COMMENTS ON
RWM STABILIZATION BY PLASMA ROTATION

La Haye's results assume Q=0, $\Omega_{\perp} = \Omega_{E}$

It is expected that for Q > 0, Ω_{E} will decrease

La Haye's results assume $\Omega_{p} > 0.02\Omega_{A}$ for RWM stabilization

This MARS scaling has been tested on a very small parameter range

La Haye's results assume no self-acceleration of the plasma

Observed in Alcator C-Mod

ANALYSIS OF RESISTIVE WALL MODE STABILIZATION BY MAGNETIC FEEDBACK IN ITER

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RWM 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.

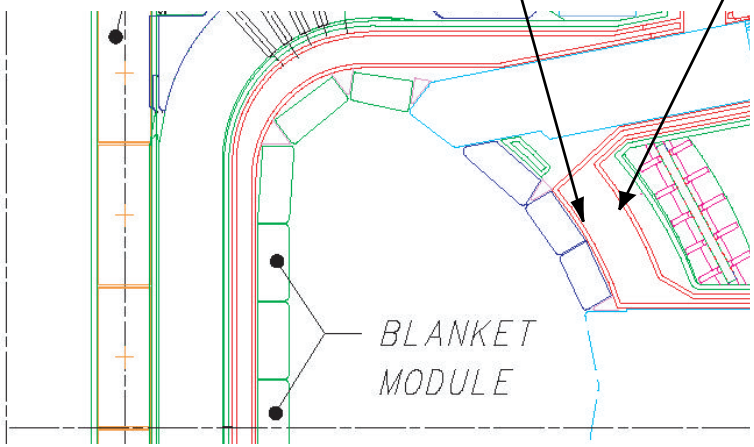
- Control coils well coupled to the RWM (m,n) structure, and possibly decoupled from the wall.
- Sensors which are well coupled to the RWM, highly decoupled from the control coils, and possibly insensitive to other MHD modes and noise.

ITER

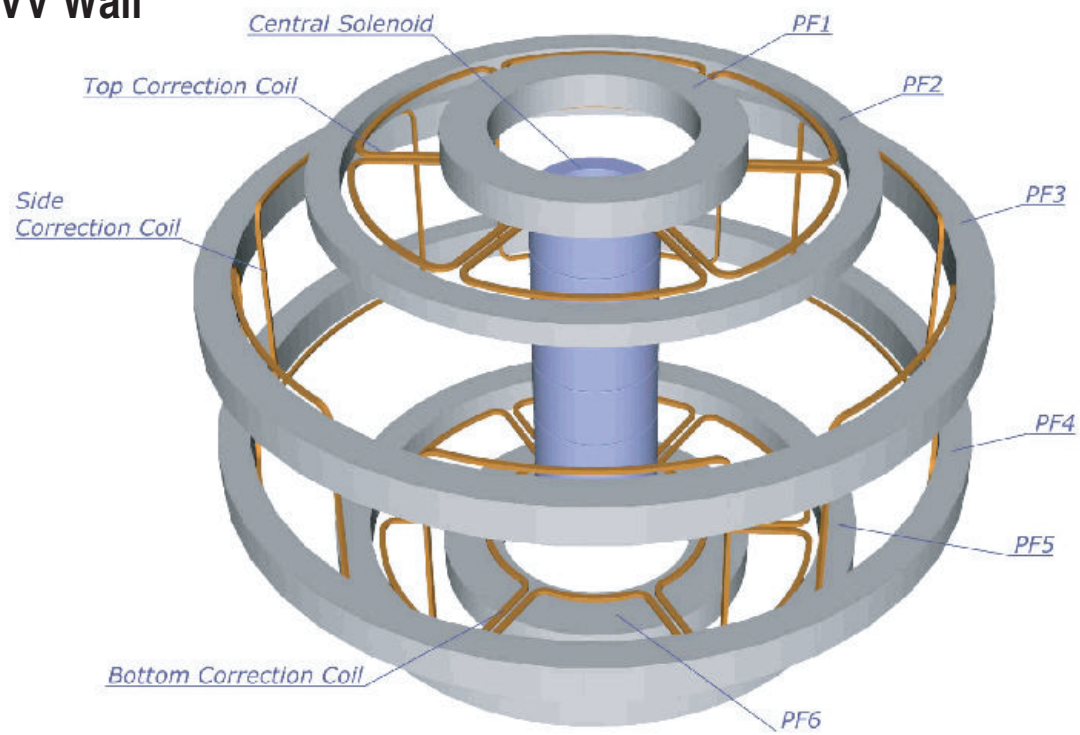
PASSIVE STABILIZER AND ACTIVE CONTROL COILS

Inner Vacuum Vessel Wall (6 cm-thick stainless steel)

Outer VV Wall



The stabilizing eddy currents induced by an RWM should flow from module to module through the attachments to the stainless steel vessel.



Three sets of six saddle coils, outside the vessel, should provide good coupling to poloidal mode numbers m =1,2,3,4, and toroidal mode numbers n=1,2.

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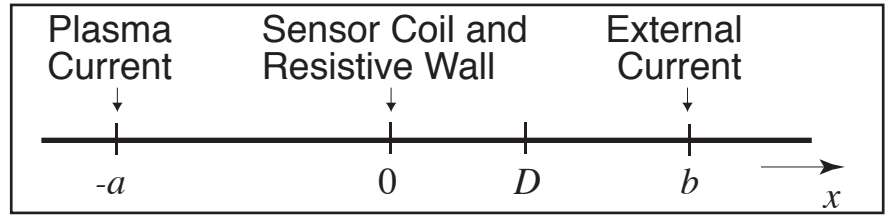
ANALYSIS OF PROPOSED FEEDBACK SYSTEMS CARRIED OUT USING SIMPLE FEEDBACK MODEL

(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 □ $\square = \square \frac{e^{-2kD}}{1 - e^{-2kD}} \square$ 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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SIMPLE FEEDBACK MODEL -- PARAMETERS FOR ITER

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

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 $k_p = m/a$.

ITER: τ_w^M = 33 ms (SS inner VV wall).

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):

ITER: τ_w^F = 40 ms (SS outer 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

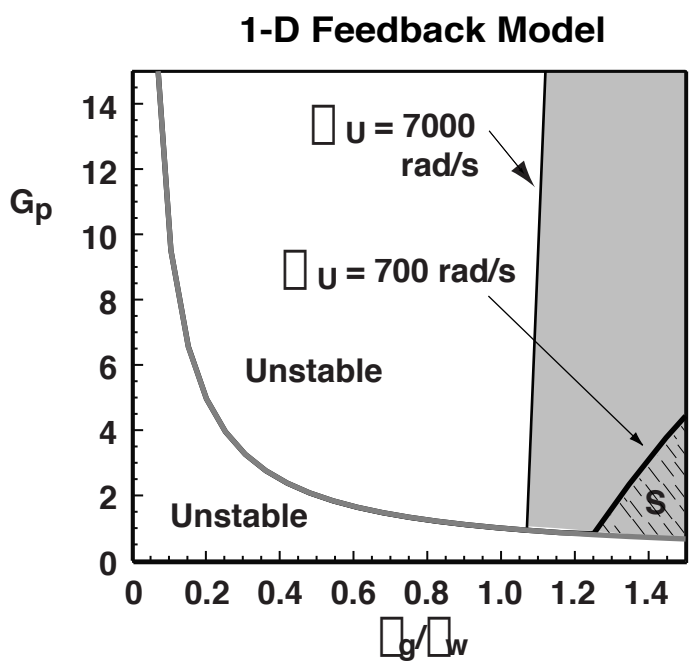
Smart Shell feedback dispersion relation: $\square\ \square\ i\square\square_W\ \square\ G(i\square) = 0$

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

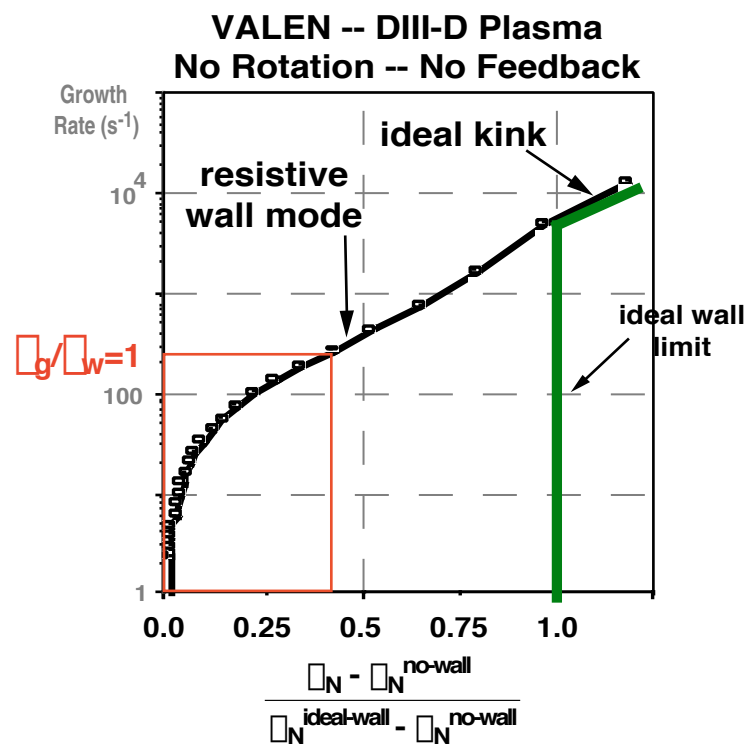
From VALEN calculations of the RWM growth rate vs. $\square_N$ (Bialek, Phys. Plasmas, 2001),

- 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 ITER



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SUMMARY

ITER:

SS inner VV shell sets time scale for RWM growth.

Outer VV shell located at too large distance from plasma to affect RWM growth time.

Outer VV shell located between control coils and plasma,

- slows down the time response of the feedback system.

RWM feedback control should be able to raise the stable β_N up to ~30% between

- the ideal-wall and the no-wall limit, even without plasma rotation.

Control coils are designed to provide best versatility for error field correction.

- Plasma rotation sustainment should be very robust in ITER.