PRINCETON PLASMA PHYSICS LABORATORY

MULTI-MODE ANALYSIS OF RWM FEEDBACK WITH THE NMA CODE*

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Introduction

- The NMA code utilizes the full spectrum of MHD modes from DCON.
- With the resisitve shell included, a complete set of open loop (without feedback) eigenfunctions are calculated from energy integrals that include the dissipation in the shell.
  - These eigenmodes can have varying helicities, both positive and negative.
  - They are included as circuit elements in the circuit equations that describes the feedback process.
- We have calculated the effects of a variety of feedback coil configurations on ITER relevant equilibria, examining the mode structures before, and after the stabilization of the RWM.
- The efficiency of the feedback depends strongly on the phasing of the coils with respect to each other, and to the RWM.
- The efficiency is also dependent on the interaction of the modes with each other.
  - The RWM is deformed (non-rigid) during the feedback process.
  - Stable modes can perhaps be driven by imperfect coils.
  - Experimental demonstration of these effects could be interesting.

Normal Mode Approach to Feedback Stabilization of the RWM is based on the Extended Energy Principle

$$\delta W_p + \delta K + \delta W_v + D_w + \delta E_c = 0$$

Perturbed Plasma Energy

Kinetic Energy

Perturbed Vacuum Energy

Energy Dissipation in Resistive Wall

Energy Input from External Coil

- General static plasma equilibrium
- General external modes

Chu, Chance, Glasser, Okabayashi, NF, 43, 441 (2003)

- Without feedback, the energy principle is reduced to the self-adjoint expression

$$\delta W_p + \delta K + \delta W_v + D_w + \delta E_c = 0$$

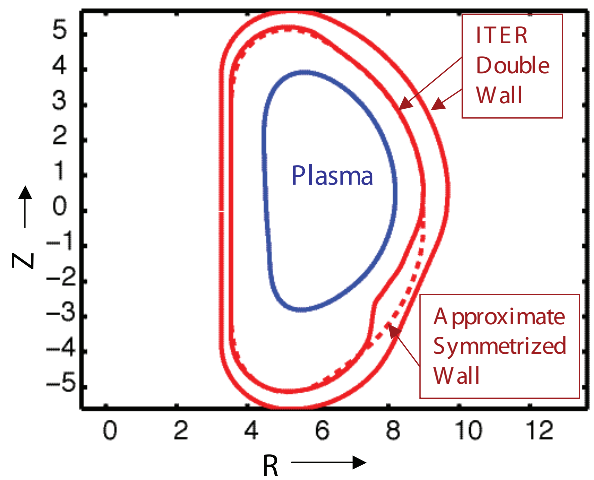
Perturbed Plasma Energy DCON

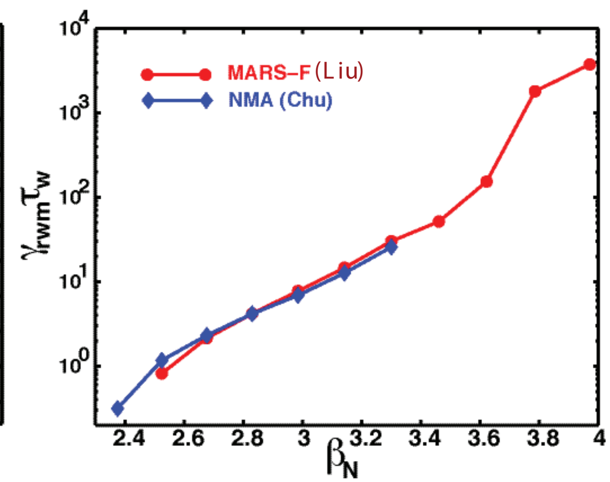
Perturbed Vacuum Energy VACUUM

Energy Dissipation in Resistive Wall Tank

- A set of normal modes can satisfy this relationship and they are the the open loop eigenfunctions (RWMs)

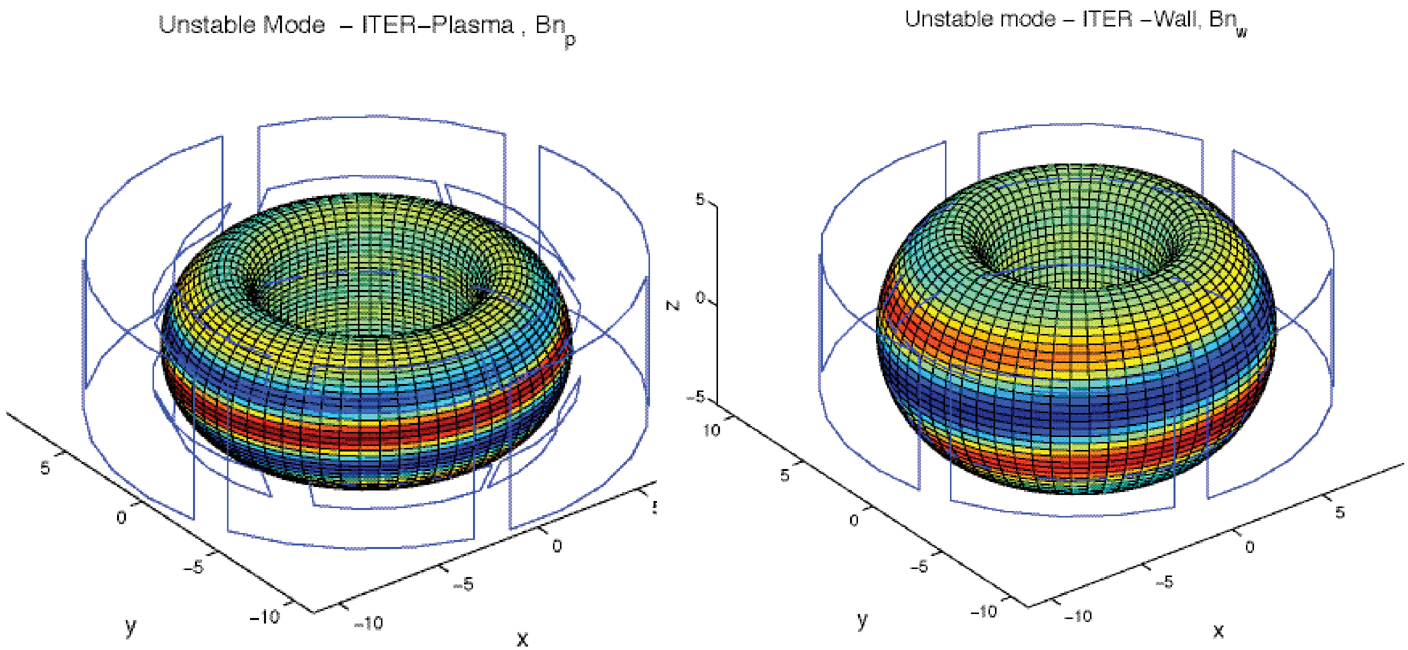
A set of Equilibria in ITER Geometry Studied with an up-down Symmeterized Approximate Wall





- The wall is an up-down symmetric approximation to the inner wall of the ITER wall structure.
- The open-loop growth rates computed by the NMA code agree with those obtained by MARS-F.

Example of the open Loop Eigenfunction (the Resistive Wall Mode) in ITER



The original proposed (Gribov) coil geometry relative to the plasma is similar to C-Coil (Gribov, private communication)

The Coils External to the Plasma Excite the RWM's Through the Feedback Logic

Amplitude of RWM; Open-Loop Growth Rate; Excitation Matrix

$$\frac{\partial \alpha_i}{\partial t} - \gamma_i \alpha_i = \sum_c I_c E_i^c$$

Coil Current

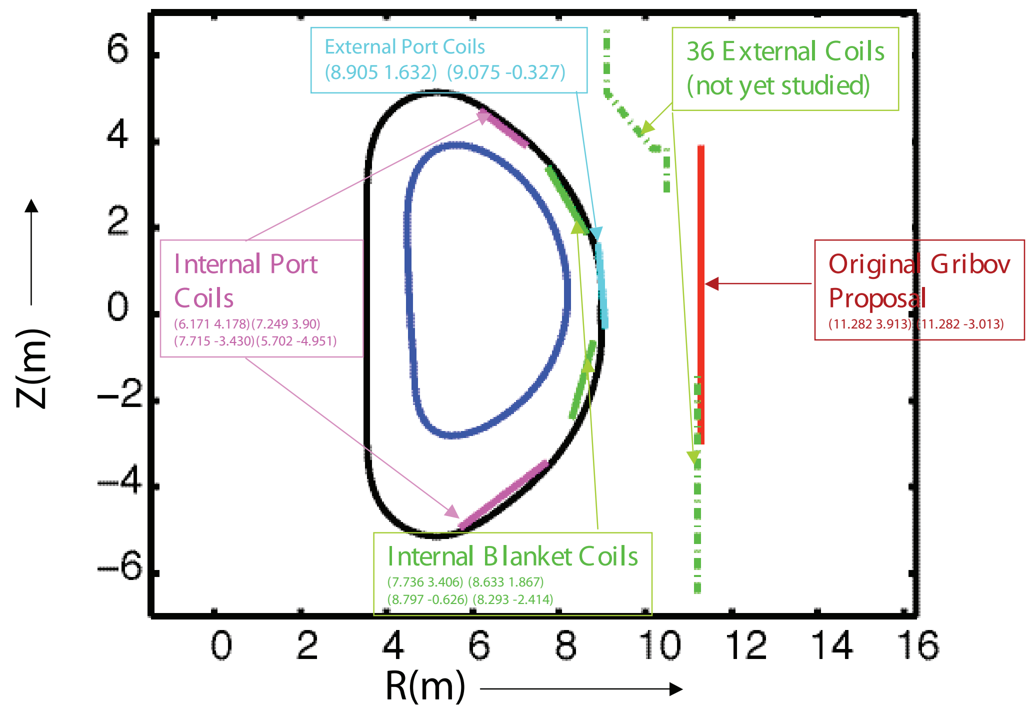
$$\frac{\partial I_c}{\partial t} + \frac{I_c}{\tau_c} = \sum_l G_c^l \, F_l^c(\{\alpha_i\},\{I_c\})$$

Time Constant of Coils; Gain Matrix; Sensor Matrix

With feedback, the growth rate is then determined by

$$D(s) = \begin{vmatrix} s\overleftrightarrow{I} - \overleftrightarrow{\Gamma} & -\overleftrightarrow{E} \\ -\overleftrightarrow{G}\,\overleftrightarrow{F} & (s + \frac{1}{\tau_c})\overleftrightarrow{I} \end{vmatrix}$$

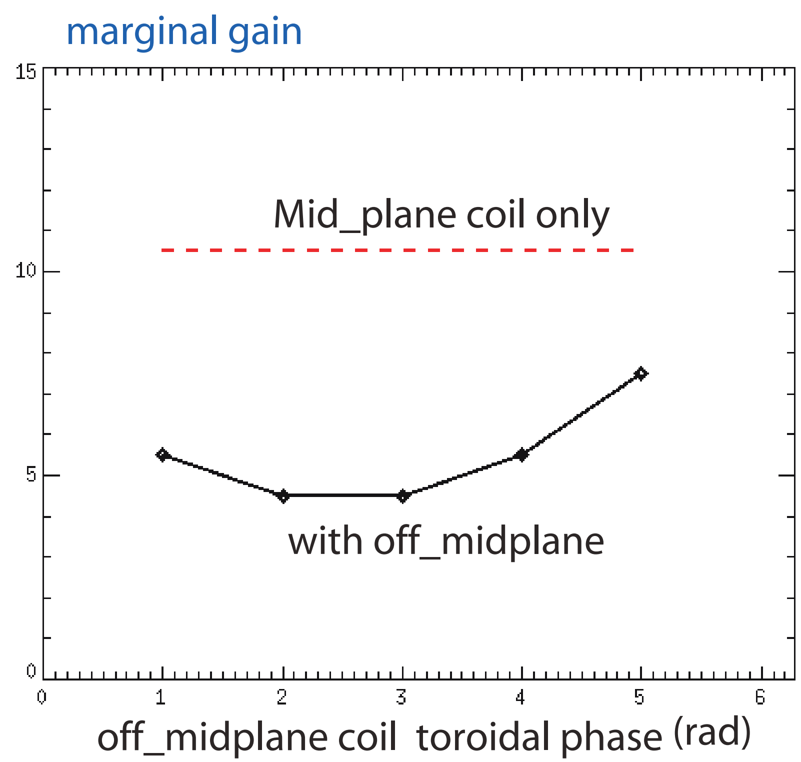
Plasma Wall Geometry and Coil Set Models



Typical Gain vs. Phase Behavior

Modeling RWM Experiments with NMA

We have used the NMA code to calculate the marginal gain versus the phasing of the feedback coils that is needed to stabilize the RWM in the ITER device.

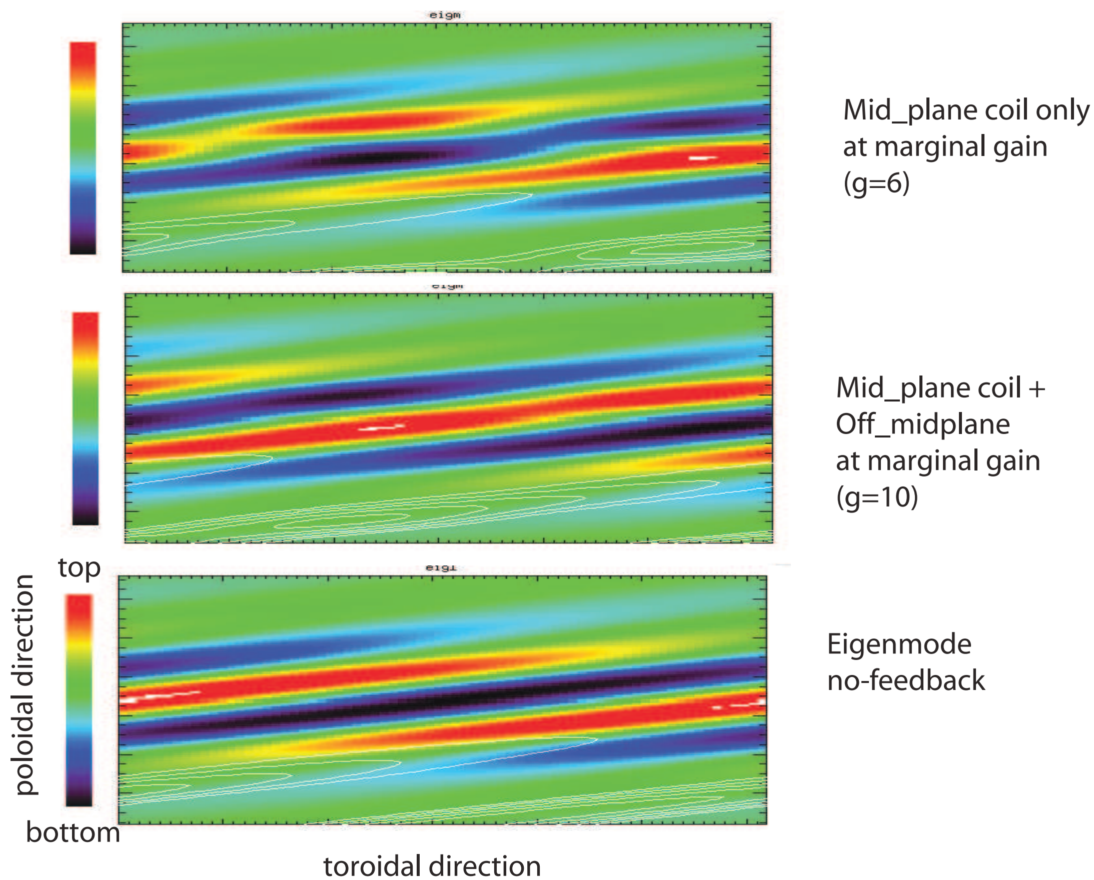


The mid-plane coil is optimized to the mode here

Mode Structures

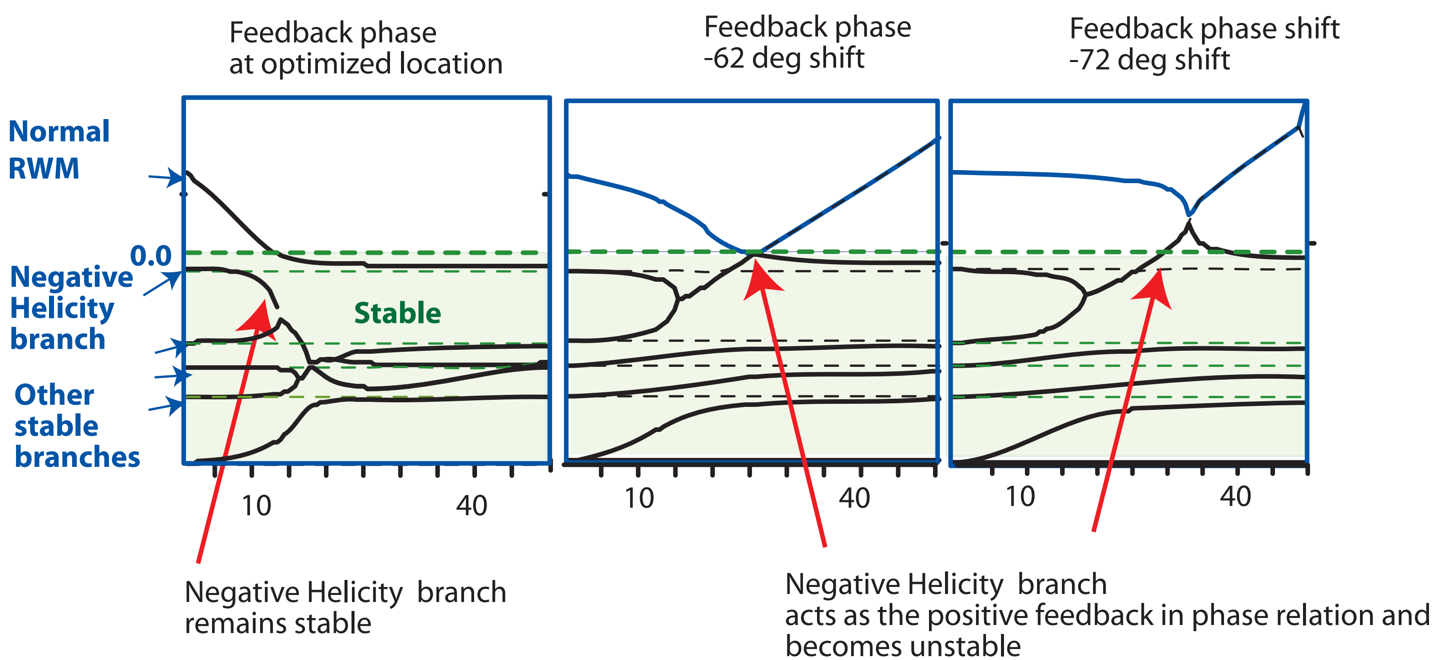
We have also looked at the mode pattern on the resistive shell with and without the feedback, showing the mode deformation due to the coils

B_n pattern on the plasma surface



Effect of Phase Mismatch to the RWM

- RWM Feedkack with with Mid-Plane Coil-only (ITER port-plug)-
Interaction between Normal RWM and Shallow Stable Branches
Destabilzes Overall Feedback when the Feedback Phase Slipps

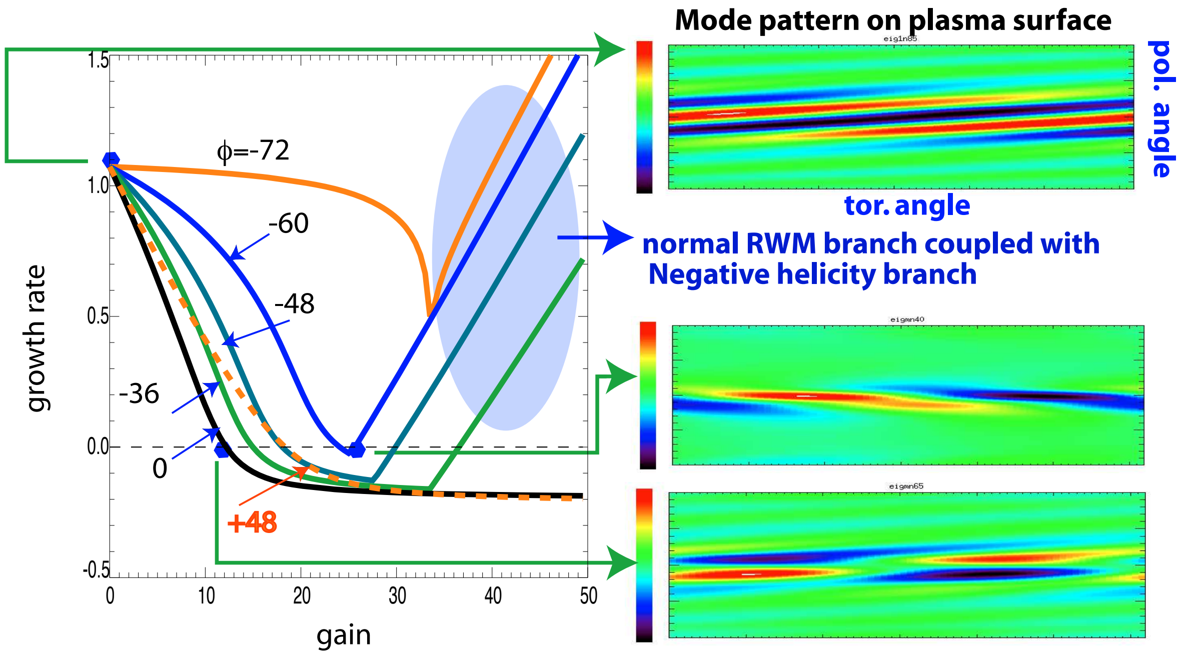


/u3/okabay/mm_code/ITER.30b_all/ITER.30b_c_w/090

Modes Coupling with the C-coil

 # 199: RWM Mode non-rigidity in low/high rotation plasmas
(M. Chance, M. Chu, A. Garofalo.....)

- ITER Mid-PLANE COIL RWM FEEDBACK -
The mode-coil phase mismatch requires higher gain.
The negative helicity mode contribution is inhibitive



φ (degrees) : **Coil pattern toroidal shift relative to the optimized toroidal coil geometry**

Conclusions

- The efficiency of the feedback depend strongly on the phasing of the coils with respect to each other and to the RWM.
- The efficiency is also dependent on the interaction of the modes with each other.
  - The RWM is deformed (non-rigid) during the feedback process. This can be minimized by optimizing the coupling to the RWM
  - Stable modes can perhaps be excited by imperfect coils and overdriving the feedback system.
  - Experimental demonstration of these effects could be interesting.