NSTX HHFW System Improvements

Phil Ryan, ORNL

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HHFW Physics Goals and Issues

- **High density, high beta heating**
- **Off-axis heating/current drive**
  - Need MSE to assist in optimizing non-inductive CD
- **Long pulse, stable scenarios**
  - Avoid MHD instabilities, central temperature collapse
  - Current drive in H-mode
  - J(r) tailoring
- **HHFW/NBI coexistence**
- **Integration with CHI startup**
- **Wave generation other than HHFW**
  - Surface modes, coaxial modes, IBW
  - RF probes around machine
- **Edge plasma fluctuations**
  - density fluctuations measurements with reflectometer, Langmuir probes

HHFW Operation on NSTX Has Made Progress

- **Up to 6 MW delivered to plasma; routine operation in the 3-4 MW range.**
- **Strong electron heating observed over a wide range of wave phase velocity ($k_{||} \sim 3, 7, 14\ m^{-1}$).**
- **H-mode (both ELMy and ELM-free) achieved with HHFW alone.**
- **Evidence of internal transport barrier in low density plasmas.**
- **Non-inductive current drive detected for both ±π/2 and ±π /4 array phasing.**
- **Power absorption on high energy neutral beam ions observed.**

HHFW Technology/Operation Issues

- **High power reliability**
  - Voltage limits in vacuum ~double what is achievable in plasma.
  - Improve voltage limits during plasma operation.
  - Modify control system so that non-arcing transmitters stay on.
- **RF noise generation**
  - RF noise pickup on instrumentation increases as array phase shift is decreased.
  - Both improve instrument shielding and identify the cause of noise generation/propagation.
  - New diagnostics for measuring edge fluctuations, rf wave amplitudes.
- **Phase-dependent loading**
  - Loading for counter-CD phasing is lower than for co-CD phasing.
  - Will we need to vary the array phase during the pulse?
  - Will we need to operate in counter-CD phasing at high power?

What is the primary cause of power trips during plasma operation?

- **Arcing due to pressure rise?**
  - Outgassing?
  - Recycling?
  - Sheaths?
  - Present antenna diagnostics on C-MOD can give useful information.
- **Degradation of antenna surfaces during plasma operation and/or machine conditioning?**
- **Trips due to rapidly changing plasma conditions?**
- **RF/edge plasma interactions?**

Determine the cause of present voltage limitations

- **Need to dedicate operation time to identifying power limitations (Experimental Machine Proposals).**
- **Possible diagnostics:**
  - Fast visible camera
  - Fast pressure gauge in antenna box
  - Surface Langmuir probes in boron nitride
  - Floating probes, emissive probes in antenna
  - Light pipes in antenna boxes
  - IR cameras, thermocouples
  - Arc detection/localization system

Improve voltage limits on HHFW system

- **Antenna array operation**
  - Develop better conditioning procedures
  - Decouple transmitter arc protection from phase control
- **Antenna array modifications**
  - Heating/baking antennas (hot coolant, heater tape, radiant heat)
- **Antenna array redesign**
  - Double end-fed design lower voltages on straps
  - Slanted straps reduce phase-dependent loading asymmetry
  - One strap per transmitter simplify system & improve phase control
- **High voltage prototype antenna to be tested on UCLA Electric Tokamak may yield information to aid in design.**

Summary

- **HHFW has obtained good physics results, needs to extend operation to higher power, longer pulses.**
- **Power is at present limited by antenna voltage.**
  - Determine the cause
    - Additional diagnostics
    - Dedicated XMPs
  - Effect a solution
    - Improve performance of present array
      - » **Conditioning**
      - » **Operating scenarios**
      - » **Detach arc protection from phase control**
    - Modify present array
      - » **Bakeout, operating temperature**
    - Design new array
- **Understand the interaction with edge plasma.**
- **Incorporate knowledge gained from other experiments (C-Mod, ET, JET, Asdex-U, DIII-D …)**