High-Velocity Liquid Jet Injection into Tokamak Plasmas for Disruption Mitigation

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Abstract

Proposed is a new concept for disruption mitigation and fast shutdown in tokamaks, the injection of hydrogen or helium liquid jets. Liquid jets can rapidly cool the plasma to reduce divertor heat loads and large halo current forces, while simultaneously raising the density sufficiently to prevent runaway electron generation. Massive ~ 40 to 100-fold density increases equivalent to ~ 50 g of deuterium are necessary for this purpose in ITER plasmas. It is shown that only 2 or 3 simultaneously injected high-velocity (800 to 1200 m/s) jets can easily deliver this amount of fuel within a period of ~ 20 ms, and thus avoid runaway electron buildup during the 50 to 500 ms current quench phase. Optimum jet parameters, radius, velocity, driving pressure, and injection time, predicted from a jet ablation/penetration model leads to an innovative pulsed injector design concept. The design concept is also based on a thermodynamic process path that allows the lowest possible temperature at the nozzle orifice, given the constraint of a high ~700 atm driving pressure. By having a cold jet exit the nozzle orifice, the potential problem of rapid boiling (flashover) during jet propagation across vacuum space between the nozzle orifice and the tokamak plasma can be overcome. A 1–D fluid-dynamic calculation, including finite compressibility, shows that a specially designed ‘‘liquid Laval nozzle’’ is needed for liquid helium injection, since the jet velocity is supersonic (Mach number ~ 4). This injector concept is being considered for a proposed disruption mitigation experiment on DIII–D.

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