Investigation of MHD Mode Structure in Shaped HBT-EP Discharges

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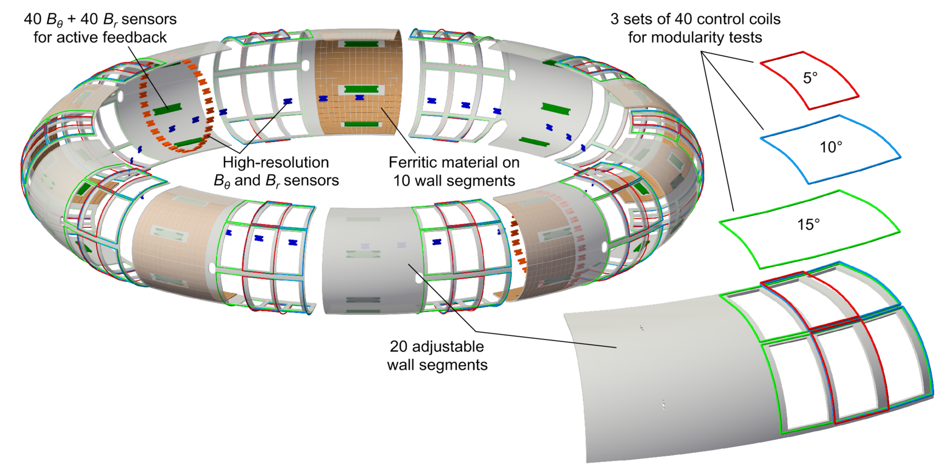
1 Abstract

We report on investigations into the effect on the structure of MHD kink modes of a newly installed poloidal field (PF) coil. The coil allows the circular, limited HBT-EP to investigate plasmas that are shaped and diverted. The coil shapes the high field side of the plasma up to and including imposing a PF null, without interfering with existing diagnostics and control systems. Shaping changes both the resonant helical characteristics of MHD instabilities[1] and the plasma response to external excitation and active control. In circular HBT-EP plasmas, multimode dynamics have been observed in naturally-rotating kink modes and during the response to 3D resonant magnetic perturbations[2, 3]. Work is ongoing to determine how the multimode dynamics of shaped plasmas differ from circular ones.

2 Hardware and Capabilities

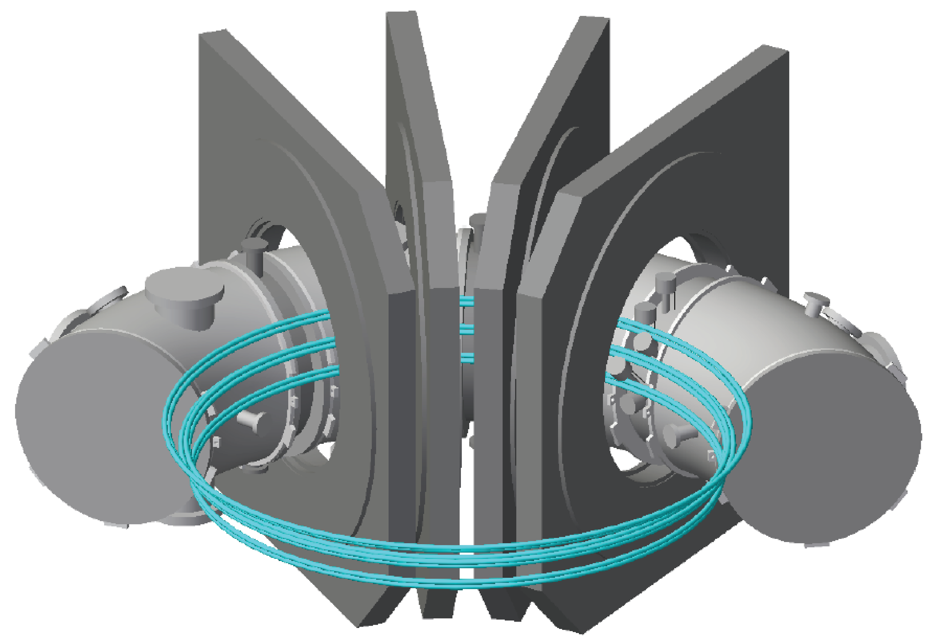
2.1 Magnetic Diagnostics and Control

- HBT-EP has a passively stabilizing wall constructed of 20 independently positionable shells
- Each shell is instrumented with two independently controlled saddle coils, allowing feedback on modes for excitation or control
- 216 magnetic sensors form 2 poloidal arrays and 5 toroidal arrays
  - 82 B_r sensors, 134 B_p sensors

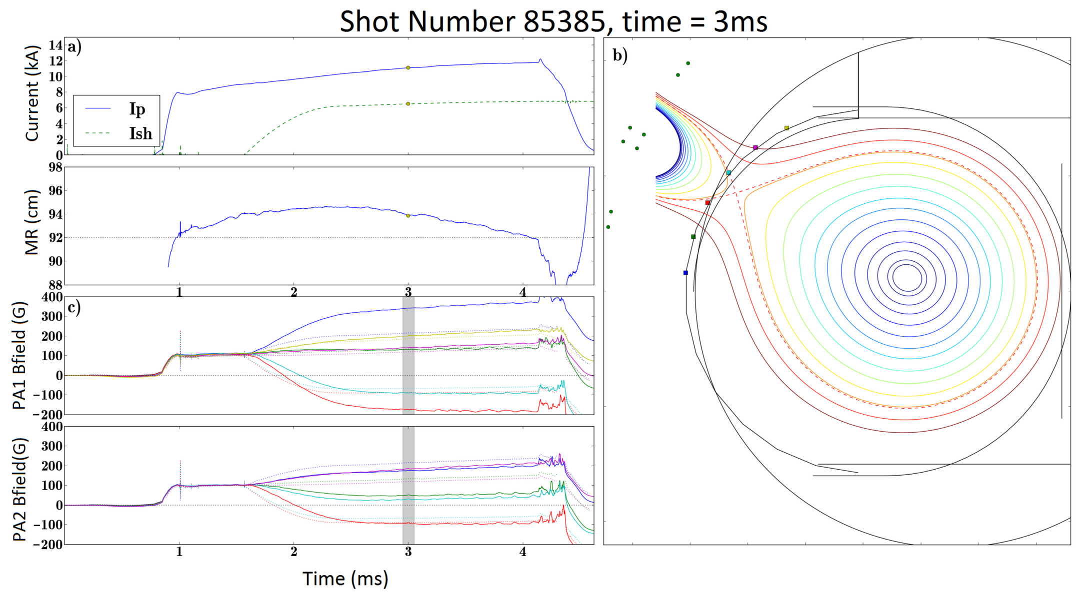


2.2 The Shaping Coil

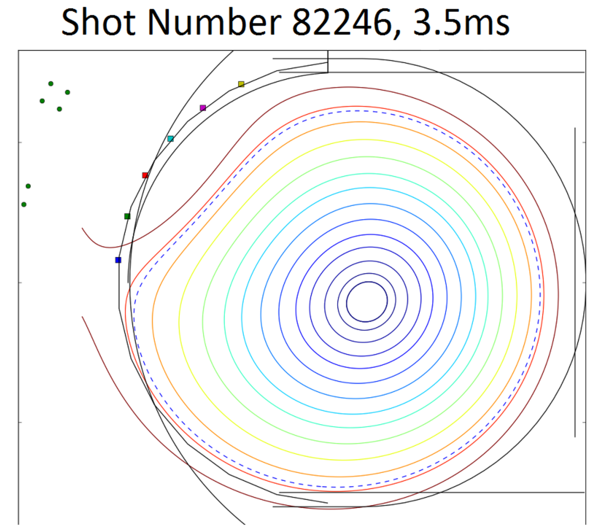
- Diverts the plasma via a single null 30° above the inboard midplane
- 4 central coils carry co-Ip current, 2 sets of two flanking bundles carry contra-Ip current
  - Reduced coupling to vacuum field coils and plasma diagnostics
  - Shaping is locally imposed



- Diversion has been measured directly via poloidal field inversions and confirmed by equilibrium reconstructions



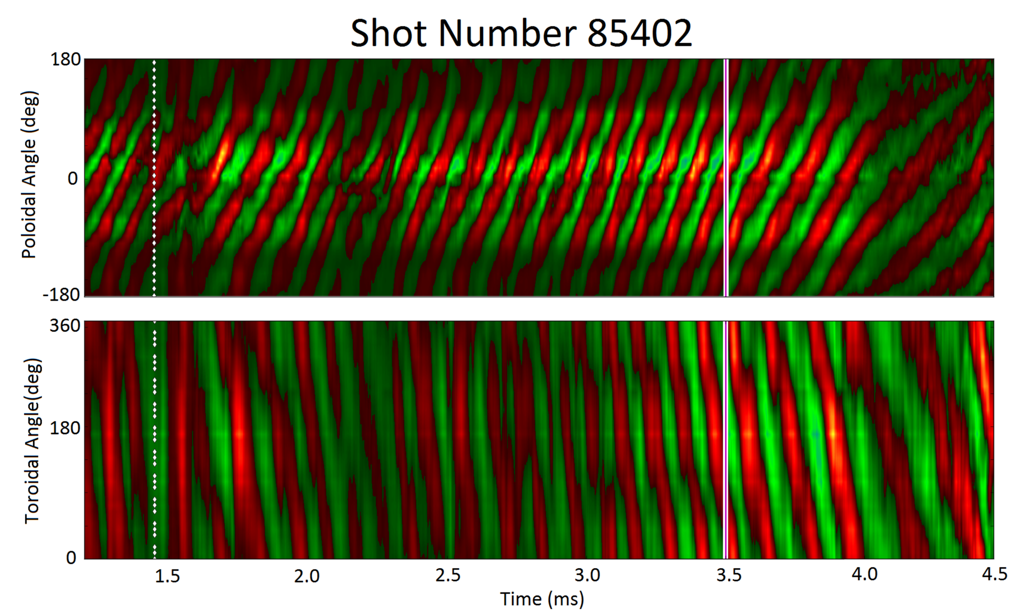
- Reversing the direction of shaping current is also possible, allowing investigation of 'bean-shaped' plasmas



3 Mode Detection and Analysis

3.1 Sensor Data

- Magnetic fluctuations are observed with high poloidal and toroidal resolution



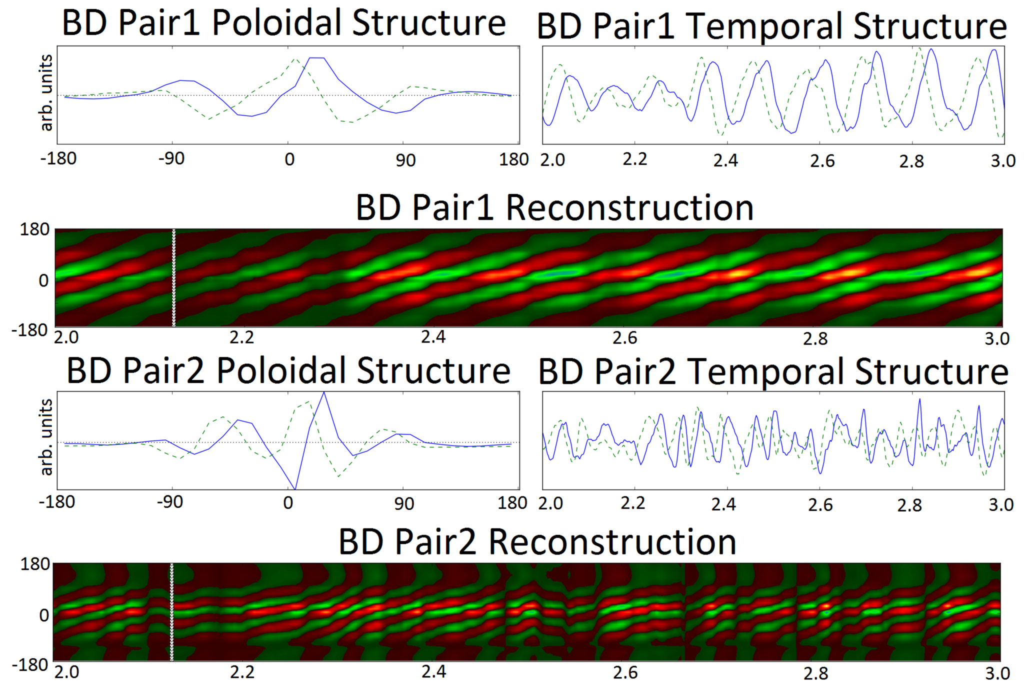
- Fluctuations are often dominated by a single mode, visible by inspection
  - Lower power modes are observed through Biorthogonal Decomposition

3.2 Biorthogonal Decomposition

- Coherent fluctuations are isolated to form a basis set:

$$\delta B(x_i, t_j) = \Sigma \sigma_k u_k(x_i) v_k(t_j) \quad (1)$$

- Rotating modes are present as pairs of BD modes with similar power σ^2, and similar spatial and temporal components, but with 90° phase difference
- Sub-dominant modes with energies $\geq 1\%$ of the total signal can be discriminated

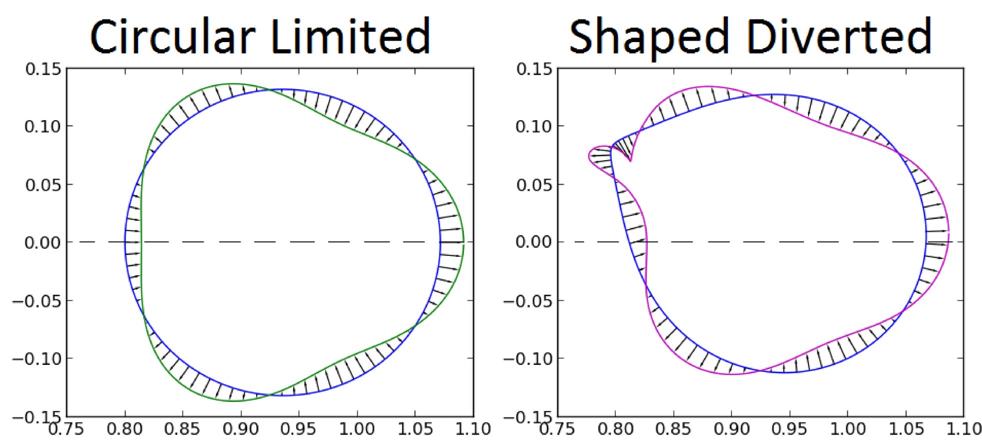


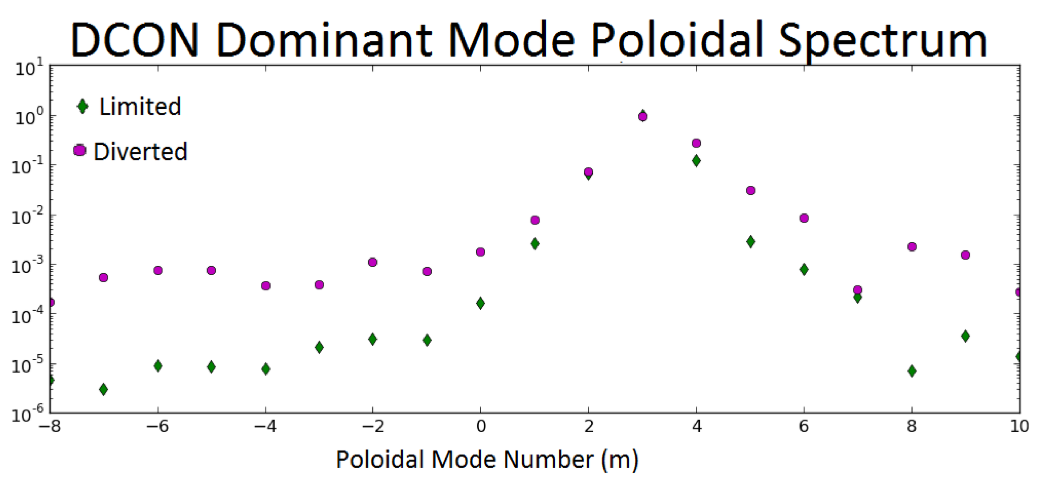
- This method is robust to dead sensors, sensor gain/alignment errors, and the modes' finite m spectrum due to toroidicity
  - These effects are included in the mode and do not give rise to artifacts, as would occur with Fourier transforms
- Mode is isolated from as-measured fluctuations
  - If mode-sensor coupling is low, mode amplitude at that sensor will be attenuated
  - Shaped plasmas are created outboard; sensors near 180° less well-coupled than those near 0°

4 Modeling

4.1 Equilibria Reconstruction

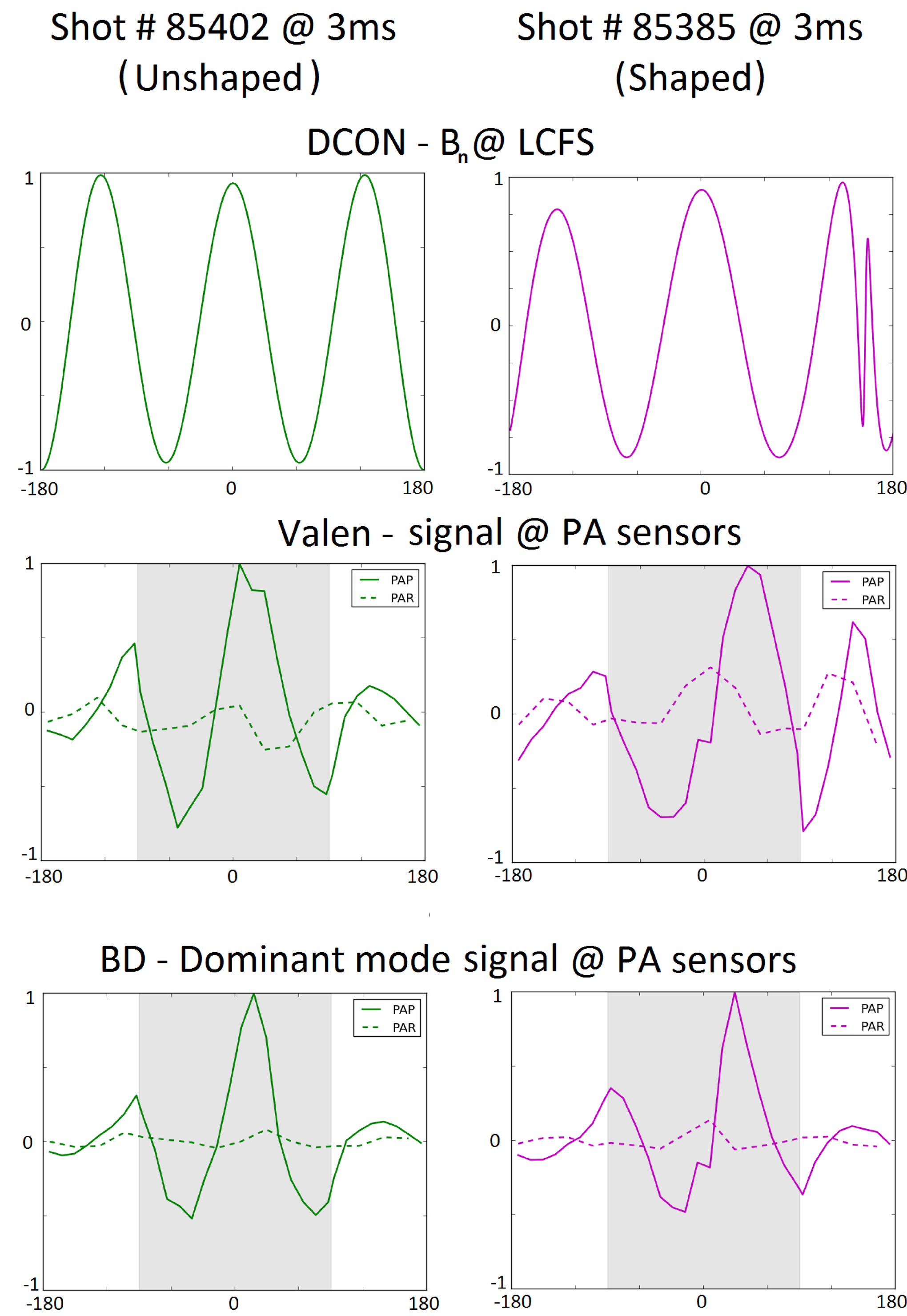
- Equilibrium/mode reconstructions using TokaMac and DCON predict significant changes to mode structure on the surface of a shaped plasma, especially near the X-point



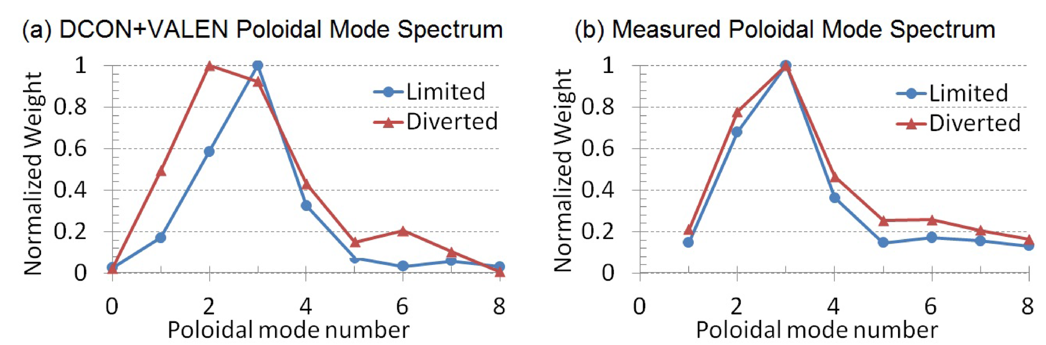


4.2 Forward Modeling of Fluctuations

- HBT-EP Poloidal sensor arrays are conformal to **circular** plasmas, centered in the vacuum vessel
  - Sensor coupling to outboard, shaped plasmas will vary poloidally and will be weak near X-point
  - Stabilizing shells will reduce B_r signal for shell-mounted sensors ($-90 \geq \theta \leq 90$), will enhance B_p signal
- VALEN is necessary to model sensor pickup of mode using a full 3-D representation of HBT-EP's conducting structures
  - Includes effects of poloidally variable sensor/mode coupling, mode rotation, and eddy currents due to shells, vacuum vessel, etc.



- Predicitons of VALEN based on DCON output are compared to actual modes measured in the plasma
  - Shell amplification of B_p, reduction of B_r is predicted and observed
  - Measured B_r amplitude is smaller than predicted by VALEN
  - Difficulty in measuring 4^{th} peak is likely. May be possible to change equilibrium parameters (MR, IP) to increase sensor coupling near X-point
- Poloidal mode spectrum is seen to broaden as expected for $m > 3$, but low-m broadening is not observed

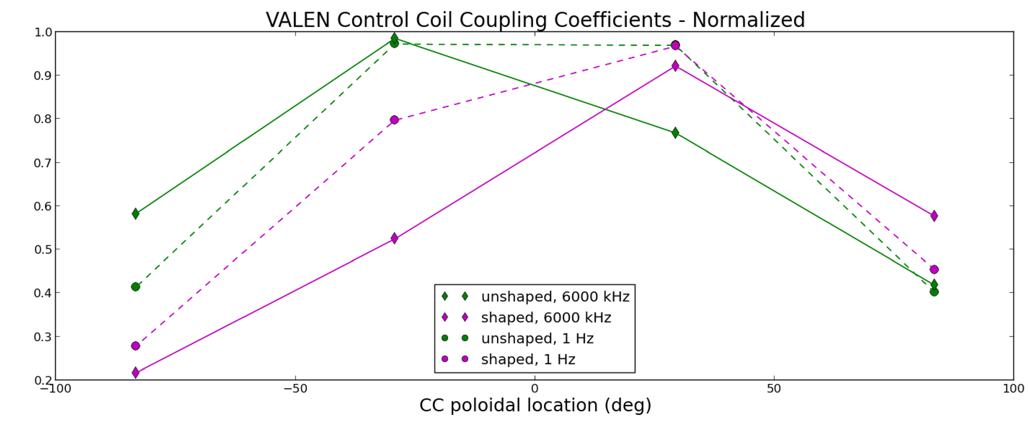


5 Resonant Magnetic Perturbation

- RMPs applied with HBT-EP's control coil array can excite one or more natural modes, allowing further investigation into mode structure and multimode dynamics
- Up to 20G of B_r is available, and imposing RMP as a phase-flip allows contrast of phases - equivalent to 40G
- RMPs on HBT-EP have been imposed as:

$$A\ f(t)\ cos(m\theta_i + n\phi_i) \quad (2)$$

- VALEN calculations show that coupling varies poloidally, due to both shaping and rotation-induced eddy currents - RMP amplitude should be $A(\theta_i)$



6 Conclusions & Future Work

- HBT-EP has been upgraded with a divertor coil which has successfully been used to create a variety of shaped plasmas
- For the first time, HBT-EP has used TokaMac, DCON, and VALEN together to model an equilibrium and its MHD modes, and from that the expected sensor signal, for comparison to direct measurements
- Differences in measured mode structure between shaped and unshaped plasmas are subtle, but this is in agreement with predictions
- We will continue to develop shaped equilibria for improved lifetime, positional stability, and sensor resolution near X-point
- We will apply RMPs to enhance sensor/mode coupling, and detect differences in shaped plasma's resonant mode spectrum w.r.t. circular
- VALEN predictions for control coil coupling will be used when choosing RMP structure to improve control efficiency

References

[1] D. A. Maurer, *et. al.*, Plas. Phys. Control. Fusion, (2011) Vol. 53 Iss. 7

[2] J. P. Levesque, *Multimode Structure of Resistive Wall Modes Near the Ideal Wall Stability Limit*, Ph.D. Thesis, Columbia University (2012).

[3] D. Shiraki, *High Resolution MHD Spectroscopy of External Kinks in a Tokamak Plasma*, Ph.D. Thesis, Columbia University (2012)

Acknowledgements

Design, fabrication, and installation were all aided greatly by the contributions of Nick Rivera and James Andrello

This work was supported by DOE grant DE-FGO2-86ER53222