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Modeling of neutral beam particle orbits in Wendelstein 7-X

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Simulations of neutral beam injection, slowing down and losses to the first wall in Wendelstein 7-X (W7-X) are being used to assess plasma performance, operational limits, and the necessity of additional component armoring. Comparison of measurements to simulations helps to validate our models and better understand the confinement characteristics of the optimized three-dimensional stellarator magnetic fields.

Accurate modeling of neutral beam heating, current drive, and fast ion wall loads depends on accurate and validated models of neutral beam deposition. The inertially cooled diverter experimental campaign (OP1.2) on W7-X saw the commissioning of two sources in the first neutral beam box. These sources provided a combined 3.6 MW of neutral beam power when operated in Hydrogen (5 MW in Deuterium). Accurate simulations have required the inclusion of injector acceleration grid geometry, port geometry and STELLOPT reconstructed VMEC equilibrium. Simulations of neutral beam injection with the BEAMS3D code have been validated against measurement of neutral beam attenuation from spectroscopic measurements along the neutral beam line [1,2]. Good agreement is found for a range of densities in W7-X providing a validation of the neutral beam injection model in the code. Such work lays the foundation for the slowing down and wall load estimates.

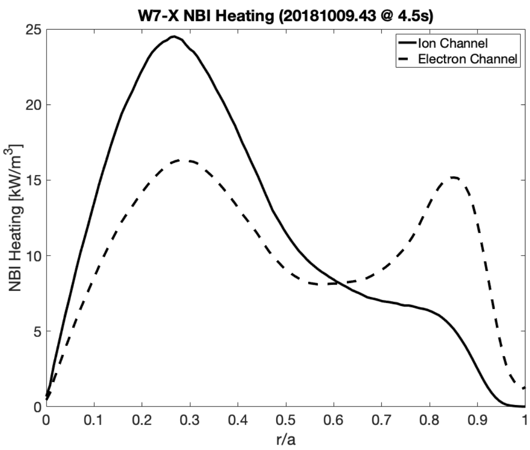

Figure 1 Deposited power to ion and electron species as calculated with the BEAMS3D code for W7-X discharge 20181009.43 @ 4.5s

The neutral beam fueling, heating and current drive is determined through simulations including slowing down and pitch angle scattering operators. A 5s purely NBI heated discharge serves as a validation case for the slowing down calculations in the BEAMS3D code. Simulations show the preferential heating of the ion channel in the core (figure 1). This discharge had a strongly peaked density profile, achieving the highest densities in W7-X. Fueling from energetic particles alone does not appear sufficient to explain the density rise, suggesting a change in transport character. Estimates of driven beam current agree with a measured change in sign of the total toroidal current. Particles which do not fully slow down in the plasma are then lost to the wall.

Validated neutral beam deposition and slowing down simulations allow for estimates of fast ion wall loads under a variety of plasma configurations and conditions. Particles which reach the last closed flux surface in BEAMS3D calculations are then used to initialize full orbit simulations with the ASCOT5 code. Each particle is multiplied and perturbed in pitch angle space, taking care to preserve kinetic energy and total weighing of particles. The full orbit collisionless simulations allow for estimates of wall loads given arbitrary wall complexity. Comparisons are made between IR camera images of the diverter region and simulated diverter loads. Such simulations have informed the armoring of in-vessel components against wall loads [3]. These simulations are informing development of future upgrades, diagnostic placement, and machine operation.

References

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[3] Äkäslompolo, S, et al. "Armoring of the Wendelstein 7-X divertor-observation immersion-tubes based on NBI fast-ion simulations." *Fusion Eng. and Design* 146 (2019): 862-865.