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Vessel Forces from a Vertical Displacement Event in ITER

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1. Introduction : Disruptions are one of the major concerns in ITER and other future tokamaks [1]. A particularly troublesome type of disruption is a vertical displacement event (VDE) where control of the vertical position of the plasma column is lost. In addition to heat, particle flux, and energetic electrons impacting the first wall, significant electromagnetic loads will arise.. For realistic modelling of a VDE disruption, a detailed 3D model of the disrupting plasma and an accurate description of the conducting structures surrounding the plasma is required. The structure affects the plasma evolution itself and the plasma acts as a source of currents and fields which produce the electromagnetic loads. Most of the VDE modeling work to date has used the axisymmetric evolving equilibrium codes TSC [2], DINA [3], and CarMa0NL[4] to describe the disrupting plasma. This paper describes our efforts to extend this analysis by using the fully 3D MHD codes M3D-C1 [5], NIMROD [6], and JOREK [7]. We describe our efforts in benchmarking these 3 codes on VDE relevant calculations, validation with some experimental data, and projection to ITER vessel and plasma conditions. Attention is given to the role of the currents shared by the plasma and the structure (halo currents).
2. 2D and 3D benchmarking of M3D-C1, NIMROD, JOREK in simplified geometry We have undertaken two VDE code benchmarking exercises for the 3 MHD codes M3D-C1, NIMROD, and JOREK. The first was in 2D (axisymmetric) [8] and we obtained excellent agreement for the linear and early nonlinear growth rates and for the motion of the magnetic axis, induced wall currents, and distribution of the halo current. The second benchmark, currently in progress, is fully 3D, beginning at the time the plasma first makes contact with the vessel.
3. Simulation of the sideways force in JET: M3D-C1 simulations of asymmetric vertical dis-placement events (AVDEs) in JET are in progress. The simulations were compared with previous M3D simulations [9] and with the JET 2011-2016 ILW disruption database. The computed and experimentally measured Noll approximations to the sideways force are in reasonable agreement. An important feature of the simulations and the data is that the sideways wall force is small when the current quench time is less than the wall penetration time.
4. 2D benchmark of M3D-C1 and CarMa0NL for ITER geometry with no halo currents We performed a separate nonlinear but axisymmetric VDE benchmark between M3D-C1 and CarMa0NL using a uniform thickness resistive wall located at the position of the ITER first wall. A 6 cm thick wall with resistivity of 7.4E-7 ohm-m gives a time constant of 235 ms for the wall current to develop when a constant loop voltage is applied (no plasma). Modeling of both a “hot” and “cold” VDE with the 2 codes, both without halo currents present, gave excellent agreement. [10]
5. The effect of Halo Currents on the vertical force: We have performed extensive axisymmetric studies with M3D-C1 of the effect of different assumptions regarding the temperature distribution of the halo region during an axisymmetric VDE in ITER geometry with the wall model described in #4 above. These studies use spatially and time varying parallel and isotropic thermal conductivities to model the thermal quench which then caused the current quench with differing amounts of halo current. We found the result that when a larger force from the halo current is present, it is at least partially offset by a smaller force due to the induced toroidal currents [11]. Slower current quenches generally lead to larger vertical forces, but the presence of a halo region can modify this scaling. Also, sheath-type boundary conditions are found to slow the evolution, increasing impulse in NIMROD computations [12].
6. 3D VDE simulations in ITER geometry: Building on these successful code benchmarks and axisymmetric parameter studies in ITER geometry, we have performed several 3D VDE simulations with M3D-C1 using the ITER vessel model described in 4.

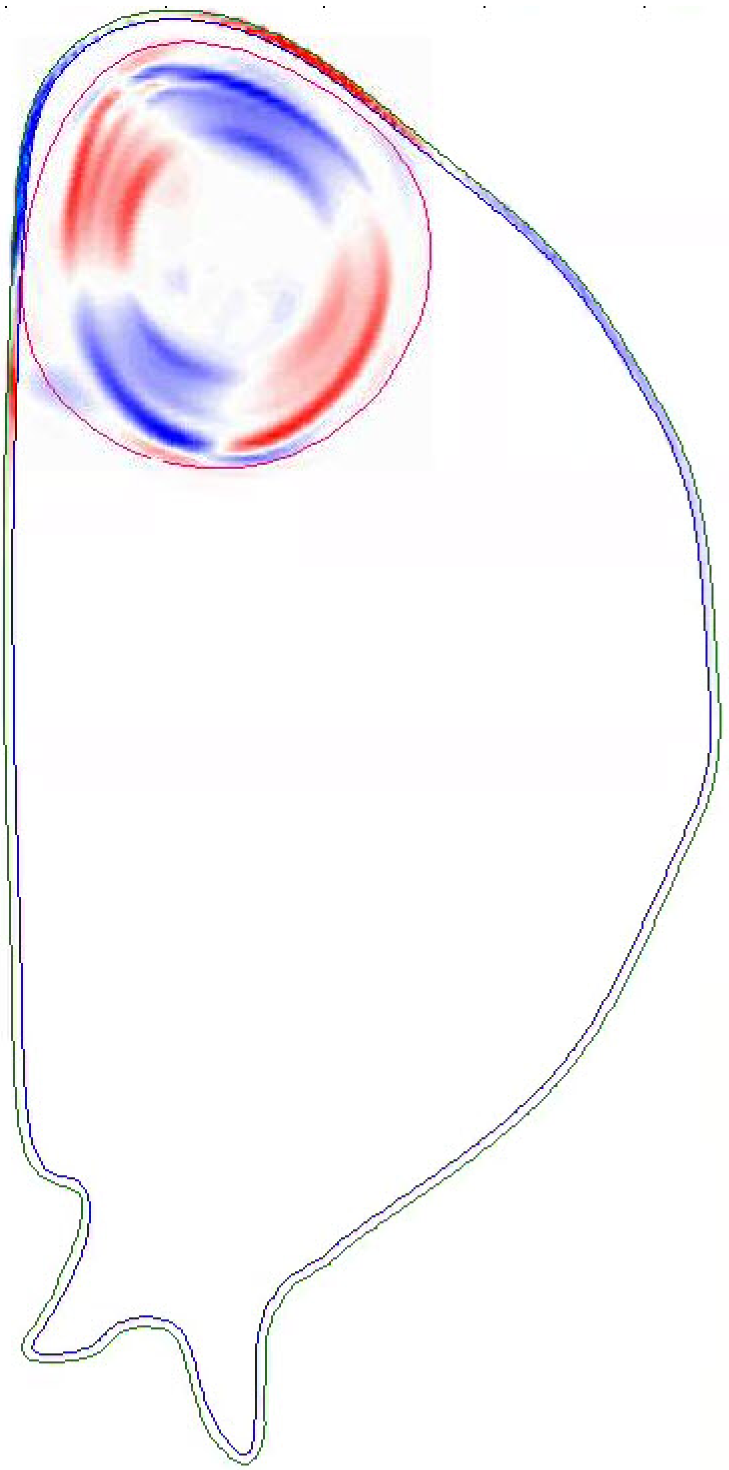

Figure 1:

Currents and fields from these simulations are input to the CARRIDI code for detailed force calculations. Our initial result is that the intrinsically 3D “sideways force” is much smaller than the vertical force, largely because the kinking motion of the plasma occurs on a time scale much faster than the vessel time constant. This is largely consistent with an earlier scaling obtained with the M3D code. [13]

7. Summary and Conclusions: For the first time, we have applied massively parallel implicit 3D magnetohydrodynamics codes to predict the wall forces produced during ITER disruptions using realistic values for the wall resistivity and time constant. Extensive code verification and validation has been performed. We are in the process of refining the wall model to make it more realistic, and in developing a tighter coupling of M3D-C1 with CARRIDI in order to refine our present results. Acknowledgments: This work was supported by US DOE Contracts No. DE-AC02-09CH11466, and No. DE-SC0018001the SciDAC Center for Tokamak Transient Simulations, EUROfusion Researcher Fel-lowship programme

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