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A 2-D model has been developed to test the hypothesis that the evolution of the halo region width (W_{halo}) during vertical disruption events (VDEs) is governed by magnetic diffusion. Understanding the physics basis for halo width evolution is critical for developing predictive disruption models for ITER that provide the local magnitude and distribution of forces on internal components. The 2-D diffusive model provides good qualitative agreement with experimental measurements of halo width during VDEs, suggesting that magnetic diffusion is the dominant process governing halo width evolution (Fig. 1).

The electromagnetic loads produced by halo currents during VDEs impose stringent requirements on the strength of ITER vessel and in-vessel components [1,2], as well as those of future burning plasma devices. Those loads, directed perpendicular to the vessel wall, are produced by the $J \times B$ interaction of the poloidal halo current and toroidal field. A predictive understanding of halo current evolution is necessary for ensuring the robust mechanical design of those components.

Halo current evolution is governed by two intrinsic quantities: the halo region width and resistivity. Together, those quantities specify the total resistance and inductance of the halo region, determining the amount of halo current induced by the core plasma motion and current decay during a VDE [3]. It has been noted [4] on DIII-D that VDEs with cold post-thermal quench plasma and a current decay time much faster than the vertical motion (Type I VDE) possess much wider, faster growing halo region widths than warmer plasma VDEs where the current decay is much slower than the vertical motion (Type II) (Fig. 1, dashed lines). The halo width is measured using the JFIT [3] reconstruction code. This observation suggests that the halo width growth is driven by magnetic diffusion, as core current should diffuse into the halo region faster in a cold plasma than a warmer one.

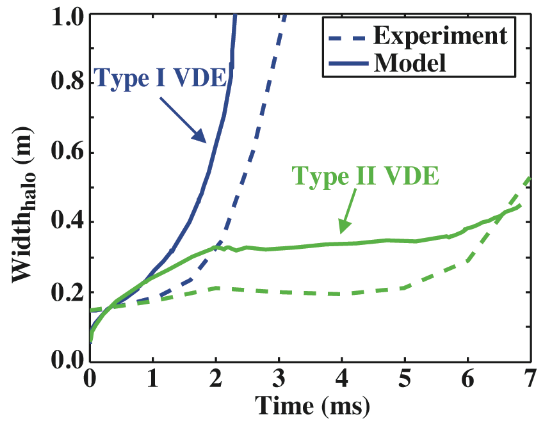

Fig. 1. Halo width vs time after first contact with vessel wall. Dashed lines are experimental JFIT reconstruction values, solid lines are model results. Type I VDE (blue), Type II VDE (green).

A 2-D finite element model (FEM) has been developed to test this hypothesis of diffusive halo region growth. The model is implemented using Comsol Multiphysics®. The plasma consists of a core region of uniform T_e and initially uniform current density within the last closed flux surface (LCFS) surrounded by a halo plasma, also of uniform T_e but initially no current, that fills the vessel outside the LCFS. The LCFS motion during the VDE is prescribed to match experimental observations, as are all coil currents. A deformable mesh algorithm adjusts the FEM mesh to move with the LCFS. The core and halo temperatures are derived from best fits to a 0-D halo current evolution model [3], and assumed to remain constant in time. The FEM model solves the magnetic diffusion equation as the LCFS compresses against the vessel wall (Fig. 3). It is assumed that all halo region currents travel in a force-free manner along open field lines, so that the toroidal halo current (I_{htor}) is related to the poloidal halo current (I_{hpol}) by the relation $I_{htor} = I_{hpol} * q_h$, where q_h is the halo region safety factor [3].

Both the Type I and Type II VDE discharges of Fig. 2 have been modeled using this 2-D method. Both discharges possess similar LSN shapes prior to the VDE. Post thermal quench plasma temperatures of 2 eV and 16 eV for both the core & halo regions were assumed for the Type I and Type II VDEs, respectively, based upon best fits to the 0-D model. The resulting halo width evolutions, displayed as the solid lines in Fig. 1, compare favorably with the experimental values (dashed lines). This supports the initial hypothesis that halo width growth is driven by magnetic diffusion. Further refinement of the initial conditions and assumptions of the 2-D model (constant T_e, initially uniform J in core, T_e based upon 0-D model) should enable closer quantitative agreement.

A dimensionless 1-D, closed form diffusion model has also been developed. This model provides the ratio of the halo width growth rate to the I_p decay rate (γ_w/γ_p) as a function of the ratio of the halo to the core resistivities (η_h/η_p). It is based upon fits to halo width growth and I_p decay curves from a 1-D diffusion model over widely varying resistivity ratios. While lacking the detail of the 2-D model, it can be readily integrated into more complex simulation and scenario development codes to provide a physics basis for their VDE modeling.

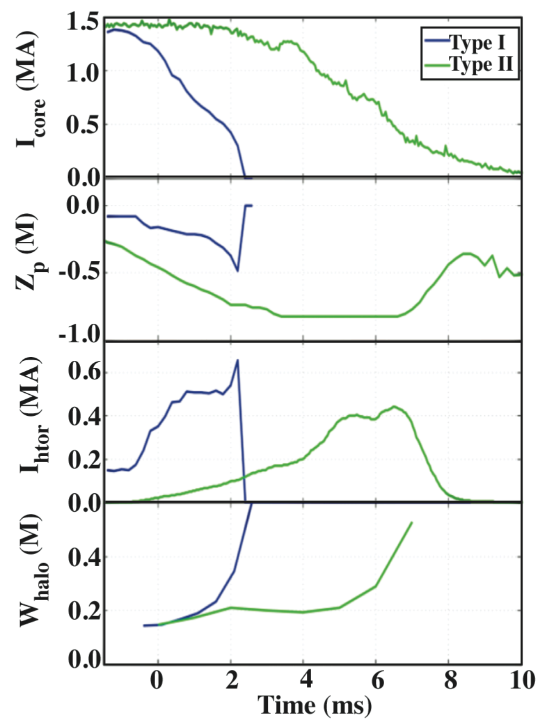

Fig. 2. Comparison of Type I (blue) #110216 and Type II (green) VDE 293204. From top: core plasma current, current centroid height, toroidal halo current, and halo width. Time is relative to first contact with vessel floor. Note that the reversal in current centroid z velocity is due to halo expansion.

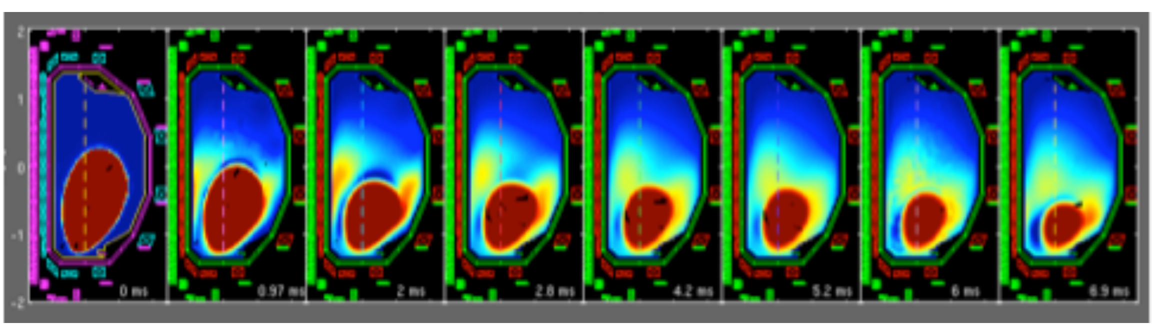

Fig. 3. Simulation of current density evolution during Type II VDE #93204.

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