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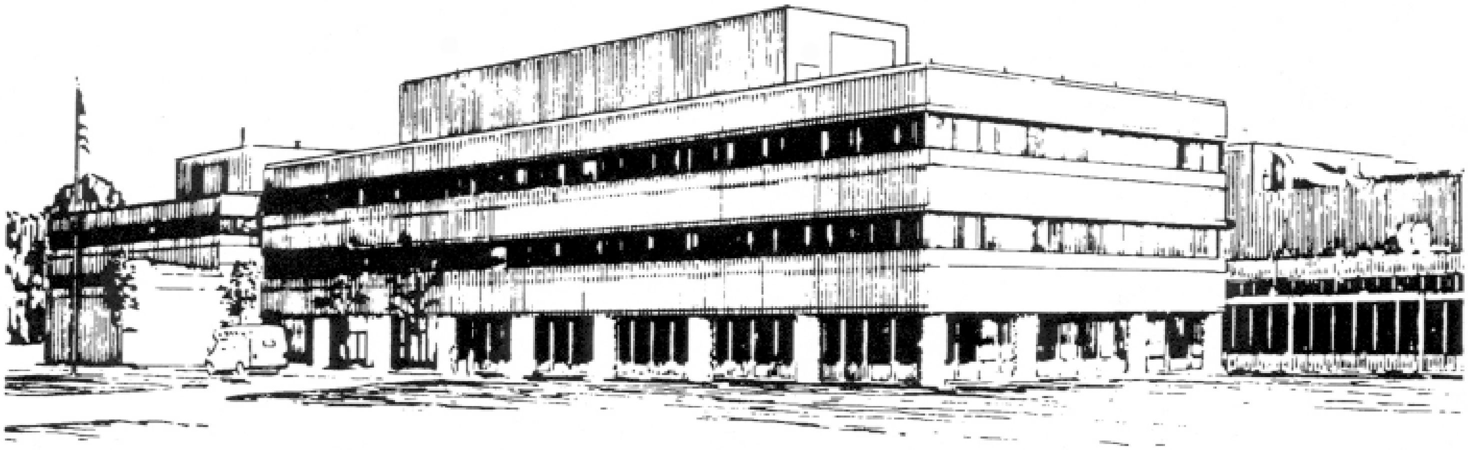

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Profile Modifications Resulting From Early High-Harmonic Fast Wave Heating in NSTX[1]

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Abstract. Experiments have been performed in the National Spherical Torus Experiment (NSTX) to inject high harmonic fast wave (HHFW) power early during the plasma current ramp-up in an attempt to reduce the current penetration rate to raise the central safety factor during the flat-top phase of the discharge. To date, up to 2MW of HHFW power has been coupled to deuterium plasmas as early as t=50ms using the slowest inter-strap phasing of $k_{\|} \approx 14\text{m}^{-1}$ ($n_\phi = 24$). Antenna-plasma gap scans have been performed and find that for small gaps (5-8cm), electron heating is observed with relatively small density rises and modest reductions in current penetration rate. For somewhat larger gaps (10-12cm), weak electron heating is observed but with a spontaneous density rise at the plasma edge similar to that observed in NSTX H-modes. In the larger gap configuration, EFIT re-constructions (without MSE) find that resistive flux consumption is reduced as much as 30%, the internal inductance is maintained below 0.6 at 1MA into the flat-top, q(0) is increased significantly, and the MHD stability character of the discharges is strongly modified.

INTRODUCTION

High-harmonic fast waves (HHFW) have been proposed as a means of efficiently heating electrons in high β plasmas [1] and have already been used to heat Spherical Torus (ST) plasmas [2] at the multi-megawatt level in the National Spherical Torus Experiment (NSTX) [3] at PPPL, USA. At present, however, NSTX relies on ohmic current drive to reach the 1MA plasma current level required for good neutral beam absorption and confinement. In addition, many NSTX high-β discharges have performance limited by the onset of MHD activity associated with q(0) dropping below 1. Application of HHFW during the I_P ramp-up has been attempted in an effort to raise q(0) and reduce OH flux consumption by lowering the central resistivity. Profile measurements and analysis for these experiments are presented below.

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EXPERIMENTAL RESULTS

Application of early HHFW power in NSTX required growing the plasma quickly to nearly full-bore for good antenna-plasma coupling. With this discharge programming, it was possible to couple up to 2MW of HHFW power during the I_P ramp-up as early as t=50ms. Figure 1 shows the electron temperature, density, and pressure profiles at t=97ms for two inboard-limited deuterium discharges with an antenna-plasma gap of 6cm. The dashed lines represent ohmic reference profiles (104286), while the solid lines correspond to the HHFW heated discharge (104277). As seen in the figure, 2MW of HHFW power (lower right) is able to double the central electron temperature (upper left) of a 200eV ohmic target plasma. The figure also shows that the electron density (upper right) is doubled in the region between the axis and the core and results in a factor of 2.5 increase in the electron pressure (lower left). Achieving 1MA flat-top ohmic discharges is often difficult in NSTX at 0.3T, and an MHD ‘‘event’’ at 120ms interrupts the current ramp-up of both the ohmic and HHFW heated discharges (lower right). By t=130ms, the central Te of the HHFW heated discharge is similar to that of the ohmic reference, and the central electron pressure is 70% higher. Figure 2 shows the electron temperature, density, and pressure profiles at t=97ms for the same ohmic

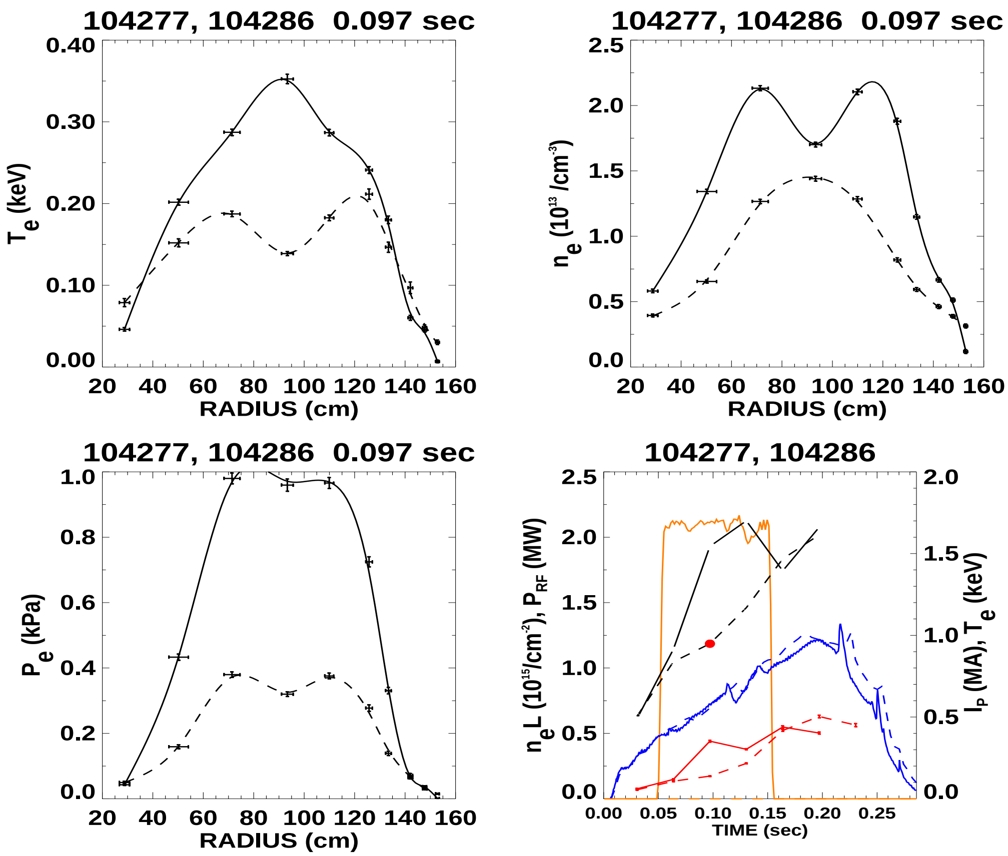

FIGURE 1. Thomson scattering profiles for ohmic (dashed) and 6cm gap HHFW plasma (solid).

reference discharge shown above, while the solid lines correspond to a HHFW heated discharge (104284) with an antenna-plasma gap of 12cm. As seen in the figure, for

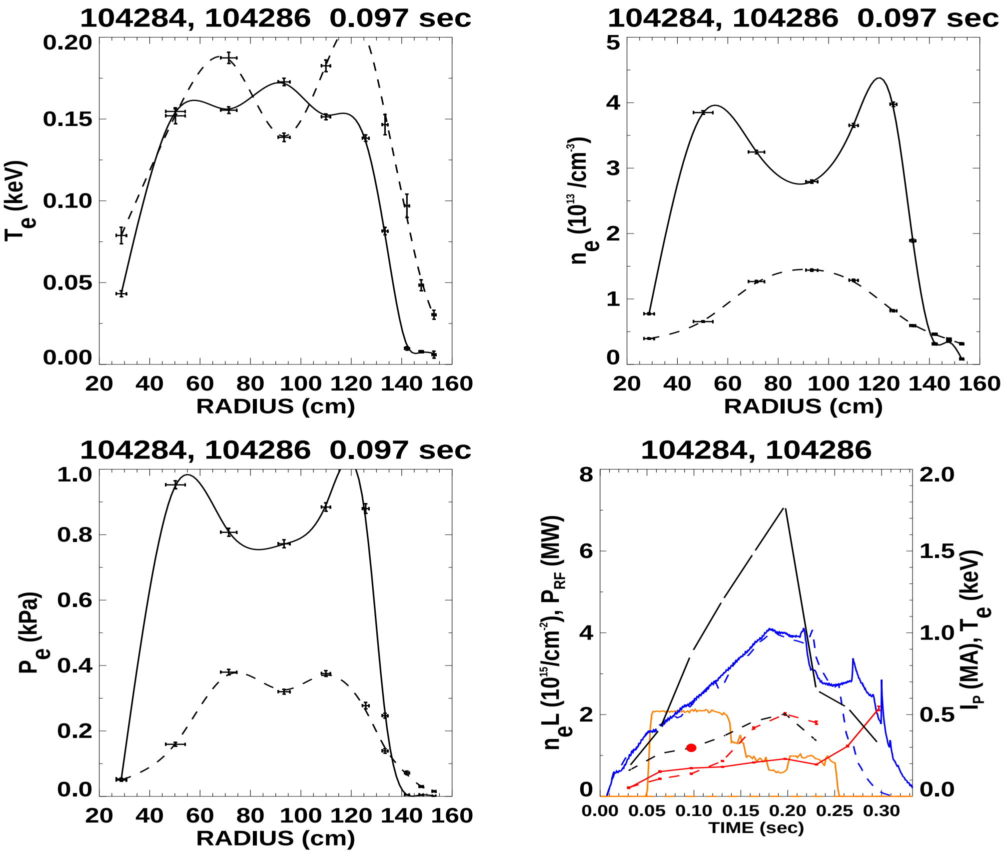

FIGURE 2. Thomson scattering profiles for ohmic (dashed) and 12cm gap HHFW plasmas (solid).

the larger antenna-plasma gap of 12cm, 2MW of HHFW power raises the central Te only slightly, but the electron density is increased (on average) by more than a factor of 4. The electron pressure is increased by a factor of 2 in the core, a factor of 5 near the edge, and has a hollow profile. Impurity transport modeling coupled with soft X-ray data [4] suggests that the rapid density rise may be caused by an edge particle transport barrier similar to H-modes observed on NSTX, although the role of HHFW as a particle and ionization source cannot be ruled out. Importantly, the MHD event typical of the ohmic and 6cm gap HHFW ramp-up plasmas is routinely suppressed in the 12cm gap HHFW discharges. One possible explanation of this effect is suppression of locked tearing modes with high density operation. Another possibility is that high edge density modifies the edge plasma resistivity profile and thus changes the current profile evolution.

Whatever the cause, this mode of operation has allowed access to 1MA flat-top discharges with significant broadening of the equilibrium current profile as reconstructed by EFIT [5,6] (without MSE). The OH coil current swing required to reach 1MA was reduced by as much at 25% for the 12cm gap discharges, and a similar fractional decrease in resistive flux consumption was measured by EFIT. Figure 3 shows the time evolution of the reconstructed internal inductance and q(0) for the 6cm (dashed) and 12cm (solid) gap HHFW discharges discussed above. As seen in the figure, EFIT shows a significant increase in q(0) for the 12cm gap case until the ‘‘reconnection-event’’ at t=220ms disrupts the I_P flat-top. In both shots, the toroidal Mirnov array and ultra-soft X-ray data observe what is most likely a m=2/1 island near r/a = 0.7-0.8 just prior to reconnection. Thus, if the 12cm gap discharges truly do have a broader current profile, the event which terminates the I_P flat-top phase must be relatively insensitive to the current profile shape.

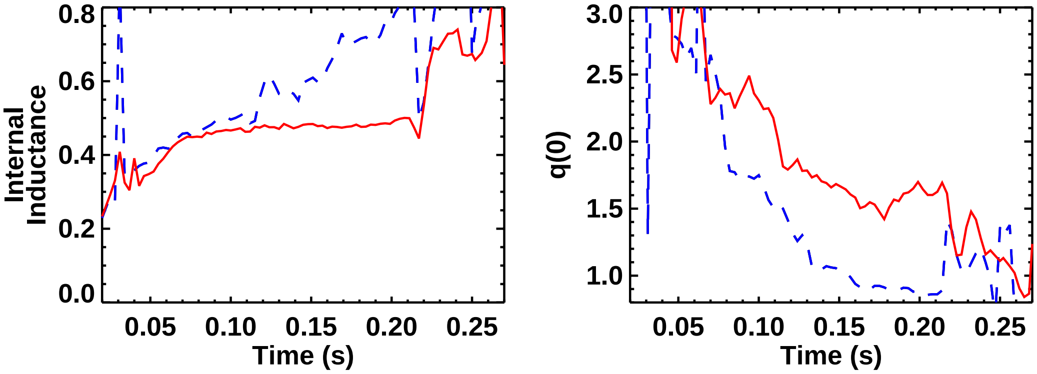

FIGURE 3. li and q(0) evolution for 6cm (dashed) and 12cm gap (solid) HHFW plasmas.

CONCLUSIONS

Experiments attempting to heat during the I_P ramp-up phase using HHFW have been carried out in NSTX in deuterium plasmas. Discharges with an antenna-plasma gap of 6cm display early central heating by HHFW, but the heating appears to be interrupted by MHD during the I_P ramp-up. Discharges with a larger gap of 12cm show much weaker central heating, achieve very high densities, very broad pressure profiles, and appear to suppress ramp-up MHD activity. For these discharges, the poloidal flux consumption is significantly reduced and the current profile as reconstructed by EFIT is broadened. This new equilibrium regime has already been used as an NBI target on NSTX, and future work will attempt to eliminate MHD activity during the early I_P flat-top phase in an effort to further extend the pulse-length.

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