**Confinement and Equilibrium with Internal Islands in a Configuration Scan with respect to iota in W7-X**


1Max-Planck-Institute for Plasma Physics, Greifswald, Germany
2Los Alamos National Laboratory, Los Alamos, NM, USA
3Laboratorio Nacional de Fusión, CIEMAT, Madrid, Spain
4Centre for Energy Research, Budapest, Hungary
5Institute of Climate and Energy Research — Plasma Physics, Forschungszentrum Jülich, Jülich, Germany
6Princeton Plasma Physics Laboratory, Princeton, NJ, USA
7Auburn University, Auburn, AL, USA
8Max-Planck-Institute for Plasma Physics, Garching bei München, Germany
9National Institute for Fusion Science, Toki, Gifu, Japan

**MOTIVATION**

- Confinement changes in stellarators connected to rotational transform via low-order rational islands or islands at the boundary or close to it (W7-AS, Heliotron-J, T-11)
- Investigate confinement by systematic scan of configurations
- W7-X has flexible coil system
- Non-planar coils (1 to 5) for main field
- Planar coils (A, B) for B & magn. axis variation
- Control coils (C) for island size and shape
- MHD-equilibrium calculations
- VMEC (assumes nested flux surfaces) approximate consideration of internal islands by combination with EXTENDER
- HINT-code (no assumption of flux surfaces) consistent treatment of internal islands

**SCANN OF MAGNETIC CONFIGURATIONS**

Configuration Scan
- upper bound
- high-iota config. (A) i=5/4
- lower bound
- stand. config. (M,I)
- intermediate configs.
- limiter-type config.
- internal 5/5-islands
- fine scan with
  - "x10/9"
  - 5/5-islands moving towards divertor plates
- Island width variation for config. i=5/3
- Decreased isl. width
- Increased isl. width
- Island width dependence on changing 5/5 island width

**EXPERIMENTS & RESULTS**

- Experimental setup iota-variation (A to M) (2018-09-27)
  - P\text{source} = 2MW (140GHz, X2)
  - duration 4s
  - from t=3s to 4s power mod.
  - Target density: \(n_d = 3.5 \times 10^{19} m^{-3}\)
- Island size variation (N to Q) (2018-10-17)
  - P\text{source}, duration, power mod. like A to M
  - Density: \(n_d = 4 \times 10^{19} m^{-3}\)
  - NBi-blips (ca 1MW), 20ms every 200ms (O&Q)
- Results
  - Energy increase with lowering iota
  - Diamagnet. energy & V3F7-reconstr. agree well
  - Highest energies when 5/5-islands close to boundary: H to F
  - Persist when accounting for volume and density variation
  - \(W = \frac{W_{Lix}(31.5mV)}{\sqrt{c}}\) V\text{source} \(1.5 \times 10^{17} m^{-2}\)
  - with \(a = 0.15, 0.3, 0.545(\text{SSO})\)
  - Crushing MHD-activity at 5/5 islands
  - MHD-activity increases with better confinement
  - Island localized modes ("ILM")
  - 5X-camera system identifies location
  - ILM-activity level grows with island size

**MHD-EQUILIBRIUM WITH INTERNAL ISLANDS**

- No assumption of flux surfaces
- Iterative relaxation of resistive MHD-equations on Eulerian grid in two steps, repetitively:
  1. Pressure relaxation with B-const.
  2. With p-const. advancing force balance, Faraday’s Law + Ampere’s Law
- MHD-equilibrium with press. distribution and equilibrium currents consistent with magn. field

**HINT-CALCULATIONS FOR IOTA-SCAN-CONFIGURATIONS**

- Configuration
- C: begin of fine-scan
- C: around best confinement
- Initial pressure profile \(\sim (1-s)^2\)
- Final pressure distribution with flattening inside 5/5-islands
- Toroidal current density with PS-dipole structure
- Depletion of current in island region
- \(i\) increases island width
- Note: no matching of experimental profiles yet

**COMPARISON HINT / VMEC-EXTENDER (VMEX) - INTERNAL ISLANDS**

- Configuration C
  - FEHINT press. profile
  - used for VMEX (same \(W_{Lix}\))
  - press. w/ and w/o flat region
  - EXTENDER for full-field generation
  - General agreement between VMEC & HINT
  - Flux surfaces, Shaf-shift
  - Expected disagreement at islands and boundary

**ISLAND WIDTH VARIATION WITH CONTROL COILS (CCs)**

- Significant island width variation produced
- Island size reflected in HINT press. profiles
- Last closed flux surface ( LCS) defined by divertor
- Stochasticity around and beyond 10/9 islands by use of CCs
- Increased island size distances to ICs

**SUMMARY**

- Investigation of confinement in configuration scan (iota) between two divertor configurations: high-iota (i=5/4) and standard-iota (i=5/5)
- Best confinement with 5/5-islands close to plasma boundary; better confinement accompanied with increasing MHD-activity at 5/5 islands (ILMs); activity level also dependent on island size.
- Calculations of consistent MHD-equilibria with internal islands using HINT for configuration-scan with flat-pressure regions of islands reflected in equilibrium current densities, e.g. P3-currents
- Comparison with VMEX and VMEX-approach give good general agreement, but disagreement at and around internal islands: underestimated island size shows shortcoming of VMEX-approach.