Time-Dependent Simulations of Fast-Wave Heated High-Non-Inductive-Fraction H-Mode Plasmas in the National Spherical Torus Experiment Upgrade

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Introduction

- A Fusion Nuclear Science Facility based on spherical tokamak (ST) concept needs to operate with little or no inductive drive from a central solenoid [1]
- The National Spherical Tokamak Experiment Upgrade (NSTX-U) [2] research program aims to develop fully non-inductive plasmas
- Fast-wave heating on NSTX-U may effectively ramp low plasma current (I_p) plasmas non-inductively to a level suitable for 12 MW of neutral beam injection [3]
- On NSTX, at toroidal field, $B_T(0)$ = 0.55 T, 1.4 MW of 30 MHz fast-wave power (P_{rf}) increased central electron temperature, $T_e(0)$, from 0.2 to 2 keV in 30 ms:
  - *An H-mode was generated (shot #138506) with non-inductive fraction, f_{NI} ~ 0.7 at I_p = 300 kA [4] (Figure 1)*

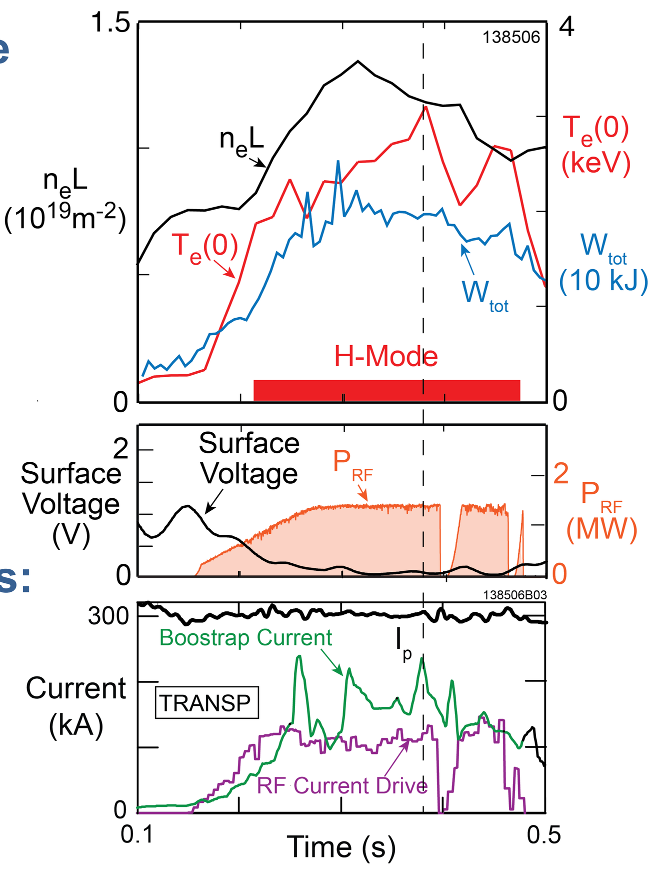

Figure 1

- On NSTX-U P_{rf} up to 4 MW will be coupled into plasmas with $B_T(0)$ up to 1 T
- TRANSP free boundary transport simulations [5] have been run for NSTX-U I_p = 300 kA plasmas to predict the dependence of f_{NI} on $B_T(0)$ and P_{rf}
- The TORIC full wave spectral code [6] was used in the simulations to calculate fast-wave heating and current drive

Predictive Modeling Assumptions

- Multimode MMM7.1 [7] thermal transport model used in simulations gave reasonably good agreement to plasma parameters obtained during NSTX shot #138506
- Effective charge, impurity, plasma rotation and other profiles were taken largely from NSTX shot #142305, part of an experimental campaign to support NSTX-U and next-step ST devices [8]
- Simulations used $k_{//}$ = 8 m^{-1} antenna phasing, the current drive antenna phasing used for shot #138506
- Electron density profile and central density ($n_e(0)$) were initially chosen to be similar to shot #138506, which had $n_e(0)$ = 1.15x10^{19} m^{-3}:
  - *$n_e(0)$ was ramped in 100 ms, a H-mode transition was then imposed by flattening the density profile (Figure 2)*

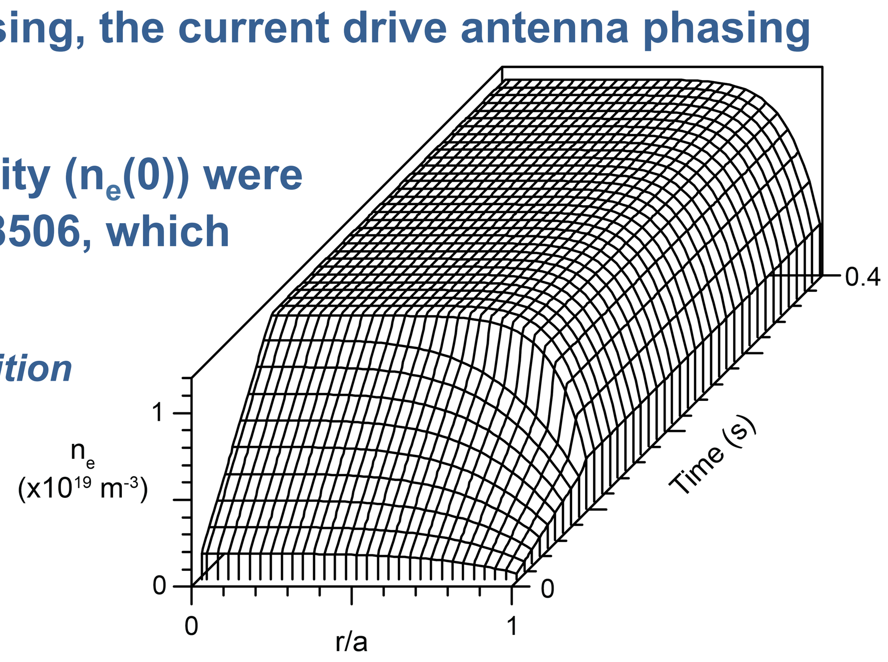

Figure 2

Results

- Simulation were run for a NSTX-U plasma with the same P_{rf}, I_p and $n_e(0)$ as NSTX shot #138506, and $B_T(0)$ = 0.5 T, compared to $B_T(0)$ = 0.55 T for shot #138506 (Figure 3):
  - *$T_e(0)$ during simulation was 2.2-2.4 keV, compared to 2.5-3 keV during shot# 138506*
  - *f_{NI} during the simulation reached 0.6, compared to the f_{NI} = 0.7±0.2 achieved during shot #138506*

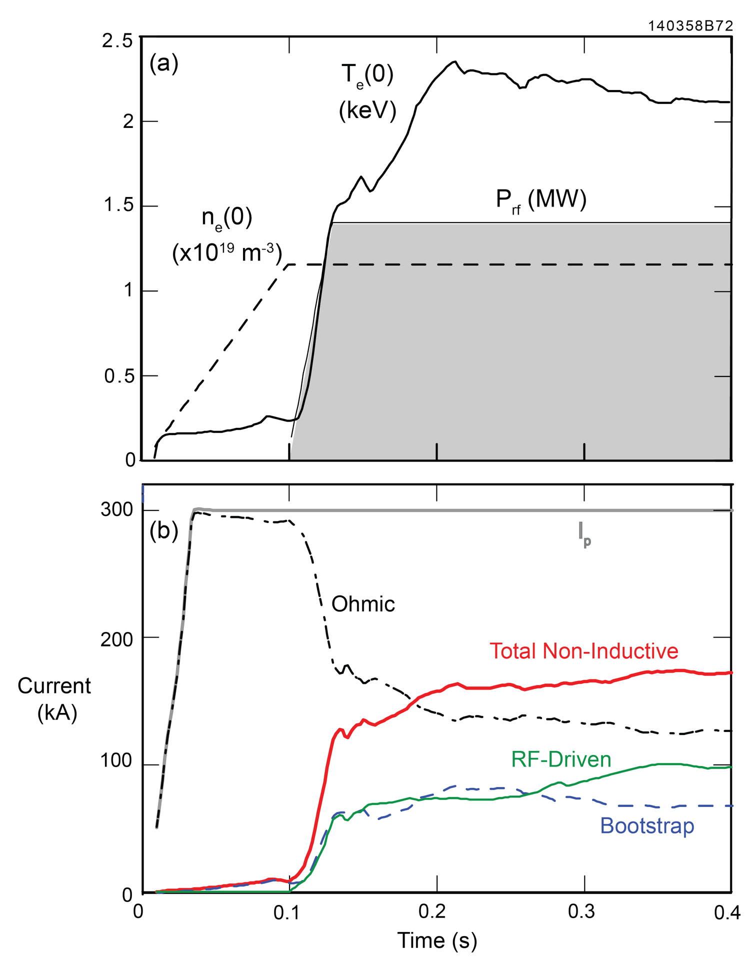

Figure 3

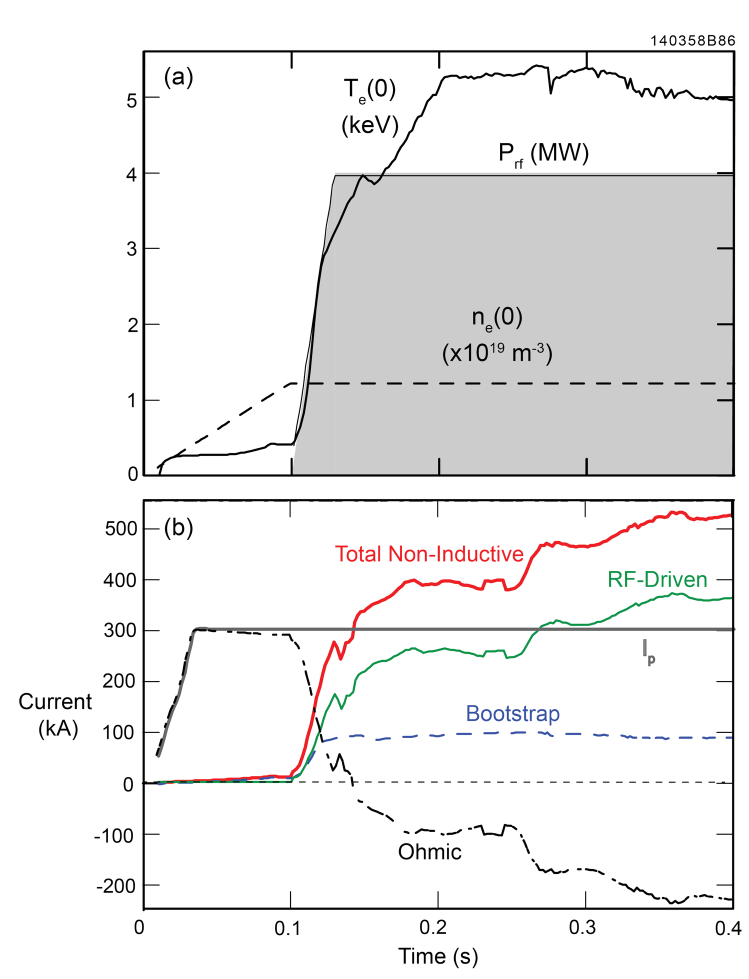

Figure 4

- f_{NI} reached 1.7 during $n_e(0)$ = 1.15x10^{19} m^{-3} simulations when P_{rf} = 4 MW was coupled into a $B_T(0)$ = 0.65 T plasma (Figure 4):
  - *During the RF pulse bootstrap current remains constant around 100 kA and the RF-driven current reaches 370 kA at 0.4 s*
- For the case shown in figure 4, the T_e profile becomes very peaked during the RF pulse (dashed line in figure 5(a))
  - *90% of the RF-driven current is within r/a = 0.2 at 0.4 s (figure 5(b))*
  - *Peaking of $T_e(0)$ and the RF heating profile at higher P_{rf}, and particularly at higher $B_T(0)$, caused simulations to become unstable and terminate ~ 0.2 s*

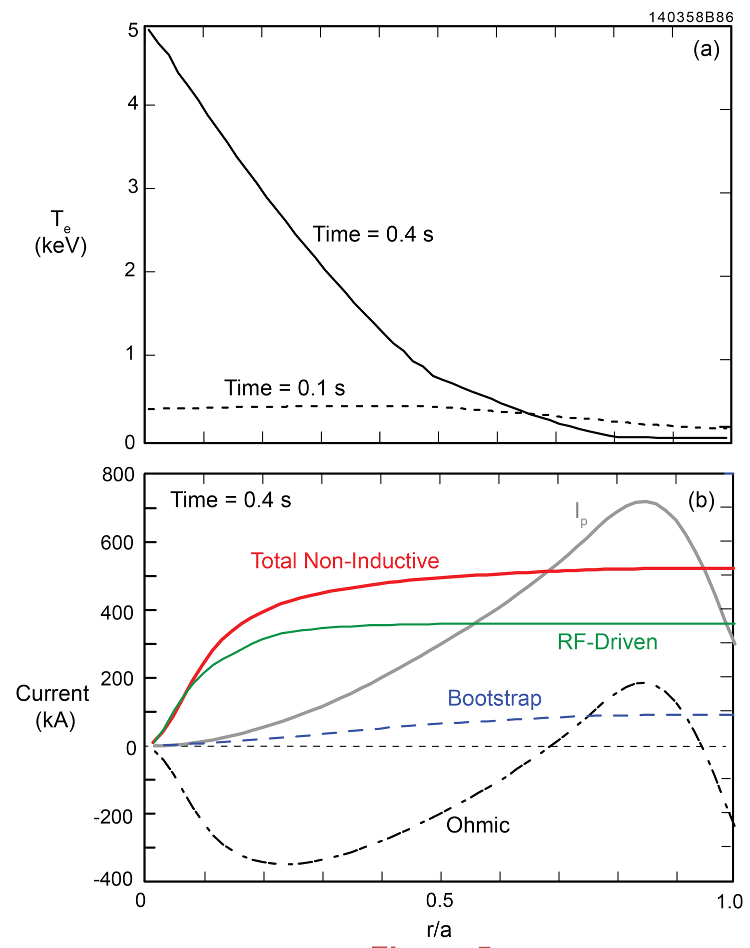

Figure 5

- f_{NI} versus P_{rf} for $n_e(0)$ = 1.15x10^{19} m^{-3} simulations is shown in figure 6, the f_{NI} achieved during NSTX shot #138506 is shown by the pink symbol:
  - *All the $B_T(0)$ = 1 T simulations and the $B_T(0)$ = 0.89 T simulations with P_{rf} > 2 MW became unstable and terminated ~ 0.2 s*
  - *Increasing P_{rf} from 1.4 to 4 MW at least doubles f_{NI} for the $B_T(0)$ = 0.5 T, 0.65 T and 0.75 T simulation*

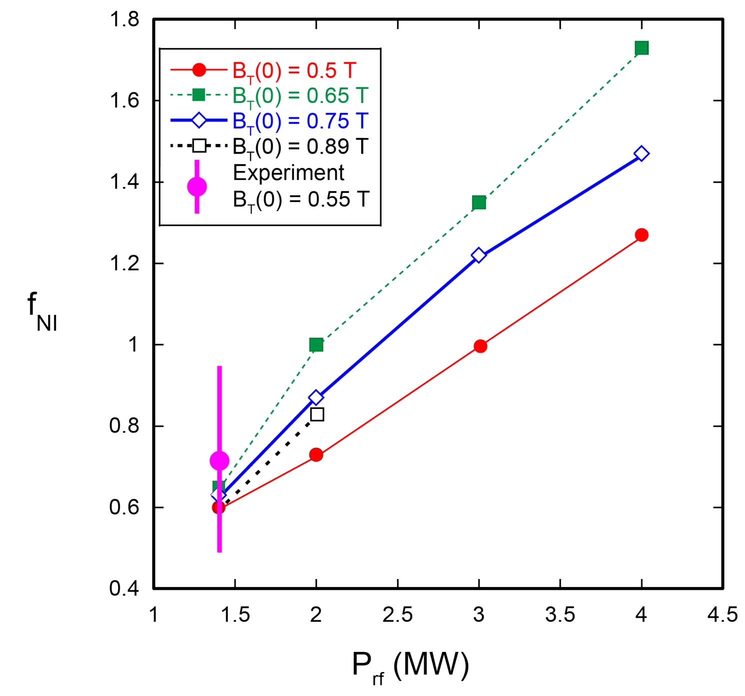

Figure 6

- Increasing $B_T(0)$ from 0.5 to 0.65 T significantly increases f_{NI}, however f_{NI} decreases for simulations with $B_T(0)$ > 0.65 T, at all values of P_{rf} (figure 7)

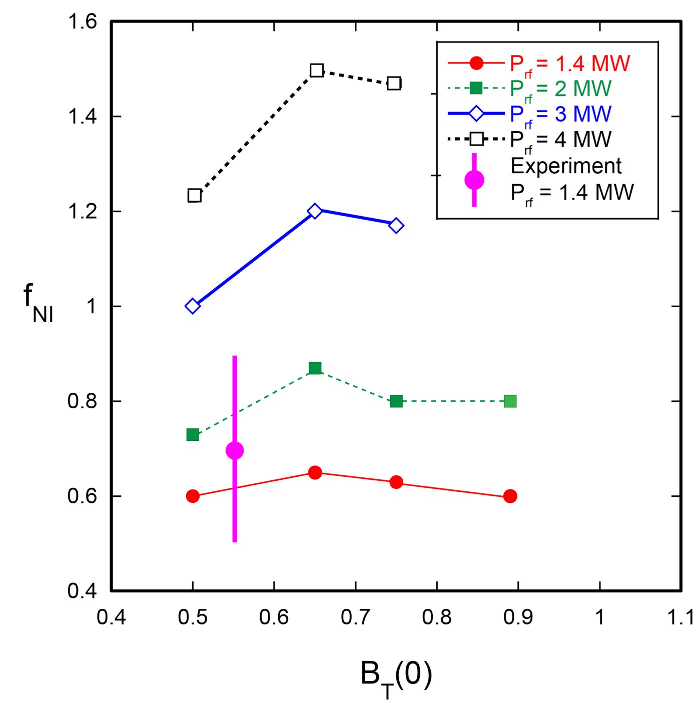

Figure 7

- Increasing $n_e(0)$ to 1.43x10^{19} m^{-3} allowed stable simulations up to P_{rf} = 4 MW at $B_T(0)$ = 1 T, f_{NI} at 0.4 s versus P_{rf} for $n_e(0)$ = 1.43x10^{19} m^{-3} simulations is shown in figure 8:
  - *With P_{rf} = 4 MW all simulations with $B_T(0)$ ≥ 0.65 are fully non-inductive, however f_{NI} is lower compared to the $n_e(0)$ = 1.15x10^{19} m^{-3} simulations at same P_{rf} and $B_T(0)$*

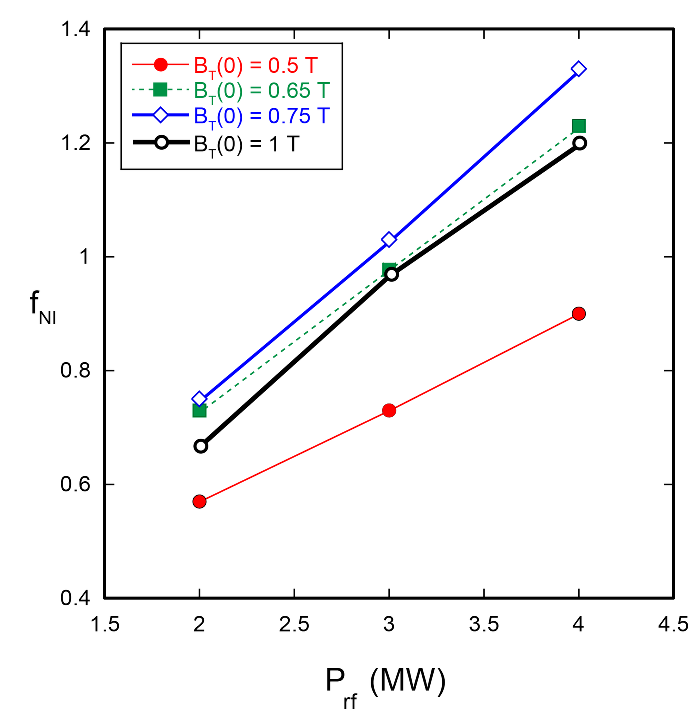

Figure 8

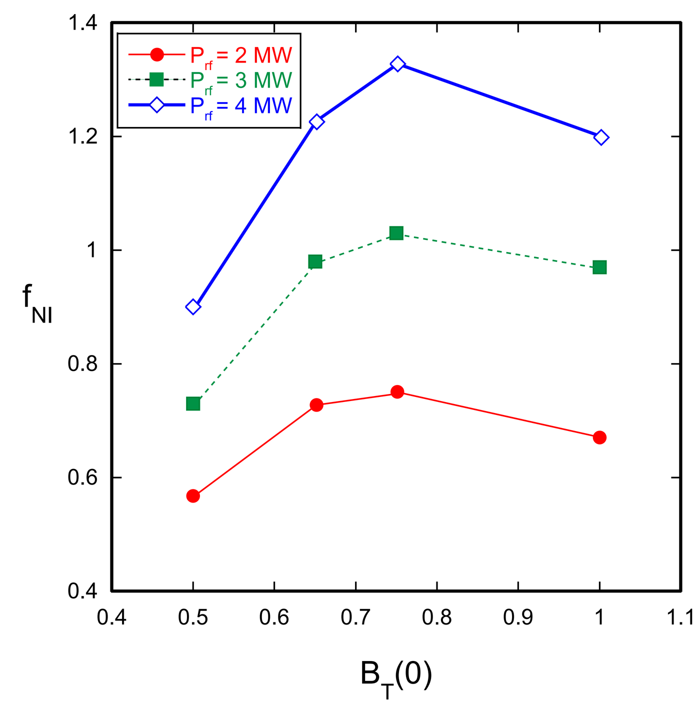

Figure 9

- f_{NI} increases significantly when $B_T(0)$ is raised from 0.5 T to 0.65 T, but decreases when $B_T(0)$ increases from 0.75 to 1 T, as for the $n_e(0)$ = 1.15 x 10^{19} m^{-3} simulations (Figure 9)

Conclusions

- Simulation results support the possibility of achieving a stable I_p = 300 kA NSTX-U plasma with f_{NI} ≥ 1 with P_{rf} > 2 MW
- However the simulations also predict that the plasma may become more unstable as P_{rf} and $B_T(0)$ are increased if $n_e(0)$ is too low, and increasing $B_T(0)$ above 0.65 T is predicted to lower the f_{NI} achievable at a given P_{rf}
- These simulation predictions must now await experimental validation on NSTX-U

References

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