TH-S

Nonlinear 3D M3D-C1 Simulations of Tokamak Plasmas Crossing a MHD Linear Stability Boundary

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1.0 Introduction:

The goal of the present work is to better understand and develop a predictive capability for when approaching and crossing a MHD linear instability boundary leads to a thermal quench and subsequent disruption (hard limit), and when it just leads to increased transport or small amplitude oscillations(soft). Understanding the difference between hard and soft limits is crucial for effective disruption prediction and avoidance. We present several examples of both hard and soft beta limits.

2.0 Computational Procedure

Recent advances in implicit numerical algorithms for solving the 3D extended magneto-hydrodynamic equations in strongly magnetized plasmas have enabled massively parallel simulations of the internal global dynamics of tokamaks that can use very large time steps which allow one to span the timescales of ideal MHD stability, magnetic reconnection, and particle, energy, and momentum transport [1,2,3]. It is now possible and feasible to run these high-resolution time-dependent initial value simulations for 10^6 or more Alfvén times so as to span all relevant timescales in a single simulation. In addition, a new multi-region and adaptive meshing capability allows simulation of the self-consistent interaction of the plasma with a resistive wall. In the examples presented here, we begin the simulation with the plasma stable to all modes. During the simulation the plasma crosses a stability boundary due to evolving profiles, loss of control, or injection of mass, energy, and or flux. This can lead to saturation or disruption.

3.0 Hard disruptive limits:

3.1 Current Rampdown Disruption: In NSTX discharge 129922, the applied loop voltage was suddenly reversed and the plasma disrupted. M3D-C1 simulations of this event show that as the current reverses near the outside, edge ballooning modes with toroidal mode number (10,11,12) first become unstable. As these grow, they drive both higher and lower mode numbers, and this process continues until stochastic processes cause a thermal quench which subsequently causes a current quench.

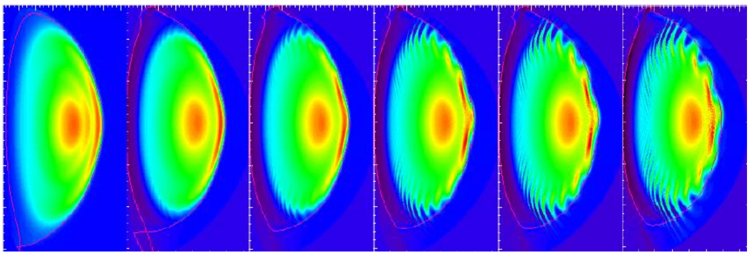

Figure 1: Toroidal current density at several times during a rapid current rampdown that leads to a major disruption.

3.2 3D VDE: We have used the new resistive wall capability to model a fully 3D vertical displacement event in NSTX and DIII-D. Once vertical control is lost, the plasma drifts downward with the linear growth rate until it makes contact with the vessel. Then, an n=1 resistive wall mode develops, which accelerates to a external kink. This n=1 mode is mostly external

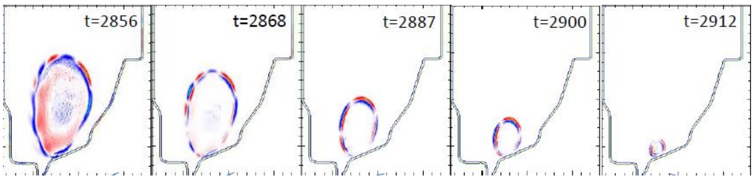

Figure 2: Toroidal derivate of toroidal current at 5 times during VDE.

with dominant poloidal mode number m = n qedge. This continues to grow in amplitude until the plasma disappears.

3.3 Island Overlap Disruption: We have investigated the dynamics of the ITPA JA-2 equilibrium that is unstable to both (2,1) and (3,2) tearing modes. We present results where these both exist, and others where the modes overlap sufficiently to destroy the confinement.

4.0 Soft limits:

4.1 Heating past the beta limit: We have identified regions in parameter space where central heating of the plasma up to and beyond the ideal MHD beta limit does not lead to a disruption, but instead to increased transport which self-regulates the pressure increase. Shown in the figure is a NSTX plasma discharge 124379 at time 0.64 s. Increased central neutral beam heating causes an internal (4,3) mode to go unstable near the q = 1.33 surface. This instability distorts the magnetic surfaces in such a way that parallel thermal conductivity acts to reduce the pressure in the center of the discharge to the point where it becomes linearly stable and the magnetic surfaces reform

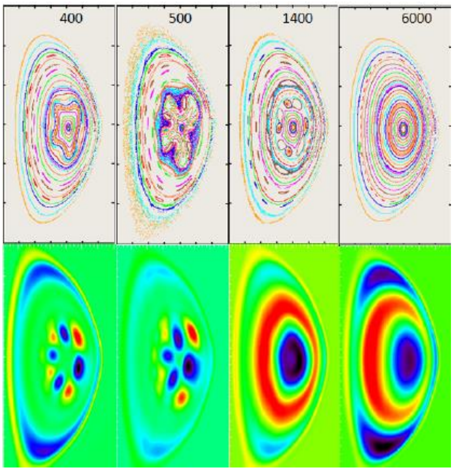

Figure 3: Top is Poincare plots, bottom is temperature differences.

4.2 Self-organized non-sawtoothing stationary states with q_0=1. We find that under certain conditions, and for sufficiently high plasma β, the plasma can self-organize to contain a shear-free region in the center with q=1. This configuration is unstable to a (1,1) interchange mode, which is driven just enough to both prevent further increase of the central pressure and to nonlinearly generate a (0,0) dynamo voltage that sustains the configuration. This (1,1) mode causes other islands to form through toroidal and other mode coupling. We have extended our previous study [3] to include the effects sheared toroidal rotation, and to map out the region in parameter space where these stationary states are expected to occur.

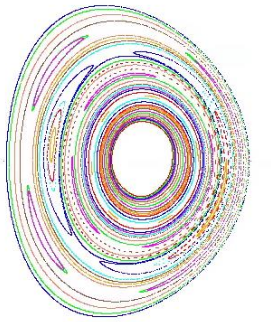

Figure 4. Poincare plot of stationary state.

4.3 *Pacing Edge-Localized modes with pellet injection:* We present simulation results showing that injection of Lithium pellets into a pedestal near marginal stability can trigger an edge localized mode (ELM) without further disrupting the discharge.

5.0 Concluding Remarks

The concept of using stability maps or real-time linear stability analysis to avoid disruptions needs to be informed by the likelihood that crossing a linear stability boundary leads to a disruption. The present work is a step in providing that information.

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References:

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