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Measurements of the plasma edge profiles using the combined probe on W7-X

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

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The measurements of the edge profiles were carried out in the scope of the first operational phase (OP 1.1) of the stellerator Wendelstein 7-X (W7-X) at the Max Planck Institute for Plasma Physics in Greifswald. The manipulator is located in module 4 at the toroidal position $\Phi = -159°$. Figure 1. shows the poloidal cross section at the location of the manipulator. Indicated in black is the accessible range covered by the manipulator. The red dashed line is the position of the predicted last closed flux surface in the standard limiter configuration. The Multi-Purpose Manipulator (MPM) was set up in 2015 and completed commissioning in early February 2016 [1], in order to mount a wide array 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 pick-up coil arrays (similar to those in [2]), ii) five Langmuir probe pins [3], and a Mach setup [4]. This allows simultanously measuring, the edge radial

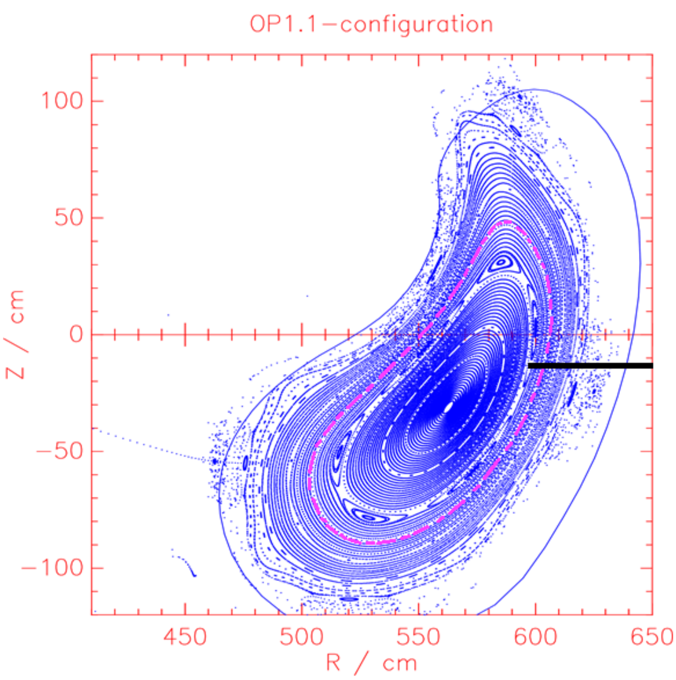

Figure 1: *Poincaré plot in the cross section of the position of the multi-purpose manipulator, possible range of the manipulator indicated in black*

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 deliberatly differ in radial and poloidal position, for the calculation of the electic field and correlation. In addition one pin is negatively biased in order to measure the ion saturation current and another pin is positively biased to collect electrons. The electron temperature T_e is calculated using [5]:

$$T_e = \frac{U_+ - U_{\text{floating}}}{\ln 2}, \tag{1}$$

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 [5]:

$$n_e = \frac{I_{\text{sat}}}{0.49 A_{\text{eff}} C_s}, \tag{2}$$

with 0.49 as the sheath expansion coefficient for plasmas in strong magnetic fields [6], A_{eff} is the effective collection area and C_s is the ion sound speed:

$$C_s = \sqrt{\frac{T_i + Z T_e}{m_i}} \tag{3}$$

The calculation of the ion sound speed requires knowledge of the species of ions, their ratios and charge states, which can be provided by diagnostics for example spectroscopy. For the shots considered the assumed main impurity carbon was measured with the visible light spectrometer [7] at about 2% concentration and hence the hydrogen approximation is valid.
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 $R = 6.28$ m to $R = 5.93$ 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 not found to exceed 50 °C. This finding is promising, since it is aimed to operate the probe at internal temperatures below 300 °C and the loads will increase in the high perfomance plasmas of the planned divertor operation.

Inserting the probe proved to cause little disturbance to the overall plasma. The experiments of particular interest were the trim coil scan, the iota scan and the nitrogen puffing experiment. Figure 2. shows the temperature profiles obtained from the iota scan experiment. It is worth mentioning that in the last week, the machine conditions were considerably improved through the means of wall conditioning. The iota scan conducted also included a shift of the magnetic axis by tuning the planar coil currents. In this set of shots it is clearly visible that the last closed surface is further moved inwards with every shot.

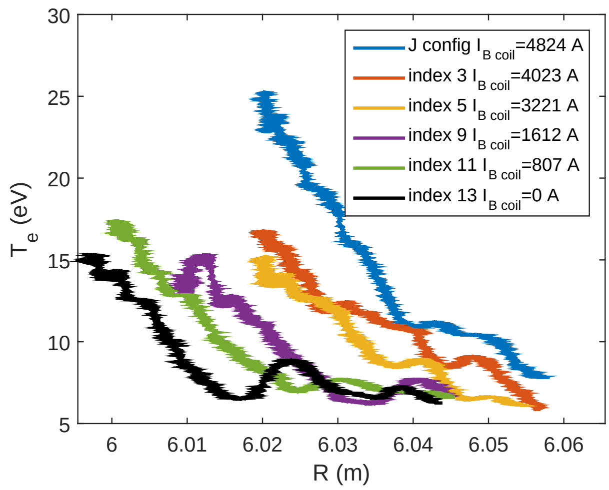

Figure 2: *Temperature profiles obtained during the iota scan*

The manipulator also allows stationary measurements at a fixed position. The time trace, of such an experiment are shown in figure 3. Shot #160308034 and #160308037 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 shots.

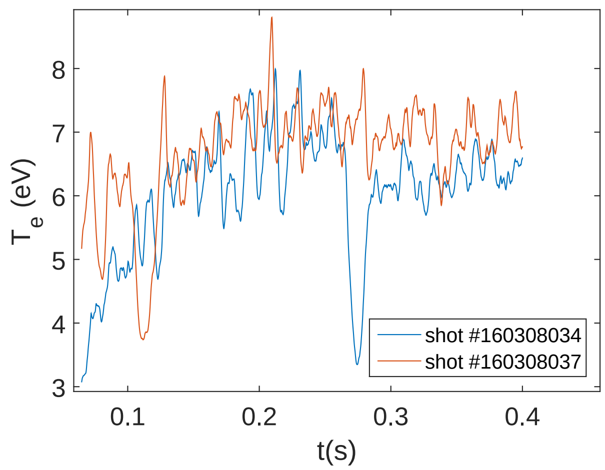

Figure 3: *Temperature time trace with nitrogen puffing at* $T = 0.1\,\mathrm{s}$ *and* $T = 0.25\,\mathrm{s}$

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 [8]. This measurement is very usefull as it validates the code. The magnetic field was calculated 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.

The offset from the integration can in turn be taken from the calculation to compare it with the measurement. 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 simulataneous measurement allows to calculate 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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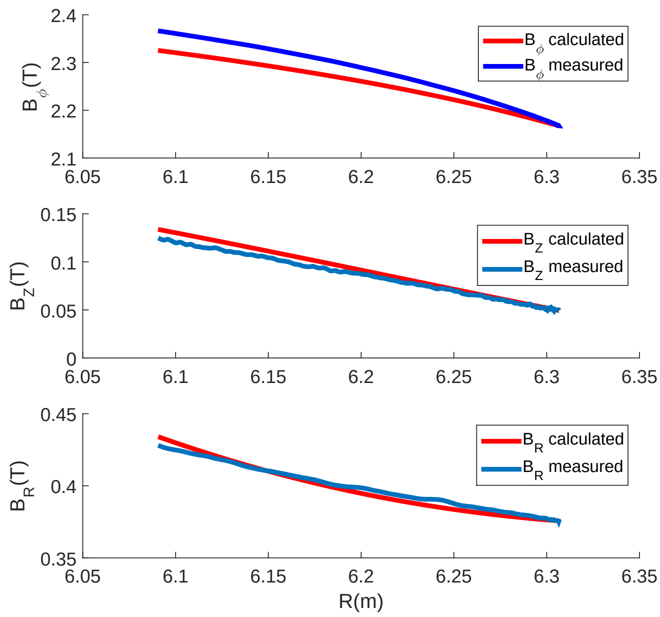

Figure 4: *Magnetic profiles in comparison with the prediction*

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