Characterization of electrostatic fluctuations in the low-density plasma of the linear device GyM

D.Ricci, A.Cremona, S.Garavaglia, G.Granucci, S.Alocci, M.DeAngeli, F.Dell'Era, G.Gatto, G.Gervasini, G.Gittini, M.Lontano, V.Mellera, D.Minelli, V.Muzzini, A.Nardone, R.Schiavone, C.Sozzi

IFP–CNR, Euratom-ENEA-CNR Association, Via R. Cozzi 53, 20125-Milano, Italy

Introduction. The linear machine GyM, operating at IFP-CNR (Milan) since 2008 [1], has started experiments aimed at characterizing drift waves excited in its non-uniform magnetized plasma. In GyM it is expected to access interesting regions of dimensionless parameters to perform experimental investigations on low-frequency electrostatic turbulence (1-100 kHz) and its origin. Indeed electron plasma density fluctuations are easily observed in a linear magnetized plasma column where radial pressure gradients can excite drift waves and produce fluctuations in density [2,3]. Furthermore, a radial electric field (spontaneous or externally produced) is expected to induce a drift in the azimuthal direction, causing a rotation of the plasma column, which can further act on density fluctuations characteristics. By means of a non-uniform neutral gas density flow, different plasma conditions have been studied on GyM. Using the two available sources (a hot W filament or a radio frequency (RF) source at 2.45 GHz) in highly collisional H plasmas, electron density fluctuations have been observed in the above mentioned frequency range. Intensity and frequency spectra have been measured, with a radially moveable probe, in different conditions; a preliminary study of the dependence of such fluctuations on the plasma parameters are presented and discussed.

Experimental setup. GyM is a linear device consisting of a vacuum chamber (radius R = 0.25 m, length L = 2.11 m) mounted in a 0.13 T linear magnetic field (limit in the present configuration). The base pressure inside the chamber is of the order of 10^{-7} mbar and the chosen working pressure in hydrogen gas is typically $5.0 \cdot 10^{-4}$ mbar. Plasma can be generated by a thermionic source (with an emitting surface of 12 cm^2 made of W wire cloth) or by means of microwave power in the electron cyclotron frequency range. The position of the filament source has been chosen in order to facilitate the flow of the plasma along the magnetic field: the main ionization occurs in a region of relatively strong field gradient (~0.6 mT/cm) followed by an experimental region with a constant field at a reduced ripple (1.3%) where plasma naturally flows. Microwaves are produced by a commercial microwave power generator at a frequency of 2.45 GHz, which delivers CW power up to 1.6 kW and pulsed mode power up to 8kW with a 1-20% of duty cycle. The source consists of a water-cooled magnetron, a directional coupler to measure the reflected/transmitted power and an impedance automatic adapter to protect the head and maximize the coupling. The power is injected into the vessel using a truncated copper waveguide (WR340) as an antenna, placed after a simple rectangular (not cooled) window based on a thick (~ 6 mm) low absorption dielectric (SiO_2 water-free). In the present configuration the TE_{10} rectangular mode is injected in Ordinary Mode polarization perpendicularly to the magnetic field lines, with the resonance (0.0875 T) located on the opposite end. Increasing the magnetic field intensity, more and more resonant surfaces (perpendicular to the machine axis) appear close to the magnetic coils. The RF source is able to produce an electron density of one order of magnitude higher than the hot filament ($5 \cdot 10^{10}$ cm^{-3}) and with an electron temperature (T_e) of the same level (~2 eV). The present diagnostic setup consists of two movable Langmuir probes located along the plasma column to perform measurements of the mean plasma quantities as well as of the fluctuating ones (up to 1 MHz with the present data acquisition system). A spectroscopic technique based on the relative intensities of hydrogen Balmer lines is proposed as non-intrusive diagnostic complementary to Langmuir probes for T_e measurement. The light from a central line-of-sight of the plasma is focused through an optical fiber onto the entrance slit of a monochromator coupled with a CCD camera (overall resolution of 0.06 nm). The electron temperature is estimated from the intensities ratio of the H_α and H_β lines on the basis of a steady state corona model [4]. This model is valid for optically thin plasmas and assumes a balance between the rate of collisional excitation by electron impact from the ground state, which depends on T_e, and the rate of spontaneous radiative decay. Figure 1 shows the agreement between the values obtained by mean of the spectroscopic measurements (Optical Emission Spectroscopy) and those obtained

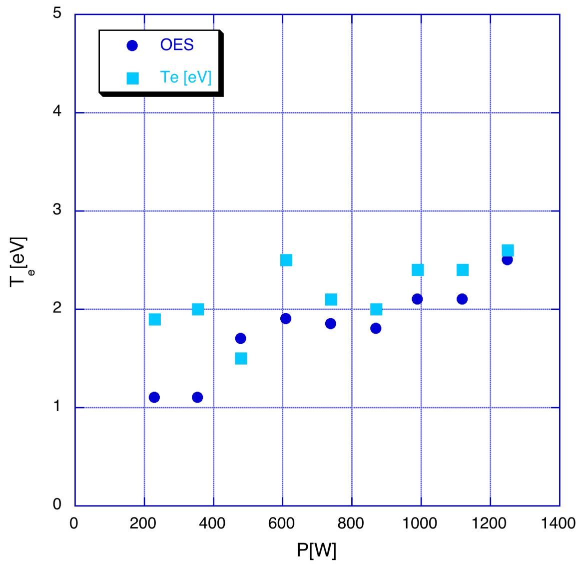

Figure 1 Electron temperature as a function of the ECR power obtained by Langmuir probe and OES measurements. The magnetic field configuration is such that many resonance layers go through the vacuum chamber. Langmuir probe is at the position r = 0 mm.

by the Langmuir probe (located at the center of the plasma column) as a function of the applied RF power. A further development of this diagnostic will consist in adding more line-of-sights to reconstruct the whole T_e profile by means of inversion techniques.

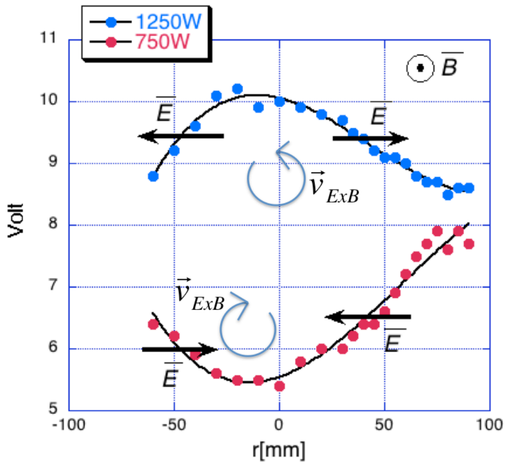

Figure 2 Plasma potential profiles along the chamber diameter for two different power values. Increasing the EC power, plasma potential profile can be modified inducing an azimuthal **E**x**B** drift.

Experimental results. The experiments presented here are mainly performed using the RF 2.45 GHz source with a magnetic field configuration for the ECR heating with a single resonance layer (0.0875 T). Plasma profiles shapes depend on RF power: as a consequence of the anisotropic neutral gas inflow, plasma formation, at low EC power, is concentrated in the peripheral region of the chamber, where the neutral density is higher. This gives rise to a peculiarity in the plasma density profile, which results to be hollow. As power increases, the electrons gain enough energy to ionize also the central part of the column and fill the density profile. In this configuration the equilibrium values of plasma parameters profiles are measured with a movable electrostatic probe. In Fig. 2 the radial distribution of the plasma potential is shown for different EC powers. The profile shape can be easily modified varying the EC power level from a ‘hollow’ (at low power, red dots) to a ‘monotonic’ shape (at high power, blue dots). The electric fields change direction as the plasma potential gradients

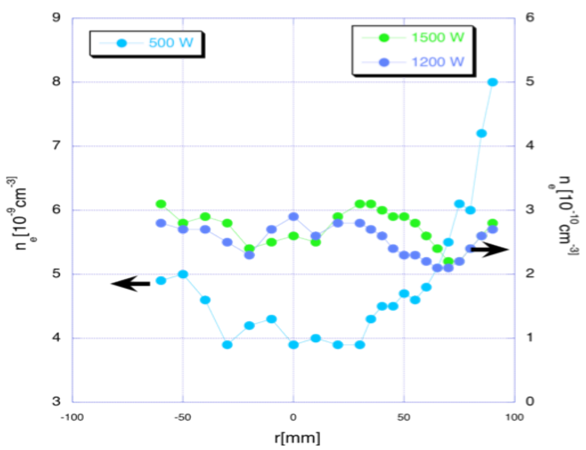

Figure 3 Plasma density profiles for different power values. Increasing the EC power, central density increases and the initial ‘hole’ is filled.

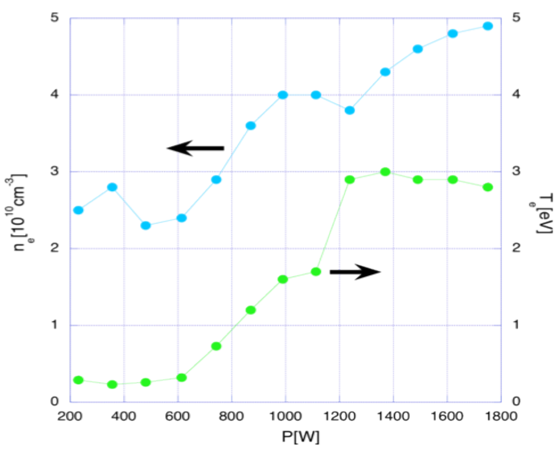

Figure 4 Central electron densities and temperature as a function of the applied EC power. The observed variation is in agreement with the variation in turbulence level.

reverses its sign: the corresponding **E**x**B** drift velocity produces anazimuthal plasma rotation clockwise (for the 'hollow' V_p profile) or counter clockwise (for 'monotonic' profile). In the meantime, the EC power level influences the electron density as observed in Fig. 3. Increasing the absorbed power, the density in the center of the chamber increases and the initial 'hole' is progressively filled. The modifications occurring in the radial profile are in agreement with the behavior of the central electron temperature and density measured at the position r = 0 mm, as a function of the applied source power (Fig. 4). The main effect of changes in potential/density profiles is observed in the spectral variations of the ion saturation current fluctuations (measured at r = 60 mm), as shown in Fig. 5. Increasing EC power, the spectrum changes its shape, i.e. from high level stochastic fluctuations at low power (corresponding to the 'hollow' profile in potential or density), to low-amplitude fluctuations, with characteristic frequencies, at high power (monotonic profile). The competitive mechanism between the drift due to the presence of the electric field and that due to the density gradient will be further studied and analyzed in order to explain the observed behavior.

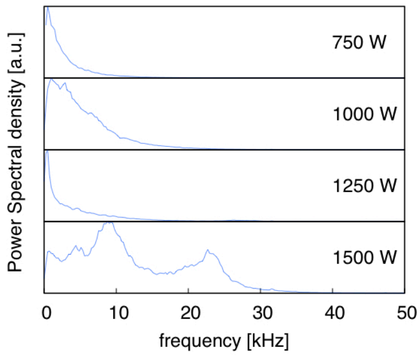

Figure 5 Power spectra density of the ion saturation current signals measured at r = 60 mm.

Conclusion. In the linear machine GyM experimental investigations aimed at studying electrostatic turbulence in low-density plasma has been started. An experimental setup has been implemented in which the neutral gas distribution is radially non-uniform. This configuration strongly influences the azimuthal drift of the charged particles and modifies the radial profiles of plasma potential and density. Such parameters exhibit a strong dependence on the applied EC power, as well as on the ion saturation current fluctuations. A spectroscopic technique based on the relative intensities of hydrogen Balmer lines is also proposed as non-intrusive diagnostic complementary to Langmuir probes for T_e measurement.

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