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SPIRAL STRUCTURE OF LOW FREQUENCY WAVES IN A MAGNETIZED PLASMA DEVICE.

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Experiments on the spatiotemporal structure of nonlinear coherent low frequency waves have been performed in a magnetised plasma. Spiral structures have been recorded. They are found to be related to the centrifugal Rayleigh-Taylor instability [1] induced by the fast rotation of the magnetised plasma column. These results were obtained either by Langmuir probe or by optical (photodiodes) measurements.

Experimental setup

The experiments were performed in a new device producing a large diameter magnetised plasma. A large (1 m × 1.4 m) multipolar source plasma is produced by an electric discharge between hot tungsten filaments and a cylindrical anode. The primary electrons created in the source plasma are injected into a cylinder (40 cm in diameter, 1 meter long) immersed in a magnetic field. The uniformity of the flux of primary electrons is controlled by two compensation coils following a design first used in the device Mirabelle [2]. The neutral pressure (Ar gas) is about 2×10^{-4} mbar. The magnetised plasma column has a maximum diameter of about 30 cm. The typical plasma parameters are as follows: electron density $n_e = 5\times10^8 \sim 5\times10^{10}$ cm^{-3}, electron temperature $T_e = 2 \sim 4$ eV, ion temperature $T_i \leq$ 0.1 eV, typical electron and ion Larmor radii 0.01 cm and 0.5 cm.

Spatiotemporal structure of the coherent regimes

The diameter of the plasma column is restricted to 15 cm by a metallic diaphragm at the entrance of the column. It is thus possible to study the diffusion or convection mechanisms of the plasma towards the region in the shadow of the limiter, where no ionisation processes exist. A high transparency floating grid is inserted between the source chamber and the magnetised plasma column. Primary electrons overcome the negative potential of the grid and ionise the gas inside the column. The injection of the primary electrons into the column leads to a negative charge on the axis. On the other hand, ions are weakly magnetised and contribute to a radial (outwards) loss of positive charges. The balance between the radial flows of positive and negative charges leads to an equilibrium radial electric field with axial symmetry. Due to the resulting **E**×**B** drift, electrons and ions drift both in the same direction at the same velocity, leading to an azimuthal convection of the whole plasma. The plasma column rotates as a rigid body if the radial profile of the potential is parabolic. Furthermore, the radial density gradient induces a diamagnetic drift in opposite direction for electrons and ions.

Unstable low-frequency waves are observed in the column when the grid is biased at a negative or floating potential. The potential of the source plasma then acts as a control parameter: a negative bias leads to the instability of the low-frequency waves. At a magnetic field intensity B=0.02 T, a coherent $m = 2$ mode is easily recorded. The transition to the $m = 1$ mode is obtained by decreasing the potential of the source plasma. A further decrease leads to the occurrence of a turbulent state.

The spatiotemporal structure of the coherent modes was recorded using two probes. One fixed probe is the reference probe that triggers the digital scope. The other probe is moved both horizontally and vertically (15 mm steps) across a whole section of the magnetised plasma column. A typical map of the electron density is depicted on figure 1 for a coherent $m = 2$ mode.

It is clearly seen that two spiral arms surround the core plasma. The central plasma rotates as a rigid body but the plasma in the shadow of the limiter has a slower azimuthal velocity. This velocity shear induces the bending of the two arms. The mode exhibits no phase variation along the axis ($k_{||} \approx 0$), like a flute mode. Behind the limiter the average plasma density is very weak outside the spiral arms. In fact, the plasma is convected to the wall along the spiral arms. This leads to the conclusion that this phenomenon is a Rayleigh-Taylor instability driven by the effective gravity corresponding to the centrifugal force [1]. The physical picture leading to the existence of the radial drift is the following. Due to the difference between the azimuthal drifts of ions and electrons, a charge separation occurs. It drives an azimuthal electric field, which in turn leads to a radial drift of the ions.

Similar measurements performed in the magnetised plasma column of the device Mirabelle also show the spiral structure of the $m = 2$ mode. To the best of our knowledge, the observation of spiral structures in a magnetised plasma column has been reported only in the case of plasma created by a plasma gun [3].

Plasma density fluctuations due to the unstable modes produce light fluctuations that can be measured. Preliminary experiments have been carried out to develop a fast imaging diagnostic as a non intrusive tool for instability and turbulence analysis.

First, a spectral study of the plasma light has been performed to determine the optimal spectral response of the photodetector. The results show that the main emission is due to neutral argon in the near infra-red region (700 nm-900 nm). Therefore, a silicon phototransistor with a maximal sensitivity around 850 nm has been chosen.

Second, the temporal evolution of the light emission I_{ph} obtained with a single photodetector has been performed. The collimated line of sight used to collect the plasma light has been aligned with the axis of Mistral at 7.5 cm from the centre, since it is expected that the plasma conditions do not vary much along the line. Figure 3 shows that the fluctuations of I_{ph} are indeed strongly correlated with the plasma density fluctuations I_{lp} obtained with a Langmuir probe located in the path of the line of sight. This result can be explained by the low plasma density ($n_e \leq 5\times10^{10}$ cm^{-3}), for which spontaneous emission is directly proportional to the electron density through electron excitation from the ground state.

Linear analysis of the stability of the rotating plasma column

The linear analysis of such a system has been realised by Kono *et al*. [4]. The analysis includes the collisional drift wave instability, the centrifugal instability and the Kelvin-Helmholtz instability. Using the fluid model, assuming quasi-neutrality and small amplitude perturbations, one obtains the linear differential equation for the radial dependence of the perturbed potential $\phi(r)$ and density n(r). With the parameters of the experiment the solution for the m = 2 density perturbation is shown on fig. 2. The solution exhibits a spiral structure with a weak winding of the two arms around the axis, in agreement with the experimental observation. This is mainly due to the small value of the axial wavenumber and the sharp density and velocity gradients caused by the limiter. The spiral structure develops in the sharp gradient region. Of course, this linear calculation is not self-consistent because the saturated state results from the effect of nonlinear processes.

Conclusion

Strongly nonlinear low-frequency waves are recorded when the rotation of the plasma column is induced by the negative space charge injected on the axis of the column. A spiral structure has been recorded when the m = 2 mode is present. The bending of the arms is related to the existence of an azimuthal velocity shear layer. The spiral motion induced by the radial electric field and the centrifugal instability seems to be a rather generic phenomenon in linear and curved magnetised plasma columns. Preliminary experiments have shown the potentiality of an imaging diagnostic for the study of these structures. Previous studies have concluded to the crucial role of the axial acceleration of the plasma in the transition between azimuthal modes and towards turbulence [5]. Our preliminary results on the turbulent regimes show that the underlying control parameter is rather the intensity of the radial electric field inside the magnetised plasma column.

References

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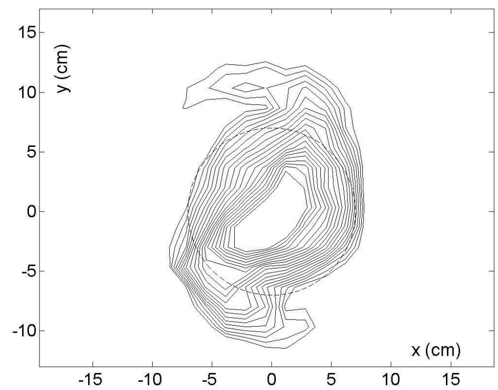

Fig. 1 – Experimental map of the electron density (m = 2 mode) in a cross-section (x, y) of the plasma. The circle is the limiter.

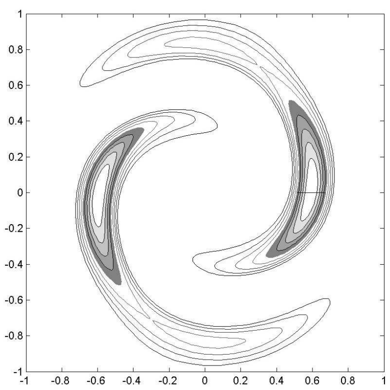

Fig. 2 – Linear solution of the contour lines of the perturbed density. The circle is at the position of the density gradient.

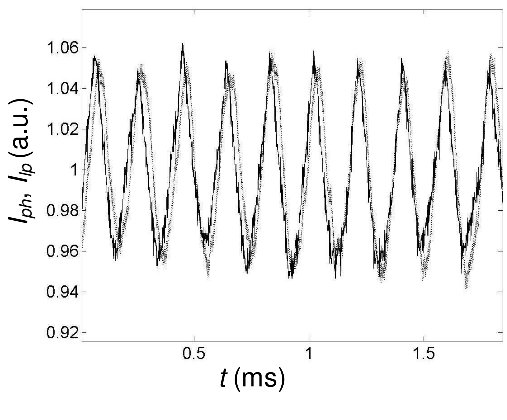

Figure 3 – Comparison of the time evolution of the photo-diode signal I_{ph} (—) and the Langmuir probe signal I_{lp} (- - -).