Dependence of the intrinsic toroidal current on heating power and density in the W7-X stellarator

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The intrinsic, diffusion driven toroidal (bootstrap) current [2, 3] has been measured in the stellarator Wendelstein 7-X (W7-X) for several magnetic configurations at line integrated plasma densities between 2 and 16×10^{19} m^{-2} and heating powers between 0.5 and 6 MW. While previous experiments already showed that W7-X meets its optimisation criterion of a small bootstrap current for different magnetic configurations [4], this study now furthermore covers density and power dependencies.

A Rogowski coil [5] was employed to measure the net toroidal current in the plasma. This consists of the intrinsic bootstrap current and the counteracting, resistively dampened shielding current.

The plasma parameters (with the exception of the shielding current) were kept constant over a time in the order of the decay time of the shielding current. The measured time trace of the net current was then fitted by a constant bootstrap current from which an exponentially decaying shielding current was subtracted.

The experimental uncertainties are still a work in progress.

The measurement of the toroidal current was calibrated [6] to within 3%.

The fit formula was checked against the modelled current evolution and yields the saturation value within less than 1 kA.

In case of noisy or decreasing currents, the fit delivers a value between the minimum and maximum values. In the worst case of an increasing current, the fit overshoots by less than 1 kA.

The main contribution to the experimental error is expected to be the unintentional current drive by the electron cyclotron resonance heating. It is expected to be in the order of 1 kA in most cases (increasing with the number of gyrotrons used).

In total, 134 bootstrap currents were inferred in six magnetic configurations (fig. 1).

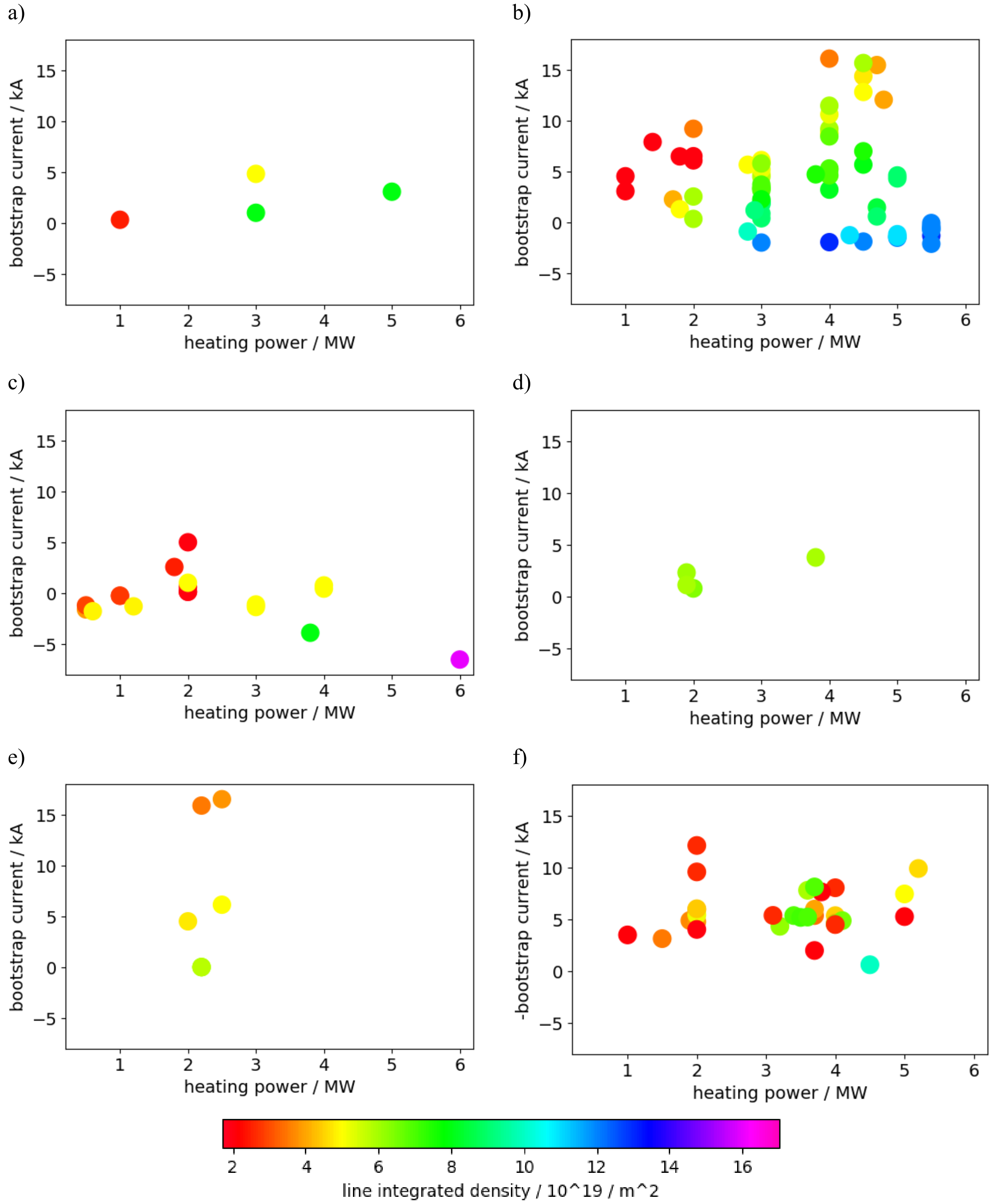

Fig. 1: Bootstrap currents measured during the operational phase OP1.2b of W7-X for six magnetic configurations: a) high mirror, b) standard, c) high iota, d) intermediate (limiter), e) low iota and f) reversed field low iota. Experimental uncertainties are still a work in progress. It has to be kept in mind that these views are projections of differing impurity contents, profile shapes, heating methods and other program parameters.

The measured values are being compared to simulations with the NTSS code [7,8].

With regard to the predictive simulations performed for OP1.2b, the low density / low power values and the power dependencies seem mostly to be in agreement, the density dependencies only partially and the high density / high power values mostly not.

Work has started on the first programs to include the measured plasma profiles (electron temperature and density from Thomson scattering, ion temperature from the X-Ray Imaging Crystal Spectrometer (XICS) and Z_{eff} measurement) into the simulations. In the first datapoint (high mirror configuration, line integrated density 8×10^{19} / m², heating power 3 MW) measurement and simulation differ by 2 to 3 kA, with the experimental uncertainty so far estimated to be below 3 kA and the uncertainty in the simulated current below 1 kA.

Work has also begun to compare the measured dependence of the current on the heating power with the simulated one (with the simulation being based on the measured profiles). In the first datapoint (high mirror configuration, line integrated density 8×10^{19} / m², heating power between 3 and 5 MW), the measured and the simulated values differ by 1 to 2 kA / MW, with the uncertainty in the measured value so far estimated to be below 4 kA / MW and the uncertainty in the simulated value around 1 kA / MW.

It is expected that future analysis work will decrease the current estimates of the uncertainties.

In conclusion, the bootstrap currents obtained in the way described above varied between -7 and 5 kA for the high mirror and high iota configurations, which are optimized for small bootstrap currents, and between -3 and 17 kA for the standard, intermediate (limiter) and low iota configurations.

Currents generally decreased when the density was raised at constant heating power and generally increased when the heating power was raised at constant density.

The optimisation of W7-X for small bootstrap currents holds, if power and density are raised simultaneously.

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References

*[1] T. Klinger et al., Nuclear Fusion **59** (2019) 112004 doi: 10.1088/1741-4326/ab03a7*

*[2] R. J. Bickerton et al., Nature **229**, 110-112 (1971)*

*[3] A. A. Galeev, Sov. Phys. JETP **32**, 752-757 (1971)*

*[4] A. Dinklage et al., Nature Physics **14**, 855-860 (2018)*

*[5] M. Endler et al., Fusion Eng. and Design **100**, 468 (2015)*

*[6] U. Neuner et al., Fusion Eng. and Design **123** (2017), 10.1016/j.fusengdes.2017.03.074*

*[7] Y. Turkin et al., PHYSICS OF PLASMAS **18**, 022505 (2011), http://dx.doi.org/10.1063/1.3553025*

*[8] Y. Turkin et al., Fusion Sci. Technol. **50**, 387(2006)*