3D plasma dynamics studies in TORPEX using a dual Langmuir probe array

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Introduction

Langmuir Probes (LPs) are widely used diagnostics in plasma physics. Through suitable assumptions, LPs provide means to deduce local values of plasma density (n), plasma potential (V_p) and electron temperature (T_e).

In TORPEX [1], as well as in other basic plasma experiments with toroidal [2] and linear geometries [3, 4], arrays of LPs have been used to observe and study the evolution of plasma structures in 2D sections of the devices, thereby greatly contributing to the understanding of the dynamics of plasmas in different geometries and magnetic configurations. In particular, LP arrays have been instrumental in studies of plasma blobs and their perpendicular dynamics [5, 6]. There are still, however, many open questions on experimental 3D features and dynamics of blobs [5]. We have designed a new diagnostic, dubbed HEXTIP-U, which allows us to study TORPEX plasmas and incorporate basic 3D features to the observations. The diagnostic consists of two independent, identical, 2D hexagonal arrays of LPs placed at different toroidal locations and a set of data analysis routines that, by combining data from both arrays, allow us to reconstruct properties of plasmas on the cross section and along the parallel direction to infer a basic 3D picture of plasma structures.

The arrays include a linear-motion mechanism that can radially displace LPs located on the Low Field Side (LFS) of the apparatus for easy changes in the magnetic field configuration through adjustments of the position of the in-vessel Toroidal Conductor (TC) [7].

The HEXTIP-U diagnostic

HEXTIP-U comprises two identical LP arrays installed on opposite sides of the toroidal vessel (Figure 1a). Each array is composed of 95 Langmuir-probes made of stainless steel, distributed on a total of 22 cylindrical ceramic supports, or *arms*. Eleven of these arms are mounted on two stainless steel rings which are then installed inside the TORPEX vacuum vessel and secured in place with a set of screws. This part of the setup provides LP coverage of the High Field Side (HFS). The remaining probes rest on a different set of 11 arms which are not fixed to rings but rather are secured to two stainless-steel arcs attached to a newly-designed in-vacuum linear-motion structure. Each full arc assembly can be moved in the radial direction, independently of the other, by up to 20 mm towards the HFS or up to 70 mm towards the LFS. When neither of the arcs is displaced, this setup, together with the probes installed on the HFS, provides complete coverage of the poloidal cross section with a hexagonal grid of lattice constant 35 mm (Figure 1b). Turning the linear-motion actuators makes it possible to displace both arcs to, for example, 18 mm towards the LFS, thereby opening a gap between ceramic arms for TC height adjustments.

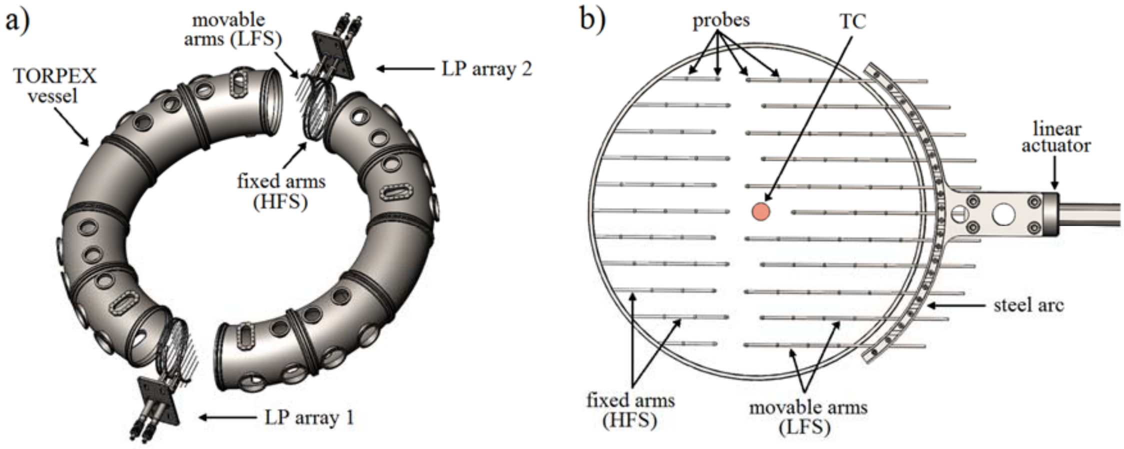

Figure 1: HEXTIP-U setup. (a) Location of the complete LP arrays installed on opposite sides of the TORPEX vessel. Notice that the movable arms are installed separately from the fixed HFS arms and therefore have a slight toroidal separation (< 10°) from the latter. (b) Front view of one complete array showing the location of the probes as well as the ceramic arms on which they rest. The HFS LPs are fixed, while the LFS LPs can be displaced by means of the linear actuator. The picture shows the location of the TC for experiments with closed magnetic field lines.

The monopole wires coming from all probes are bundled and connected to the exterior of the vacuum vessel through four DSUB-25 plugs welded onto the flange that supports the movable system, providing a vacuum-safe connection of the probes to the front-end electronics.

The electronics of each array consist of 12 independent boards, each one dedicated to 8 probes, which can be set remotely and independently from one another to measure probe floating potential (V_{fl}) or probe current (I_{prb}). In the latter case, a fixed bias voltage can be set for measurements of ion saturation currents ($I_{i,sat}$), or a variable voltage can be provided externally, for swept probe measurements. In all cases, the output is a voltage in a range well suited for digitization by one of two 96-channel,16-bit, D-tAcq ACQ196CPCI data acquisition systems sampling at a frequency of 250 kHz.

We performed a careful calibration of V_{fl} and I_{prb} in all complete measurement channels, on both arrays, to have an accurate interpretation of the digitized signals as probe currents or floating potentials. We also studied the AC response and circuit noise. The results show that total I_{prb} uncertainties are smaller than 4 µA for the range -5 mA to +5 mA, in all channels. As we expect $I_{i,sat}$ values of the order of ≈ 0.1 mA - 1 mA, we conclude that uncertainties are small compared to the signal level, allowing plasma evolution studies without further additional filtering. This capability is demonstrated in a series of experimental tests below. V_{fl} measurements are comparatively noisier, but they are nonetheless fully calibrated and functional. Future studies will be performed that make use of the V_{fl} measurement functionality.

Experimental tests

In a first set of tests in TORPEX, we create a hydrogen plasma in a Simple Magnetized Torus (SMT) configuration with parameter values known to generate intermittent field-aligned plasma structures that propagate radially outward [8]: A microwave power P_{mw} = 600 W, on-axis toroidal magnetic field B_ϕ = 72.6 mT and vertical field B_z = 1.2 mT - 2.1 mT (the calculated number of field turns around the toroidal vessel for these parameter values is N = 2.2 to N = 3.8). We then measure coherences between points on two different toroidal locations of TORPEX using the probes on the two different LP arrays of HEXTIP-U. In this measurement, the TC is set to its maximum vertical position (removed from the plasma) and left de-energized.

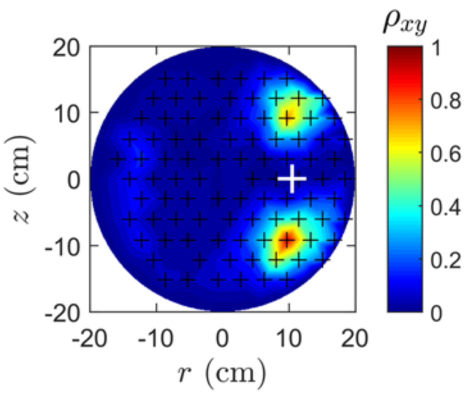

Figure 2: Normalized cross correlation ρ_{xy} of the recorded $I_{i,sat}$ of a probe on one HEXTIP-U LP-array (white cross) with all probes on the other array (black crosses) for experimental shot 67372. The results are interpolated for all other points in the poloidal plane.

All HEXTIP-U probes are biased at -42V and $I_{i,sat}$ data, which constitutes a proxy for the density n assuming a known T_e, is collected in trials of duration 1s. The results, shown in Figure 2, are consistent with the expectation that higher correlations should be observed between probes lying near the same magnetic field line.

In the second set of tests, we use HEXTIP-U to image hydrogen plasma structures in an SMT configuration. We obtain 2D poloidal images of $I_{i,sat}$ in each LP-array by interpolating probe data over the poloidal cross section and assuming $I_{i,sat}$ = 0 at the vessel wall. Then, we single-out disjoint sets of image pixels for which $I_{i,sat}$ > 0.16 mA (which corresponds to $n \approx 10^{16}$ m^{-3} using a simple model for $I_{i,sat}$ in an LP of the known dimensions and T_e = 5 eV), and we identify simple 3D plasma structures by determining the pixel sets that are linked by magnetic field lines on the same or opposite LP arrays. Finally, we repeat this procedure at every acquisition time step and combine the results for consecutive times to obtain the time evolution of the simple 3D structures. Figure 3 shows the results obtained for one particular TORPEX experimental shot.

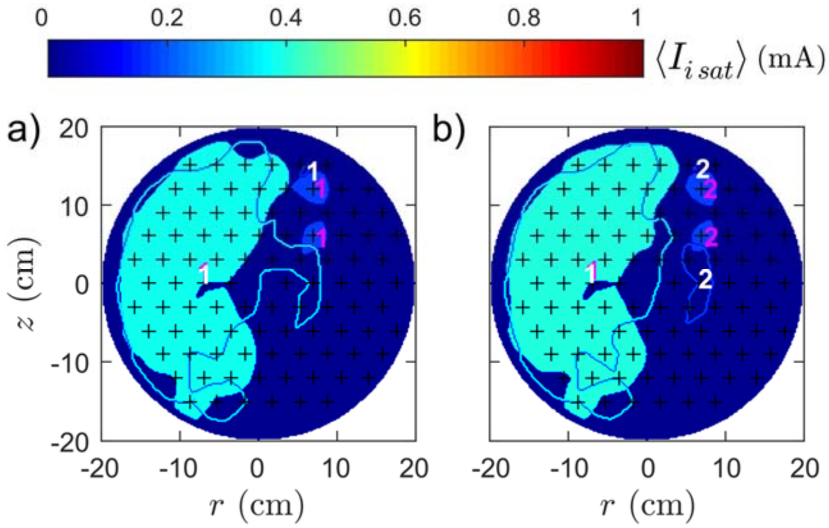

Figure 3: Plasma structures identified with HEXTIP-U in shot 67372. Solid shapes correspond to one array and hollow shapes come from the other array (the interior is left blank only to superpose data from both arrays in the same plot). The color of a shape shows its average $I_{i,sat}$. (a-b) Successive time frames, separated 4 µs, in which independent plasma structure “2” forms upon separation from structure “1”.

Conclusions

We have designed and commissioned a new diagnostic that allows us to determine basic 3D features of plasma structures in TORPEX. This diagnostic has the capability of following the evolution of the structures in time, a feature that will be of great use in future studies of intermittent events and plasma blobs.

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