3D Nonlinear Simulations of Disruptions, Saturated Modes, and Soft Beta Limits in NSTX

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In this paper we apply the M3D-C1 [1,2] extended magnetohydrodynamics code to model several discharges in NSTX in which the ideal and/or resistive β-limits are approached and exceeded at some point in the discharge. The goal is to understand when and by what mechanism exceeding the stability limits leads to a disruption, and by what mechanism the plasma self-limits itself by some form of enhanced transport when it does not. The self-limiting mechanisms are a form of enhanced transport that occurs when MHD β-limits are approached, and are not well described by gyrokinetic codes.

Figure 1 shows some of the global quantities vs. time for two M3D-C1 time dependent simulations of NSTX shot 129922 starting at time 860 ms into the discharge (denoted here as time t=0), near the termination of the discharge. The curves in black (2D) used an axisymmetric version of the code, whereas the curves in red (3D) used the full 3D version of M3D-C1 with 32 cubic Hermite finite elements used to represent the toroidal variation of each (R,Z) node. Both versions had identical transport coefficients chosen to match experimental profiles. Before t = 4 ms, a current controller was used to apply a loop voltage at the boundary to keep the plasma current constant in time. At t = 4 ms, the controller was turned off and the loop voltage was suddenly reversed and decreased to -10V, similar to what happens when the OH coil currents are brought to zero at the end of the discharge.

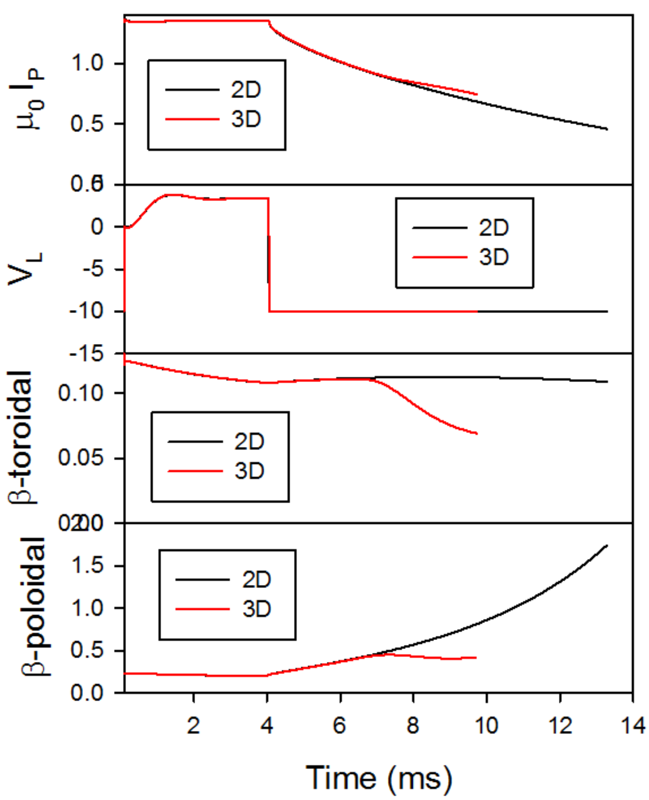

Figure 1. Traces of scalar quantities for 2D and 3D simulation of NSTX shot 129922 starting at time 860 ms.

It is seen from Fig. (1) that when the loop voltage is reversed, the plasma current, I_P, begins to decrease, as expected. The trajectories of the plasma current, β_T, and β_P are nearly identical for the 2D and 3D calculations until approximately t=7ms, at which time the β_T and β_P in the 3D calculation begin to decrease and level off, respectively, while those in the 2D calculation remain level and increase.

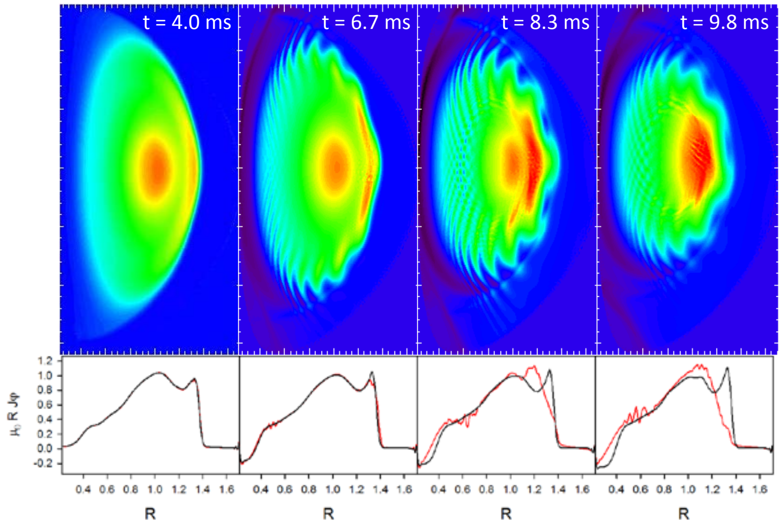

Figure 2: Snapshots of 2D slices of the toroidal current at several times. Red curves show midplane profiles for 3D calculation, while black curves show results for corresponding 2D calculation.

Figure 2 shows 2D slices from the 3D calculation of the plasma toroidal current at several times during the current ramp-down. It is clear that a high poloidal mode number instability develops at about 6.7ms and continues to grow before it begins to saturate at around 9ms. Fourier analysis of the output shows that the mode with toroidal mode n=8 has the maximum amplitude and growth rate. Comparison of the midplane profiles of the 3D and the 2D run shows that the primary effect of the 3D modes is to shift the outboard current peak inward, while reducing the amount that the current reverses on the inboard side.

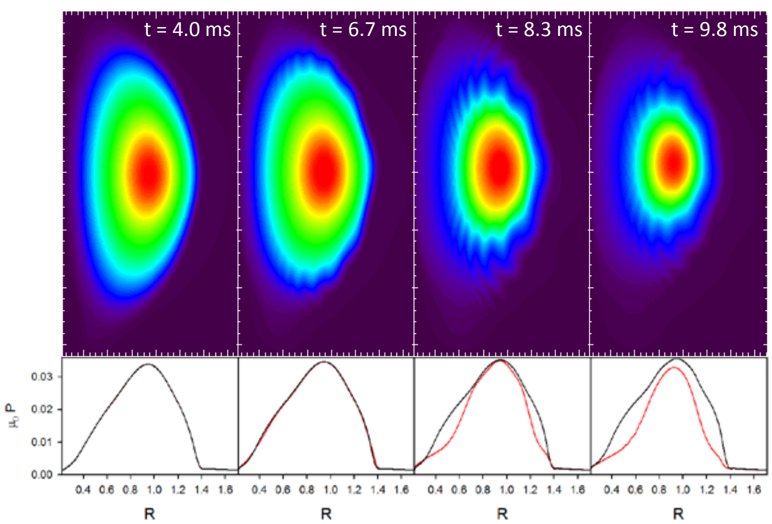

Figure 3: The analogue of Figure 2, except for pressure contours. Red curves show midplane profiles for 3D calculation, while black curves show results for corresponding 2D calculation.

In Figure (3) we show the corresponding 3D slices and midplane profiles of the plasma pressure. In comparing the 2D (black) and 3D (red) mid-plane profiles, we see that the primary effect of the 3D mode was to reduce the pressure near the plasma boundary, with very little effect near the axis.

In this study, the unstable mode was localized near the edge. We present other examples of the beta limit being exceeded first near the axis [3], and give other examples of when exceeding the beta limit leads to a hard disruption.

References:

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