Multi-mode analysis of RWM feedback with the NMA Code
– M. S. Chance, M. Okabayashi, M. S. Chu

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Introduction

- The NMA code utilizes the full spectrum of MHD modes from DCON.

- With the resistive 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

\[ \delta W_p + \delta K + \delta W_v + D_w + \delta E_c = 0 \]

- General static plasma equilibrium
- General external modes
  - Without feedback, the energy principle is reduced to the self-adjoint expression

\[ \delta W_p + \delta K + \delta W_v + D_w + \delta E_c = 0 \]

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

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

Unstable Mode – ITER–Plasma, $B_{n_p}$

Unstable mode – ITER –Wall, $B_{n_w}$

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

With feedback, the growth rate is then determined by

\[
\frac{\partial \alpha_i}{\partial t} - \gamma_i \alpha_i = \sum \Sigma c E^c_i
\]

\[
\frac{\partial I_c}{\partial t} \tau_c + \frac{I_c}{\tau_c} = \sum \sum G^c_l F^c_l(\{\alpha_i\},\{I_c\})
\]

Amplitude of RWM
Open-Loop Growth Rate
Excitation Matrix
Coil Current
Time Constant of Coils
Gain Matrix
Sensor Matrix

\[
D(s) = \begin{vmatrix}
\leftrightarrow & \leftrightarrow & \leftrightarrow \\
\leftrightarrow & \leftrightarrow & \leftrightarrow \\
\leftrightarrow & \leftrightarrow & \leftrightarrow \\
\end{vmatrix}
\]

\[
D(s) = \begin{vmatrix}
\begin{array}{ccc}
sl - \Gamma & -E \\
-GF & (s + \frac{1}{\tau_c})I
\end{array}
\end{vmatrix}
\]
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\textsubscript{n} pattern on the plasma surface

Mid\_plane coil only at marginal gain (g=6)

Mid\_plane coil + Off\_midplane at marginal gain (g=10)

Eigenmode no-feedback
Effect of Phase Mismatch to the RWM

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

Feedback phase at optimized location

Feedback phase -62 deg shift

Feedback phase shift -72 deg shift

Negative Helicity branch

Other stable branches

Negative Helicity branch remains stable

Negative Helicity branch acts as the positive feedback in phase relation and becomes unstable

/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.