NSTX-U

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XP1509: Combined β_N and l_i control

Group Review

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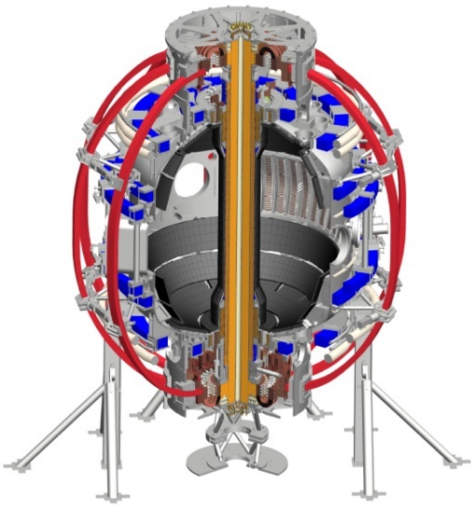


XP-1509: Combined β_N and l_i control

- Motivation:
  - **Safe operation near stability boundaries**
  - **Controlled, repeatable experiments**
  - Steer stored **thermal/magnetic energy** during **shut down**
  - Planning **current profile and rotation profile control strategies** that **will use similar approach** (actuators, control laws, software)
- Goals:
  - Demonstrate capability of **new multi-input-multi-output control algorithm**
  - Generate **control oriented models,** assess **controllability and limitations**
  - Attempt to **demonstrate control** during **ramp-up, flattop,** and **ramp-down**
- Allocation:
  - 0.75 days, split over multiple days, 1 additional day possible

Global parameter control category ("DBC") in PCS

- Framework for **combined control** of many measurements using many `higher level' actuators
  - **Example measurements:** betaN, li, q0, qmin, etc…
  - **Example actuators:** beams, Ip, density, shape control points, etc…

- **Flexible** control implementation
  - **PID control** hand-tunable, similar to ISOFLUX
  - **State-space control** more general, for more complex control laws

Pre-requisites for running XP

- PCS code updates
  - NBI category
    - Code specifications are written, need to be coded and tested offline
  - GPC category
    - Code specifications are written, need to be coded and tested offline

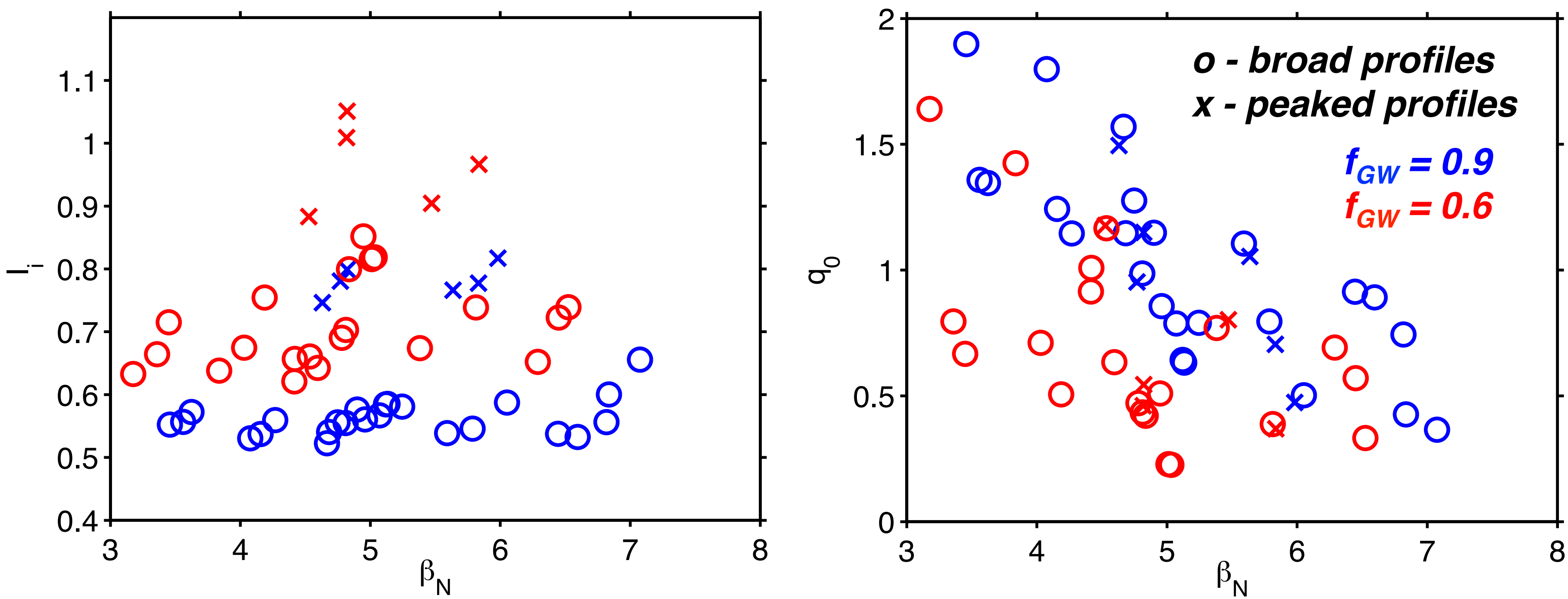
- rtEFIT commissioning
  - Needed for real-time β_N and l_i
  - ISOFLUX desired for outer gap feedback
    - Could potentially use PCC

Operational requirements

- Diagnostics
  - Real-time magnetics for rtEFIT (rtEFIT required for real-time β_N and l_i)
  - Magnetics for **EFIT reconstructions**
  - Profile diagnostics for **TRANSP analysis**
- Hardware requirements
  - **Beams** under PCS control by GPC category
- Analysis during XP
  - Between shots EFIT
  - Between shots TRANSP (optional, but expected to be available)

Control of li may not be easy…

- 30 TRANSP runs with different combinations of beams for beam characterization XP
  - f_{GW} = 0.9 and 0.6, 10cm outer gap, I_p 700 - 1000kA, B_T 0.5T - 0.75T
- For q_0>1, very little variation in l_i with beam mix
- Profile peaking variations may help



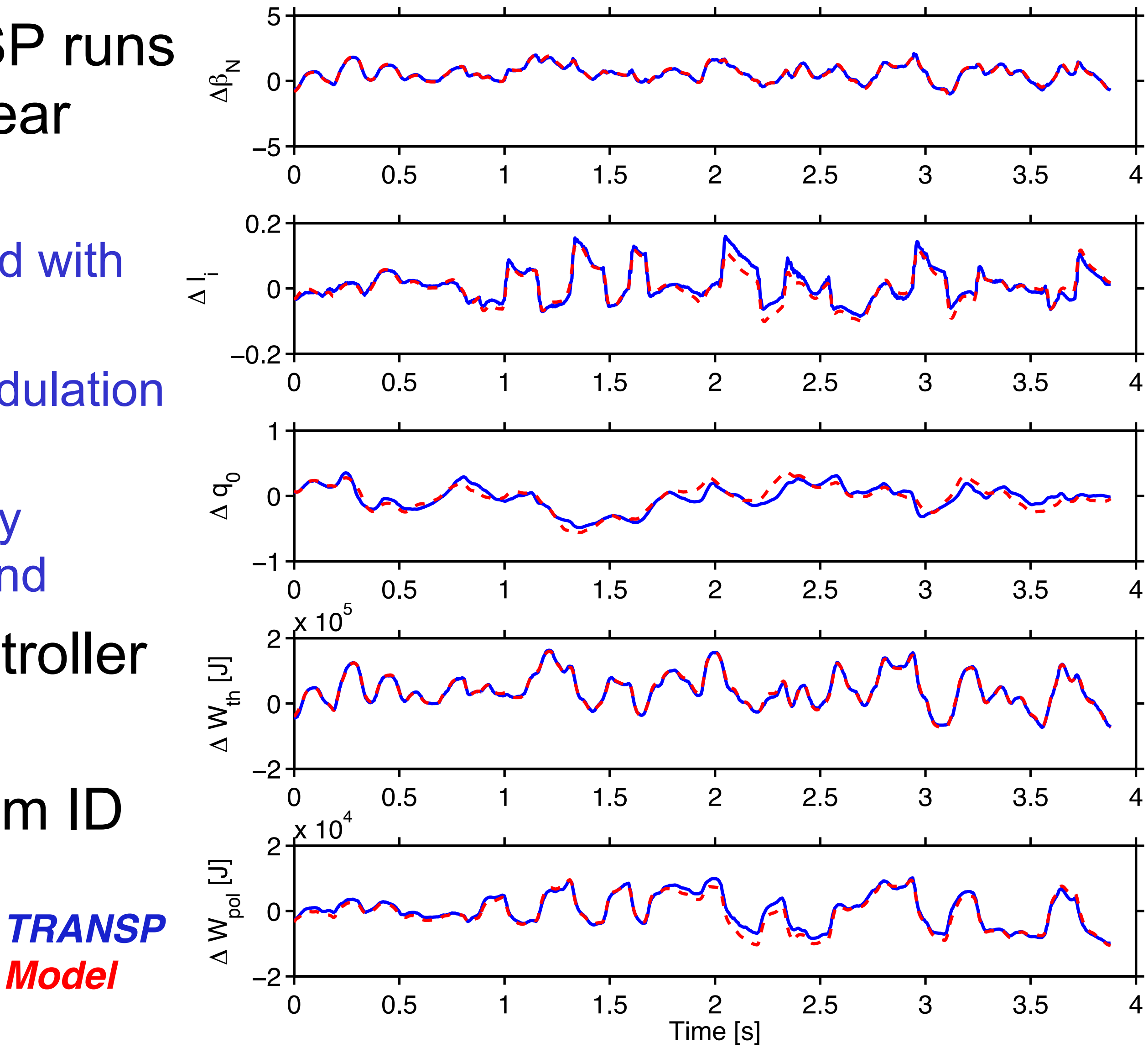
Shot Plan – Step 1: System identification

- Establish reference shot
  - >1s flat top, 0.65 T (as high as possible), ~700kA, ~12cm outer gap, fGW as low as possible while keeping qmin above 1
- Conduct modulation around reference for system identification
  - Modulate beams and outer gap early in shot
  - Include plasma current modulation later in shot
    - If discharges are too short, may require separate shots
- Repeat at higher current or lower density reference

Number of shots: 6-12

TRANSP used for preliminary system identification

- Modulated TRANSP runs used to identify linear model
  - TRANSP compared with model prediction
  - Beam and gap modulation only until 1s
  - Current and density modulation 1s to end
- Used for initial controller testing/tuning
- Use to guide system ID shot design



Shot Plan - Step 2: Flattop β_N and l_i control, ramp up study

- Initial condition error rejection
  - During ramp-up, vary current ramp rate, beam timing, gap to vary li
    - Will be used to assess controllability during ramp-up
  - Specify **target trajectory** for β_N and l_i from the reference shot, activate control shortly after flattop
    - Use **control gains derived from TRANSP** analysis as default
    - If possible, use **gains derived from system identification** shots
- Disturbance rejection
  - Apply an input disturbance (vary feedforward current and/or injected power)
  - Attempt to track reference β_N and l_i
  - If discharge length is long enough, turn off feedback later in shot
    - Demonstrate effect of disturbance, improvement gained with controller
  - Use beam+gap feedback initially, add current later on

Number of shots: 6-10

Shot Plan - Step 3: Ramp up control of l_i, flattop stored thermal and magnetic energy control

- Ramp-up control of li
  - During ramp-up, use feedback on plasma current or gap request to track li trajectory
    - Initially track reference if repeatability is an issue
    - Later try to track a lower target for vertical stability
- During flattop, switch phases to control thermal and magnetic stored energy
  - Use beam+gap only initially, then add current feedback
  - Initially track reference trajectory
    - Attempt to control during ramp-down
  - Later track target
    - Ramp down to 10% level
    - Ramp down to 20% level

Number of shots: 6-10

Analysis of Results

- EFIT
  - Compare **evolution of β_N and l_i** to target
  - Assess effect of feedback on **shaping, current profile**
- TRANSP
  - Analyze **heating and current drive**
  - Open and closed loop TRANSP simulations will be compared to experiments to **assess use of TRANSP as a control design tool**
- Control oriented modeling
  - Control oriented q profile modeling efforts (Z. Ilhan, Lehigh U.)