Disruption Mitigation With High-Pressure Noble Gas Injection*

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A viable solution on the issue of disruption mitigation must be developed as tokamak fusion research approaches the realization of burning plasmas. In-vessel components are damaged by three disruption effects: divertor surface melting/ablation by plasma heating, mechanical stresses from halo currents, and the amplification of relativistic electrons (runaway electrons) that eventually are lost into, and damage the wall. Since the magnitude of the damage increases with the plasma energy density and device size, in future burning plasma experiments the damage caused by a single disruption may necessitate the halt of further operation and the costly replacement of internal components.

Recent experiments on the DIII–D tokamak have demonstrated a technique that mitigates simultaneous all three disruption effects. A high-pressure jet of a noble gas (neon or argon) is injected into the plasma. The gas jet is found to penetrate to the central plasma at the gas sound speed (300–500 m/s). Apparently, the high gas density ($>10^{24}$ m^{-3}) and pressure (>20 kPa) of the jet, which exceeds the plasma pressure, allows it to penetrate. The deposited jet increases the atom/ion content of the plasma a factor of 50 in several milliseconds. As a result, the plasma energy is dissipated uniformly by UV radiation from the injected impurity species to the entire wall. The conducted heat flux to the divertor is found to be only ~2%–3% of the stored kinetic energy of the plasma, compared to 20%–40% found for natural disruptions. The resulting plasma is also extremely cold and resistive, resulting in a rapid current quench with the plasma remaining well centered in the vessel, effectively reducing halo currents. Runaway electrons are controlled on DIII–D by the large collisional drag on runaway electrons caused by the large density of bound electrons in the plasma volume, despite the large parallel electric field caused by the cold plasma.

Experiments carried out on the DIII–D tokamak have measured and verified the effectiveness of this technique. A practical implication for DIII–D was the observation that the initial phase of subsequent plasma discharges was much cleaner after a mitigated disruption than after a non-mitigated disruption — presumably from the reduced ablation damage of the carbon walls.

Based on simple physics models, we show that the high-pressure noble injection extrapolates favorably to burning plasma experiments. Detailed theoretical models of the gas jet penetration and runaway electrons are being developed. The results of these efforts will be discussed.

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