A plug-probe diagnostics for the measurement of electric field fluctuations in the turbulent state of the simply magnetised toroidal plasma device THORELLO

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Experimental investigation of magnetised plasma turbulence is actively pursued in fusion aimed as well as in basic plasma physics toroidal devices [1,2]. In particular the understanding of turbulent transport mechanisms has a great interest for the improvement of the magnetic confinement [3]. A key component in this phenomenon is the formation of local electric fields which control the plasma flow through the ExB drift velocity. In low temperature, magnetised plasmas this happens mainly through the build-up of electrostatic potential fluctuations [4]. Here we discuss the use of plug-probes, a suitable modification of traditional Langmuir electrostatic probes [5], for an experimental investigation of plasma potential fluctuations of a turbulent, low beta, low temperature plasma in a simply magnetised toroidal configuration. The experiments have been executed on the Thorello device, operating at the University of Milano-Bicocca [6]. In this device, a low temperature, high density plasma can be produced in a steady configuration by driving a hot cathode discharge in low pressure hydrogen gas. The goal of the experiments lies in the observation that in toroidal magnetised plasmas a large fraction of anomalous particles and energy transport is attributed to the propagation of coherent structures [7]. These are isolated and intermittent structures, with density and temperature above the surrounding plasma, extending along field lines and propagating away from the bulk. In simply magnetised toroidal devices, like Thorello, the propagation is controlled mainly by the ExB drift velocity [8]. The local electric field is determined by the overall discharge conditions as well as by the electrical potential fluctuations, in particular the contribution arising from the coherent structures themselves. So a diagnostics specifically targeting plasma potential, like the plug-probe is particularly appealing to study this phenomenon. Traditional Langmuir probes get insight about the electric field by measuring, in different locations, the so called floating potential and its
fluctuations. This corresponds to the condition when no current is drawn by the probe tip from the plasma. Within the thin, non-collisional sheath approximation this condition is met when the probe potential is shifted a few electron temperatures below the truly plasma electrical potential [5]. Thus the measurement is prone to the uncertainties connected with the measure of the electron temperature and its fluctuations. A direct estimate based on the plasma parameters extraction from the full I(V) Langmuir characteristics is impractical too for measurements of the fluctuations, be it was achieved by some fast-sweeping of the probe potential [9] or by the triple probe method [10]. A smart proposal was the plug probe, where the collection of electrons by the probe tip, aligned to the magnetic field, is reduced by interposing a barrier (the plug), exploiting the differences in the Larmor radii of electrons and ions (see Fig.1). We tested two probes, with 2 mm tungsten pins and plug diameters of 1.6 and 3.2 mm respectively. To have a perspective, in the experiments reported here, the toroidal magnetic field is 67 mT, while the electron temperature ranges between 1 and 4 eV. At $T_e=2$ eV, the electron gyro-radius is about 50 μm. On the other hand, hydrogen ion gyro-radius is 0.25 mm, increasing to 2 mm when entering the probe sheath, according to the Bohm sheath criterion [11]. The probes were mounted on a rotating holder (scanning, with a stepper motor, a diameter of the poloidal section of the device) to locally align the probes to the magnetic field lines. The effect of the procedure can be glimpsed in Fig.2, where the sharp decrease of the electron saturation current and the corresponding shift in the zero-current floating potential can be appreciated, whereas the ion saturation current is almost unchanged. The resulting Langmuir characteristics is displayed in Fig.3, where the region the current changes sign is enlarged. This happens at a voltage in close agreement with the estimated plasma potential, based on standard Langmuir curve analysis, whose position is generally affected by large uncertainties too, especially when the thin sheath approximation does not hold [5]. Besides the characterization and the optimization of the probe performances, some properties
related to the plasma structures that develop and propagate in the edge region are presented too. The zero-current probe potential, which, in the following, we refer to as plug potential, can be easily recorded with a high impedance, fast speed digitizer, as a digital scope. The sampling rate could easily exceed the bandwidth of the plasma turbulence and the typical autocorrelation times of plasma parameters fluctuations [6,8]. Because of the proximity of the plug potential to the real plasma potential, information about the instantaneous electrostatic field can be extracted with limited contamination arising from other correlated plasma fluctuations. As a first test, we measured the average plug potential profile across an oblique line passing through the center of the oblique cross-section of Thorello. The profile is shown in Fig.4. A broad potential well is formed with a minimum, slightly shifted towards the internal, high field side, of about -15 V. The potential turns slightly positive at both edges, before decreasing towards zero, as dictated by the grounded chamber walls. This is interesting because of the sign change it implies in the radial electric field and in the corresponding ExB velocity. Indeed, besides the central part of the potential well, where a plasma column rotation could be guessed, a region of velocity shear develops at edge, as shown in Fig.5. Fluctuations of the plug potential could be analysed too. In Fig.6 we display the fluctuation probability distribution function (PDF) measured during a conditional sampling experiment.
Here a dataset of about 0.4 GSamples of fluctuations was recorded at a location broadly corresponding to the edge of the potential well [8]. This allows a fairly detailed reconstruction even of the tails of the PDF. Substantial deviations from Gaussianity are observed, as expected [6]. However, we observe also some marked differences in the PDF tails by comparing plug with floating potentials. Thus it could be expected to observe correspondingly significant variations when we evaluate physical quantities depending from the electrostatic fluctuations, such as the radial component of the ExB drift velocity, whose PDF, based on floating potential measurements, is plotted in Fig.6 too. This is crucial for the evaluation of anomalous transport and its impact on magnetic confinement [3]. This embodies well the advantages brought in by the plug probe diagnostics. As a final example, we report the results of the so called auto-conditional average of the plug potential fluctuations [8]. Here plug potential fluctuation events, corresponding to a peak amplitude exceeding $3\sigma$ were selected and time windows were averaged. More than $10^4$ events were averaged. The plot in Fig.7 shows the formation of a positive fluctuation reaching about 1 V with a duration of about 100 $\mu$s. This hints to the formation of coherent structures in electric field in the edge of the plasma column, controlling the fluxes and adding to anomalous transport.

References