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Near-field models and simulation of the ablation of pellets and SPI fragments for plasma disruption mitigation in tokamaks

Numerical studies of the ablation of neon pellets and shuttered pellet injection (SPI) fragments in tokamaks in the plasma disruption mitigation parameter space have been performed using a pellet ablation model based on the Lagrangian Particle (LP) code [R. Samulyak, X. Wang, H.-S. Chen, Lagrangian Particle Method for Compressible Fluid Dynamics, J. Comput. Phys., 362 (2018), 1-19]. The code implements the low magnetic Reynolds number MHD equations, kinetic models for the electronic heating, a pellet surface ablation model, equation of state with multiple ionization support, radiation and a model for grad-B drift of the ablated material across the magnetic field [P.B. Parks and L. R. Baylor, PRL 94 125002 (2005)]. The Lagrangian particle algorithm is highly adaptive, capable of simulating a large number of fragments in 3D while eliminating numerical difficulties of dealing with the tokamak background plasma. The code achieved good agreement with theory for spherically symmetric ablation flows. Axisymmetric simulations of neon and deuterium pellets in magnetic fields ranging from 2 to 6 Tesla have been performed using a fixed 16 cm shielding length for ablation clouds. Simulations were compared with another pellet computational model based on the FronTier code with explicit tracking of interfaces and good agreement was achieved. For a 2 mm radius neon pellet in a tokamak plasma of 2keV temperature and 10^{14} 1/cc density, the computed ablation rate is 25.4 g/s in 2 T field which reduces to 15.4 g/s in 4 T field and to 12.2 g/s in 6 T field. The corresponding values for the deuterium pellet are 32 g/s in 1.6 T field, 28.8 g/s in 2 T field and 20 g/s in 4 T field.

Using the Lagrangian particle code with the grad-B drift model, we demonstrated the dependence of the shielding length on the curvature and strength of magnetic fields. For the 2 mm neon pellet in a 2T magnetic field with 1.6 m major radius (DIII-D), the grad-B drift of the ablation cloud established the shielding length of 16.5 cm and resulted in the ablation rate of 25.4 cm. The shielding length reduced to 11 cm in 6 T field with the same curvature. However, in magnetic fields of the ITER major radius (6.2 m), the shielding length and the ablation rate were correspondingly 38 cm and 21.5 g/s in 2 T field. These values changed to 27 cm and 16 g/s in 6 T field. We conclude that the magnetic field curvature has an important effect on pellet ablation rates.

Current work includes simulation of SPI fragments at conditions relevant to DIII-D experiments and on coupling of the LP pellet model to global tokamak MHD codes. It is based on self-consistently evolving the ablation cloud in the LP code and using the grad-B grift to establish a physics-based separation of scales: the ablated material that drifted beyond the ablation cloud is transferred to the tokamak code. LP input has been successfully incorporated in NIMROD.

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