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Electron Energy Confinement For HHFW Heating and Current Drive Phasing on NSTX

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Abstract. Thomson scattering laser pulses are synchronized relative to modulated HHFW power to permit evaluation of the electron energy confinement time during and following HHFW pulses for both heating and current drive antenna phasing. Profile changes resulting from instabilities require that the total electron stored energy, evaluated by integrating the midplane electron pressure P(sub)e (R) over the magnetic surfaces prescribed by EFIT analysis, be used to derive the electron energy confinement time. Core confinement is reduced during a sawtooth instability but, although the electron energy is distributed outward by the sawtooth, the bulk electron energy confinement time is essentially unaffected. The radial deposition of energy into the electrons is noticeably more peaked for current drive phasing (longer wavelength excitation) relative to that for heating phasing (shorter wavelength excitation) as is expected theoretically. However, the power delivered to the core plasma is reduced considerably for the current drive phasing, indicating that surface/peripheral damping processes play a more important role for this case.

Keywords: RF Heating, Electron Energy and Confinement Time, Spherical Torus

PACS: 52.50.Qt, 52.55.Hc

INTRODUCTION

HHFW heating should occur via electron heating for ion temperatures less than ~ 2 keV [1] for the experiments considered here so that the incremental electron energy divided by the electron energy confinement time can serve as a good indicator of the RF power that is deposited in the bulk of the plasma in this case ($\Delta P_{RFB} = \Delta W_e/\tau_{We}$). With the introduction of a second Thomson scattering laser on NSTX [2] it is now possible to measure τ_{We} and W_e by synchronizing the two laser pulses relative to the modulated HHFW RF power. This then permits the comparison of bulk RF power deposition for different antenna phasing to determine if phasing (i.e., launched spectrum) affects the efficiency of the power reaching the core plasma. The equation governing this technique is

$$W_e = W_0 - [W_0 - W_F] \times [1 - \exp(-t/\tau_{We})] \quad (1)$$

where W_0 is the energy at the starting point of the rise or fall of energy (t = 0), and W_F is the final energy that would be reached after several confinement times. By placing one of the laser pulses near the end of the RF pulse on and off periods, and placing the other laser pulse in between, three measurements are obtained from which W_0, W_F and τ_{We} can be derived in principal for each on and each off period.

ELECTRON PRESSURE RESPONSE FOR HEATING AND CO-CURRENT DRIVE PHASING — k_ϕ = 14 m^{-1} AND – 7 m^{-1}

Discharge conditions were selected for providing a near constant density condition over the time of interest of HHFW modulation and the $P_e(r = 0)$ time traces were observed with the lasers synched with the RF pulses as indicated in Fig.1. Initial

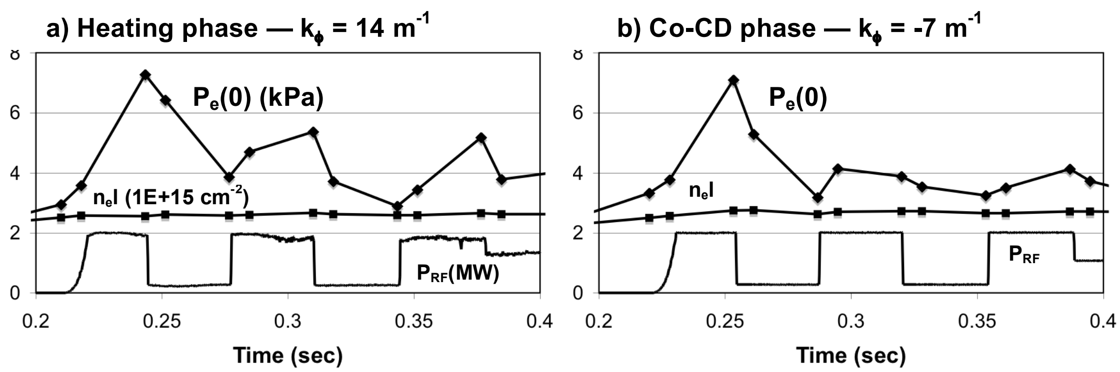

Figure 1. $P_e(r = 0)$ versus time for a) k_ϕ = 14 m^{-1} (Shot 112699) and b) k_ϕ = -7 m^{-1} (Shot 112705). Gas = He, I_P = 0.6 MA, B_T = 0.45 T for both cases.

attempts to apply Eq. 1 to the three measured $P_e(0)$ values for each rise or decay period for the RF pulses were not generally successful (e.g. note that $\tau_{Pe0} \approx \infty$ after the first RF pulse in Fig. 1a and is undefined during the second RF pulse of Fig. 1b) due to fluctuations of $P_e(0)$ caused by MHD instabilities and/or radial displacements.

The P_e radial profiles at the ends of the 1st and second 2nd pulses are given in Fig 2

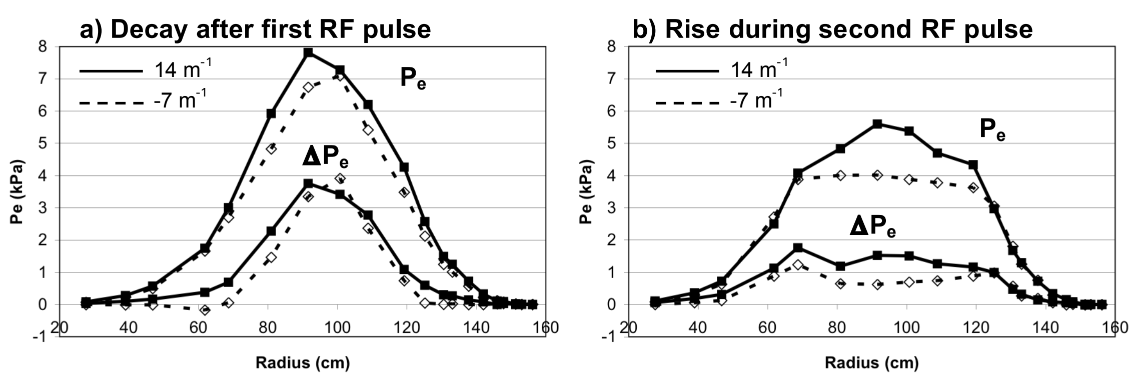

Figure 2. P_e versus radius at end of RF pulse and ΔP_e during a) the decay after the first RF pulse and b) the rise during second RF pulse. Discharge conditions as in Fig. 1.

along with the ΔP_e values over the associated decay and rise periods. For the first decay period the profiles are peaked and the ΔP_e profiles indicate that the RF deposition profile is somewhat narrower for the smaller k_ϕ as expected theoretically [3]. Minor profile perturbations can change $P_e(0)$ (the point near 100 cm) in Fig 2a and a sawtooth instability hollows out the pressure profile in Fig. 2b for the k_ϕ = -7 m^{-1} case (the laser time is only 0.2 ms after the crash). To compensate for profile changes, the total electron energy contained in the plasma can be calculated versus time in order to determine values of τ_{We}.

ELECTRON STORED ENERGY AND ESTIMATED RF POWER DEPOSITION FOR k_ϕ = 14 m^{-1} AND -7 m^{-1}

In order to determine $W_e(t)$, the Thomson scattering electron pressure $P_e(r, t)$ measurements taken on the midplane of the plasma are integrated over the EFIT magnetic surface defined volumes [4]. Generally, the $P_e(r)$ profile on the midplane does not exactly match the $P_{Total}(r)$ profile obtained with EFIT (the EFIT profile is usually somewhat broader and shifted somewhat outward in major radius) so the inner and outer (from R_o) values of $P_e(r)$ are each integrated over the EFIT defined volumes and the resulting W_e values are then averaged. $W_e(t)$ values thus obtained are given in Fig. 3 and compared with the corresponding $W_{EF}(t)$ values. A flattening of W_e during

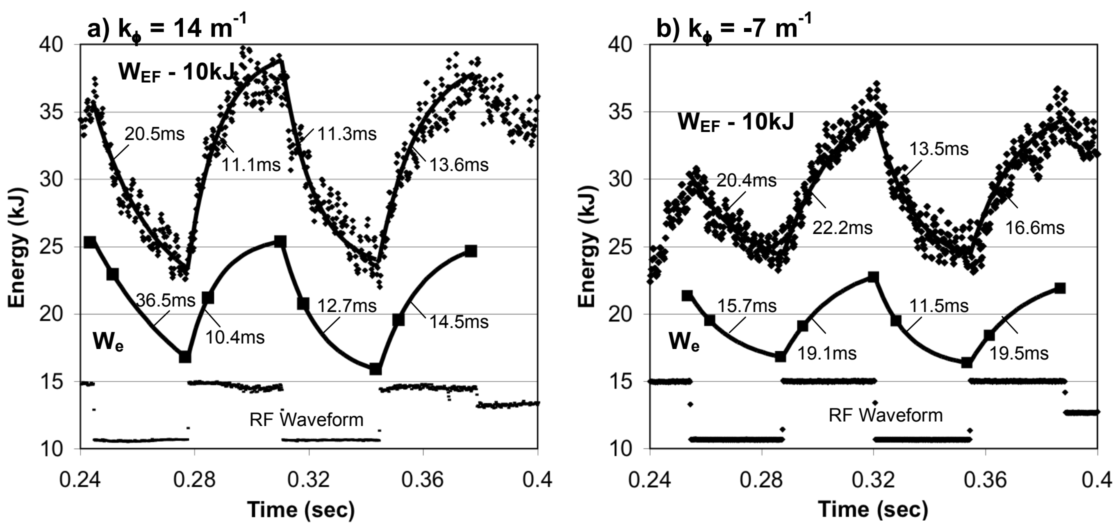

Figure 3. Electron stored energy W_e and total EFIT stored energy W_{EF} versus time for a) k_ϕ = 14 m^{-1} and b) k_ϕ = -7 m^{-1}.

the second RF pulse for the -7 m^{-1} case is not observed as it was for $P_e(0)$ (see Fig. 1) and τ_{We} can be calculated straightforwardly. The resulting τ_{We} values for the W_e are qualitatively similar to the corresponding τ_{WEF} values for W_{EF}.

An estimate of the core power deposition, $\Delta P_{RFD,}$ to the electrons to produce the observed W_e values during the RF pulses can be obtained from $\Delta W_{eF}/\tau_{We}$ where ΔW_{eF} is the difference in final W_{eF} values (Eq. 1) with and without the RF pulse, and similarly from $\Delta W_{EFF}/\tau_{WEF}$ for the EFIT total stored energy. Table 1 summarizes the power estimates for the second and third RF pulses. These estimates indicate that the

TABLE 1. Estimate of power delivered to the bulk plasma from W_e and W_{EF}.

	ΔW (kJ) $\Delta W_{eF}/\Delta W_{EFF}$	**τ (ms)** τ_{We}/τ_{WEF}	**ΔP_{RFD} (MW)** $\Delta P_{RFDe}/\Delta P_{RFDEF}$	$\eta = \Delta P_{RFD}/\Delta P_{RF}$ η_e/η_{EF}
14 m^{-1} 2nd pulse	15.1/19.4	10.4/11.1	1.45/1.75	0.84/1.01
14 m^{-1} 3rd pulse	10.6/16.0	12.7/13.6	0.834/1.18	0.48/0.68
-7 m^{-1} 2nd pulse	7.9/15.1	19.1/22.2	0.413/0.680	0.24/0.39
-7 m^{-1} 3rd pulse	7.2/12.6	11.5/16.6	0.626/0.759	0.36/0.44

RF power reaching the electrons is on average about 3/4th that going to the bulk ($\eta_e \div \eta_{EF}$), and that the delivered power to the electrons is substantially less than that launched from the antenna, especially in the -7 m^{-1} co-current drive case.

CONCLUSIONS

The electron energy confinement time obtained from an integration of $P_e(r)$ over the EFIT magnetic surface defined volumes tracks reasonably well the total energy confinement time obtained from EFIT analysis for both the heating 14 m^{-1} and co-current drive -7 m^{-1} cases. However, considerable RF power does not reach the core of the plasma, especially in the longer wavelength -7 m^{-1} case. Many processes are possibly contributing to this “surface” power loss – surface wave excitation, RF sheath dissipation, and parametric decay wave excitation to name a few. The presence of decay waves was detected in these cases and edge power loss, attributable to helium ion heating via the Bernstein wave, was determined from analysis of ERD (edge rotation diagnostic) measurements to be several hundred kilowatts and to increase with wavelength (16%, 23% of P_{RF} loss for 14 m^{-1}, -7 m^{-1}, respectively) [5,6]. The dramatic difference in apparent surface power loss between the two phasing cases considered here, suggests that accurate modeling of these cases should help to resolve the dominant loss mechanism(s) at play.

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