Unified parametric dependence and reconstruction of 3D equilibria in the RFP

Brett Chapman
representing MST, Auburn, Consorzio RFX, UCLA
3D structures, equilibria in tokamak & RFP of current interest

Snakes in tokamaks
(Weller et al. PRL 1987)

SHAx in RFP’s
(Lorenzini et al. Nat. Phys. 2009)

Helical equilibrium in ITER
(Cooper et al. PPCF 2011)
Several reasons for 3D interest in the RFP

- Interesting physics, cross coupling with stellarator and tokamak
- Natural state of hottest RFP plasmas (for certain equilibria)
- One route to improved confinement
- Potential divertor solution
Outline

- A bit about the RFP and MST
- Optimization for spontaneous 3D equilibria
- Comparison between MST and RFX-mod
- 3D equilibrium reconstruction
RFP explores the limit of small applied Bt

- After startup, Bp and Bt primarily from poloidal field circuit
Multiple resonant surfaces for tearing modes

When 3D structure occurs, associated with innermost mode

In this talk

B_t(a) = 0

(m,n) = (1,5)
(1,6)
(1,7)...

When 3D structure occurs, associated with innermost mode
A bit about the MST

- $R = 1.5 \text{ m}$
- $a = 0.52 \text{ m}$
- Toroidally axisymmetric
- Magnetic diagnosis:
  1. Edge sensors
  2. Faraday rotation
  3. MSE
At low Ip, mode spectra fairly flat, no 3D structure

$\text{l}_p = 0.18 \text{ MA}$

$b/B(a) \sim 1\%$

$n = 5$

$n = 6-10$
At higher Ip, mode spectra very peaked

Ip = 0.6 MA

b/B(a) > 7%

m = 1 mode amplitudes, bt (G)

n = 5

n = 6-10
Can now routinely “dial up” large mode

- Keys: high Ip, low density, Bt(a) ~ 0

Ip = 0.6 MA

10 consecutive shots

m = 1, n = 5 (G)
With peaked spectra, core is helical

- Reconstructions based on edge data + equilibrium model
- Moderately peaked spectra common in the RFP

F. Auriemma et al. PPCF 2011
Comparison to RFX-mod
A bit about RFX-mod

- \( R = 2.0 \text{ m} \)
- \( a = 0.46 \text{ m} \)
- \( I_{p_{\text{max}}} \approx 2 \text{ MA} \)
- \( B_t(a), q(a) < 0 \)
- More complicated boundary than MST
Spectral bifurcation in RFX-mod occurs at higher Ip than in MST
MST & RFX-mod spectral trends unified in terms of $S$

- Disparate ranges of $I_p$, common range of $S$
- $S \sim I_p T_e^{3/2} Z / (m_i n_i)^{1/2}$
- Important parameter in nonlinear resistive MHD
- RFX-mod plasmas higher density, lower $T_e$
- With higher $I_p$ and higher $S$, spectra more and more peaked
Persistence trends also unified in terms of S

- Persistence is duration of peaked spectrum normalized to duration of Ip flattop.
- With higher Ip and higher S, peaked spectra last longer.
Direct detection of the bifurcation
Faraday rotation zero-crossing reflects structure location
Faraday rotation detects magnetic bifurcation

\[ \int n_e B_z \, dz / \int n_e \, dz \]

\[ [B_z(-2\text{cm}) - B_z(13\text{cm})] / B(a) \]

- First measurement of its kind in tokamak or RFP

W.F. Bergerson et al. PRL 2011
Development of V3FIT for MST
Motivated in part by MST’s diagnostic set

- Helical structure stationary but orientation varies shot to shot
Optimization of V3FIT for MST in progress

- Working only with external magnetics at present
- Working on proper inclusion of image current in MST’s conducting shell
- Other challenges include proper handling of q profile
Initial V3FIT reconstruction for MST

• Working toward inclusion of Faraday rotation...
Summary/conclusions

- 3D equilibria now routine in MST
- MST and RFX-mod trends unified through S
- Advancing 3D reconstruction with V3FIT