Disruptions in the High-β Spherical Torus NSTX

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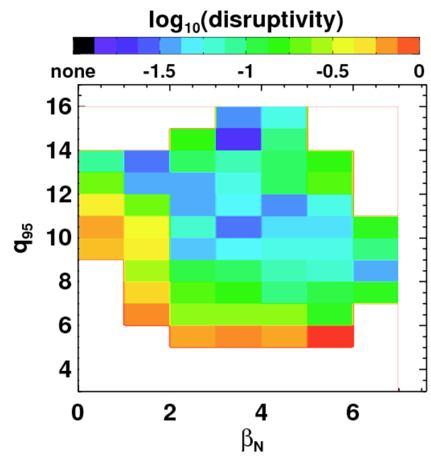

Fig. 1: Disruptivity per 100 ms as a function of β_N and q_{95}.

The spherical torus is being considered for the fusion core of facilities designed to study fusion nuclear science [1] or to generate fusion power [2]. These missions, as well as successful ITER operation, require that the disruptivity be quite low, that means of detecting impending disruptions be developed, and that the consequences of disruptions for the plant be understood and minimized. This paper examines these issues with data from the high-β National Spherical Torus Experiment (NSTX).

Disruptivity: Fig.1 shows the disruptivity, defined as the fraction of discharges which disrupt per 100 ms of operational time, as a function of β_N, indicative of the global β limit, and q_{95}, indicative of the global current limit, for a database of ~35,000 evenly sampled time slices during the high-performance phase of discharges. There is a strong increase in disruptivity below q_{95}=6, but no clear dependence on β_N alone; other parameters such as rotation, error field physics, and kinetic stabilization play a significant role in determining the maximum achievable β_N. The figure shows a minimum disruptivity in the range of ~5-8%. The current profile in nearly all of these discharges evolves toward q_{min}<1, with core m/n = 1/1+2/1 kink/tearing modes often growing and degrading confinement, and sometimes locking to the wall and leading to disruption [3,4]. Only at moderate to high q_{95} and high β_N, where the bootstrap current is large, can the evolution of q_{min} be arrested at values stable to these modes.

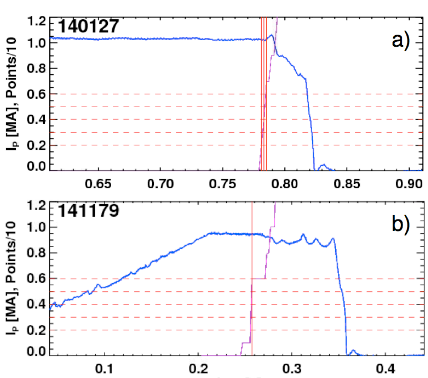

Fig. 2: Plasma current traces (blue), warning level (magenta) and time of declared disruption warning (red).

Disruption Detection: Disruptions in H-mode scenarios typically show many precursors. We have examined ~2000 disruptions occurring during the current flat-top for precursors such as n=1 resistive wall modes (RWMs) or locked modes, large amplitude low-frequency rotating n=1 modes, thermal or particle confinement degradation, increased flux consumption, uncontrolled vertical motion, rotation damping, increases in

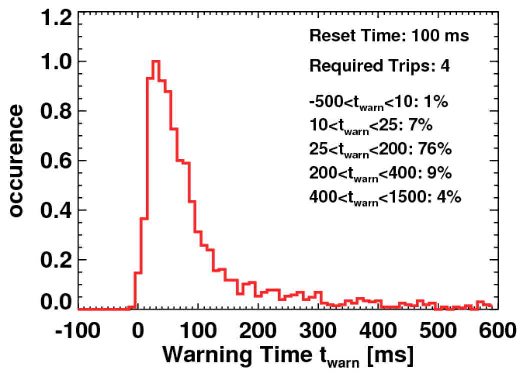

Fig. 3: Distribution of disruption warning times for compound threshold based detection.

the pressure peaking or too-small plasma-wall gaps, and anomalously low neutron production. For each quantity, thresholds beyond which disruptions are common are defined. Where possible, these threshold tests are framed in terms of physics based models, for instance, 0D models for the loop voltage and neutron rate. Compound warning rules are then formed by summing the binary outputs of individual threshold tests with pre-defined weights. As shown in Fig. 2, these compound threshold tests can be used to determine imminent disruption onset. When applied to the database, Fig. 3 shows that these tests can predict ~99% of disruptions with ~10 ms of warning time, with a false positive rate of ~4%. The 1% of disruptions not detected sufficiently in advance by the compound warning rule are typically high-β_N RWM disruptions.

Halo Currents: Halo currents flow when the vertically displaced disrupting plasma comes in contact with the plasma facing components. These halo currents have been measured at many locations in the NSTX divertor. Halo current fractions greater than 30% have been measured, with the largest currents often coming from Ohmic and L-mode vertically unstable disruptions. The largest halo currents are often associated with large plasma current quench rates. As shown in Fig. 4, halo currents are sometimes observed to flow when q_{edge}>3, but an increase in the amplitude typically occurs when q_{edge} drops below 2. Fig. 4 also shows that the halo currents can have a significant toroidal asymmetry, and that this asymmetry is observed to rotate toroidally. Up to 7 toroidal transits have been observed in rare cases, with 2-3 revolutions fairly common. The toroidal rotation frequencies are typically 0.5-2 kHz, though the rotation tends to be non-steady, often with a low rotation phase followed by a period of rapid rotation. The rotation frequency tends to be anti-correlated with the halo current fraction. The non-axisymmetric part of the halo current typically decays before the n=0 part, and filament modeling of the plasma indicates that the loss of the n≠0 current corresponds to the time when the last closed magnetic surface vanishes.

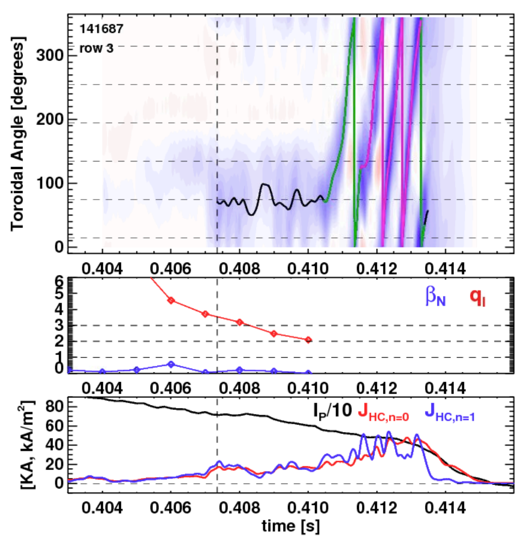

Fig. 4: Contours of halo current density in the lower divertor vs. toroidal angle and time for a downward VDE, showing the strong toroidal rotation, and time evolution of various quantities. The halo currents are measured by specially instrumented divertor tiles.

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