ITER disruptions and wall force

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Outline

- **Introduction**
- **VDE destabilization of n = 1 mode**
  - **Scrape off of magnetic flux changes q at last closed flux surface**
  - **Model of wall force with n=0 and n=1 modes**
- **Velocity boundary conditions**
  - **Effect of absorbing boundary conditions**
- **Blanket and coil forces**
  - **Simulation options**
- **Summary and future plans**

Introduction

- **disruptions in ITER**
  - **Vacuum vessel and mechanical structures could be damaged by excessive electromechanical loads from 3D magnetic fields**
  - **“sideways” force is hard to compensate**
  - **Other issues: heat load, runaway electrons, mitigation**
  - **Worst case scenario: a Vertical Displacement Event (VDE) n=0 mode causes hot plasma to contact the wall**
    - **destabilizes n=1 mode**
- **Previous work**
  - **Simulations with M3D code with resistive wall boundary conditions**
  - **started with equilibrium that was VDE and kink or Resistive Wall Mode unstable**
  - **Now done self consistently**

Wall force

- Wall force is calculated from the jump in magnetic field across thin resistive shell

$$\text{current in wall is given by } J_{wall} = \frac{\hat{n}}{\delta} \times \left(B_{vac} - B_{plas} \right)$$

$$\delta \text{ is wall thickness}$$

External field calculated with GRIN code

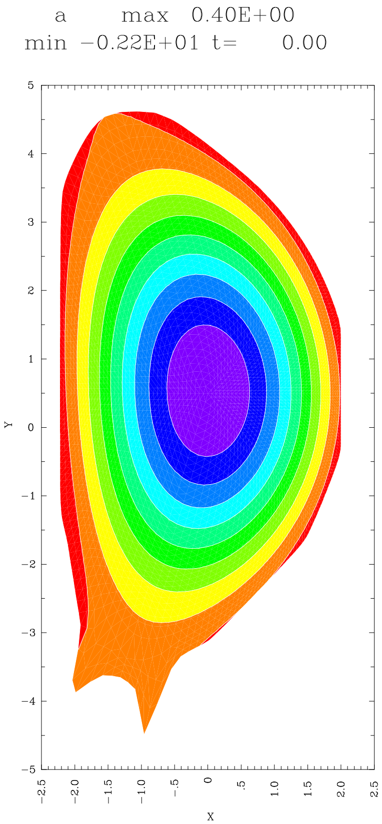
$$\text{sideways wall force is given by } F_x = \delta \int d\varphi \int dlR \left(J_{wall} \times B_{wal} \right) \bullet \hat{x}$$

$$\text{where } \hat{x} = \hat{R} \cos\varphi - \hat{\varphi} \sin\varphi$$

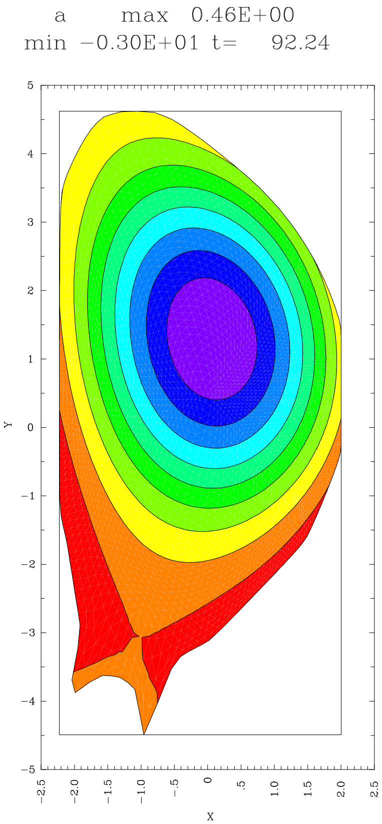
- **Indicates that n=1 perturbations required for sideways force**

$$\text{resistive wall penetration time } \tau_{wall} \sim \frac{\delta}{\eta_{wall}}$$

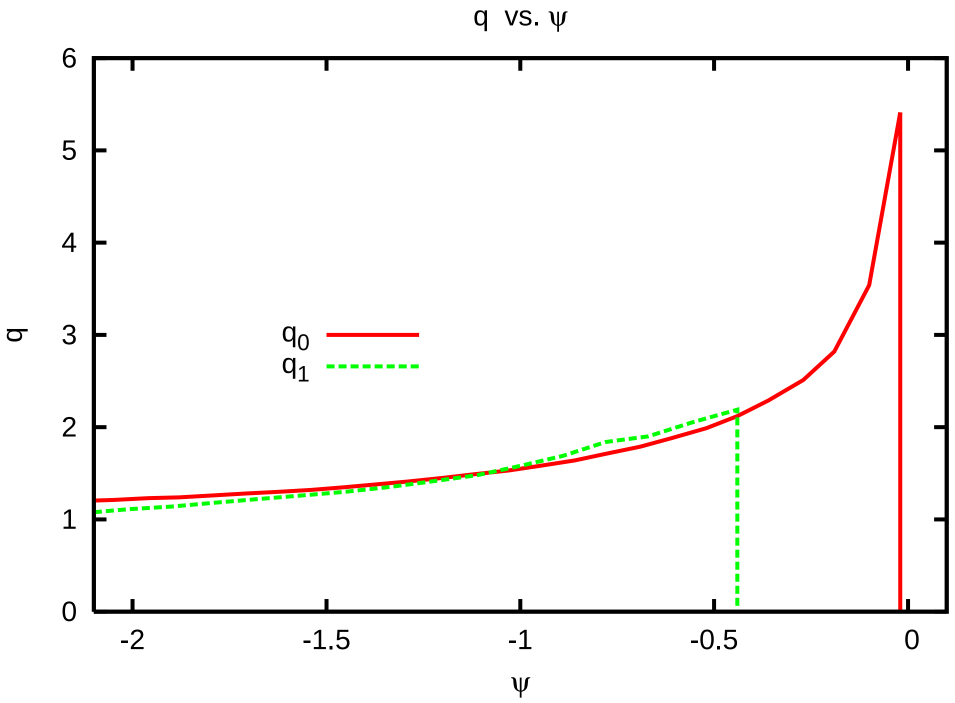
VDE destabilization of n=1 mode



ψ initially



ψ during VDE

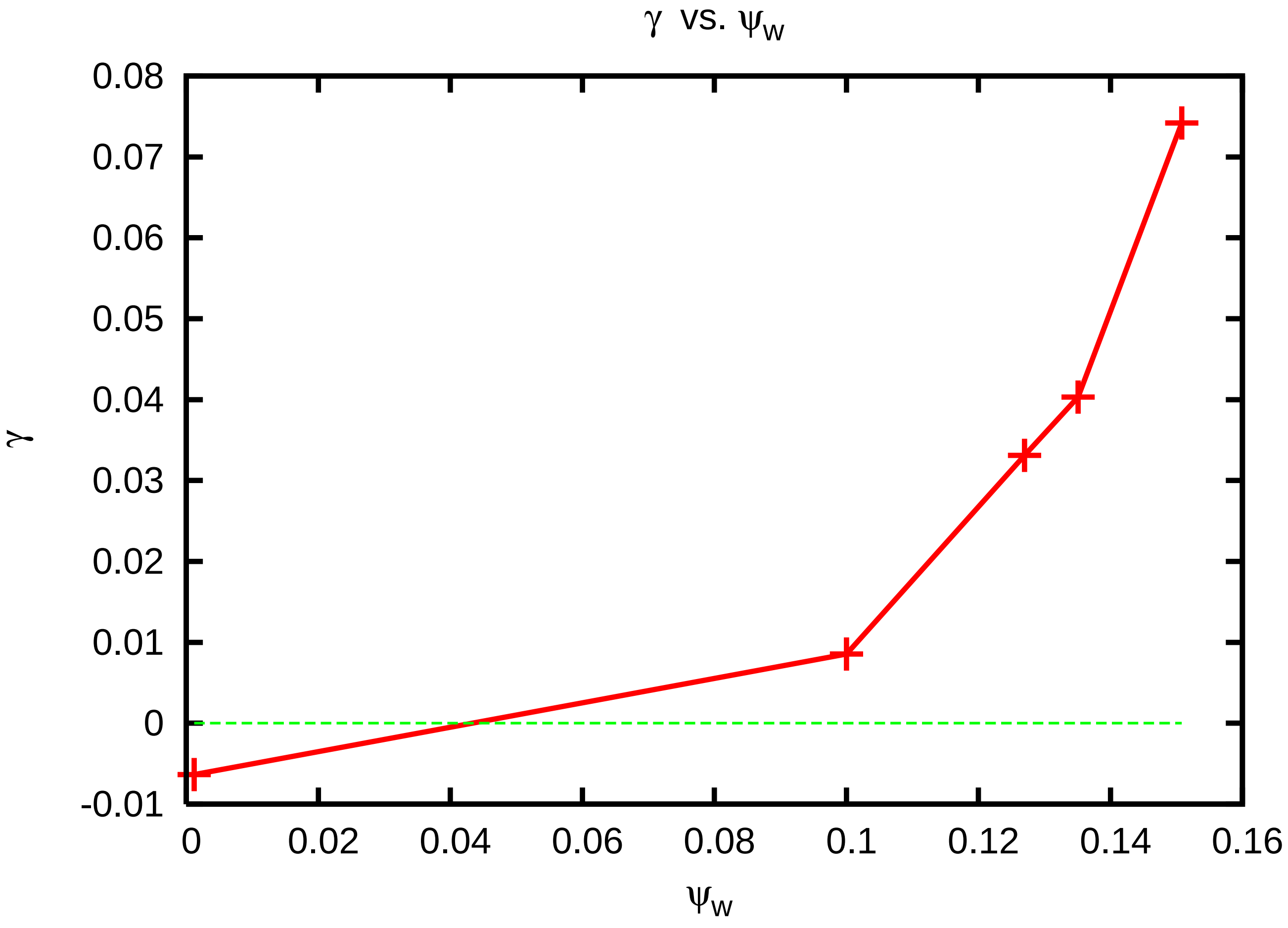


When separatrix flux surface penetrates wall, last closed flux surface has q~2-3. This destabilizes n=1 mode. Psi-wall-min was also measures flux scrape off

VDE does not have to move plasma very far

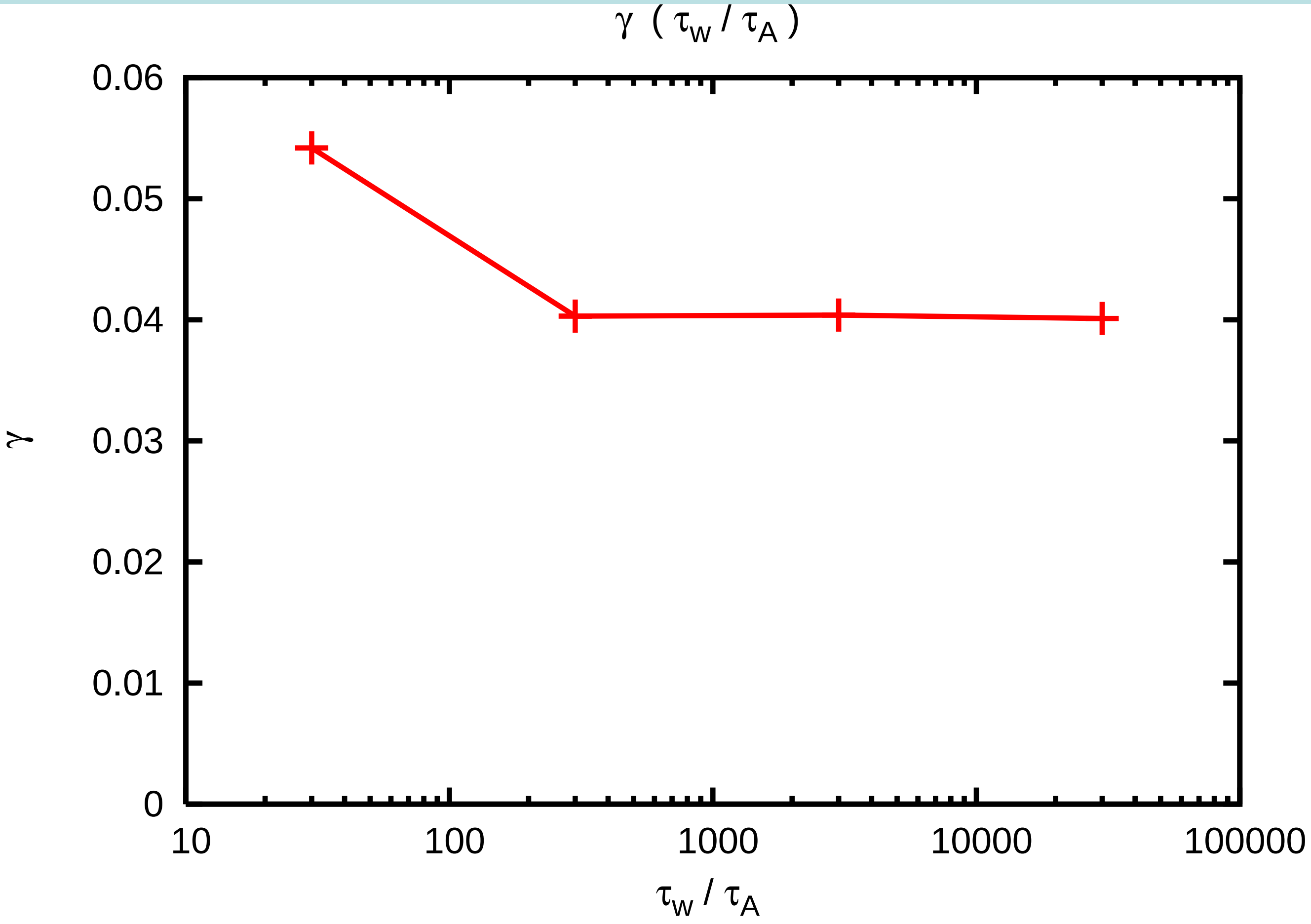
Manickam et al. 2011

Growth rate of n=1 mode as a function of psi_wall_max



growth rate increases as magnetic flux penetrates the wall
VDE was evolved, then stopped for linear simulation

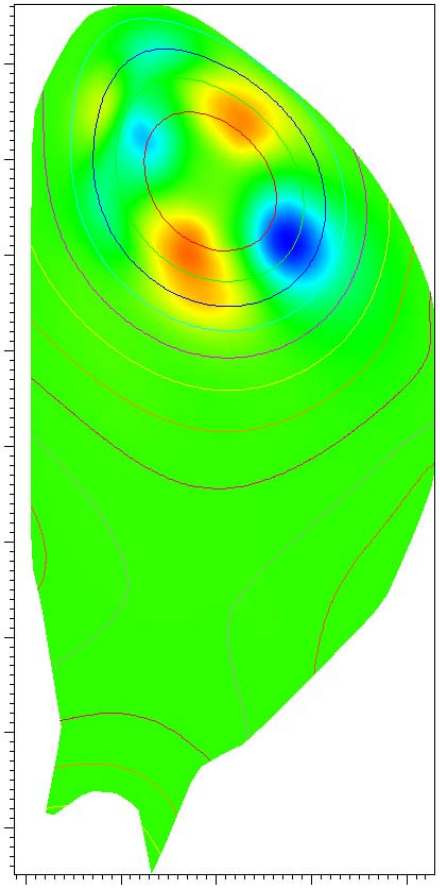
Growth rate of n=1 mode as a function of tau_w



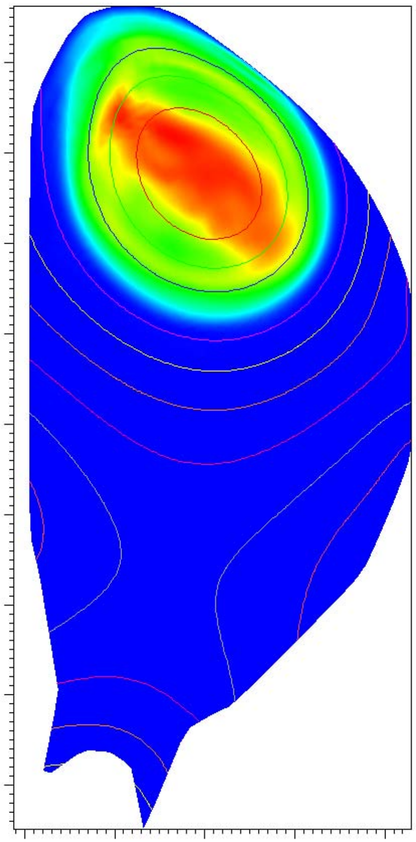
Not a resistive wall mode. Don't have scaling with plasma resistivity.

τ_{wall} is resistive wall penetration time

Linear psi and nonlinear pressure

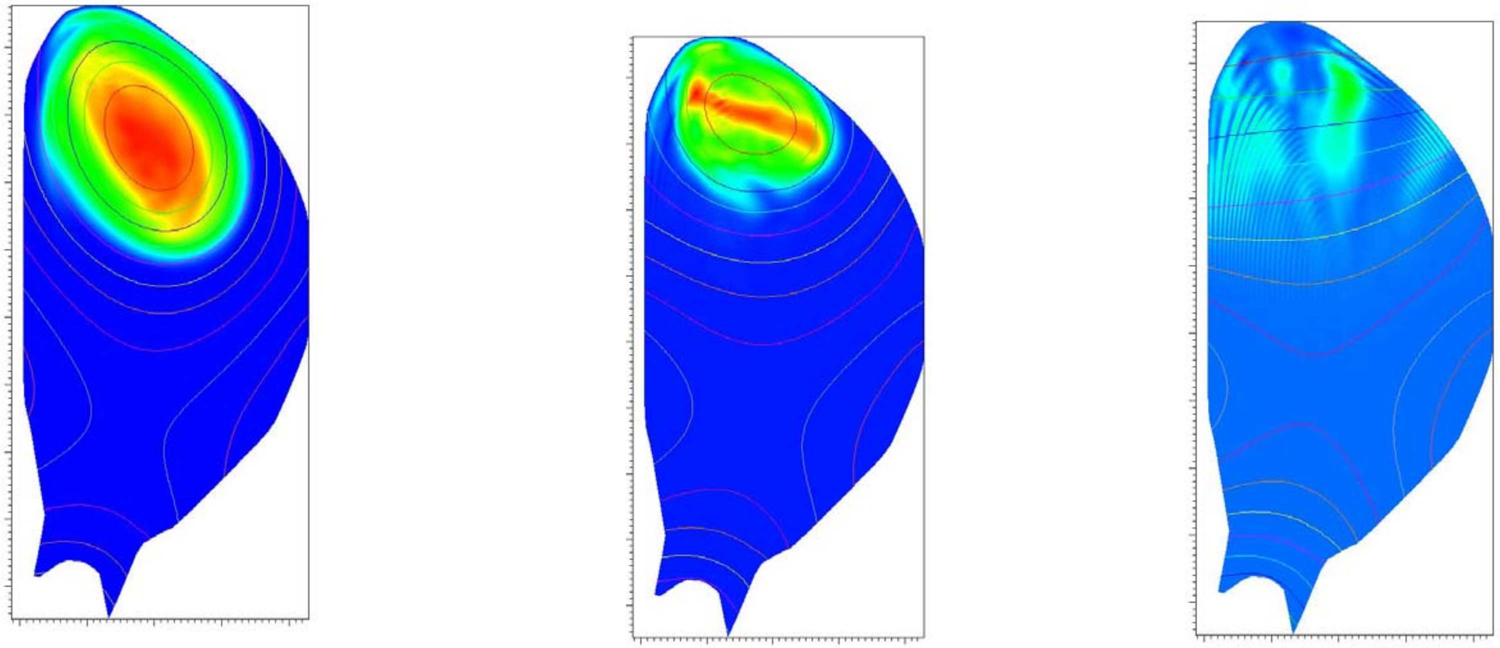


Linear perturbed psi shows it's Not a RWM-doesn't reach wall



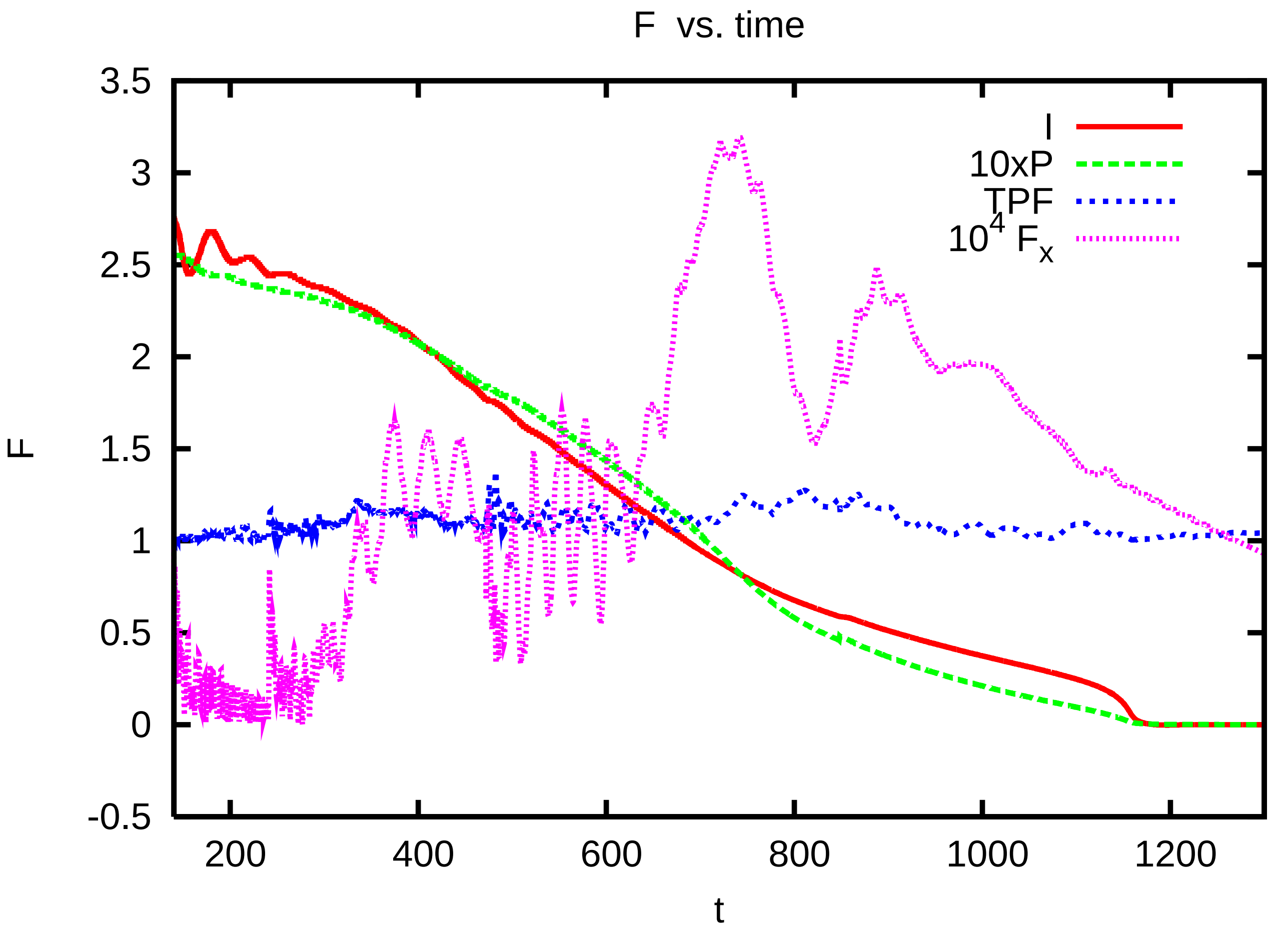
Nonlinear pressure: 2,1 kink/ tearing mode

Time evolution - p



Mode growth along with VDE growth
Pressure shrinks and disappears
Tearing mode?

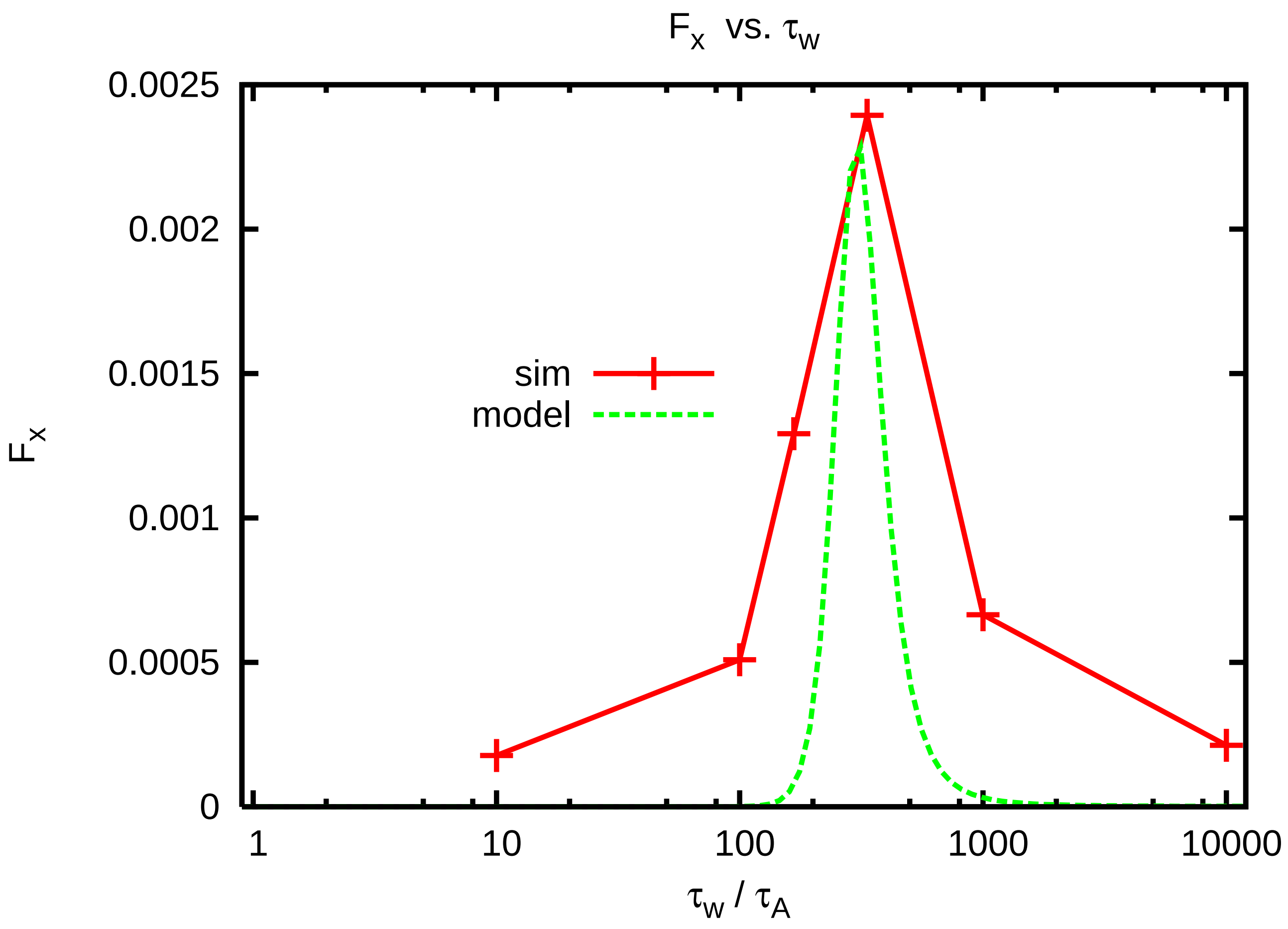
Time history



Thermal and current quench are almost simultaneous.

TPF is low, moderate wall force. S = 10^6, 1000 Alven times

Wall force depends on wall penetration time



Simulations like the previous example were done for different values of wall penetration time. Similar effect was seen in previous simulations.

Model of n=0,1 wall force

In previous work, modeled sideways force produced by (m,n) = (1,1) mode
Simple circular cross section equilibrium model for sideways wall force F_x

$$F_x \approx \gamma \tau_w B_\theta^2 (m - nq)\xi_1$$

ξ_n is displacement of mode n = 0,1

Displace plasma by a VDE, Taylor expand

$$\xi_1(r - \xi_0 \sin\theta) = \ldots - \frac{\partial \xi_1}{\partial r}\xi_0 \sin\theta$$

This leads to a force

$$F_x \approx \gamma \tau_w B_\theta^2 (2 - q)\xi_0 \xi_1$$

Model of n=0,1 wall force - 2

$$F_x \sim \xi_0 \xi_1$$

Model of exponential growth and decay, alpha is initial perturbation amplitude

$$\xi_n = \frac{a}{\cosh(\gamma_n t - \alpha_n)}, \text{ n=0,1}$$

Decay of n=0 mode models penetration of plasma into the wall

Maximum value of F occurs at t for which

$$t = \frac{\alpha_0}{\gamma_0} = \frac{\alpha_1}{\gamma_1}$$

$$\gamma_1 \tau_{wall} = \frac{\alpha_1}{\alpha_0}, \text{ where } \gamma_0 = \frac{1}{\tau_{wall}}$$

dependence of F_x on $\gamma \tau_{wall}$ depends on initial conditions

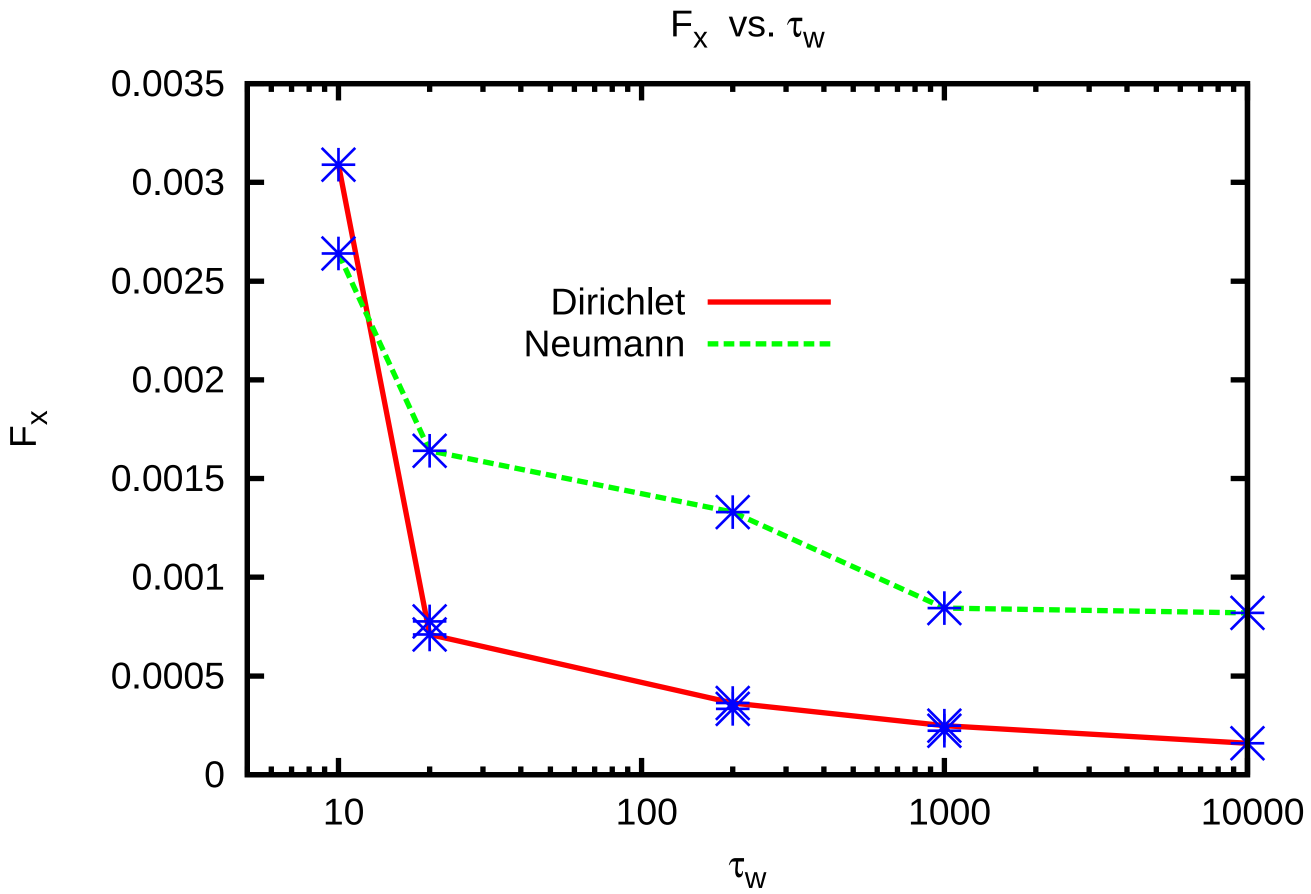
Boundary conditions

- assumed Dirichlet, no flow through the wall, “salt water” boundary condition
- Robbins boundary condition: partially absorbing

$$\frac{\partial v_n}{\partial n} = -\frac{v_n}{d} \qquad v_n = -d v_n' \cong 0$$

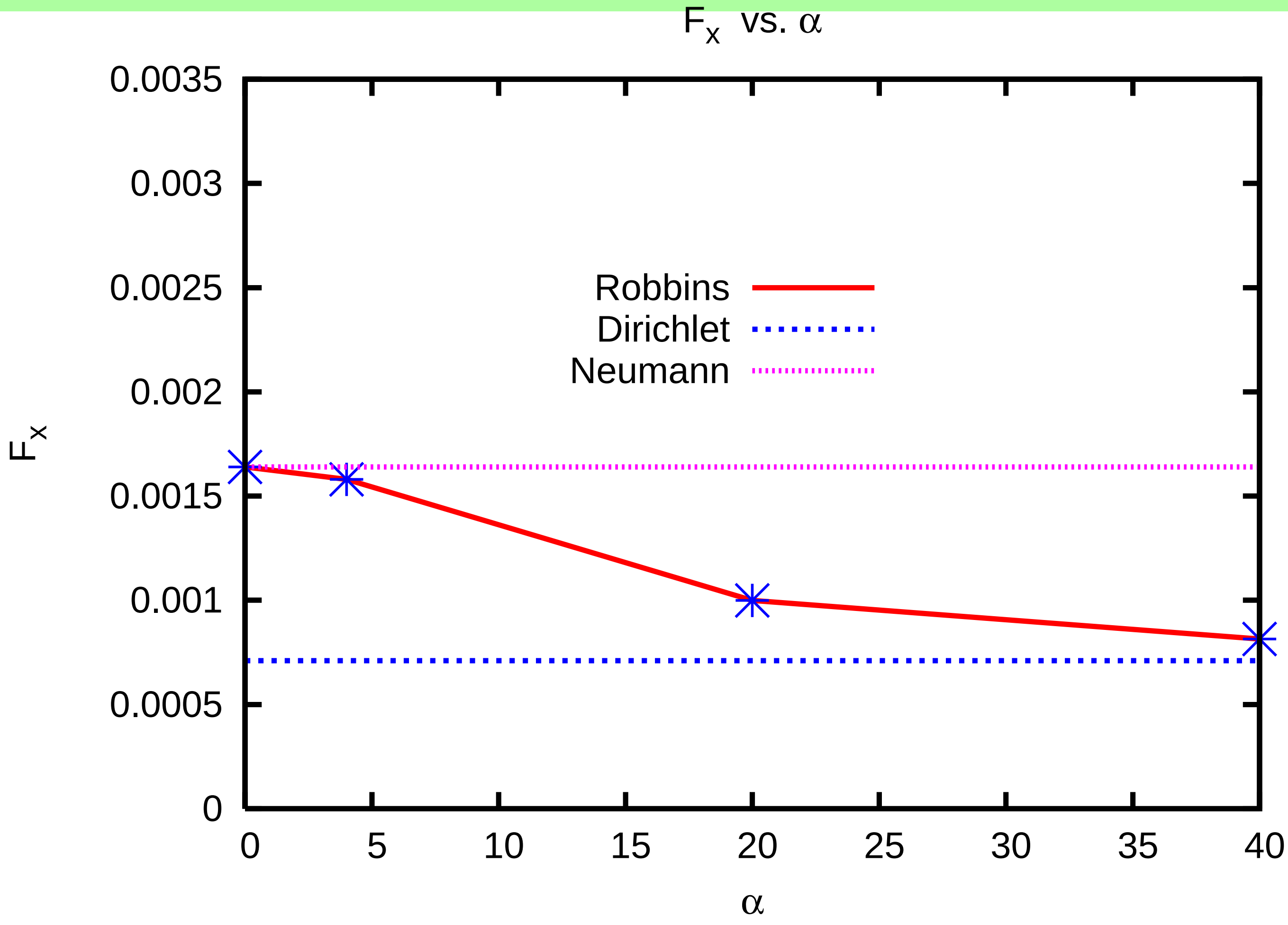
- if d >> a, Neumann, absorbing wall boundary (a is plasma radius)
- If d << a, similar to Dirichlet
- There is no theory of absorbing boundary condition for normal velocity,   only parallel velocity

Wall Force with Dirichlet, DEBS, and Neumann boundary conditions as a function of wall time



Neumann boundary condition gives larger force than Dirichlet, but maximum value is about the same

Robbins b.c.: for thin wall tends to Dirichlet



$$\alpha = a / d$$

For wall thickness = d << a = plasma radius, boundary condition tends to Dirichlet

Calculation of n=1 force on blanket modules, TF coils

Options:

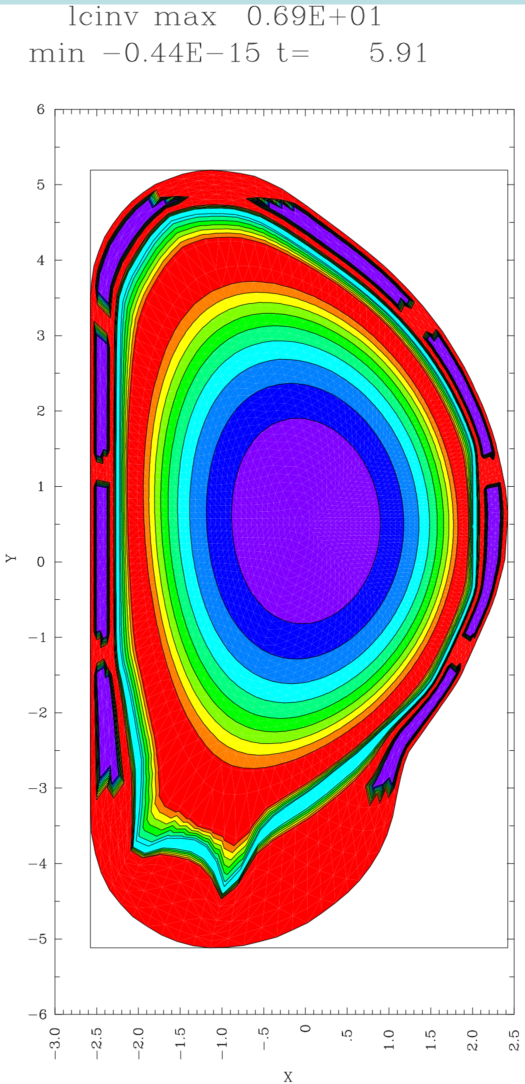
GRIN Green's function code non-self consistent method use GRIN to calculate magnetic perturbations in blanket and in TF coil region. Assume superconducing structures exclude magnetic field perturbations. Calculate magnetic stress integrated over the structures

$$F = \int dS\hat{n}\bullet\left(\vec{B}\vec{B} - \overleftrightarrow{I}B^2\right)$$

Not self consistent because response of coils in neglected.
If modules are toroidally symmetric (they aren't), GRIN could be used to calculate coil response self consistently

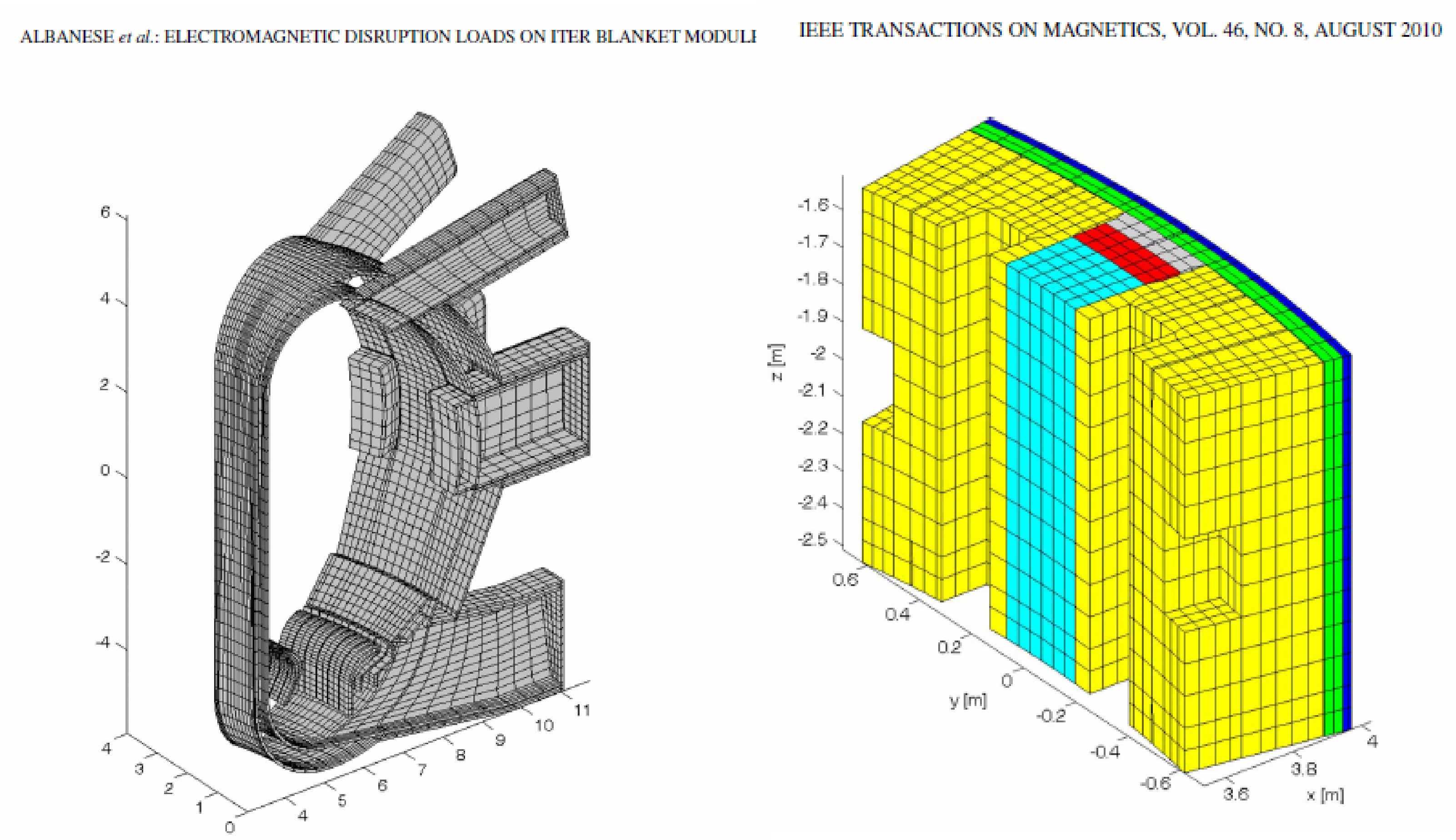
FEM Blanket model

Finite element option:
GRIN is used for thin outer wall. Inner wall and blanket are modeled as resistive region, with variable resistivity. Can model 3D structures. Could also use finite element mesh outside the vacuum wall.



Log of resistivity

EM code

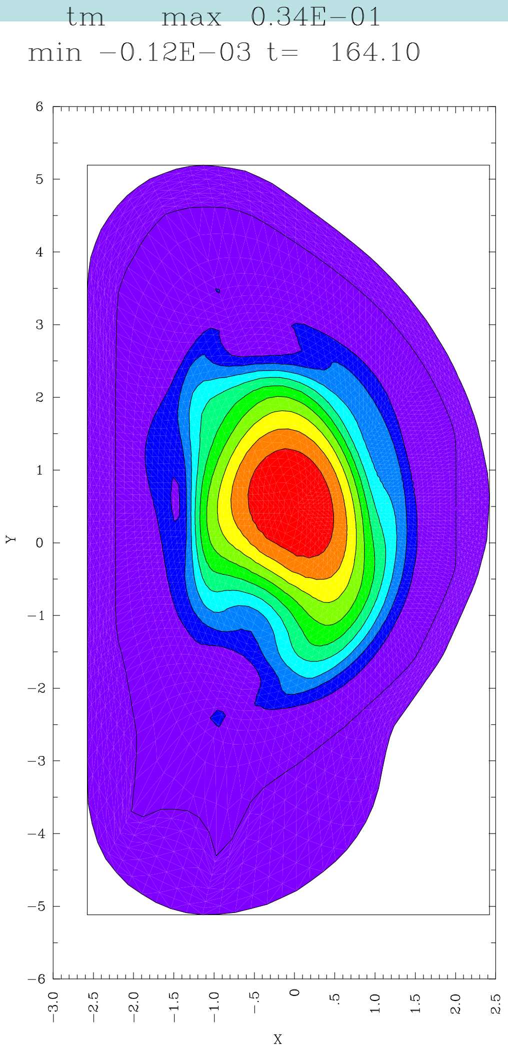


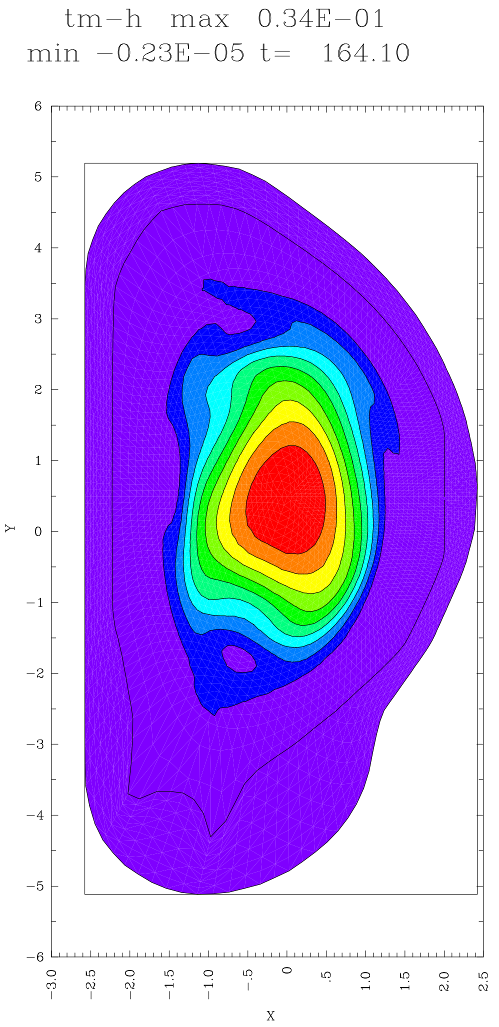
ALBANESE *et al.*: ELECTROMAGNETIC DISRUPTION LOADS ON ITER BLANKET MODULI

IEEE TRANSACTIONS ON MAGNETICS, VOL. 46, NO. 8, AUGUST 2010

EM code option:
Provide wall perturbations to code like CARIDDI, but it is not designed for n=1 perturbations. Calculates a toroidal segment.

Interaction between blanket and mode





Might possibly lead to a passive mitigation scheme

summary

- Calculated sideways force in ITER disruptions
  - Disruption caused by VDE which scrapes off plasma on the wall and causes 3D kink/RWM
  - Model of wall force from n=0 and n=1 modes
- Absorbing b.c. increases wall force
  - effect is small for thin wall
  - Does not change maximum
- 3D halo current gives toroidal variation of toroidal current
  - Not hiro current
  - Toroidal current variation ~ 10%
- Calculation of force on blanket and coils

Future Plans

- Perform simulations at higher
- Perform simulations with ITER blanket model
  - Calculate forces in the blanket
  - Forces of TF coils
- Simulate disruptions in NSTX, JET, Asdex
  - Compare simulation results to experiment
- Mitigation
  - How much does massive gas injection reduce the wall force?