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The new linear plasma device GyM at IFP-CNR

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Introduction. Linear plasma devices or small toroidal ones [1][2] allow one to carry out experimental measurements aimed at studying the turbulence response to variation of key plasma parameters, controlled almost independently of each other. In these devices, exploiting a principle of physical similarity, it is possible to access interesting regions of dimensionless parameters to perform experimental investigations on low-frequency electrostatic turbulence (10-100 kHz) in long lived plasmas. In this frame the new linear machine GyM has started its preliminary experiments at the Istituto di Fisica del Plasma, CNR, Milan. GyM is a linear plasma device capable of 3 kG of maximum magnetic field with a transverse plasma cross section of 10 cm of diameter. Presently, a hot tungsten filament continuously generates a plasma column with a radial extension and density gradient defined by filament dimensions or by the presence of a co-axial diaphragm. A set of electrostatic probes for density, temperature and ions flow (Mach probes) measurements, spatially distributed for coherent structures detection, has been installed, together with an optical emission spectrometer. In preliminary highly collisional H plasmas electron density fluctuations have been observed in the above mentioned frequency range. The fluctuation intensity and frequency spectra have been measured with a radially moveable probe. Dependence of such fluctuations on the plasma parameters is presented and discussed. Further foreseen steps to produce fully ionized collisionless plasmas are discussed, together with a preliminary study of experiments aimed at detection of 'sheath driven instabilities' [3].

Motivations for GyM experiment. Construction and operation of a small plasma machine must be, nowadays, considered in the framework that includes all the operating machines and, of course, ITER. The effort in designing such a machine is to maintain the versatility and the simplicity of operation, which is one of the main benefits in operating a small dimension experiment, together with the necessity to guarantee the scientific importance of results obtained. The ways that we have chosen to pursue these objectives are (i) to profit of the existence of suitable dimensionless parameters characterizing specific physical processes, independently of the actual dimensions of the machine (similarity conditions), and (ii) to reproduce typical plasma conditions which are met in the peripheral and in the divertor regions of a tokamak plasma.

In addition, it should be also considered that experimentation in a linear device allows one to control the various physical quantities, as for example temperature, density, electric field, azimuthal plasma rotation, axial plasma flow and the relative spatial gradients, which otherwise in a tokamak device would be all connected to each other via the plasma current. In the right columns of Fig. 1, we report few dimensionless parameter calculated for the GyM plasma in two regimes of operation, compared with the same quantities calculated for ITER plasmas. It is seen that, even if the dimensional parameters differ by several orders of magnitudes, plasma characteristics in terms of dimensionless quantities are similar. Here, the 'bounce' frequency ω_B of the j-species (j=e,i) in GyM is calculated as $\frac{2\pi}{t_{transit,j}} = \frac{2\pi v_{th,j}}{L}$.

	a /L (cm)	$n_0(cm^{-3})$	$T_e(eV)$	$T_i(eV)$	B(kG)	$\nu_e^*=\nu_{en/ei}/\omega_B$	$\nu_i^*=\nu_{ii}/\omega_B$	ρ_e^*	ρ_i^*
GyM-I	5/150	10^9	10	0.01	1	1.5×10^{-5}	-	1.5×10^{-3}	2×10^{-3}
GyM-II	5/150	10^9	10	10	2.5	5.4×10^{-2}	3.8×10^{-2}	6×10^{-4}	2.6×10^{-2}
ITER	200/3896	10^{14}	25×10^3	25×10^3	50	1.5×10^{-3}	1.1×10^{-3}	3.6×10^{-5}	1.5×10^{-3}

Figure 1: The main plasma parameters reachable in GyM for two different configurations (GyM-I and GyM-II). Resulting dimensionless parameters compared to ITER show similar plasma regimes. Here, a and L are, respectively, radius and length of the plasma column.

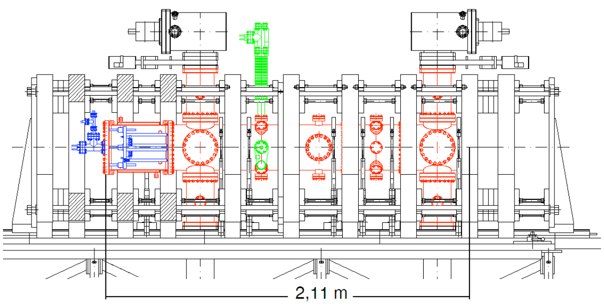

Figure 2: GyM design: in red the vacuum chamber, in blue the source and in green the electrostatic probes

Machine description and diagnostic system. Gym is a machine (Fig. 2) with a vacuum vessel (vv) (R_v = 0.25 m, L_v = 2.11 m) mounted in a linear magnetic field generated by 10 coils with the possibility (in the present configuration) to reach 0.13 T on the axis. The plasma section can be varied using diaphragms installed in the vv or with the use of plasma source of different transversal extensions (Fig. 2). The magnetic configuration has been chosen in order to locate the plasma source (hot filament) in a region of relatively strong field gradient (∼6 G/cm) followed by an experimental region with constant field at a reduced ripple (1.3%). An accurate magnetic mapping has verified the good uniformity of the field distribution. A reduced (±1cm) mismatch between geometrical coils center and magnetic measure axis has been found and it will be taken into account during the data analysis. The diagnostics system to be installed in GyM is particularly suited for fluctuation (Langmuir probe) and energy/momentum measurements (Mach probe and grid energy analyzer). The first plasmas obtained in GyM have been measured with moveable Langmuir probe connected to a fast acquisition system (1MHz) in order to perform fluctuations measurements. The spatial resolution required for turbulence (i.e. vortex) detection will be guaranteed by the introduction of a probe array in order to detect, using fast contemporary data acquisition, phase correlation between spatially displaced fluctuations. A tool for optical emission spectroscopy has been employed to reveal the hydrogen radiative emission at different magnetic field intensities. The spectra were acquired in the wavelength range of 300-1000 nm with a spectral resolution of 0.2 nm.

Plasma sources. The plasma source (Fig.3) consists of a W mesh (expected to operate at a current level of $\sim$ 80 A) that emits electrons (emitting surface $\sim$12 cm^2) accelerated in a background gas (Ar or H_2) by a polarized stainless steel grid. The distance between the mesh and the grid as well as the extension of the emitting surface itself can be easily modified. Between the hot mesh and the grid is placed a Langmuir probe in order to measure the characteristics of the source plasma. The position of the source has been chosen in order to facilitate the flow of the plasma along the magnetic field. The implementation, in the near future, of a RF source will allow the production and sustenance of the plasma column and comparative studies of the turbulence characteristics occurring with the thermoionic source already present. Microwaves will be produced by a commercial microwave power generator, which delivers CW power up to 3 kW at a frequency of 2.45 GHz. The design of the microwave system consists of a magnetron with a circulator and a directional coupler, followed by an impedance tuner to match manually or automatically the microwave source to the plasma. The microwaves are fed into the GyM vacuum chamber through a dielectric window and propagate through a decreasing magnetic field profile until they are absorbed by the EC resonance at B = 0.875 kG.

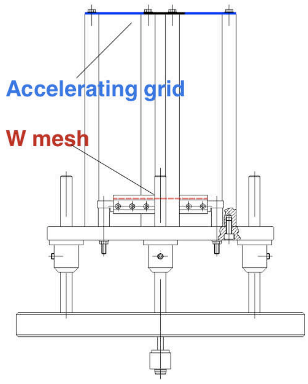

Figure 3: Hot filament source

First achieved plasma and fluctuation measurements. The first hydrogen plasma obtained in GyM has been produced by a prototype version of the hot filament source. The measured light spectra show continuous emission of the tungsten filament with the hydrogen atomic lines H_α and H_β superimposed. There is no evidence of molecular hydrogen bands. Fig 4 shows electron density produced by a small portion of W tissue (1$\times$2.4 cm) heated by 43 A. The grid is placed at 20 cm from the filament and it is polarized at +390 V. The working gas is H_2 and the pressure ranges from 2.4 to 6.5 10^{-4} mbar. Frequency spectra of plasma fluctuations are

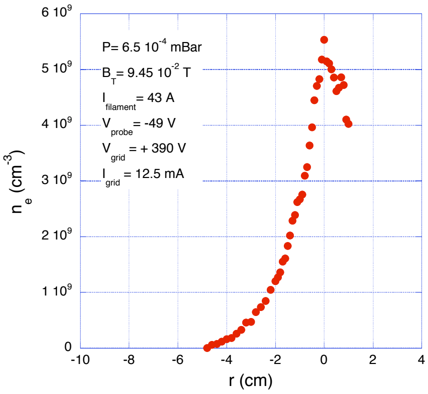

Figure 4: (left) Electron density profile from the ion saturation current, measured at 60 cm from the grid.

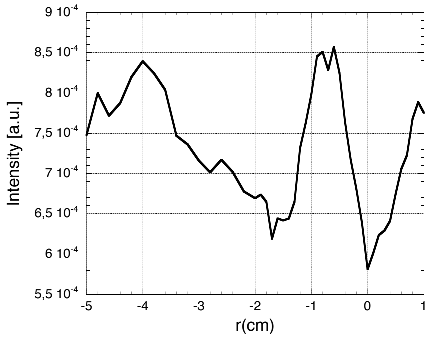

Figure 5: (right) FFT amplitude versus radius at 60 kHz

obtained from current fluctuations of a Langmuir probe. A bias voltage of -49 V with respect to the vessel ground is applied to the probe tip and it is verified to yield the current in the ion saturation region. FFT analysis of I_{sat} profile at different magnetic field shows the presence of frequencies that have a radial dependence of the amplitude ($\sim$60 kHz at 0.9 kG in Fig. 5, which is consistent with the electron diamagnetic drift velocity $v_{*e} = \frac{k_B T(\nabla n/n)}{eB} \sim 1.8 \times 10^3$m/s).

Sheath driven instabilities under similarity conditions. A theoretical study on possible future experimental investigations on GyM has been carried out. A particular kind of drift instabilities has been studied, the so-called 'sheath driven instabilities', which occur when the magnetic field lines, crossing a plasma region with a transverse density gradient, hit a metallic surface, making an angle α with the normal to the surface. If α is close to 90° (grazing incidence) the plasma fluid becomes unstable. This instability is expected to occur in the limiter and in the divertor regions of tokamak. It has been shown that the characteristics of the instability are similar in very different plasma devices like GyM and ITER, provided suitable dimensionless parameters are chosen (see Fig. 6).

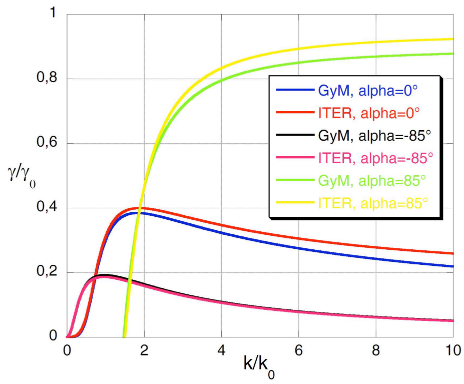

Figure 6: The imaginary part γ of the frequency versus the wavevector k for $\alpha = \pm 85°, 0°$, for typical GyM and ITER parameters. γ and k are normalized according to the rules discussed in [3].

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