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Selecting, characterizing, and acting on drift waves and flute modes turbulence in a low-β magnetized plasma column

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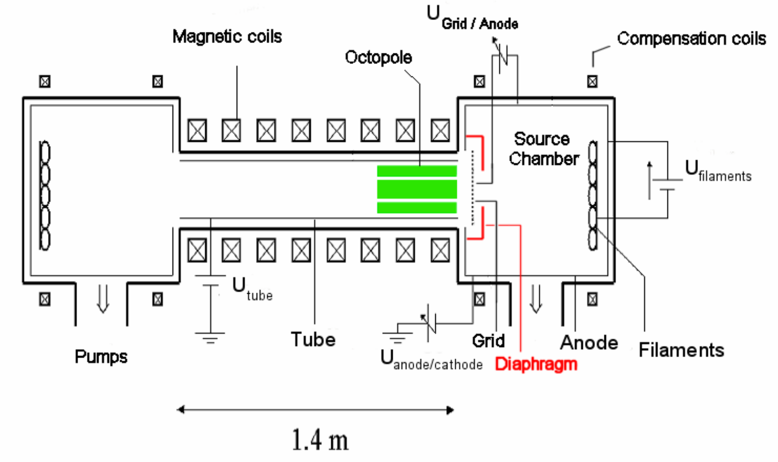
1. INTRODUCTION

In fusion experiments, turbulence of low frequency instabilities driven by huge cross-field gradients is responsible for convective transport, whose effect on confinement and on device walls can be dramatic [1]. Thus, in order to improve the efficiency of controlled fusion experiments, turbulence and the related anomalous transport have to be controlled. A few years ago, encouraging results have been obtained in controlling a weakly developed drift waves turbulence regime, by using a spatio-temporal open-loop synchronization method [2]. In this contribution, we present experimental results obtained with the same method acting on a Kelvin-Helmholtz instability.

2. EXPERIMENTAL SET-UP AND CHARACTERIZATION OF THE INSTABILITIES

The experiments are performed in the linear magnetized plasma device Mirabelle [3], whose scheme is displayed in Fig. 1. Langmuir probes are used for all measurements. Electric control fields of the same order of magnitude as the azimuthal electric field of the fluctuations are externally applied to the plasma using the octopole displayed in Fig. 2. Criteria used for the identification of the instabilities are those derived by Jassby [4]. When a diaphragm is inserted at the entrance of the plasma column, the characterization of the unstable modes yields to the conclusion that increasing the magnetic field induces transitions between different types of instabilities. More precisely, at low magnetic field the strong $E_r \times B$ velocity shear drives a Kelvin-Helmholtz instability, whereas at higher magnetic field only drift waves are observed [5]. For an intermediate field, a centrifugal (Rayleigh-Taylor) instability can be observed according to other discharge parameters. This transition can be seen in Fig. 3 through the evolution of the axial wave number according to the magnetic field magnitude.



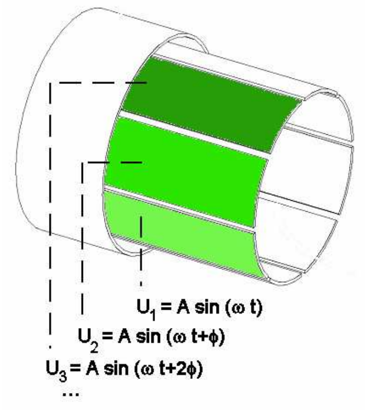


Fig.1 – The magnetized multipolar plasma device MIRABELLE.

Fig.2 – Detail of the octopole

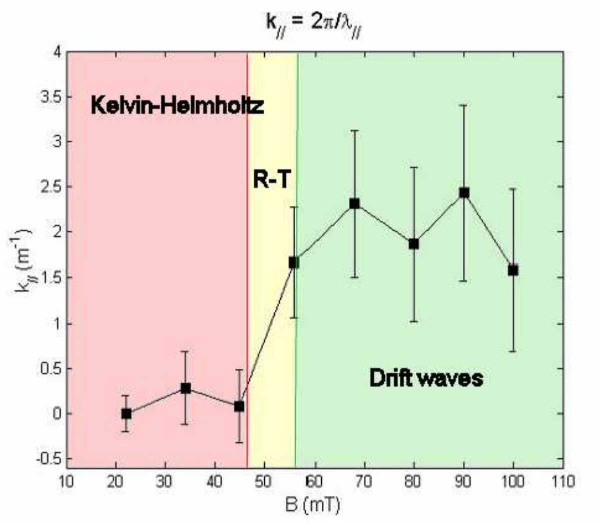


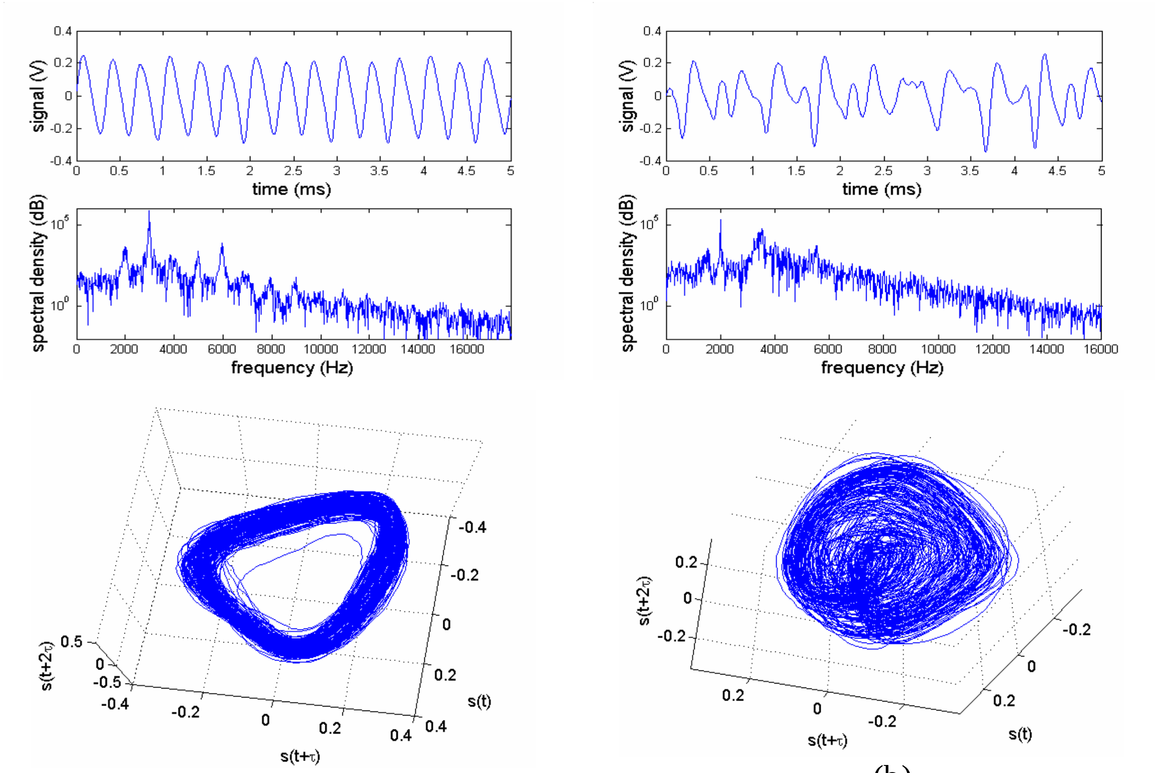
Fig. 3 – Evolution of the axial wave number according to the magnetic field magnitude, with a ∅ 15 cm limiter, showing the transition from Kelvin-Helmholtz or Rayleigh-Taylor (R-T) flute modes to drift waves.

3. RESULTS OF SPATIO-TEMPORAL CONTROL

3.1 DRIFT WAVES

When used on a drift waves regime, the octopole allows to stabilize a chaotic or weakly turbulent state by weak perturbations of the plasma equilibrium [2]. The basic idea consists in synchronizing the plasma fluctuations by applying to the octopole a signal whose frequency is close to a maximum of amplitude of the Fourier spectrum. By introducing the appropriate phase shift between the 8 plates, it is possible to produce a rotating electric field with the azimuthal structure m = 1, 2 or 4. Experiments and simulations have shown that control can only be achieved if the electric field produced by the octopole rotates in the same direction than the plasma fluctuations. Thus it is a spatio-temporal synchronization.

Conversely, the octopole can also be used to produce spatio-temporal chaos and turbulence. In this case, the octopole is used to introduce a new frequency, incommensurate with the dominating one of the pre-existing regular state (Fig. 4). This is in agreement with the Ruelle-Takens-Newhouse scenario for drift waves turbulence [6].



(a) (b)

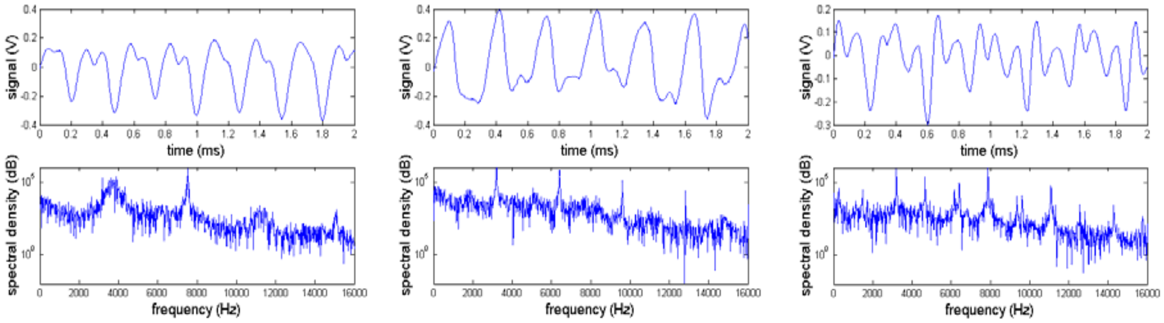
Fig. 4 – Time series (detail), Fourier spectrum, and phase portrait illustrating the generation of a spatio-temporal chaos for a drift waves state : initial state exhibiting a slightly quasi-periodic behaviour (a), and spatio-temporal chaos obtained after excitation of an azimuthal $m = 2$ mode at 2 kHz.

3.2 KELVIN-HELMHOLTZ INSTABILITY

Since both drift waves and flute instabilities follow the same route to turbulence [7], it was interesting to test the open-loop synchronization method on a flute mode.

Experiments with a Kelvin-Helmholtz instability show mostly the same kind of response as for drift waves. An example is given in Fig. 5. Without any control, the initial frequency spectrum exhibits a wide peak between 3 kHz and 4 kHz, and a more localized peak at the frequency 7.5 kHz (Fig. 5(a)). Spatio-temporal measurements, not represented here, show competition between azimuthal mode $m = 1$ and $m = 2$. By applying to the octopole a co-rotating signal at 3.2 kHz with a $\pi/4$ phase shift between each plate, synchronization on the $m = 1$ mode is easily obtained, while the azimuthal mode $m = 2$ is suppressed (Fig. 5 (b)). As for drift waves, the control is spatio-temporal since no regular regime can be obtained when a counter-rotating biasing is applied (Fig. 5 (c)). However, the efficiency of the synchronization varies with respect to the location of the velocity shear layer: while the synchronization works well in this layer and its outer part with a modest voltage applied to the octopole (~ 1 V of amplitude), control of the inner part of the column needs more power (~5 V of amplitude).

Cross-correlation measurements between simultaneous measurements recorded with two azimuthally aligned probes axially distant of 30 cm and 70 cm from the octopole give $k_{//} = 0$ in each state. Hence, using the octopole does not change the nature of the instability.



(a) (b) (c)

Fig. 5 – Detail of the time series and spectral density for a Kelvin-Helmholtz instability, without and with external biasing (F_{exc} = 3.2 kHz): (a) without control, (b) with a co-rotating biasing, and (c) with a counter-rotating biasing.

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