Investigating the outer magnetic field of Wendelstein 7-X using the magnetic probe

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Wendelstein 7-X (W7-X) is a 5-fold-symmetric stellarator optimized for low plasma currents and good confinement. The aim of W7-X is to demonstrate long-running steady-state operation in Tokamak-like performance regimes [1], [2]. W7-X uses an island divertor configuration for handling heat- and particle-exhaust. In standard configuration, the magnetic field boundary topology consists of a $n/m = 5/5$ chain of separate islands intersected by the target plates of the divertor. In high-iota configuration the islands form a connected 5/4 chain. Due to pressure gradient driven currents, the island topology can change significantly at high plasma beta values, potentially changing island width and phase as well as their radial position. Figure 1 shows an example in a 5/5 configuration obtained through a VMEC/EXTENDER calculation [3].

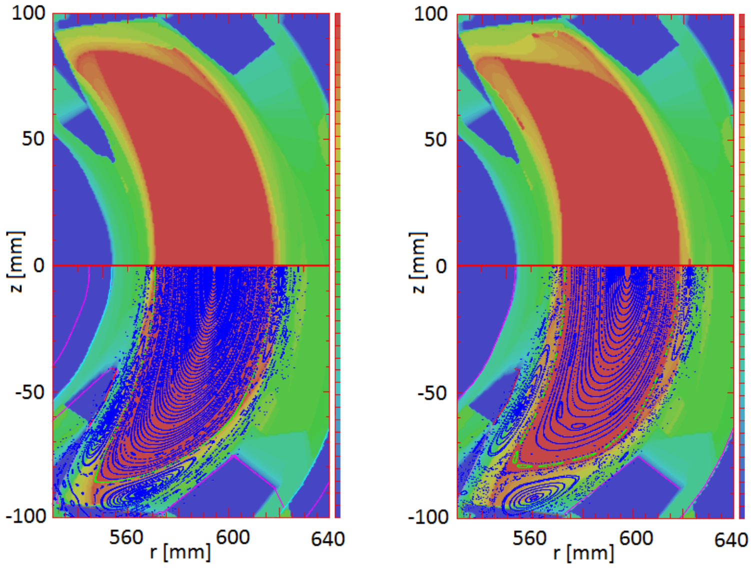

Figure 1: Poincaré maps and connection length plots of VMEC equilibria with $\beta = 1\%$ (left) and $\beta = 3\%$ (right) for edge $\iota = 1$ calculated using VMEC/EXTENDER [3]

The Probe Manipulator and the Combined Probe

The multi-purpose manipulator (MPM) at W7-X can be used to insert probe-heads into the plasma edge. The probe heads can be exchanged during the campaign. The manipulator is located in a bean plane at $-159.3°$, 17 cm below the midplane axis.

The combined probe has a length of 150.2 mm. It features a variety of measurement systems:

- 5 Floating potential pins
- Langmuir probes in triple probe configuration for electron temperature & density measurements
- An experimental ion sensitive probe for ion temperature and density measurements

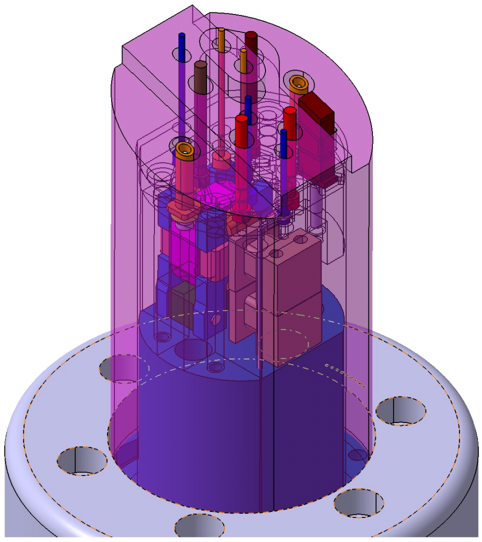

Figure 2: The combined probe *FZJ-COMB2*

Coil	Winding no.	Eff. area
3D - Radial	500	$1.342\,\mathrm{cm}^2$
3D - Toroidal	500	$1.464\,\mathrm{cm}^2$
3D - Vertical	500	$1.83\,\mathrm{cm}^2$
Differential	2198	$\approx 1\,\mathrm{cm}^2$

Table 1: Coil parameters

- Magnetic coils
- A tungsten material sample

The magnetic coil system (as seen in figure 2 in the center of the probe) consists of 3 concentric coils for measurements of the toroidal, radial and vertical field components as well as a differential coil pair for measurement of $\partial B_{\mathrm{tor}}/\partial r$. Details about the coils can be found in table 1.

Magnetic Configurations

During the second week of probe operation data were recorded in standard configuration as well as in high-iota configuration. The edge of the standard configuration is characterized by a $5/5$ chain of disconnected islands intersected by the divertor target plates. In high-iota configuration the islands form a connected $5/4$ island chain. As seen in figure 3, the manipulator travel path intersects the inside of the islands near the O-point.

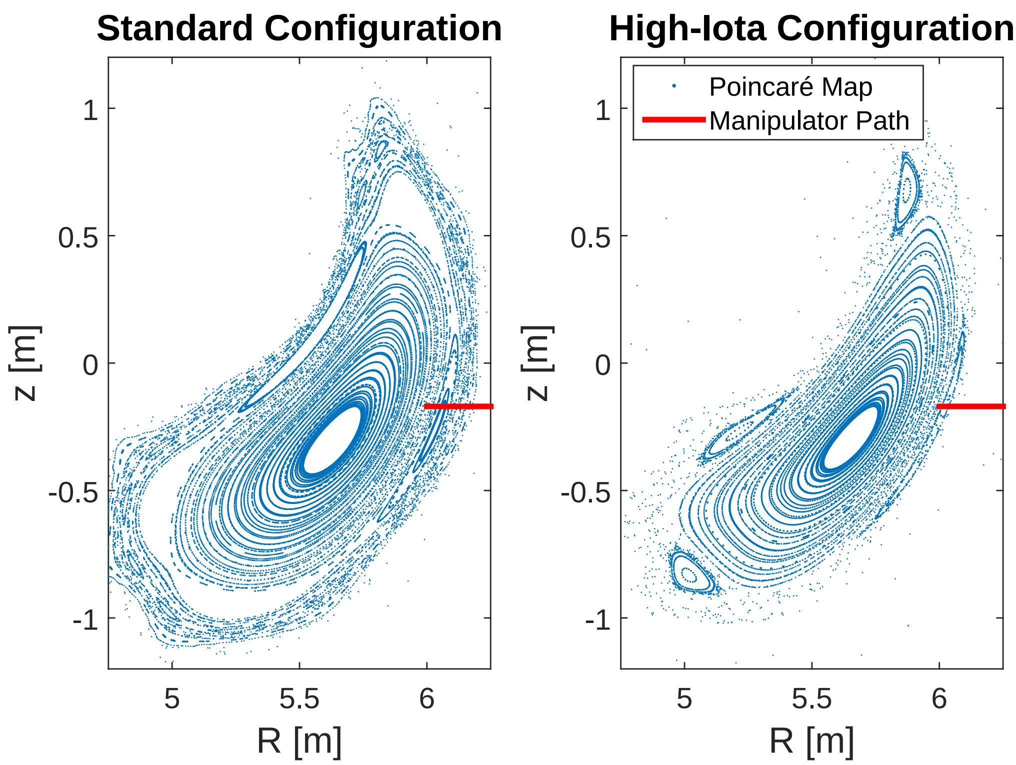

Figure 3: Poincaré Maps of the Standard- and High-Iota configuration in the manipulator plane, calculated using [6]

Observations from OP1.2a (first divertor campaign)

For each measured discharge two manipulator plunges were performed:

- A vacuum measurement right before plasma startup
- A plunge into the active plasma

Linear drifts both in-between plunges and between beginning and end of each plunge were compensated. This relies on the assumption that the magnetic field does not change significantly over the plunge duration.

Figure 4 compares two discharges, one with higher beta and a larger negative toroidal current (orange) and another one with lower beta and a smaller positive toroidal current (blue). The discharge indicated in orange (171025.044) shows plasma current contributions of about 3 mT to the radial and 4 mT to the toroidal magnetic field. The vertical field measurement saturated during the second plunge, shifting the integrated signal. The comparison discharge in blue shows lower-sloped profiles. However, the plasma in this discharge lasted longer than the signal acquisition time. Therefore the drift correction is not necessarily accurate in this discharge, which gives a potential explanation for the profile shifts.

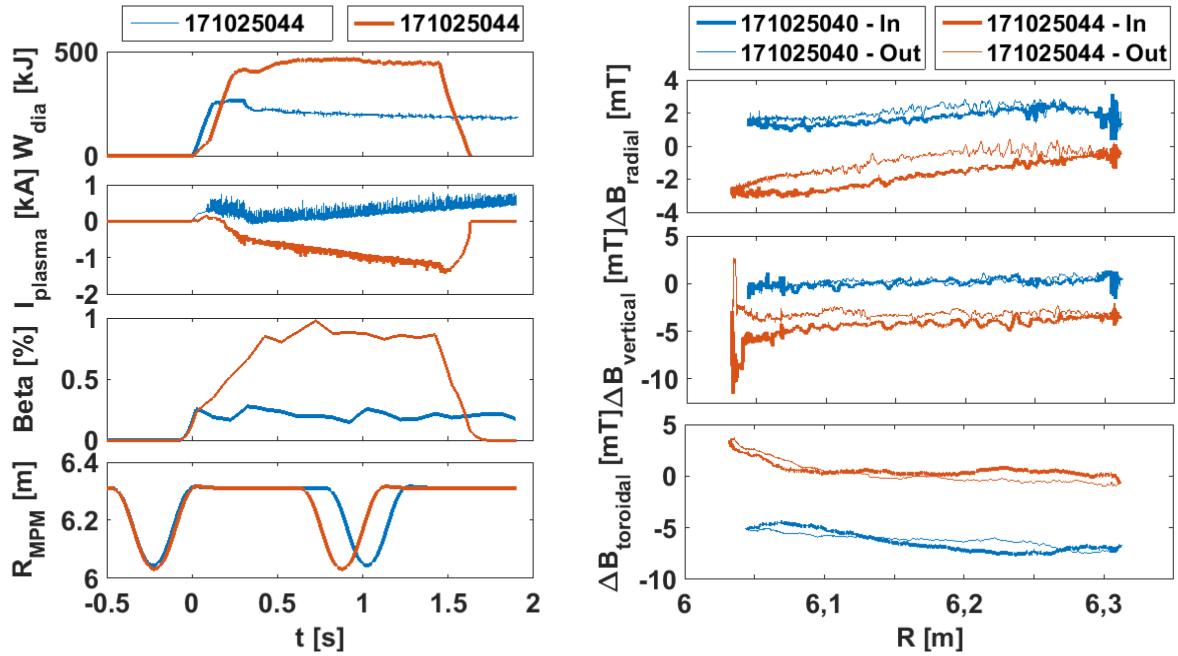

Figure 4: Overview plot (left) and plasma contribution to magnetic field acquired through the magnetic probe (right)

Improvements for the upcoming Campaign OP1.2b

In order to improve the magnetic field measurements in the upcoming campaign, the magnetic signals will be split into a slow and a fast channel. This will reduce contention between high bandwidth and low drift requirements. The slow channel will then be integrated by an analog low drift integrator before digitization.

Acknowledgements

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References

[1] L.Wegener, Status of Wendelstein 7-X construction, Fusion Engineering and Design **84**(2-6), 84 (2009)

[2] J. Nührenberg et al, Overview on Wendelstein 7-X Theory, Fusion Technology **27**(3T), 27 (1995)

[3] J. Geiger et al, Plasma Effects in Full-Field MHD-Equilibrium Calculations for W7-X, Proceedings of the 26th IAEA-FEC conference, Kyoto, Japan, 2016, 2016

[4] A. Werner et al, 7-X magnetic diagnostics: Rogowski coil performance for very long pulses, Review of Scientific Instruments **79** (10), 79 (2008)

[5] M. Endler et al, Engineering design for the magnetic diagnostics of Wendelstein 7-X, Fusion Engineering and Design **100**, 100 (2015)

[6] S. A. Bozhenkov et al, Service oriented architecture for scientific analysis at W7-X. An example of a field line tracer, Fusion Engineering and Design **88**(11), 88 (2013)