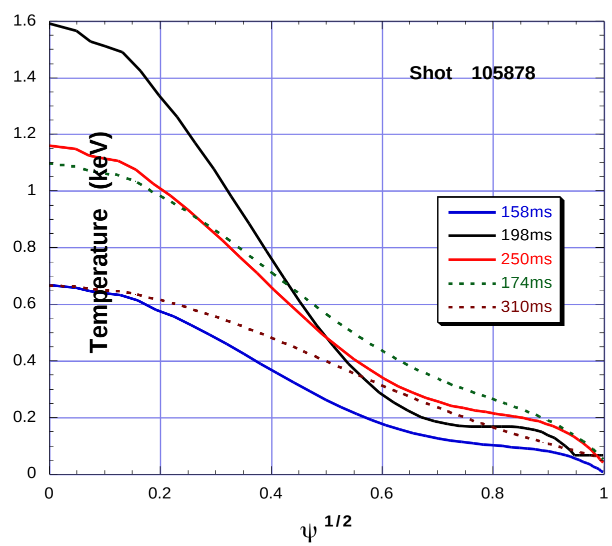
Modeling of HHFW Current Drive And Experimental Tests

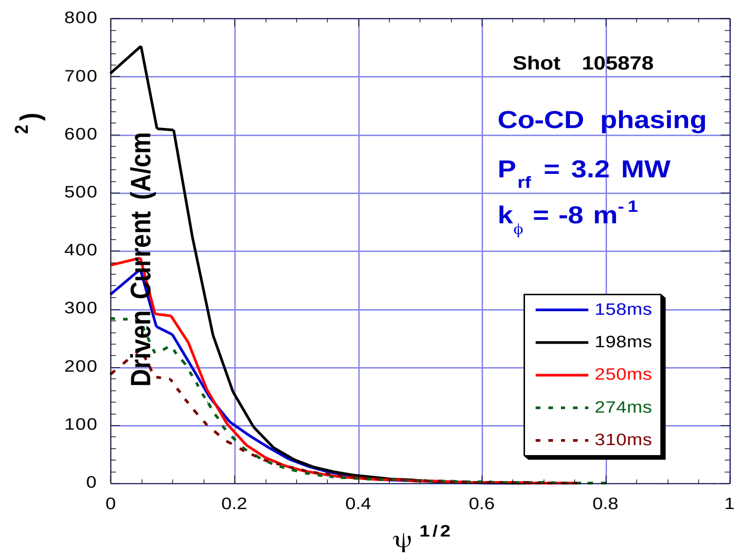
T.K. Mau
University of California, San Diego

NSTX Research Forum
November 28-30, 2001
Princeton Plasma Physics Laboratory

Status of CURRAY Modeling of HHFW CD

- Driven current profiles calculated for a number of time slices in a discharge, using reconstructed EFIT equilibrium and measured n, T profiles :





- Self-adjoint technique invoked in evaluating local CD efficiency. 25 - 110 rays used to simulate launched CD spectrum, P (θ,n,m).

- For experimental analysis, this calculation process needs to be automated and incorporated with TRANSP.

Improved Modeling in Support of Experiments

- Status of interface to TRANSP:
  - CURRAY as an NTCC module is an on-going effort; about half done
  - Direct coupling to TRANSP, an alternative solution
- Make code run faster with parallelization of ray tracing.
- Quasilinear diffusion effect on electron velocity distribution:
  - Cardinali calculated higher CD efficiency with QL effects
  - Need detailed benchmarking between his code and CURRAY that uses linear model
- Electric field effect on CD efficiency:
  - In CURRAY, $j/p \longrightarrow j/p \times [1 - C(Z_{eff},w_{te})(T_e/n_e)E_{loop}/(j/p)_o]$ where $w_{te} = v_{||}/v_{te}$, $(j/p)_o$ is CD efficiency w/o neoclassical effects. Need to re-establish validity of this correction factor
- Benchmark with CQL3D QL Fokker Planck code (Harvey).

Experimental Test of CD Predictive Model

- Objectives for testing and verification of CURRAY CD predictive model for HHFW in NSTX (8-10th harmonics) :

  - **To demonstrate HHFW as an efficient current driver**
  - To establish validity of model for use in designing and analyzing future high-performance discharges.
  - To help understand HHFW CD and profile control physics in spherical tokamaks.

- CURRAY calculates the HHFW driven current profile and CD efficiency I/P using measured equilibrium data, density and temperature profiles.

  - Empirical CD model, valid for r/R < 0.3 : central CD
  - Self-adjoint technique, valid for all r/R : off-axis CD at high β.

- CURRAY has been shown to agree with DIII-D FWCD results at ~ 4 to 6th ion harmonics.

Measuring Non-inductively Driven Current Profiles

NSTX

- **Loop Voltage Technique**: [C.B. Forest]

  - Need MSE spectroscopy of NBI D-atoms to directly measure internal magnetic fields; detailed reconstructions of magnetic configuration ψ (R, Z, t) at time slices.
  - Ampere's law : $j_{||} \sim \psi, \; \Delta^*\psi$

    Faraday's law : $E_{||} \sim \partial\psi / \partial t$ at same Φ_{tor} surface.

    Noninductive current: $j_{ni} = j_{||} - \sigma_{nc} E_{||}$ $(= j_{HHFW} + j_{BS})$
  - Take the difference between HHFW discharge and a fiducial discharge with symmetric antenna phasing to obtain j_{HHFW}.
  - For off-axis localized CD, additional local basis function representation [Lao]

- **MSE Simulation Technique**: [C.C. Petty]

  - Compare measured internal fields from MSE spectroscopy to simulation of expected MSE response to calculated localized current drive.
  - Obtain best fit by adjusting total driven current, current peak location and profile width.
  - Need to take difference between HHFW CD discharge and a fiducial one with HHFW heating only

Requirements for Both Techniques

- **Measurements**:
  - MSE spectroscopy for internal magnetic fields:
    To reconstruct detailed equilibrium at different times, ψ (R, Z, t).
  - Profiles of T_e, n_e and Zeff:
    To calculate noninductive current profiles (HHFW, Bootstrap) and local neoclassical resistivity
  - Direct electron power absorption profile (helpful but not needed)
  - Repeat for a fiducial discharge.

- **Optimum Plasma Conditions**:
  - MHD quiescent discharge with slowly varying conditions;
    Total current can be evolving.
  - Sufficiently high RF power to ensure non-negligible current drive;
    Minimal HHFW interaction with beam ions.

- **Analysis Codes**:
  - Ray tracing code with valid CD efficiency package
  - EFIT equilibrium reconstruction tool (may need local basis function)
  - Time-dependent transport code to simulate MSE response

What Needs to be Done

- Couple CURRAY to TRANSP, either as an NTCC module via Xplasma or as a subroutine called by TRANSP.
  - Speed up code by parallelization, automation, etc.

- Study both CD measuring techniques further, and work out detailed plan for proposed experiment.

- Implement and test software for reconstructing equilibrium including MSE measurements.
  - Include local basis representation for off-axis localized CD.

- When MSE spectroscopy comes on line, test CURRAY CD package with NSTX discharges for various antenna phasing and plasma operating conditions.

- This project requires close collaboration with PPPL experimentalists.