2014-18 SFPS and Ramp-up Research Plans

Solenoid Free Plasma Start-up and Current Ramp-up

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2014-18 SFPS and Ramp-up Research Thrusts

Thrust 1: Demonstrate and Understand Solenoid-free current start-up

– Establish initial transient CHI discharges (YR 1 & 2)
  - Using graphite divertor plates
  - Use full Li coverage to reduce low-Z impurities
  - Test benefits of upper inner metal divertor and Li during absorber arcs
  - Initially couple to induction, then assess coupling to NBI
  - Use NIMROD and M3D-C1 to simulate discharges

– Maximize CHI current start-up in NSTX-U (YR 3)
  - Using metal divertor plates
  - Use full Li coverage to reduce low-Z impurities
  - Use 1MW ECH to heat CHI plasma
    - Model ECH heating using GENRAY
  - Characterize CHI plasma properties
  - Improve coupling to NBI
    - Model coupling using TSC/PTRANSP
  - Partial validation of CHI start-up discharges with NIMROD/M3D-C1
    - Injector gap width
    - Injector current ramp rates
    - Voltage programming history
    - Voltage programming for static and time varying injector flux

– Establish point source helicity injection plasmas in NSTX-U (YR 3 & 4)
    - Required radial insertion of gun into vessel
    - Current scaling and plasma parameters vs. insertion depth
    - Current scaling with TF
    - Limits of injection current
    - Current scaling with machine size (NSTX-U vs. Pegasus)
    - Characterize gun generated plasma properties
    - Initially couple to induction
    - Simulate using NIMROD

2014-18 SFPS and Ramp-up Research Thrusts

Thrust 2: Use CHI and Point source helicity injection as initial seed for subsequent non-inductive current ramp-up

– Ramp CHI started discharges to 1MA using NBI (YR 4 & 5)
  - Using metal divertor plates
  - Use full Li coverage to reduce low-Z impurities
  - Use ECH to heat CHI plasma & HHFW later during ramp

– Validate CHI started discharges
  - Full start-up and ramp-up model using TSC/TRANSP/GENRAY
    - Assess CHI current generation potential in FNSF with TSC
    - Model start-up and ramp-up scenario for FNSF
  - Improve validation using NIMROD and M3D-C1
    - Impact of impurities and ECH heating
    - Impact of plasma resistivity near X-point
    - Limits on bulk plasma n_e and T_e for coupling to NBI
    - Model CHI start-up scenario for FNSF

– Assess current ramp-up of gun generated discharges using NBI (YR 5)
    - Couple to induction with NBI assist
    - Assess direct coupling to NBI/RF without reliance on CS
    - Simulate & understand coupling to NBI using NIMROD
    - Assess scaling and current generation potential in FNSF

2014-18 Solenoid Free Plasma Start-up and Ramp-up Research Timeline

FY13 | 14 | 15 | 16 | 17 | 18

5 year plan period → **5 year goal**

Physics

- Re-establish CHI startup (graphite tiles, full Li coverage) Test benefits of upper metal divertor
- Maximize CHI current startup and ramp to 1MA using NBI, ECH, HHFW Test benefits of metal divertor Test benefits of upper divertor cryo pump
- Benchmark start-up with NIMROD and M3D-C1
- Benchmark full ramp-up with TSC Understand NBI CD of CHI target with NIMROD
- Benchmark ECH heating of CHI using GENRAY
- Test gun plasma start-up
- Test current ramp-up using gun plasma start-up

5 year goal: 1) Demonstrate and understand full solenoid-free current start-up and ramp-up. 2) Understand requirements for designing FNSF without a solenoid

Tools

Diagnostics

New: Improved flux loops & voltage monitors on up/low divertor & CS magnetics
Multi-point Thomson, Visible and UV Spectroscopy, Soft X-ray arrays, bolometers,
Divertor Langmuir probes, divertor thermocouples, IR camera, fast cameras

Theory

TSC – Current start-up, ramp-up and sustainment
PTRANSP – NBI coupling to low Ip CHI target
NIMROD, M3D-C1 – Primary goal: Physics of closed flux current generation. Secondary goal: NBI current ramp-up
GENRAY – ECH heating of CHI

Facility

New: 1MW ECH (28 GHz) to heat CHI plasma
New: Second Tangential NBI for current ramp-up
New: Metallic Divertor plates to reduce low-Z impurities
New: Li evaporator for upper divertor for impurity control
New: Improved injector coil to increase injected poloidal flux
New: 4kV CHI system, Improved: Capacitor bank, absorber coil

Plasma Control

Initial pre-programmed phase followed by gap control, followed by rtEFIT control during high current ramp-up and sustainment phases

Plasma formation and Current Ramp-up

Lead writer, supporting writers

Raman, Mueller, Nelson, Jarboe, Jardin – CHI
Redd, Raman, Mueller – Gun plasma start-up
Taylor, Raman, Mueller - ECH (closely coupled to Wave Particles TSG)

7. Research Goals and Plans for Plasma Formation and Current Ramp-up

7.1 Overview of goals and plans
7.11 Establish predictive capability for the performance of FNSF

7.1.1 Thrusts and goals by topical area
7.1.1.1 Demonstrate and understand solenoid-free current start-up
7.1.1.2 Use CHI and point helicity injection as initial current seed for subsequent non-inductive current ramp-up

7.2 Research Plans

7.2.1 **Years 1-2:**
7.2.1.1 Establish initial transient CHI discharges
7.2.1.2 Use graphite divertor plates
7.2.1.3 Use full Li coverage to reduce low-Z impurities
7.2.1.4 Test benefits of (partial) upper metal divertor and Lithium during absorber arcs
7.2.1.5 Initially couple to induction, then assess coupling to NBI
7.2.1.6 1 MW ECH coupling to NBI during Year 2

7.2.2 **Years 3-5:**
7.2.2.1 Establish discharges using metal divertor plate electrodes
7.2.2.2 Assess benefits and compare to QUEST results (if available)
7.2.2.3 Assess benefits of cryo pumping in the absorber region
7.2.2.4 Maximize current start-up

7.2.2.5 1 MW ECH, then HHFW to increase Te to ~ 1keV for coupling to NBI
7.2.2.6 Test plasma gun start-up on NSTX-U
7.2.2.6.1 Collaboration with PEGASUS on point helicity injection

7.3 Summary timeline for tool development to achieve research goals

7.3.1 Theory and simulation capabilities
- 7.3.1.1 2D resistive MHD simulations – TSC
- 7.3.1.2 3D Resistive MHD simulations – NIMROD, M3D
- 7.3.1.3 GENRAY for ECH/EBW (Taylor)
- 7.3.1.4 PTRANSP for NBI coupling to low-Ip CHI plasma

7.3.2 Diagnostics
- 7.3.2.1 New additional fast voltage monitors for upper divertor
- 7.3.2.2 Additional dedicated current monitors near injector
- 7.3.2.3 Special set of EMI shielded inner vessel magnetics
- 7.3.2.4 Additional flux loops and Mirnov coils on lower and upper divertor
- 7.3.2.5 Langmuir probe array on lower divertor
- 7.3.2.6 Multipoint Thomson scattering, Filter scopes, multi chord bolometers and SXR arrays

7.3.3 Other facility capabilities including plasma control

- 7.3.3.1 2nd NBI for coupling to low-Ip CHI plasma

- 7.3.3.2 Baseline capacitor bank power supply
  - 7.3.3.2.1 Voltage increased to ~2 kV & improve voltage snubbing systems
  - 7.3.3.2.2 NSTX-U to support 4kV Ops including transients
  - 7.3.3.2.3 Design study of next generation power supply system

- 7.3.3.3 Upgraded capacitor bank power supply
  - 7.3.3.3.1 Voltage increased to ~3 kV, bank energy increased to 200 kJ
  - 7.3.3.3.2 Additional modules for improved voltage control

- 7.3.3.4 1MW → 2MW ECH for heating low-Ip CHI plasma

- 7.3.3.5 Point helicity sources/plasma guns