Preliminary results on the measurement of plasma edge profiles using the combined probe on W7-X

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During the initial phase (OP1.1) of the stellarator Wendelstein 7-X at the Max Planck Institute for Plasma Physics in Greifswald, first measurements of the plasma edge profiles were carried out using the multi-purpose manipulator (MPM) designed and built by the Forschungszentrum Jülich. The MPM is located at an intermediate toroidal position ($\phi = -159°$) in the fourth module of the five-periodic device. Figure 1 shows the poloidal cross section with the black line indicating the accessible range that can be covered by the manipulator. The red dashed line marks the flux surface defined by the uncooled limiters [1] protecting the plasma vessel wall and other in-vessel components during OP1.1. The MPM was set up in 2015 and completed commissioning in early February 2016 [2], in order to mount a wide variety of diagnostic probes for measurements of the plasma edge profiles and for plasma wall interaction studies. The first diagnostic to be used was the so-called combined probe. The combined probe includes i) two 3D magnetic

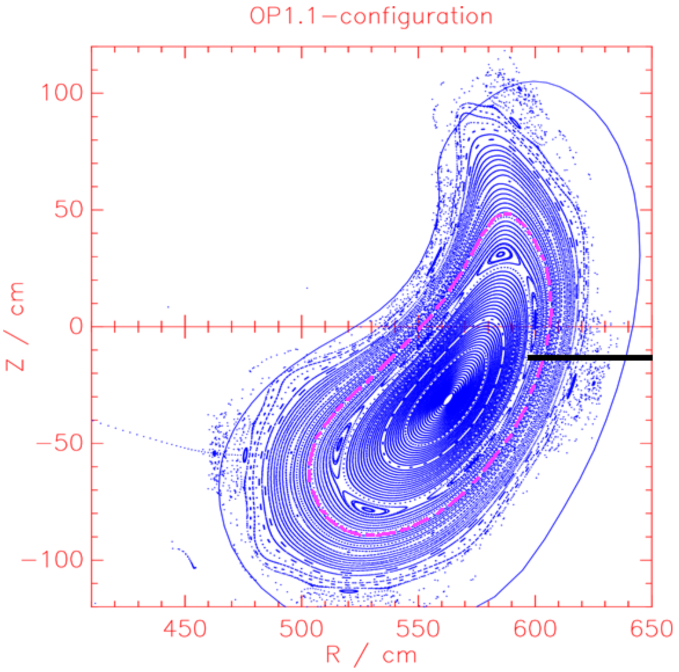

Figure 1: *Poincaré plot in the cross section of the position of the multi-purpose manipulator, possible range of the manipulator indicated in black*

pick-up coil arrays (similar to those in [3]), ii) five Langmuir probe pins [4], and iii) a Mach setup [5]. This allows simultanously measuring, the edge radial profiles of the magnetic fields, the electron temperature and density, the electric field and the plasma flow. Due to the graphite cover, the magnetic coils are constrained in their frequency spectrum as the higher frequencies are increasingly attenuated beyond 50 kHz. The Langmuir probe array consists of three floating potential pins, that deliberately differ in radial and poloidal position, for the calculation of the electric field and correlation. In addition, one pin is negatively biased in order to measure the ion saturation current I_{sat} and another pin is positively biased with voltage U_{+} to collect electrons. The electron temperature T_{e} is calculated using [6]:

$$T_{\mathrm{e}} = \frac{U_{+} - U_{\mathrm{floating}}}{\ln 2}, \tag{1}$$

where U_{floating} is the averaged value of the two floating potential pins at the same radial location. The electron density n_{e} can be calculated using [6]:

$$n_{\mathrm{e}} = \frac{I_{\mathrm{sat}}}{0.49 A_{\mathrm{eff}} C_{\mathrm{s}}}, \tag{2}$$

with 0.49 as the sheath expansion coefficient for plasmas in strong magnetic fields [7], A_{eff} is the effective collection area and C_{s} is the ion sound speed:

$$C_{\mathrm{s}} = \sqrt{\frac{T_{\mathrm{i}} + Z T_{\mathrm{e}}}{m_{\mathrm{i}}}} \tag{3}$$

The calculation of the ion sound speed requires knowledge of the species of ions, their ratios and charge states, which can be provided by other diagnostics e.g. spectroscopy. For the plasmas considered here, the main impurity was assumed to be carbon, whose concentration of about 2% was derived from visible light spectroscopy [8], which validates the use of the hydrogen approximation.

The advantage of the triple probe setup is that the time resolution is mostly limited by the signal conditioners. Those used here had a frequency limit of 500 kHz. Although the device is able to work with a reasonable resolution, the grounding has to be improved, as the spectrum is very much smeared at higher frequencies.

The manipulator is able to plunge up to 350 mm, from $R = 6.28\,\mathrm{m}$ to $R = 5.93\,\mathrm{m}$. During the experiment, the plunge was limited to 310 mm to ensure safe operation, though the heat loads were not expected to exceed the parameters of safe operation. In the experiment, the internal temperatures measured with thermocouples were found not to exceed 50 °C. This finding is promising, since it is planned to operate the probe at internal temperatures up to 300 °C and the loads are expected to increase in high performance plasmas of the upcoming divertor operation.

Inserting the probe proved to cause little disturbance to the overall plasma. The experiments of particular interest were trim coil scans, a configuration-scan with iota and nitrogen-puff experiments. It is worth mentioning that in the last week, the machine conditions were considerably improved through the means of wall conditioning. Figure 2 shows the temperature profiles obtained from the iota scan experiment. The way in which the iota-scan was performed – the coil current in the second of two planar coil sets providing an additional toroidal field component was reduced to zero – also induced a horizontal inward shift of the magnetic configuration. This increasing inward shift of the magnetic configuration, i.e. of the plasma limiting flux surface, is clearly seen in the radial dislocation of the measured edge temperature profiles for the different configurations. The manipulator also allows stationary measurements at a fixed position. Time traces of such an experiment are shown in figure 3. Discharge program 20160308.034 and 20160308.037 were conducted as part of a nitrogen puffing experiment with the position of the probe at $R = 6.03\,\mathrm{m}$. At $t = 0.1\,\mathrm{s}$ and $t = 0.25\,\mathrm{s}$ the puffing of nitrogen is visible as a significant drop in the temperature for the two respective time traces.

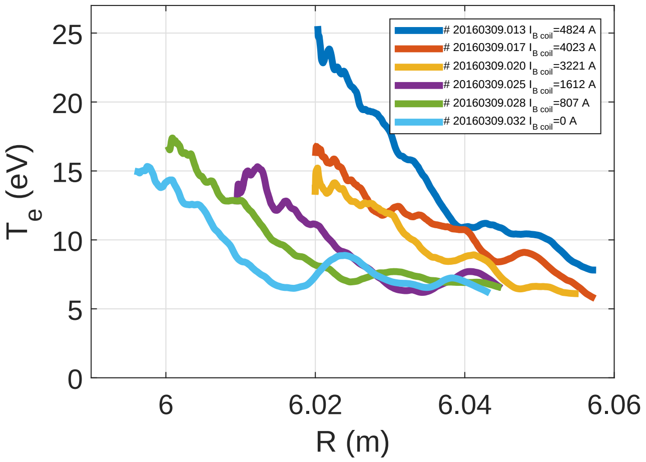

Figure 2: *Temperature profiles obtained during the iota scan*

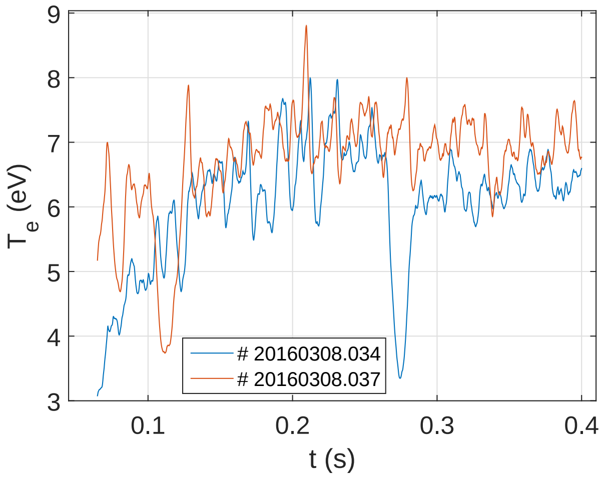

Figure 3: *Temperature time trace with nitrogen puffing at* $t = 0.1\,\mathrm{s}$ *and* $t = 0.25\,\mathrm{s}$

The magnetic coils also yield good results, as figure 4 shows that the profiles measured are quite close to the predictions from the field line tracing calculations [9]. These measurements are very useful as they allow a cross-check with the geometry and the currents of the magnetic field generating coil system of W7-X, using:

$$\dot{B} = -ANU_{\text{induced}} \tag{4}$$

with A as the pick-up coil area, N the number of coil windings and U_{induced} the induced voltage. To compare the measured and calculated field components, the measured curves use the offset from the calculated ones at the starting position. The pick-up coils have proved to be also of use in a fixed position as they were also able to measure fluctuations.

Further analysis will be carried out towards: the dependence of the turbulence and transport on the plasma parameters and the magnetic configuration. This will be done especially by using the combined nature of the probe. The simultaneous measurement enables the calculation of the $\vec{E} \times \vec{B}$ rotation, the dependency of the magnetic field on toroidal current variations and the identification of the last closed flux surface.

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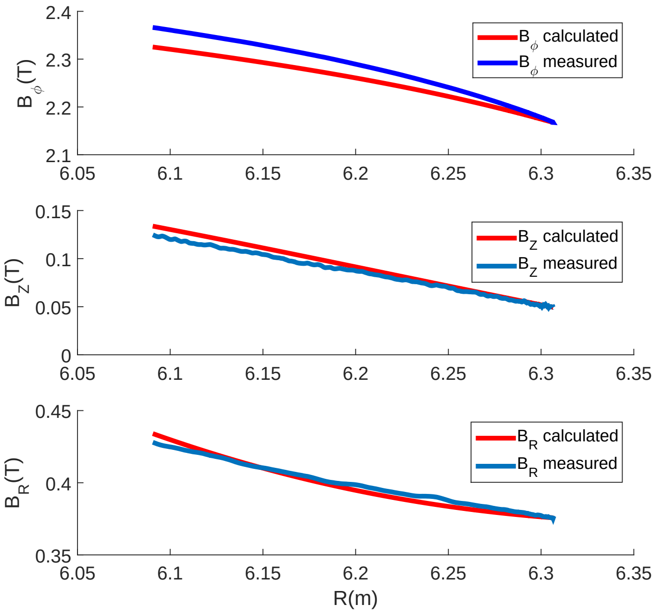

Figure 4: *Magnetic profiles in comparison with the prediction*

Acknowledgements

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.