DISRUPTIONS IN DIII–D*

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Disruptions represent a serious obstacle to the successful realization of a commercially viable tokamak reactor. The rapid and complete loss of thermal energy (thermal quench), the rapid decay of the plasma current and its associate magnetic energy give rise to unacceptably high thermal and electromagnetic loads on the vessel and its internal components. The loss of the thermal and magnetic energy result in a wide array of phenomena including a loss of plasma vertical position control, disruption induced runaway electrons, large toroidal eddy currents, and poloidal "halo" currents on the open field lines in the scrapeoff layer. Recent research has shown that some of these phenomena are highly non-axisymmetric giving rise to higher local thermal and electromagnetic loads on the vessel. Because of the large differences in device size, plasma current, stored magnetic and thermal energy between present tokamaks and future devices, such as ITER, the present results cannot be simply scaled to future devices. Given the wide array of complex phenomena associated with a disruption, it is critical that a comprehensive understanding of the disruption processes be developed. This paper describes work on the DIII–D tokamak on disruption characterization, modeling and simulation, real-time techniques for avoiding disruptions, and methods of mitigating disruption effects.

In a series of dedicated disruption experiments conducted on DIII–D, the data necessary for the development and validation of detailed models of disruption phenomena have been obtained in a variety of different types of disruptions. Simultaneous measurements of the current, temperature, and density profile evolution during the disruption have been made in radiative collapse disruptions (induced by argon injection), in high beta disruptions [1], and in density limit disruptions. In the radiative collapse disruption, the temperature following the thermal quench falls to 100 eV, the central density falls by almost 50% and the density profile is strongly peaked at the plasma edge. As the plasma energy is lost, both the temperature and density in the plasma SOL increase significantly and there is a noticeable broadening of the SOL. Modeling of the temperature and density evolution at the plasma edge and in the SOL is underway using the UEDGE code. The current density profile determined by a combination of magnetic measurements and a 16 channel Motional Stark

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Effect diagnostic show a rapid (<1 ms) flattening of the current profile from ℓ_i~1.5 to ~0.5. The current flattening is faster than can be explained by relaxation due to classical or neoclassical resistive processes.

Initial measurements of the heat flux to the divertor region during the impurity induced and high beta disruptions indicate that between 70–90% of the thermal energy lost is incident on the divertor region. There is considerable variation in the location and characteristics of the peak heat flux. In different disruptions, the characteristic of the peak heat flux varied from a peak with a relatively narrow width in the radial direction (~3 cm) located in the private flux region to a broad peak (~10 cm) located in either the inner or outer strikepoint region. Within a single disruption, the location of the peak varies in time and has been observed as far as 20 cm inward radially of the inner strikepoint with little power in the outer strikepoint region.

One of the more significant advancements both in measurements and understanding has been in the area of halo currents. One of the major findings is that the halo currents can be highly toroidally localized. Peak-to-average values have been observed in excess of 3:1 with axisymmetric components in excess of 25% of the pre-disruption plasma current. Extreme peak-to-average values of 5 and average values up to 50% are observed to have time durations short (<1 ms) compared to the duration of the total halo current and to times relevant to the mechanical structure of the DIII–D vessel. Rotation of the non-axisymmetric structure has been observed with frequencies in the range of 200–700 Hz. The rotation has been observed to lock at one toroidal location and grow in amplitude. Simulation of the detailed evolution of the axisymmetric component of the halo current is in progress using the Tokamak Simulation Code (TSC) resistive MHD codes. An analytic model has also been developed to permit scaling relationships to be determined.

To reduce the thermal loads to the divertor and possibly the halo current loads, pure neon "killer" pellets have been injected into the early stages of a Vertical Displacement Event (VDE). The injection successfully induced a rapid thermal quench and strongly influenced the subsequent plasma trajectory. Preliminary results also indicate a reduction in the halo currents. With pellet injection, the VDE halo and bulk plasmas were significantly colder (1–10 eV) than normal VDE halo and bulk plasmas (20–100 eV) during the final stages of the current quench. Comparison of the evolution of the electron temperature and the various charge states of neon are permitting the validation of a model of high Z pellet ablation. Simulation of the pellet ablation and subsequent plasma trajectory are in progress using the TSC code including the high Z pellet ablation model.

To address disruption avoidance, a high beta disruption alarm has been developed using a neural network based on a multi-layer perceptron. The system uses 33 plasma diagnostic signals including magnetics, H_α, soft x-ray, visible bremsstrahlung, and neutron emission, and line integrated density. The results indicate the neural network results in a better description of the disruption boundary than the simple Tryon limit (~I/aB) or a current profile corrected Troyon limit (~ℓ_iI/aB). The disruption boundary is predicted a few hundred milliseconds before the disruption occurs and the technique has been implemented in the real time plasma control system on DIII–D.

[1] TAYLOR, P.L., KELLMAN, A.G., RICE, B.W., and HUMPHREYS, D.A., Phys. Rev. Lett. **76**, 916 (1996).