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Tokamak plasmas in MST with density up to ten times the Greenwald limit

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Steady, non-disruptive tokamak plasmas have been produced in the Madison Symmetric Torus (MST) with an electron density up to an order of magnitude above the Greenwald limit [Hurst et al., PRL, accepted for publication]. This result is made possible in part by a high-voltage, feedback-controlled power supply driving the toroidal plasma current. Also important may be the thick, stabilizing, aluminum vacum vessel that closely surrounds the plasma. The achievable density appears to be limited only by hardware and not instability. These MST plasmas were produced with Bt ˜ 0.13 T, Ip ˜ 50 kA, and q(a) ˜ 2.2. Fueled with deuterium via standard puff valves, the circular plasmas are ohmically heated with R = 1.5 m and a = 0.50 m. The minor radius of the plasma-facing aluminum wall is 0.52 m. With a vessel-wall thickness of 5 cm, the wall penetration time is 800 ms, much longer than the typical 50 ms discharge duration. This passively allows stable operation at low q(a). Power and particle handling in MST is relatively primitive. The plasmas are limited, with graphite tiles covering about 10% of the plasma-facing wall, and pumping is achieved thru numerous small holes coupling the vacuum vessel to a pumping manifold.

Increasing the density shot by shot, the Greenwald fraction, n_e/n_G, was scanned from 0.5 to 10, with a maximum line-averaged density of about 6 x 10^{19} m^{-3}. Over this range, the loop voltage increases from 3 V to 65 V, provided automatically by the power supply. The only apparent limit on the achievable density is the flux swing in the iron-core transformer in the poloidal field system. At the highest density and loop voltage, the 2 V-s swing is exhausted before the programmed ramp-down in Ip, such that the discharge can no longer be sustained.

Although the Greenwald limit can easily be surpassed, these MST plasmas exhibit interesting features as the density crosses both n_e/n_G ˜ 1 and n_e/n_G ˜ 2. Transitioning from below to just above n_e/n_G ˜ 1, the sawtooth crashes commonly observed in these low-q plasmas transition to quasi-continuous, rotating tearing modes, and the scalings with density of the ohmic input power and impurity radiation increase sharply. As the density crosses n_e/n_G ˜ 2, these scalings become much weaker, and the toroidal current profile abruptly flattens, remaining finite up to the limiter, in contrast with the edge collapse (detachment) observed in other devices at lower n_e/n_G. In contrast to the current profile, a broad gradient is maintained in the electron density profile up to very high density.

Work is underway to understand why MST is able to operate with such a high Greenwald fraction. In addition to the obvious role played by the power supply in the global sustainment of these plasmas, it may also be key to sustaining the edge current. The conducting vessel may be important, e.g., in its recently predicted role in slowing resistive-wall-tearing-mode growth and the disruption thermal quench [Strauss et al., PPCF 2023].

Speaker's title

Mr

Speaker's email address

bchapman@wisc.edu

Speaker's Affiliation

University of Wisconsin-Madison, Madison

Member State or IGO

United States of America

Primary authors: CHAPMAN, Brett E. (UW-Madison); HURST, N.C. (UW-Madison)

Co-authors: ALMAGRI, A.F. (UW-Madison); FOREST, C.B. (UW-Madison); DEN HARTOG, D.J. (UW-Madison); FLAHAVAN, J.B. (UW-Madison); SARFF, J.S. (UW-Madison); MCCOLLAM, K.J. (UW-Madison)

Presenter: CHAPMAN, Brett E. (UW-Madison)

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