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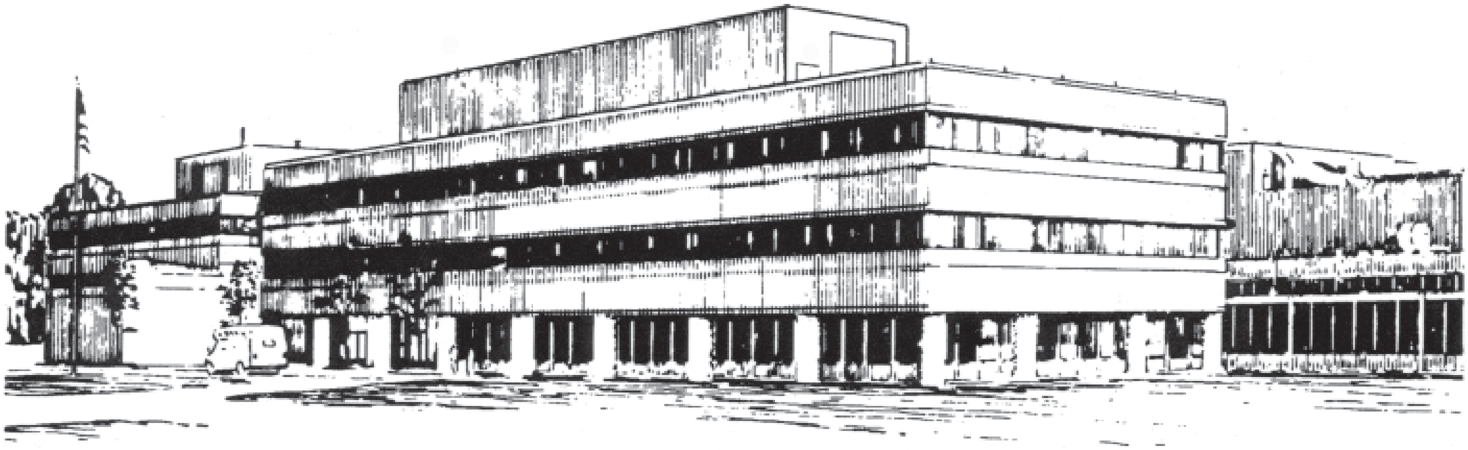

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Investigations of Low and Moderate Harmonic Fast Wave Physics on CDX-U [1]

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Abstract. Third harmonic hydrogen cyclotron fast wave heating studies are planned in the near term on CDX-U to investigate the potential for bulk ion heating. In preparation for these studies, the available RF power in CDX-U has been increased to 0.5 MW. The operating frequency of the CDX-U RF transmitter was lowered to operate in the range of $8 - 10$ MHz, providing access to the ion harmonic range $2\Omega \sim 4\Omega$ in hydrogen. A similar regime is accessible for the 30 MHz RF system on NSTX, at 0.6 Tesla in hydrogen. Preliminary computational studies over the plasma regimes of interest for NSTX and CDX-U indicate the possibility of strong localized absorption on bulk ion species.

INTRODUCTION

The physics of the low harmonic fast wave regime has been studied extensively in tokamak environments, but is largely unexplored for ST's which typically have a high dielectric constant and a higher ion beta than tokamaks. In this regime mode conversion to the IBW may become significant [1]. It has been suggested that third harmonic fast wave heating could be used for bulk ion heating in reactor scale tokamak plasmas [2]. However, little work has been done to examine the applicability of third harmonic ion cyclotron heating in the ST geometry. The two strap phasable antenna on CDX-U provides an excellent opportunity to investigate the low ion cyclotron harmonic regime of ST wave physics. Figure 1 provides an overview of the CDX-U geometry and typical operational parameters. The CDX-U operation parameter space allows for the investigation of second, third and fourth hydrogen cyclotron harmonics in both on-axis and off-axis scenarios. A similar third hydrogen harmonic regime is accessible in NSTX at 0.6 Telsa toroidal field.

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CDX-Parameters:

- $R_o = 34\text{cm}$
- $a = 22$ cm
- $b = 35 \sim 38$ cm
- $\kappa = b/a = 1.55 \sim 1.7$
- triangularly= $0.2 \sim 0.4$
- $B_{T0} = 2.3$ kG
- $I_p \sim 80$ kA
- $n_{e0} \sim 4 \times 10^{19}\ \mathrm{m}^{-3}$
- $T_{e0} \sim 100$ eV

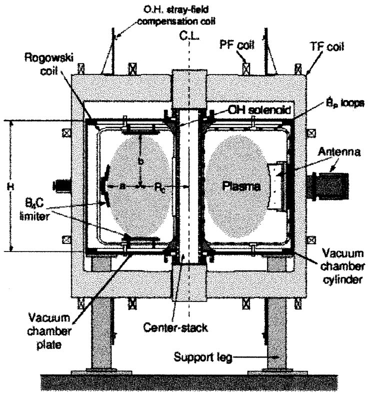

FIGURE 1. Cut-away view of CDX-U, with typical operational parameters

NUMERICAL SIMULATIONS

Two numerical simulation codes, CRF [3] and METS [4], were used to explore the feasibility of low harmonic fast wave power absorption. Both codes are 1-D slab plasma models which include a toroidal geometry induced radial k_z up shift. CRF calculates solutions to the full hot plasma dispersion relation through the entire plasma region. METS solves for the wave fields to all orders in $k_\perp \rho_i$ and produces a power absorption profile for each species present in the plasma.

Figure 2 provides an example of the CRF generated plasma dispersion relation for typical CDX-U plasma parameters, with the radial location of the hydrogen and deuterium cyclotron resonant layers highlighted. Using a simple model for wave attenuation of a ray launched radially inward, $P_{loss}(r) = 1 - exp\left[-2\int_0^r Im\left(k_\perp(x)\right)dx\right]$, one can estimate the power attenuation profile. The attenuation profile in Figure 3 indicates the potential for localized absorption in the typical CDX-U 90% H / 10% D plasmas near the hydrogen ion cyclotron harmonics. Results in a pure hydrogen plasma have similar localized behavior near the hydrogen cyclotron harmonics, suggesting that the minority species plays a negligible role in the fast wave damping process near the hydrogen harmonics.

METS was subsequently employed to obtain more detailed information about the absorbed power split between species, and to determine how much of the fast wave energy propagated onto the IBW branch. Figure 4 shows the power absorption profiles calculated by METS for a CDX-U relevant plasma, with the third hydrogen harmonic located on-axis. METS has been used to explore the applicability of third ion cyclotron harmonic heating in larger spherical tori. Figure 5 shows the fast wave power absorbed on the third hydrogen harmonic located at the magnetic axis as a function of ion beta for a target 90% H / 10% D plasma in NSTX and NSST relevant parameter regimes. The β_{ion} scans indicate that fast wave power absorption is strongly dependent on β_{ion}. Because of the smaller physical size of the CDX-U plasma, the METS code has difficulty converging for some parameter choices. Work is underway to update the numerical algorithm in METS. Upon completion, similar β_{ion} studies will be performed

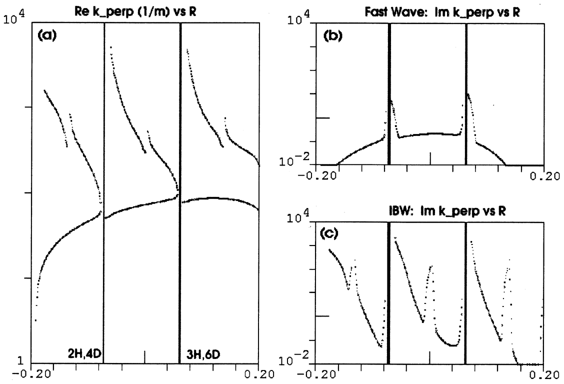

FIGURE 2. 1-D dispersion relation for a 90% H / 10% D plasma in CDX-U under typical operational parameters. Shown here is $k_\perp$ as a function of CDX-U minor radius, with the ion harmonic locations indicated and labeled. (a) Real part of $k_\perp$ for both fast wave and IBW. (b) Imaginary part of $k_\perp$ for the fast wave. (c) Imaginary part of $k_\perp$ for the IBW. Similar IBW and fast wave coupling features near the hydrogen harmonics occur for 100% H plasma simulations as well, suggesting that the minority species is not critical to the ion cyclotron heating mechanism

for CDX-U.

CONCLUSIONS

Numerical simulations, using CRF and METS 1-D codes, indicate that 3rd harmonic fast wave heating could lead to strongly localized single pass absorption on bulk ion species in ST geometries. Furthermore, simulations indicate power absorption is strongly dependent on β_{ion}. Discrepancies between the different types of β_{ion} scans, temperature, density and magnetic field variations, suggests a more complicated relationship between these primary plasma parameters. Experimental studies on CDX-U to investigate third harmonic hydrogen absorption are planned to begin in the near future. Future work also

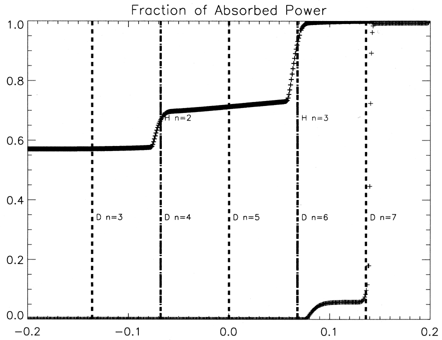

FIGURE 3. Fast wave attenuation calculation for a typical CDX-U plasma, based on the simple propagating ray approximation, $P_{atten}(r) = 1 - exp\left[-2\int_0^r Im(k_\perp(x))\,dx\right]$. Drops in wave power are localized to hydrogen harmonic regions, where the dispersion relation in Figure 2 indicates close coupling of IBW and fast wave branches.

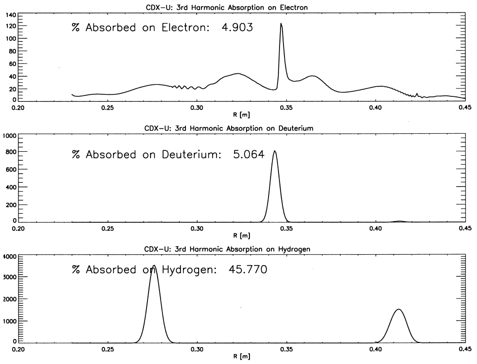

FIGURE 4. METS calculated by species power absorption profile in a 90% H / 10% D plasma for typical CDX-U operational parameters. Strong absorption on the dominant hydrogen at the 3rd and 2nd hydrogen harmonics.

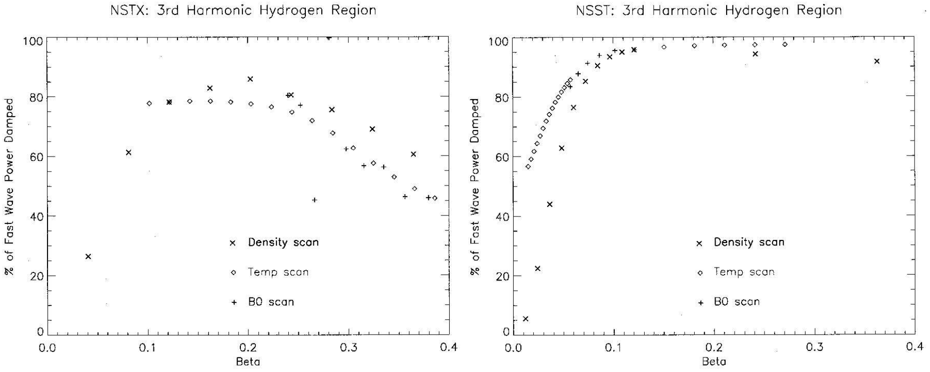

FIGURE 5. β_{ion} scan comparisons between NSTX and NSST. Both show a strong dependence on β_{ion}. ($\times$ variation in density, $\diamondsuit$ variation in T_i, $+$ variation in B_0)

includes continued investigations of absorption parameter dependence via numerical simulations, as well as work towards an understanding of the applicability of analytical models for third harmonic heating such as [2] to the the ST regime.

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