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Advances in Neutral Beam Current Drive Experiments on ASDEX Upgrade

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Neutral beam current drive (NBCD) is an efficient option for non-inductive tokamak operation. With its eight 2.5 MW neutral beams of different geometry ASDEX Upgrade offers a versatile NBI system, well suited for current drive studies.
Past studies comparing on- and off-axis NBCD at 5 MW gave contradictory results. To understand the current profiles constrained by MSE anomalous fast-ion transport needed to be assumed [1] while the fast-ion density profile constrained by fast-ion D_alpha (FIDA) spectroscopy appeared to be neoclassical [2].
To address this issue, new experiments were started in 2014 in which simultaneous MSE and FIDA measurements were achieved by adding an additional neutral beam on top of the 5 MW switched between radial on-axis and tangential off-axis beams. Remarkably constant T_e and n_e profiles were achieved by feedback-controlled ECRH. Despite the increased heating power NTMs and sawteeth were successfully mitigated by ECCD at two radial locations.
The MSE and FIDA data were compared with synthetic diagnostics data from post-processed TRANSP output. Significant improvement was brought about by new measurements of the actual beam geometries, improved accuracy of the Z_eff profiles, and correction of TRANSP's radial electric field. While initial comparisons of the MSE angles suggested relatively strong fast-ion transport with diffusion coefficients ≥ 0.5 mˆ2/s [2, 3], both MSE and FIDA are now in good agreement with the predictions with the much smaller rho-, time- and energy-dependent micro-turbulent diffusion coefficients calculated according to Ref. [4]. These are on average below 0.2 mˆ2/s. Experimentally, the study was extended to 5 and 7.5 MW of total NBI, various beam geometries as well as varying Z_eff.
In view of steady-state tokamak operation, discharges with 800 MA plasma current, q_95 = 5.5, q_min > 1.5, up to 12.5 MW NBI and 2.8 MW of ECRH recently achieved a two-seconds-long practically non-inductive phase with > 40% NBCD, > 40% bootstrap current, and approx. 10% ECCD. These discharges are now extended in duration in order to approach a truly stationary current distribution.

[1] S. Günter et al., Nucl. Fusion 47 (2007) 920
[2] B. Geiger et al., Plasma Phys. Control. Fusion 57 (2015) 014018
[3] B. Geiger et al., Nucl. Fusion 55 (2015) 083001
[4] M. J. Pueschel et al., Nucl. Fusion 52 (2012) 103018

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