*31st EPS Conference on Plasma Phys. London, 28 June - 2 July 2004 ECA Vol.**28G**, O-4.18 (2004)*

Characterization of instabilities and study of their transition to turbulence in a magnetized plasma column

F.Brochard, G.Bonhomme, E.Gravier

Laboratoire PMIA, UMR 7040 CNRS -Université Henri Poincaré
Boulevard des Aiguillettes BP 239 – 54506 VANDOEUVRE-Lès-NANCY cedex, France

1. INTRODUCTION

Low frequency instabilities in bounded magnetized plasmas have attracted much attention for many years in part because of their role in non diffusive transport processes in plasma fusion experiments [1]. Moreover, such low frequency density fluctuations are commonly observed in linear plasma columns. It is however not so easy to clearly determine to which class of instability these fluctuations belong. We recently demonstrated that using a limiter the transitions between various gradient driven instabilities occurred in our device when increasing the magnetic field [2]. Aiming at characterizing turbulent states, we studied the transition from regular regimes to spatiotemporal chaos and turbulence. We focus here on the transition to turbulence of a Kelvin-Helmholtz instability.

2. CHARACTERIZATION OF INSTABILITIES

Experiments are performed in the linear section of the low-β plasma device MIRABELLE [4], whose scheme is displayed in Fig.1. Langmuir probes are used for all measurements (density and plasma potential fluctuations and radial profiles of mean values), and criterias used for the characterization of instabilities are those derived by Jassby [5]. When a diaphragm is inserted at the entrance of the column, characterization of the unstable modes observed yields to the conclusion that increasing the magnetic field (and thus decreasing the radius of the plasma column) induces transitions between different types of instabilities. More precisely, at low magnetic fiel the strong $E_r \times B$ velocity shear induced by the limiter drives a Kelvin-Helmholtz instability, whereas at higher magnetic field driftwaves are only observed [2]. In between, we also observed in somes cases a centrifugal (Rayleigh-Taylor) instability.

Main observable features of the Kelvin-Helmholtz instability are : no axial wavenumber, a radial phase variation for the potential fluctuations of 90-180° localized in the shear layer, a wave frequency in the range 0.2-0.6 ω_{Emax}, and a magnitude of plasma potential fluctuations much bigger than that of density fluctuations.

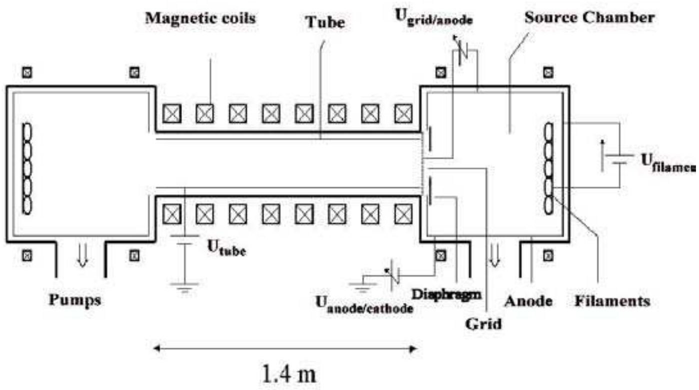

Fig.1 – The magnetized multipolar plasma device MIRABELLE.

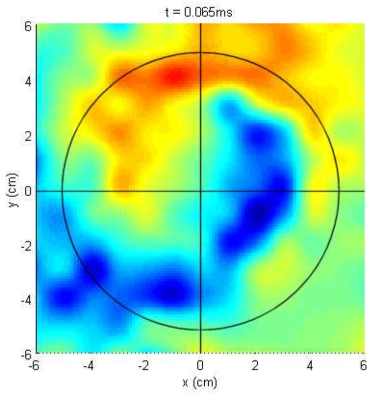

Fig.2 – Potential fluctuations in a cross section of the column for a Kelvin-Helmholtz instability.

3. TRANSITION TO TURBULENCE OF A KELVIN-HELMHOLTZ INSTABILITY

Starting with experimental conditions in which a Kelvin-Helmholtz instability is observed, i.e. a regular mode for which all the above criteria are satisfied, we look for the transitions to a turbulent state by changing the discharge voltage $U_{anode/cathode}$, which acts as our control parameter.

The initial situation, depicted in Fig.3 (a-d), reveals a periodic signal whose main frequency f_1 corresponds to an azimutal mode m=1. Here is only plotted the situation in r = 3 cm, i.e. in the inner part of the velocity shear layer ; The Fourier spectrum of the signal recorded outside the shear layer shows a less pronounced peak of frequency $f_2 = 2^* f_1 - \delta f$ as well, that we attribute to a m = 2 mode. When decreasing the control parameter the situation evolves to that depicted in Fig.3 (e-h), at first in the outer part of the shear layer, and then in the inner part. The amplitude and frequency of the recorded signal now exhibit a periodic modulation. The triangular shape of the Fourier spectrum is characteristic of a periodic pulling regime [5], while phase portrait and Poincaré section give reasonnable evidence of a quasi-periodic regime. When still decreasing the control parameter, quasi-periodicity is lost and a strongly turbulent regime finally appears (Fig.3 (i-l)).

Time-frequency investigations of the quasi-periodic signal plotted in Fig.3(e) is performed using a wavelet analysis. The result, depicted in Fig.4, clearly shows that the frequency slides periodically from $f_2 \approx 8$ kHz towards $f_1 \approx 4$ kHz. This observation can be interpreted as an incomplete synchronization of the m=1 mode of frequency f_1 by the supposed m=2 mode of frequency f_2, i.e. autonomous periodic pulling. The reason why synchronization is not complete is probably that the coupling of driver and driven wave is too weak, or the frequency mismatch too large to establish complete synchronization. Finally, for smaller values of the control parameter, the non-linear interaction between the waves broadens the Fourier spectrum in such a way that quasi-periodicity is lost and turbulence arises.

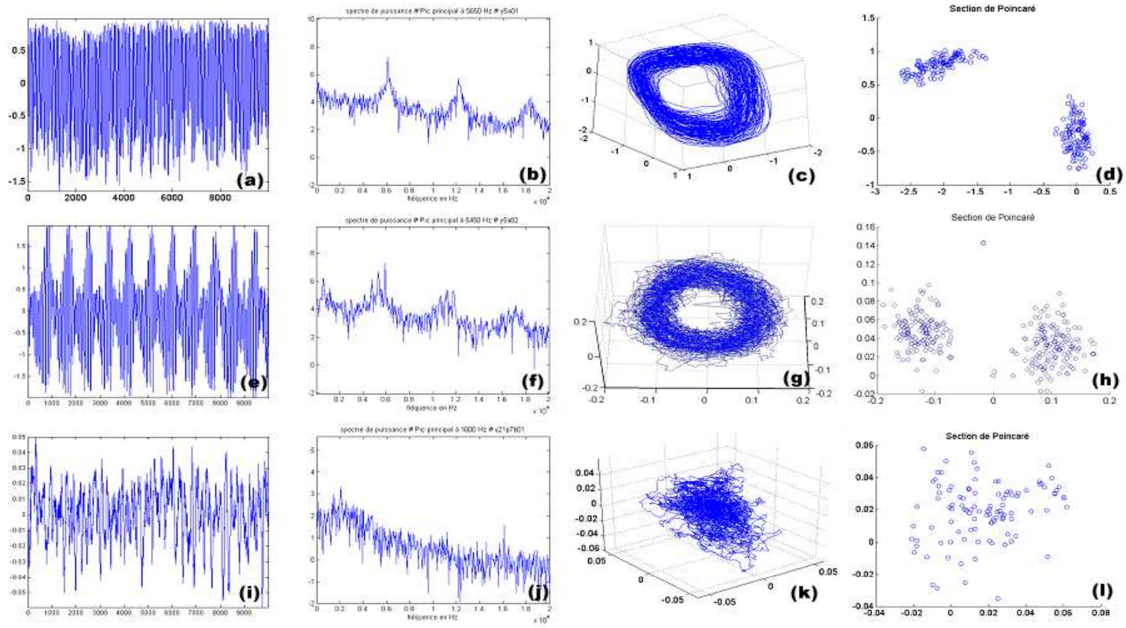

Fig.3 – Observation of the transition to turbulence : from left to right, signal, Fourier spectrum, phase portrait and Poincaré section of the periodic (a-d), quasi-periodic (e-h) and turbulent (i-l) regimes, for a signal recorded in r = 3cm (in the beginning of the velocity shear layer).

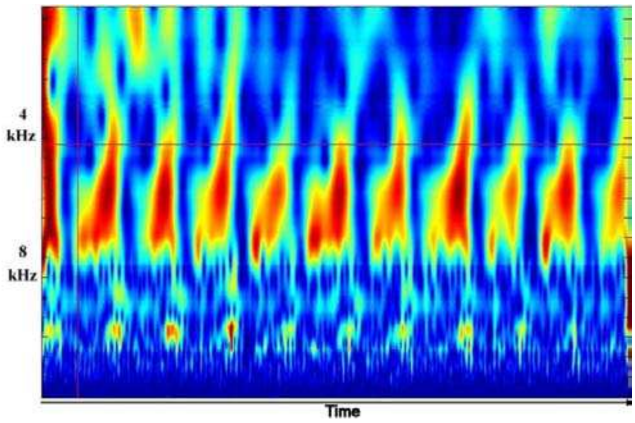

Fig.4 – Wavelet analysis of the quasi-periodic signal showing the temporal evolution of the frequency.

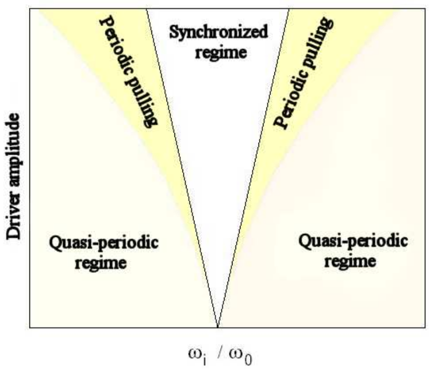

Fig.5 – Schematic drawing of an Arnold tongue.

Moreover the comparison with a forced Van der Pol oscillator [6] and the typical Arnold's tongue behaviour (Fig.5) gives very good agreement with experimental observations (Fig.7-8), what confirms our interpretation. Thus we have demonstrated that the transition to turbulence for the Kelvin-Helmholtz instability follows the quasi-periodicity (Ruelle-Takens-Newhouse) route, as it was previously observed for drift waves [7] : the non-linear coupling between two modes with incommensurable frequencies broadens the Fourier spectrum and finally leads to turbulence. Although the spatio-temporal character of this transition has not yet been fully investigated, spatio-temporal measurements of the fluctuations with a 32 probe array are under way. As a concluding remark, we can mention that preliminary results concerning the Rayleigh-Taylor instability give evidence of a similar transition scenario, that is involving the quasi-periodicity route.

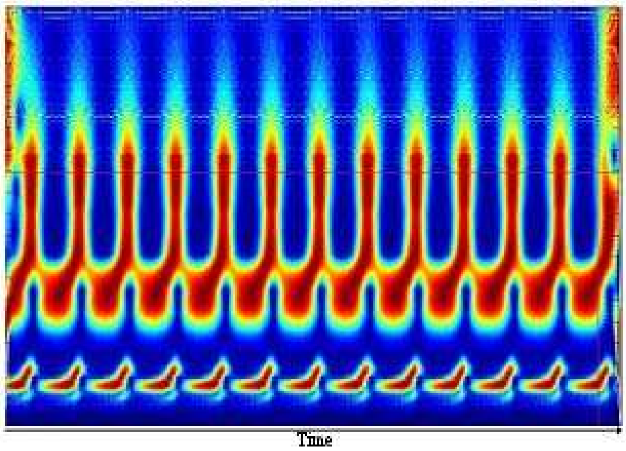

Fig.6 – Wavelet analysis of the forced van der Pol solution for the periodic pulling regime.

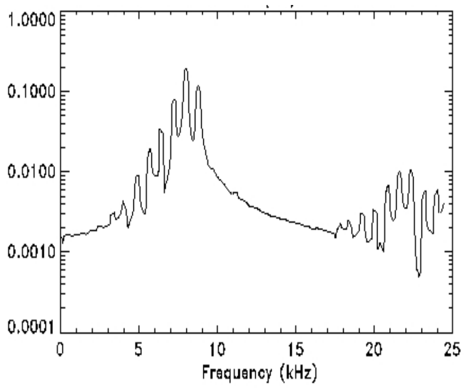

Fig.7 – Fourier spectrum of the forced van der Pol oscillator for the periodic pulling regime.

BIBLIOGRAPHY

[1] W. Horton, Rev. Modern Physics, 71, 735 (1999).

[2] E. Gravier et al., *Low frequency instabilities in a laboratory magnetized plasma column, Physics of plasmas*, **11**, 2 (2004).

[3] T. Pierre et al., *Magnetized double-plasma device for wave studies*, Rev. Sci. Instrum. **58** (1), 6-11 (1987).

[4] D.L. Jassby, *Transverse velocity shear instabilities within a magnetically confined plasma,* Phys. Fluids, **15** (9), 1590 (1972).

[5] M. Koepke et al., *Periodic nonlinear wave-wave interaction in a plasma discharge with no external oscillatory driving force*, Phys. Plasma, **3**, 12 (1996).

[6] B. van der Pol, *Forced oscillations in a circuit with non-linear resistance*, Phil. Mag. S. **7** 3, 13, 65-80 (1927).

[7] T. Klinger et al., *Route to drift wave chaos and turbulence in a bounded low-β plasma experiment*, Phys. Rev. Lett., **79**, 20 (1997).