FLUCTUATIONS AND THE SHAPE OF A ROTATING MAGNETIZED PLASMA COLUMN

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1. Introduction

The experiments are carried out in the plasma generator PSI-1 [1], a stationary low-pressure high-current arc in an axial magnetic field. The plasma is produced between a heated cylindrical hollow cathode and a hollow anode. It drifts, magnetically guided ($B = 50 \ldots 270 \, mT$), into an investigation chamber and forms a cylindrical plasma column with a diameter of $6 \ldots 10 \, cm$ and a length of about $2.5 \, m$. The following plasma parameters can be achieved $n_e \leq 10^{19} \, m^{-3}$, $T_e \leq 10 \, eV$, $T_i \leq 5 \, eV$ in noble gases. The plasma is almost fully ionized and, therefore, the ion-ion collision frequency is greater than the ion-neutral collision frequency. For heavy noble gases (Ar, Kr, and Xe) the warm ions are weakly magnetized ($\omega_{ci}\tau_{ii} \leq 1$) and their gyroradii are in the order of the plasma radius. Hence, ions are almost exclusively confined by a radial electric field which is also responsible for the rotation of the whole plasma column.

Furthermore, the plasma in the region between cathode and anode carries the discharge current that partly flows perpendicular to the magnetic field. Hence, the plasma produced in that region receives angular momentum ($\vec{j} \times \vec{B}$) and expands along the field lines streaming through the machine at a high velocity ($\approx c_s/2$). Consequently, several mechanisms are available to destabilize certain kinds of instabilities, sources of free energy exist to feed a rich population of modes, and non-linear effects are present to establish mode interaction and turbulence including a possible transition to chaos.

2. Radial fluctuation profiles and the shape of the column

The stationary radial profiles of the plasma parameters (Fig. 1) are measured with double probes [2]. As expected from the geometry of the electrodes the electron pressure profile is found to be hollow. The radial electric field is determined from the gradient of the plasma potential ($U_{Pl} = U_{Fl} - \mu k_B T_e/e$, $\mu = 5.0$ for Kr). It is remarkable, that the radial electric field changes sign near the edge. Inside the plasma column ($R < R_0$) it points to the center and the direction of the according E_r/B drift velocity is consistent with the observed plasma rotation.
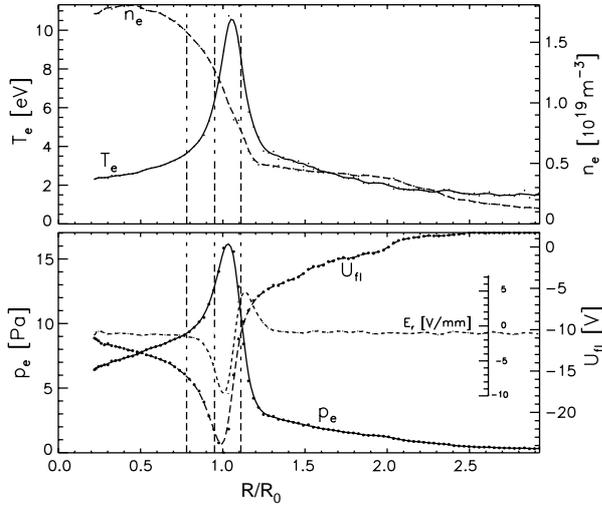
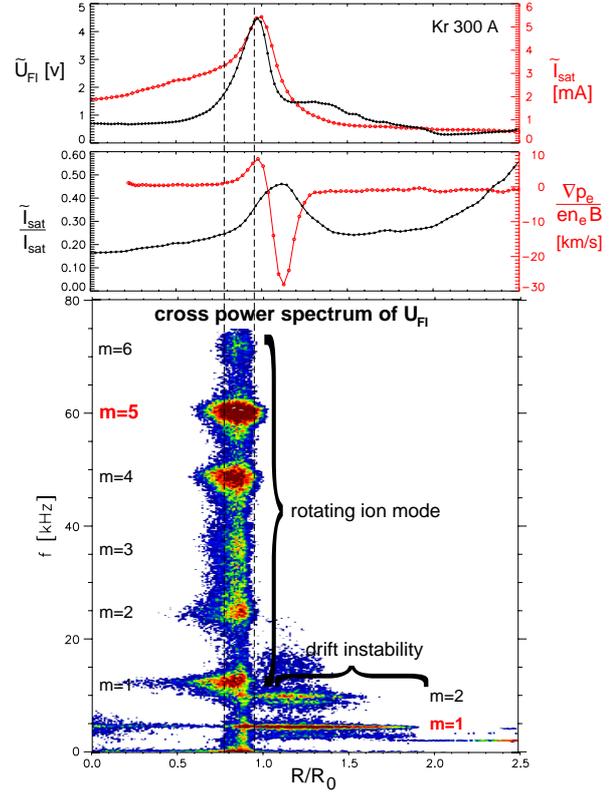**Figure 1.** Time averaged radial profiles.

Figure 2. Radial fluctuation profiles.

Outside the plasma column E_r/B can partly compensate the electron diamagnetic drift velocity.

The fluctuation population observed for the saturation current and the floating potential of probes was found to consist of several cyclic contributions at specific frequencies, a background noise of those modes at low frequencies, and a high frequency noise continuum depending strongly on the frequency following a power law. The frequencies of the individual modes are essentially independent of radius but their amplitudes peak close to the locations characterized by maximum gradients of the electron pressure (Fig. 2). This descrete contributions (modes) can obviously be described as higher order harmonics belonging of very few basic oscillations. One series of harmonics can be identified for the maximum inboard and outboard gradients introduced by the hollow profile of the column.

In the inboard series the population is dominated by modes with azimuthal numbers 1, 4, and 5 having distinct phase relations to each other (phase locking). As a consequence this mixture of phase locked higher harmonics determines the shape of the plasma columns azimuthal cross-section. The careful analyzis of frames obtained by fast CCD-cameras confirms this relation and demonstrates that the azimuthal shape holds throughout the machine without substantial
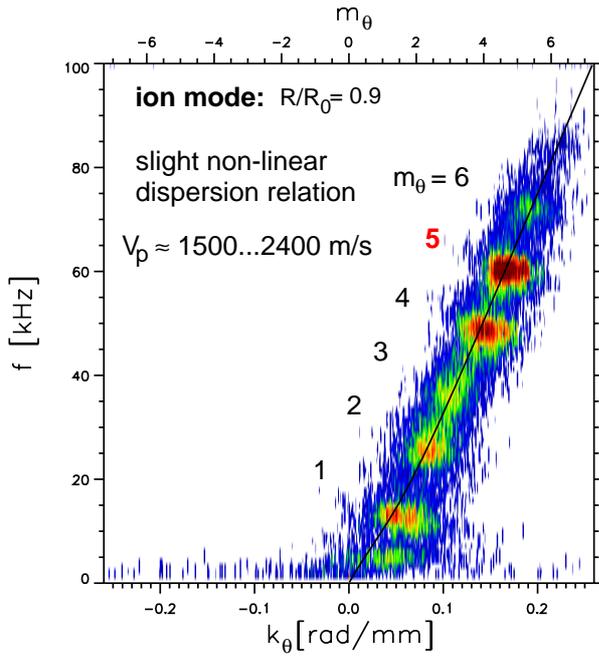
Figure 3. Azimuthal dispersion relation of the inboard series (ion modes). All modes have nearly the same phase velocity. The direction is right handed to $\vec{B}$.
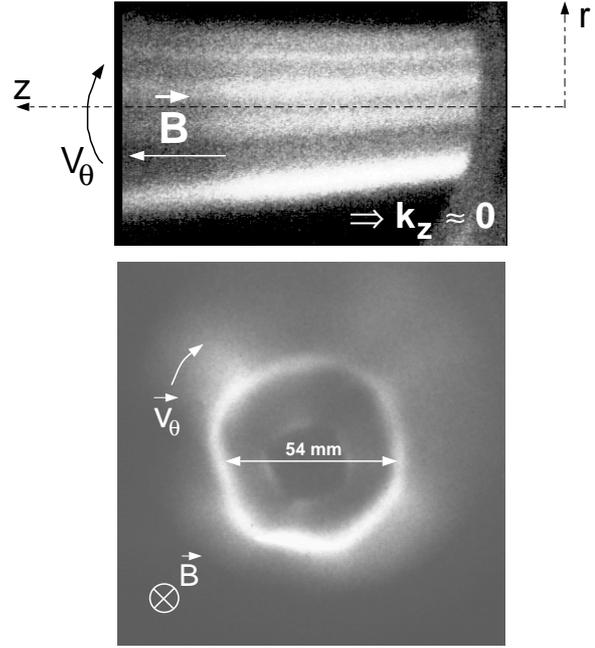

Figure 4. Side-view and axial-view of the plasma column. The side-view shows no twist of the mode structure.

shear or twist (Fig. 4). An exception is the region under the hollow anode, where the shape and the angular dependence of light intensity are more or less decoupled and only the shape reflects properties of the mode spectrum.

Exposing several probes at different azimuthal positions at the radial position of the inboard series simultaneously components of the corresponding wavevectors could be determined and have been used to construct a statistical dispersion relation for the observed mode series (Fig. 3). These relations come out to be almost linear but differ for the series obtained inboard and outboard. From the slope ω/k of the dispersion relation above, a azimuthal phase velocity of about $1500 \ldots 2400 \; m/s$ was determined for the inboard ion mode structure. The direction of the propagation is the same as the direction of the rotation of the shape in the CCD-images.

Variations of the discharge current I_{AK} show a strong variation of the spectrum of the modes (Fig. 5). It is clear to see, that a critical discharge current is necessary to destabilize the inboard ion mode series. Furthermore, variations of the magnetic field strength deliver a $I_{AK} = const./B$ dependence of the inset point for the ion mode (Fig. 6). This leads to the conclusion, that a minimal speed of the rotation of the plasma is necessary to excite the instabilities ($I_{AK} \cdot B$ is proportional to the Lorentz-force).
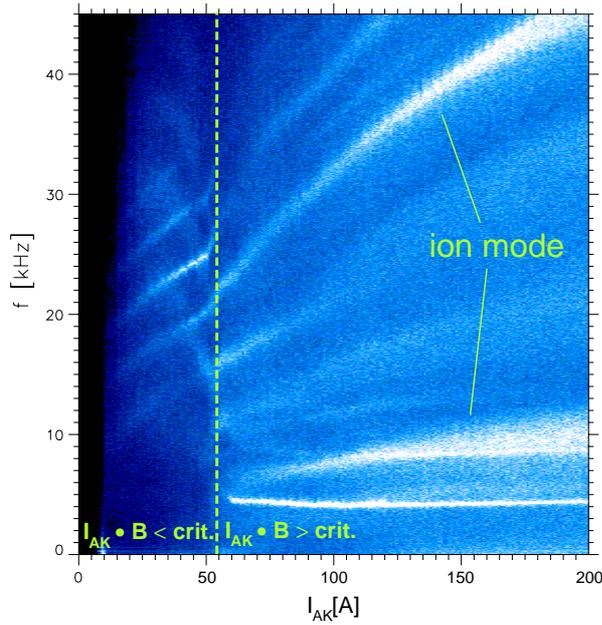
Figure 5. Dependence of the inboard mode spectrum on the discharge current. At $I_{AK} \approx 55$ A the ion mode instates.
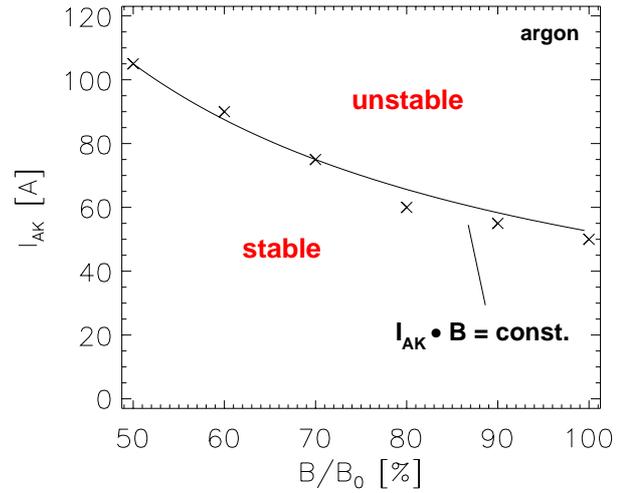

Figure 6. Variation of the inset point of the ion mode with the magnetic field strength.

3. Conclusions

In a rotating cylindrical plasma column with a hollow elctron pressure profile and therefore with two regions of steep gradients, two different mode series are observed. The inboard mode series is identified as a rotating ion density structure with a pentagonal shape. It was shown, that probe measurements and CCD-images give complementary information about the spatial and temporal structure of the observed rotating ion mode. The outboard mode series is a electron drift instability, because the maximum of the amplitude is at the radius of the maximum of the electron pressure gradient and the propagation is in the direction of the diamagnetic drift velocity. Furthermore, a critical threshold of the rotation of the plasma ($\sim I_{AK} \cdot B$) is necessary to destabilize the observed modes.

References

[1] Bohmeyer, W., et al.: *Proc. 22nd Europ. Physical Conf. on Controlled Fusion and Plasma Physics*, Bournemouth, Vol. **19C**, Part II (1995) 297

[2] Klose, S., Meyer, H., and Laux, M.: Contrib. Plasma Phys. **38** (1998) S, 80