ANALYSIS OF RESISTIVE WALL MODE STABILIZATION BY MAGNETIC FEEDBACK IN FIRE

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RESISTIVE WALL MODE STABILIZATION BY MAGNETIC FEEDBACK

Effective magnetic feedback system requires:

A conducting wall close to the plasma (passive stabilizer). This has two functions:

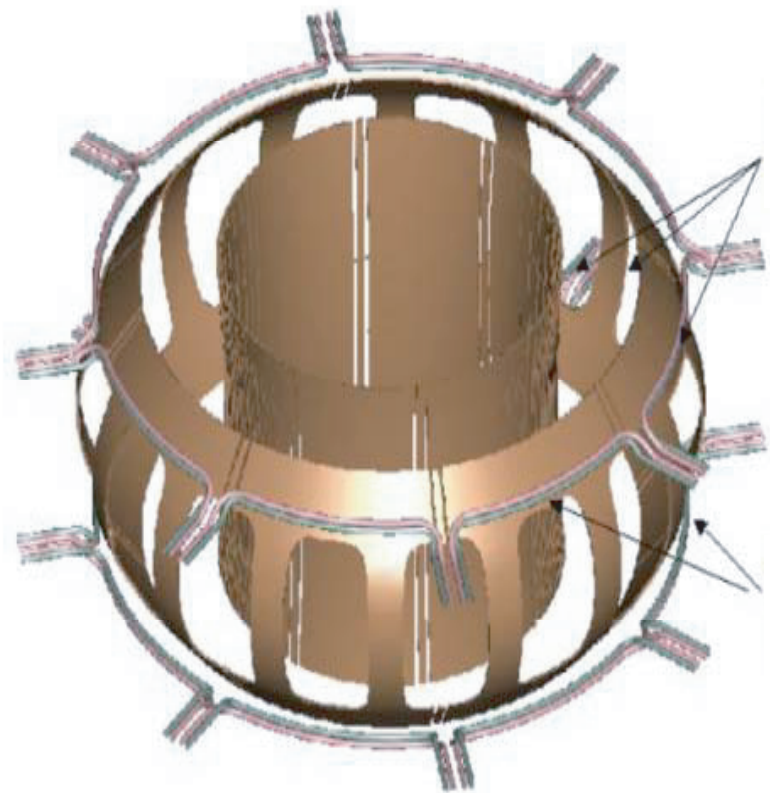
- Slows down the ideal MHD kink mode growth time to order of the conducting wall eddy current decay time, which should be manageable by the feedback system electronics.
- Determines maximum theoretically achievable beta, the ideal-wall beta limit.

- Control coils well coupled to the RWM (m,n) structure, and possibly decoupled from the wall.
- Sensors which are well coupled to the RWM, highly decoupled from the control coils, and possibly insensitive to other MHD modes and noise.

FIRE

PASSIVE STABILIZER AND ACTIVE CONTROL COILS

Vacuum vessel consists of 15-mm-thick stainless steel inner and outer wall

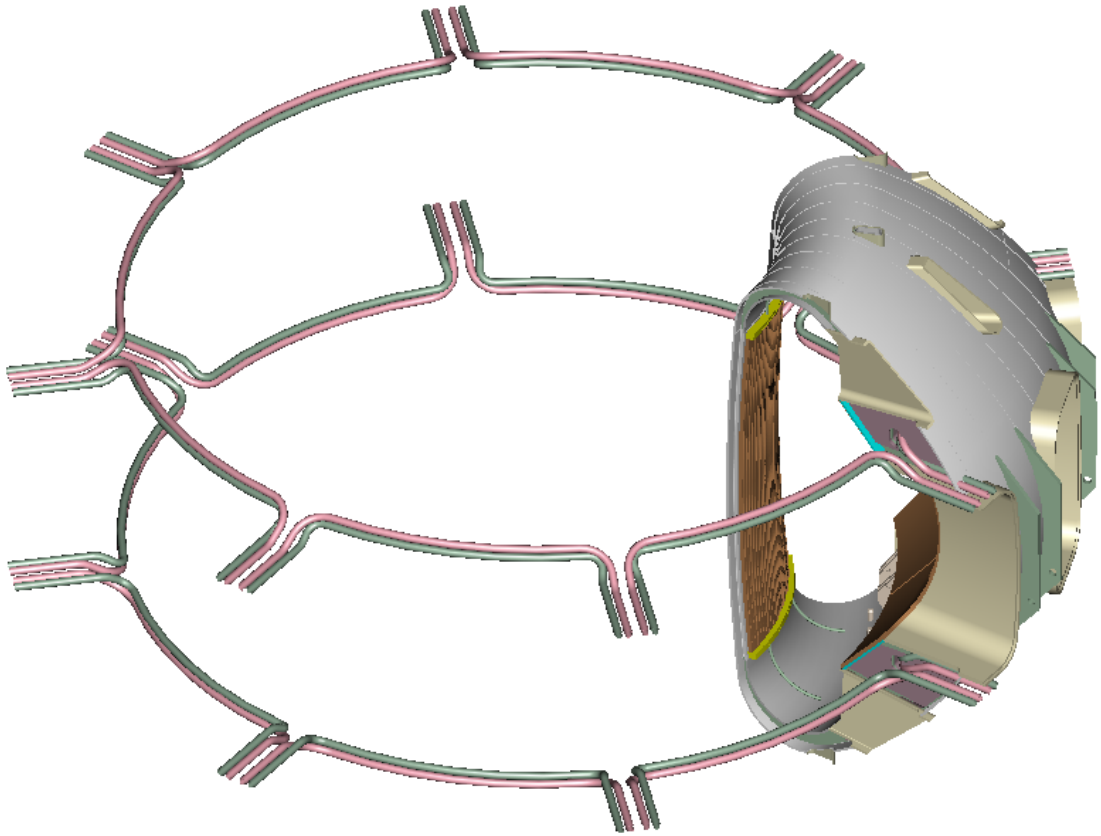


Passive stabilizer plates (30 mm-thick copper)

Two sets of eight control coils, between the outboard walls of the vessel, should provide good coupling to poloidal mode numbers m =1,2,3, and toroidal mode numbers n=1,2,3.

Active coils integrated with vessel

- 2 pairs of 40 mm ID conduits located between double walls of vessel
- MgO insulated cables inside conduit, with redundant cables
- Leads and jumpers bypass around the octant assembly joints



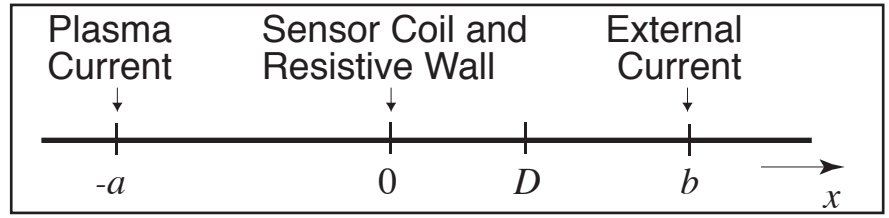
ANALYSIS OF PROPOSED FEEDBACK SYSTEMS CARRIED OUT USING SIMPLE FEEDBACK MODEL

(Garofalo, Jensen, and Strait, *Phys. Plasmas*, to be published)

All currents are singular current distributions on y-z planes:

Toroidal $\partial/\partial y = ik_t$; *Poloidal* $\partial/\partial z = ik_p$

Time derivative: $\partial/\partial t = i\square$



Perturbed magnetic field: $\bar{b} = \square \times \bar{A}$, where $\bar{A} = (\hat{y} \square \frac{k_t}{k_p} \hat{z}) A(x) e^{i(k_t y + k_p z)}$

Dispersion relation for Smart Shell feedback, with linear, current amlifiers:

$\square \square i \square \square_W \square G(i\square) = 0$ □where□ $\square = \square \frac{e^{-2kD}}{1 - e^{-2kD}}$ □and:

D = distance from resistive wall at which ideal wall gives marginal stability

$k = \sqrt{k_t^2 + k_p^2}$

$\square_W = \frac{\square \square_0}{2k\square}$: resistive wall time constant (passive stabilizers)

$G(i\square)$ = overall gain: includes feedback gain and frequency response function of

□ amplifier + control coils + conducting structures between coils and passive stabilizers

The instability strength can also be expressed as the ratio of the

□ no-feedback growth time, $\square_g$, divided by $\square_W$

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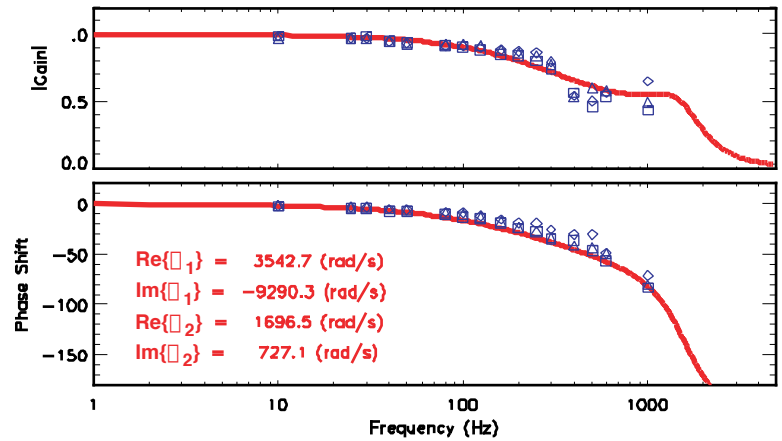
MODEL PREDICTIONS IN QUANTITATIVE AGREEMENT WITH DIII-D DATA

Measured amplifier+coils transfer function ("open-loop" gain) is fitted to analytic function

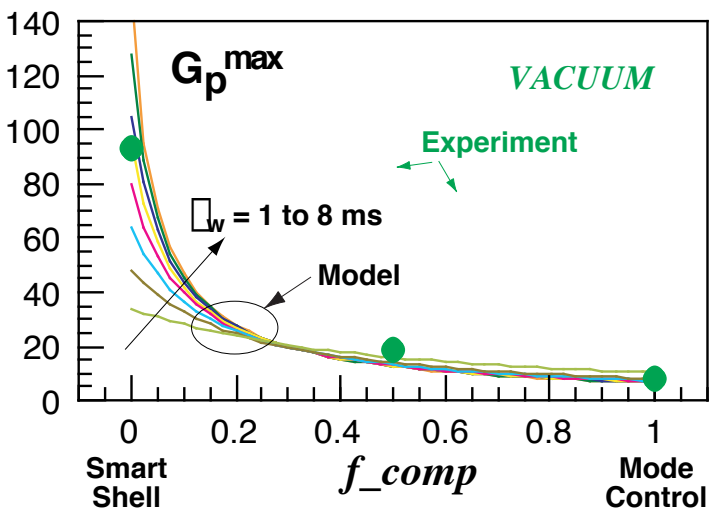
$$G(i\omega) = G^{fdbck}(i\omega) \cdot G^{open\text{-}loop}(i\omega)$$

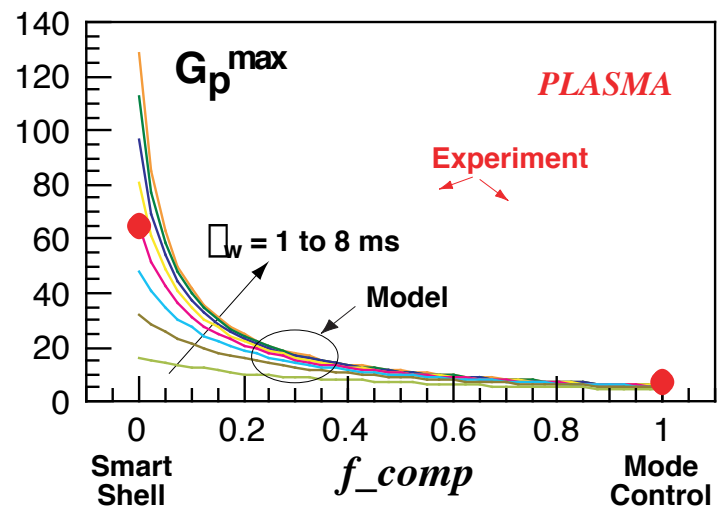
$$G^{open\text{-}loop}(i\omega) = \frac{\omega_1}{\omega_1 + i\omega} \cdot \frac{\omega_2}{\omega_2 + i\omega}$$

$$\omega - i\omega\tau_w - \frac{G(i\omega)}{1 - f_{comp}G(i\omega)} = 0$$



- Change of G_p^{max} from Vacuum to Plasma case (Smart Shell) consistent with change of "relevant" wall time constant (from ~6 to ~4 ms)





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SIMPLE FEEDBACK MODEL -- PARAMETERS FOR FIRE

Smart Shell feedback dispersion relation: $\gamma - i\omega_W G(i\omega) = 0$

Time constant for penetration of (2,1) kink mode through passive stabilizers:

$\tau_W = \frac{\mu\mu_0}{2k\sigma}$, where $k = \sqrt{k_t^2 + k_p^2}$, $k_t = n/R$, and $k_p = m/a$.

FIRE: τ_W^M = 145 ms (copper plates).

Time constant for the eddy currents in conducting structures between control coils and passive stabilizers (effective at slowing down the penetration of the feedback fields):

FIRE: τ_W^F = 28 ms (SS inner VV wall).

Overall gain of the feedback system: $G(i\omega) = G_p \omega G^{open\text{-}loop}(i\omega)$, $G^{open\text{-}loop}(i\omega) = \frac{\omega_{U1}}{\omega_{U1} + i\omega} \cdot \frac{\omega_{U2}}{\omega_{U2} + i\omega}$

One pole characterizes the amplifier bandwidth, e.g. a 100 Hz low-pass filter

ω_{U1}~700 rad/s.

Second pole given by the low-pass filter due to conducting structures between coils and passive stabilizers:

$\omega_{U2} \sim 1/\tau_W^F$.

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MARGINAL STABILITY BOUNDARIES WITH SMART SHELL FEEDBACK

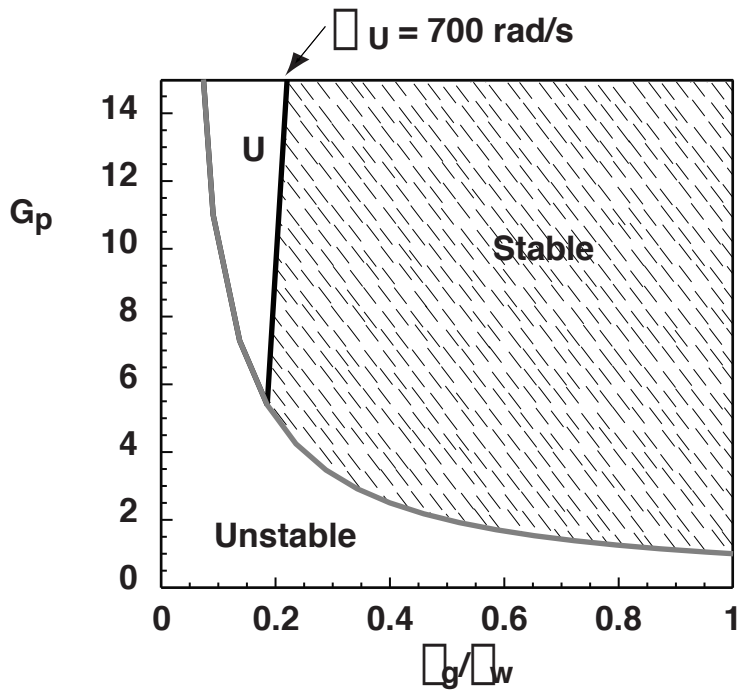
Smart Shell feedback dispersion relation: $\square\ \square\ i\square\square_W\ \square\ G(i\square) = 0$

Instability strength expressed as ratio of no-feedback growth time, $\square_g$, divided by $\square_W^M$

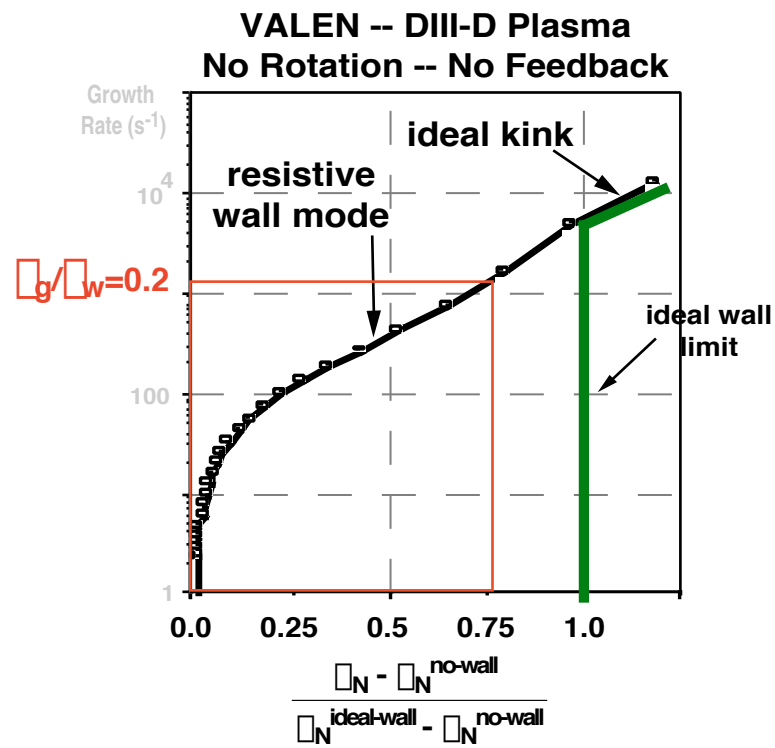
From VALEN calculations of the RWM growth rate vs. $\square_N$ (Bialek, Phys. Plasmas, 2001),

- one can estimate:

$\square_g/\square_W \leq 1.0$ at $\square_N > 40\%$ between ideal-wall and the no-wall limit



Marginal stability boundaries with RWM feedback in FIRE



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SUMMARY

FIRE:

Copper shell sets relatively long time scale for RWM growth.

Effects of SS inner VV shell and blanket not significant in this machine.

- Even if outer VV shell were between control coils and plasma, its effect on feedback time response would be negligible, compared to the very slow RWM time scale

- RWM feedback control should be able to raise the stable β_N up to ~80% between the ideal-wall and the no-wall limit, even without plasma rotation.

- Control coils are designed to address feedback stabilization of n>1 RWMs in absence of plasma rotation.