OPTIMIZATION OF GUNDESTRUP PROBE FOR ION FLOW MEASUREMENTS IN MAGNETIZED PLASMAS

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Gundestrup probes are used to measure ion flows in magnetized plasmas. The standard design consists of six to twelve conducting pins mounted around an insulating housing in order to obtain a significant variation of the angle between the magnetic field and the probe surface. According to fluid and kinetic modeling, the current density collected by each pin is largely determined by the Bohm-Chodura boundary condition [1]. Despite the rigour of the physics formulation, the precision of flow measurements by Gundestrup probes has so far been limited to large parallel and perpendicular Mach numbers ($|M_{||}|, |M_{\perp}| > 0.1$). This is because slight angular misalignments and finite gap width between the pins and the housing cause non-negligible uncertainty of the individual effective collecting areas.

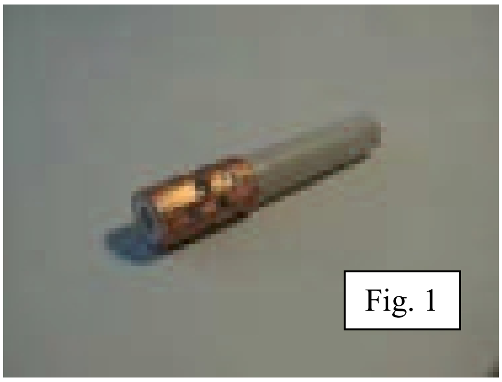

Fig. 1

The Gundestrup probe design has been improved ("Ideal Gundestrup Probe", IGP) and tested in order to render it attractive for flow measurements even in unbiased edge plasmas. The ion collecting surface is a nearly continuous cylindrical conductor (made of Cu-tube of diameter 11.7 mm) divided into eight segments separated by 0.2 mm gaps, as shown in Fig. 1. The collecting area, determining the radial resolution (2.2 mm) is defined by an insulating quartz sleeve (not shown in the picture) that is slightly shorter than the central conductors. The eight collectors are biased negatively into ion saturation in order to construct polar diagrams with good temporal resolution. A single Langmuir probe tip is installed at the front end of the IGP; its voltage is swept to obtain current-voltage characteristics and calculate the plasma parameters in the proximity of the probe. All signals are sampled at 1 MHz.

This optimized design has been validated in the CASTOR tokamak (R=40 cm, a= 8.5 cm, B_T =1 T). The poloidal and toroidal flows are measured simultaneously at the same radius by the IGP and rotating Mach probe (RMP) [2]. The toroidal lay-out of the key elements of the experiment is shown in Fig. 2. The electrode is located at the separatrix (r_b = 75 mm), and is positively biased with respect to the vacuum vessel. It has been shown recently [3] that such a biasing scheme effectively modifies the radial electric field not only in the scrape-off layer, but also in front of the electrode in the region of open magnetic field lines. The radial profile of the floating potential is monitored at the plasma edge by a rake probe [4] to derive the radial electric field in the edge plasma. All these tools are located at the same poloidal angle (at the top of the torus) to assure their respective radial positioning with a sufficient precision.

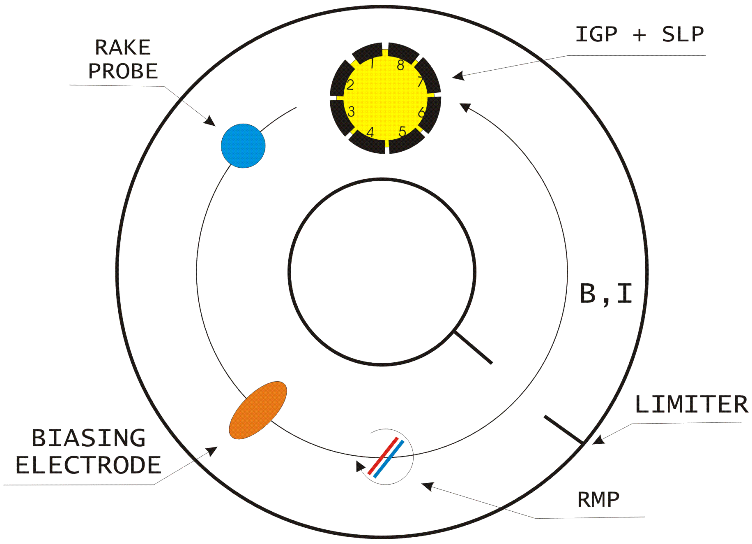

Fig. 2

Lay-out of the key elements of the experiment. The IGP and RMP are fixed to a manipulators to be possible measure the radial profiles on shot to shot basis.
The connection lengths:
biasing electrode & RMP ~ 28 cm biasing electrode & IGP ~ 98 cm

Comparison of IGP and RMP

Polar diagrams of the ion saturation current measured by the IGP and RMP at the same radial position are compared in Fig.3. The data are recorded in the same shot, during the biasing period of the discharge. Both probes are positioned inside the separatrix, at the radial electric field maximum, and consequently are not connected to any material element of the discharge chamber.

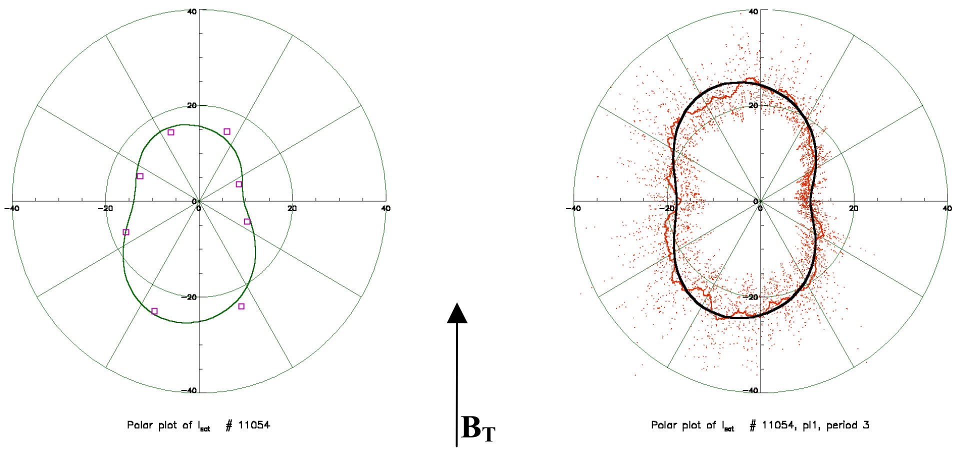

Fig. 3. *Polar diagrams of the ion saturation current as measured in the same shot by the IGP (left) and the RMP (right) located inside the separatrix (r= 70 mm). The experimental points are fitted to the KD model [2] (solid lines). #11054 .*

It is well seen that experimental data are reasonably fitted by the fluid model [2] and the resulting Mach numbers are shown in the table:

	$M_{\parallel}$	$M_{\perp}$
IGP	-0.2	-0.18
RMP	+0.0	-0.24

From this table and even from the visual inspection of the diagrams, a different shape of the diagrams, in particular in the toroidal direction is apparent. It is possible that toroidal asymmetries of the ion flow could exist in the CASTOR tokamak. Local recycling from different objects in the SOL (for example the biasing electrode or the poloidal limiter), plus viscous propagation of parallel flow from the various presheaths into the core could lead to such asymmetries. One can not exclude that the difference in the $M_{||}$ determination is partially caused by a misalignment of the probes with respect to the magnetic field lines [1].

Alternatively, the probe data are processed by the model developed by H. Van Goubergen [6]. An advantage of this method is that it provides an analytic formula for the ratio of upstream and downstream currents. However, only four pins of eight are used for processing of the raw data. Consequently, we have only two points from which we derive the Mach number using linear regression. So, an extraordinary signal from one segment (due to arcing, large density fluctuations, etc) corrupts the result. On the other hand, the KD model uses data from all eight segments and, consequently is not so sensitive to extraordinary events.

Systematic measurement of $M_\perp$ and $M_{||}$ - radial profiles

The IGP and RMP probes were moved radially by steps of 3 mm between shots. The electrode was biased to +150 V. The ExB velocity at the probe position is deduced from radial profile of the floating potential, $v_{ExB} = (-\nabla_r V_{FL} - 2.5\nabla T_e)/B$ and normalized by the sound velocity $M_\perp^{ExB} = v_{ExB}/c_S$.

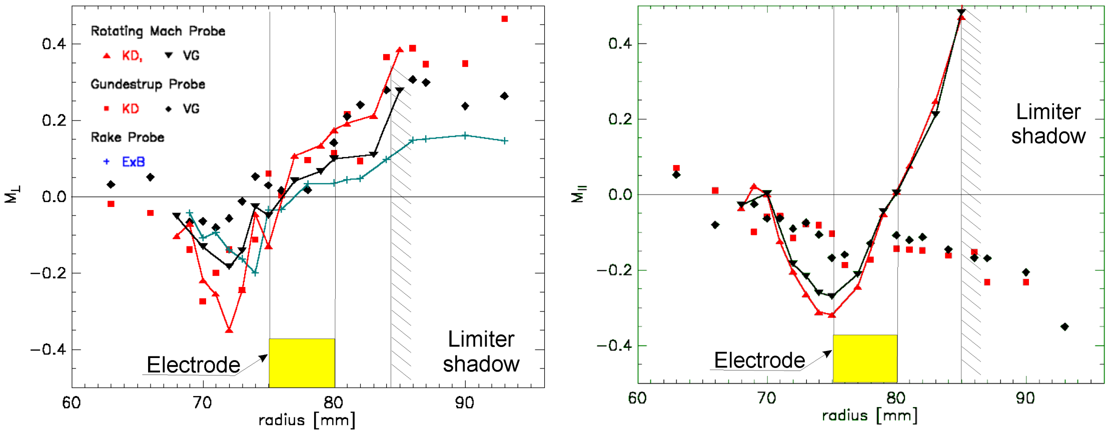

Fig. 4. *Radial profiles of perpendicular and parallel Mach numbers during electrode biasing as measured simultaneously by the RMP and the IGP. Electrode occupies the range of radii 75-80 mm, i.e. separatrix biasing with U_b= 150 V. Radial profile of the ExB velocity is shown for comparison in the left panel. Probe data are processed by two methods (denoted as KD [2] and VG [6]). #11027-51.*

A reasonable agreement between the $M_\perp$, measured by both probes is observed. This indicates the toroidal symmetry of perpendicular flow. Note that the ExB velocity is systematically lower in the SOL, if the actual profile of the electron temperature [5] is taken into account. Both probes are located on different sides of the stagnation point in the SOL (see Fig. 2), therefore the opposite sign of the $M_{||}$ is measured there as expected. The exceptional region appears in the proximity of the separatrix (r=75 mm), where the RMP is directly connected with the electrode and the parallel flow reverses in this region during biasing.

Additionally, the $M_\perp$ of RMP can not be determined for r> 85 mm (i.e. in the shadow of the material limiter), since the measured polar diagrams can not be interpreted by fluid models [2][6] because of their peculiar shape.

Swept IGP probe.

One of the open questions related to functioning of the standard Gundestrup probes is whether the signal of one particular tip is influenced by its neighbourhood? The ion current to one collector could possibly depend on whether the adjacent surfaces are insulators, floating conductors, or biased. The novel design, presented here has the capability to answer this question at least partially. The following experiment has been performed: one collector's voltage is swept (U = 100 V, f = 1 kHz) and the I-V characteristics are measured. The remaining tips are either kept floating, or negatively biased and their signals are recorded. The sequence is repeated for all eight collectors. The main results of this experimental series are presented in Fig. 5.

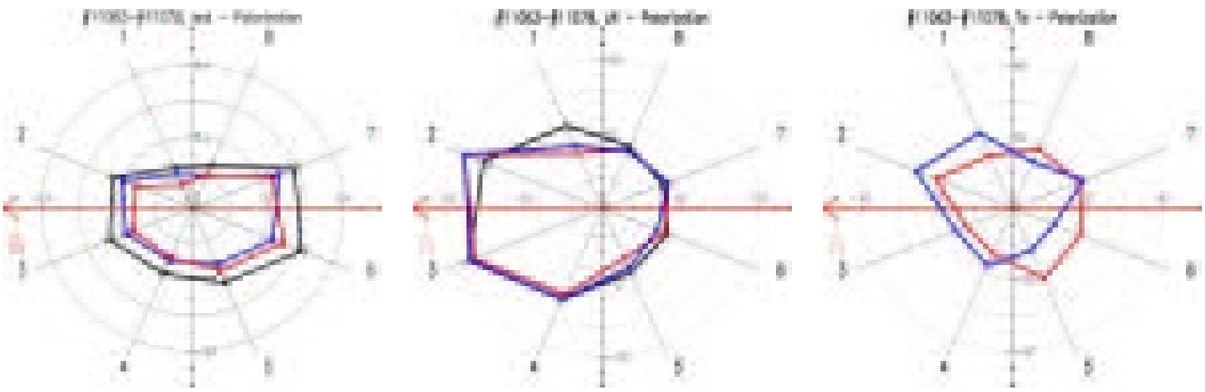

Fig. 5. *Polar diagrams of the swept IGP. From left to right: Ion saturation current, floating potential, electron temperature.* $M_{\perp} = -0.23$, $M_{||} \sim 0$.

The black lines show the standard IGP diagram, when all tips measure either I_{sat} or U_{float}. These diagrams are averaged over eight shots and the error bars are shown. Red lines correspond to the case when one tip is swept, while the remaining tips measure the ion saturation current. Blue lines connect points of the swept pin when the remaining tips are floating. It is evident from the figure that the swept and "standard" polar diagrams of I_{sat} and U_{float} are practically of the same shape. This indicates an independence of the pin signal on its neighbourhood. Interestingly, a systematic difference between biased and floating configurations seems to be apparent in the diagram of T_e. However, more statistics are necessary for definite conclusions.

This measurement is carried out in polarized discharges with a large $M_{\perp}$, but $M_{||} \sim 0$, as apparent from the polar diagram of I_{sat}. It is interesting to note that diagram of U_{float} is asymmetric just in the parallel direction, i.e. turned by of about 90^o. Understanding this feature will be worthwhile.

Conclusions:

The physics basis for this Gundestrup probe design has been validated by detailed measurements of ion collection by a rotating planar Mach probe in bias-controlled edge flows in the CASTOR tokamak. In principle, Gundestrup probes present advantages over rotating Mach probes due to their simpler mechanical design (no sliding contacts) and better temporal resolution.

The absolute magnitude of the poloidal velocity is in a good agreement with the ExB drift velocity deduced from the measured radial electric field, when the E_r and flow measurements are carried out in the same plasmas. Additional results are presented in [5].

References:

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