note a saturation for the two higher values. We also tried to observe changes introduced in turbulence for different values of plasma density and a fixed value of power injection (40 kW). The change of phase velocity direction is enhanced for higher densities. Fig. 4 shows the variation of total particle flux, $\Gamma = \langle \tilde{n}\ \tilde{V}_r \rangle$, for one discharge in time intervals (1.02 ms each) before, during, and after the power injection. Particle transport increases when the RF power is injected in the plasma.

The tendency of power injection is to damp nonlinear coupling. Fig. 5 shows the summed-bicoherence [2, 3] for a discharge without and with power injection for a plasma density of 2.5×10^{19} m^{-3}. The nonlinear coupling is significantly reduced in the presence of the wave and, for other low densities, their values are comparable to the statistical error.

III. FLUCTUATION DISTRIBUTION

The unperturbed fluctuations are recurrent. This can be seen by calculating the distribution of the returning time, i.e., the time they come back to a specific reference amplitude [5, 6]. Turbulent fluctuations with this property have statistics similar to those reported for low dimensional chaotic systems. Fig. 6 shows the distribution of returning time in discharges without (a) and with RF power injection of 15 kW (b) and 50 kW (c).

The distribution is Poisson-like only for the unperturbed fluctuations (a). Thus recurrence is lost when the wave is injected. This indicates that some kind of order is introduced by the Alfvén wave. That is confirmed by the decrease with the injected power of the symbolic entropy computed for the fluctuations of Fig. 6.

IV. CONCLUSIONS

The Alfvén wave injection modifies the scrape-off layer electrostatic turbulence in the TCABR tokamak. Thus, the wave injection increases the fluctuation amplitudes and the anomalous particle transport, slightly affects the fluctuations linear coupling and damps their quadratic coupling. Furthermore, the power injection modifies the fluctuation statistics, namely, decreasing their recurrence and symbolic entropy. In conclusion, we observe that the particle transport increase appears together with the reduction of nonlinear coupling, recurrence, and symbolic entropy, suggesting that some possible coherent structures in the plasma are crushed by the wave injection. In addition to that, the wave injection damps bursts observed in the unperturbed fluctuations. After that, turbulence recovers smoothly as the wave injection ends. Furthermore, preliminary similar analyses for lower density discharges and other values of power injection suggest that the transport depends on these parameters. This dependence will be discussed in another work.

References
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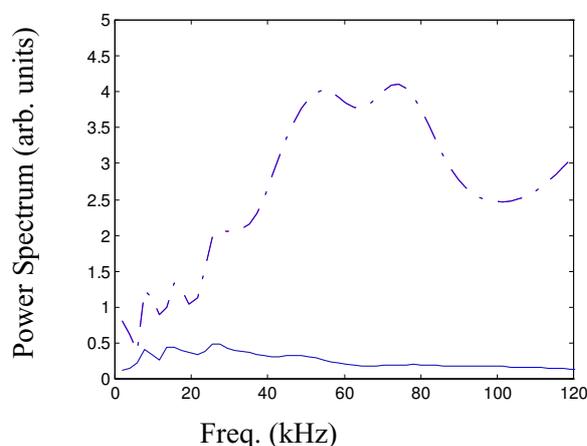
Fig. 1 Superposition of the spectra without (——) and with (----) Alfvén wave injection for potential fluctuations at r/a=1.17.
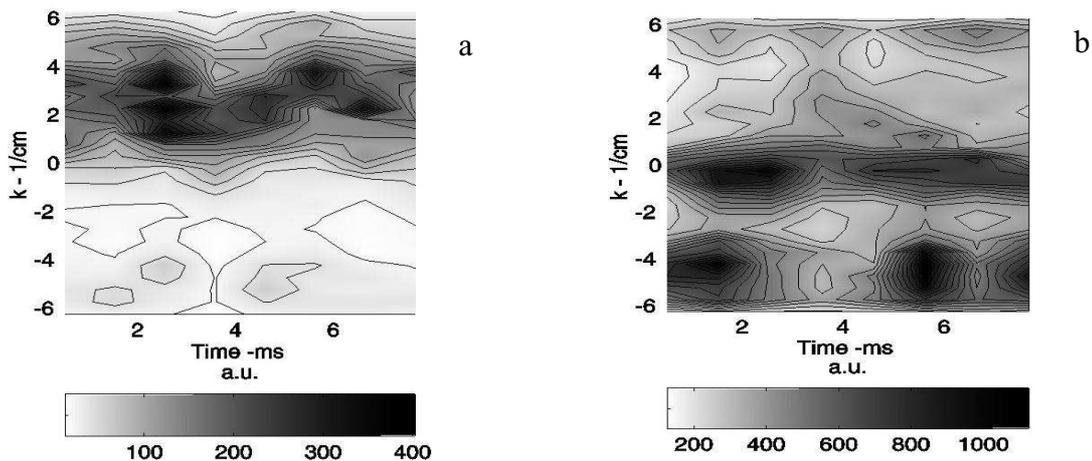
Fig. 2 Contour plot as a function of time of S(k) spectrum for potential fluctuations at r/a=1.17 without (a) and with (b) power injection.
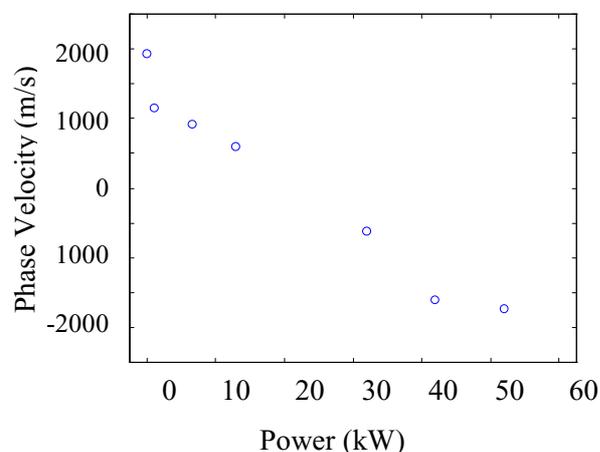

Fig. 3 Dependence of phase velocity to power injection for potential fluctuations at r/a=1.17.
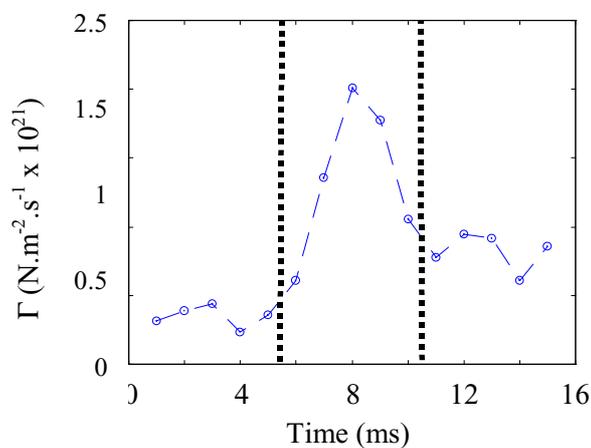
Fig. 4 Evolution of total particle transport for a discharge before, during (between dashed lines), and after RF power injection.
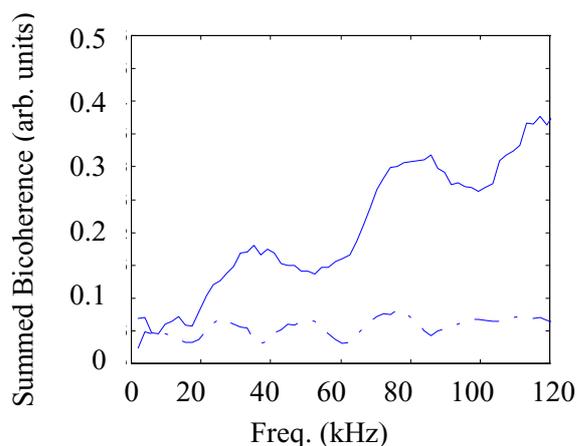

Fig. 5 Superposition of the summed bicoherence for a chosen time interval of 1.024 ms, at r/a=1.17 without (——) and with (----) Alfvén wave injection.
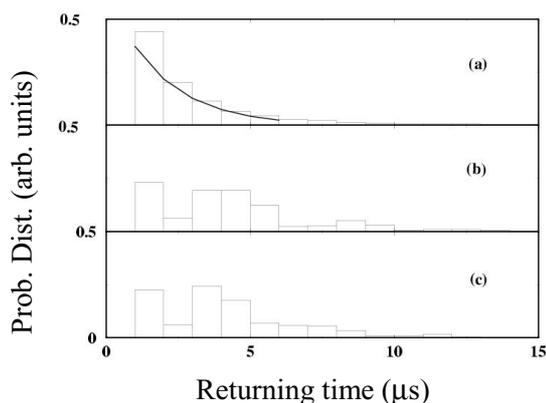
Fig. 6 Distribution of returning time for potential fluctuations without Alfvén injection (a) and for two different values of power injection 10 kW (b) and 50 kW (c).