Comparative Study of the Electro-magnetic torque application through feedback for NTM locking avoidance in DIII-D, RFX-mod and NSTX

M. Okabaayshi (PPPL) , Jong-Kyu Park(PPPL)
T. Strait (GA), R. LaHaye(GA),
P. Zanca (RFX-mod), R. Paccagnella(RFX-mod),

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Developing for ITER Locking and disruption avoidance by EM torque Feedback Control

Approach:

-DIII-D and RFX-mod carried out: a proof of principle experiments

"Avoidance of NTM locking and disruptions by the electromagnetic torque (EMT) injection by feedback."

Goal in NSTX:

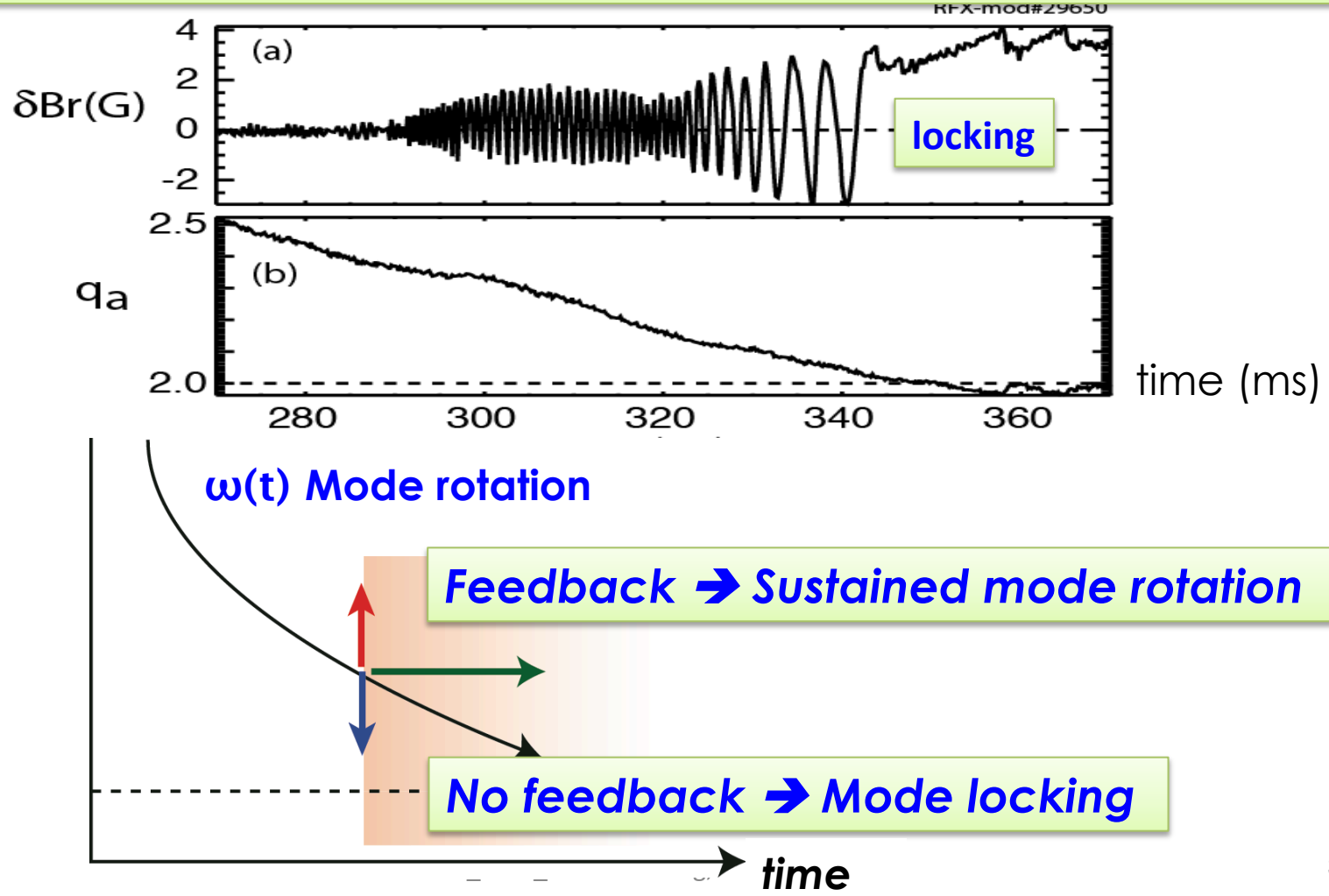
- To demonstrate the versatility of this approach by comparing in vastly different environments in three devices

" aspect ratio, plasma shape, different EFC, ulta-low q ohmic, high betan, q-profile,…"

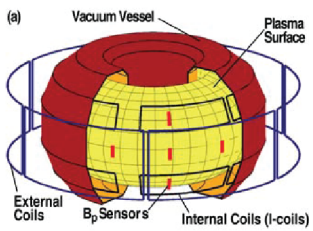
- Extremely productive for developing a better tool for ITER

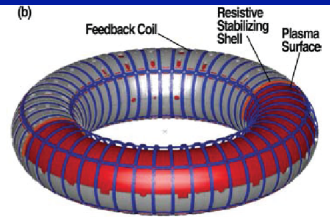
Electromagnetic Torque Avoids Disruption by Forcing Locked-mode to Rotate

- **An example: mode locking occurs with ultra-low q~2 in RFX-mod tokamak**



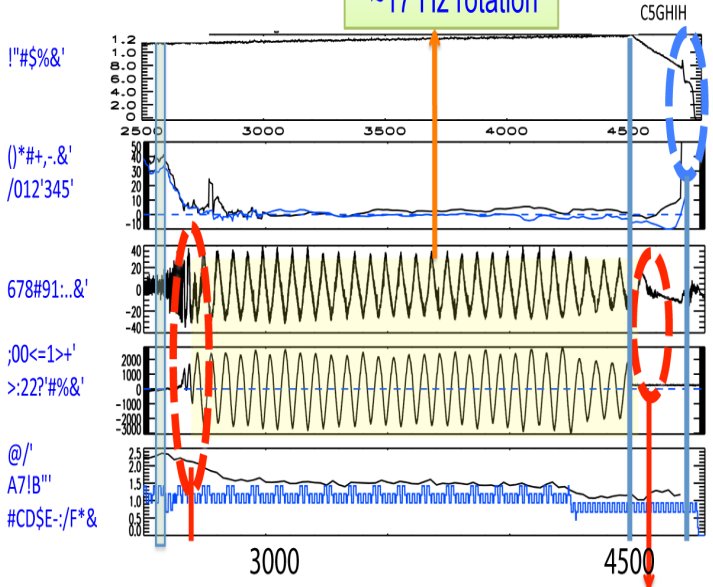
The Electromagnetic Torque injection by feedback Avoids TM locking in DIII-D and RFX-mod





DIII-D

• FB self-adjusted ~17 Hz rotation



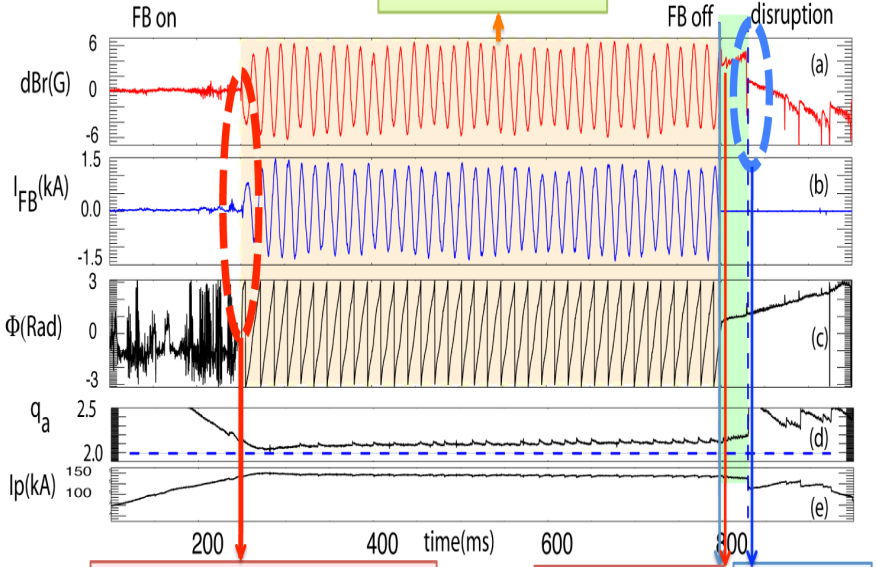
• Mode (plasma) rotation became low, then feedback current initiated (FB filter time constant = 40ms)

• Locking with ~10-15 G after FB turned off,

• Disruption

RFX-mod

• FB self-adjusted ~ 60 Hz rotation.



• Mode rotation became low, then feedback current initiated

• Locking after FB turned off,

• Disruption

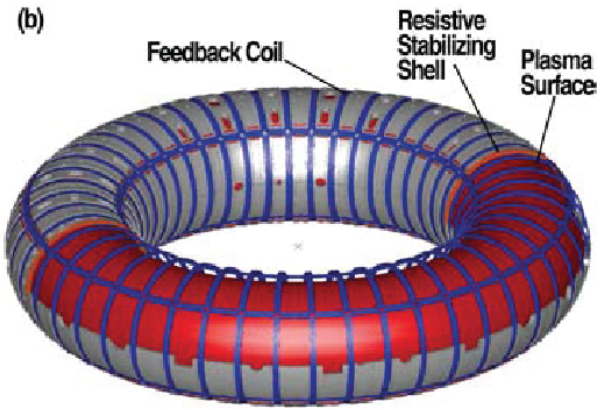
Fig. 1

To explore the versatility of EM torque injection approach by feedback

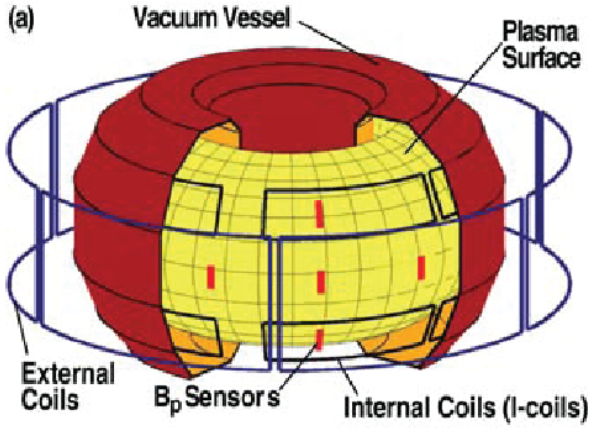
NSTX-U	DIII-D	RFX-mod
D shaped	D-shaped	Circular
R/a=1.7	R/a=2.8	R/a=4.5
shell τ = 5 ms	τ = 2ms	τ = 100 ms
3D-coil outside V.V	inside/outside	outside
n=1,2	n=1	n=1
high beta	high betaN	ultra-low q ohmic

Supplement

Plasma Condition and Hardware are Vastly Different



RFX-Mod	DIII-D
2.0 m	1.69 m
0.46 m	0.6 m
circular	D-shape
ohmic	NBI
q_{edge}~2.2	4.0-4.5
ultra-low-q	high βn



• Resistive time: τ_w	τ_w/τ_b >>1 (Thick shell)	τ_w/τ_b <<1 (Thin shell)
-Resistive shell	50 ms (Vert. Field penetration)	None
-vacuum vessel	3 ms	2-2.5 ms
• Feedback bandwidth: τ_b	~ 4 ms (latency, power sp.)	10-40 ms (feedback pre-set)
• Feedback coils	Outside the shell	Inside shell

DIIID results also is in a Good Agreement with the Analytical Model (τ_w/τ_p<<1 regime)

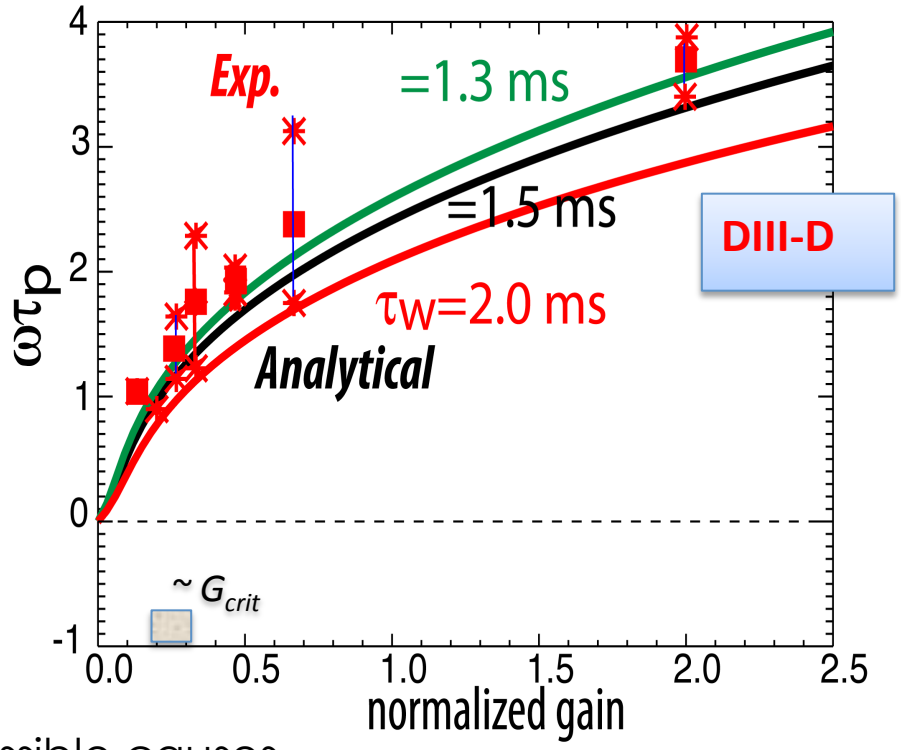
Parameters for analytical model

τ_p: band-pass by FB setting: 10ms

τ_w: RWM suggested (2-2.5ms)

α: = $1/(1+\tau_p/\tau_w)$, τ_w/τ_p ~ 0.2-0.3

ϕ_0: phase shift set 30°



- Observation is qualitatively in a good agreement with model prediction.
  However, The observed frequency is somewhat higher than predicted with τ_w = 2 ms. There are several possible causes.
  - There may exist additional phase shifts (as discussed in RFX-mod)
  - the waveform distortion with lower gain may require additional eignvalues of the wall eddy currents.
- Since the performance below G_{crit} = 0.2–0.3, where the phase shift is critical, has not been explored yet, the impact of phase shift remains to be studied.

Gain Threshold is Consistent with Analytical Model (τ_w/τ_p >1 regime: RFX-mod) .

Parameters for analytical model

τ_p: band-pass constant = 4ms
- latency (1 ms)
- coil impedance (3ms)

τ_w: 100ms

α: Calculated with large aspect ratio cylindrical model

(ϕ_0: no phase shift)