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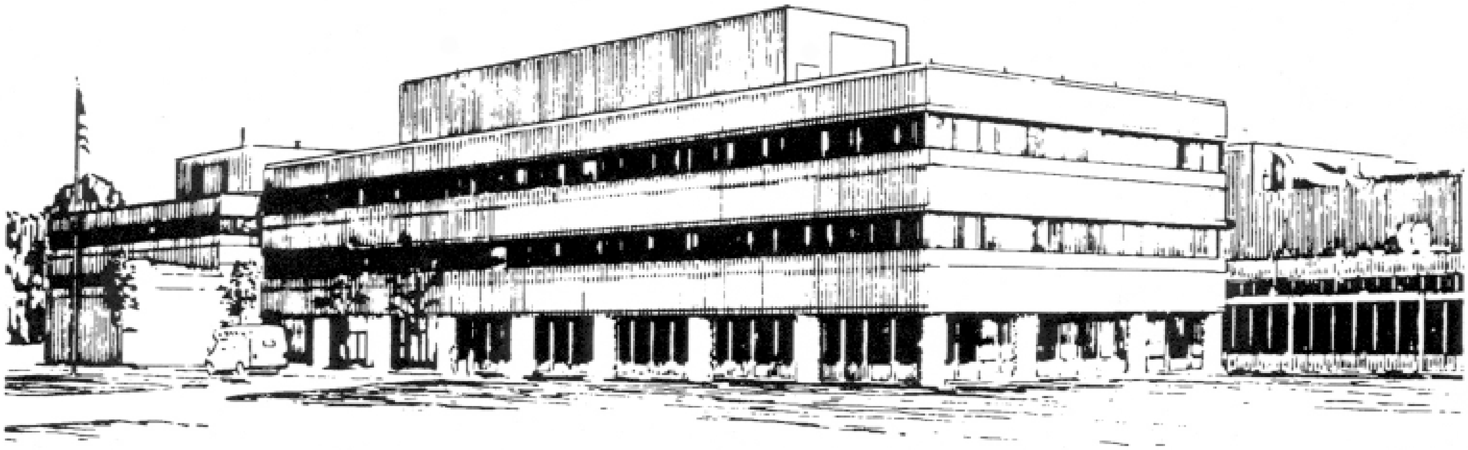

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Mode Conversion Heating Scenarios for the National Compact Stellarator Experiment

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Radio frequency heating scenarios for the National Compact Stellarator eXperiment (NCSX) are considered. The focus here is on mode conversion from the fast to the slow ion Bernstein wave as either an electron or “bulk” ion heating technique, using a high-field side launch to directly access the ion-ion hybrid layer. Modeling for the planned parameters of NCSX (R_{ave}~1.4 m, a_{ave}~0.4 m, $B_T(0)$~1.2-2T, $n_e(0)$~2-5×10^{19} m^{-3}, $T_e(0)$~$T_i(0)$~1-2 keV) for mode conversion in D-H and D-^{3}He plasmas is presented. Possible types of high-field side antennas are also briefly discussed.

Introduction

The National Compact Stellarator experiment (NCSX), a compact, quasi-axisymmetric stellarator (QAS), which is proposed for construction at the Princeton Plasma Physics Laboratory, has as one of its missions the exploration of high beta equilibria in the QAS configuration. These experiments will require high power RF heating at the 6 MW level, in addition to the baseline heating system - 6 MW of neutral beam injection. In order to make maximum use of existing facilities, a low frequency (~20-30 MHz) heating scenario is desirable. Further constraints are imposed on the choice of a heating scenario by the use of hydrogen neutral beam injection, and a desire to avoid production of a fast ion tail. During the NCSX Physics Validation Review in March, 2001[1], a decision was reached to focus on mode conversion heating as the scenario of choice.

Mode Conversion Heating

Mode conversion heating was first successfully demonstrated using a high field side launch in the TFR tokamak [2]. Efficient, localized electron heating using mode conversion was demonstrated in TFTR [3], and more recently has been extensively utilized in C-MOD [4]. In tokamaks, a low field side launch of the fast wave in D-^{3}He has now been most commonly employed. Mode conversion with a high field side launch, which is efficient with a wider variety of ion species mixes, has now been utilized successfully in stellarators, notably CHS [5]. Modeling of NCSX plasmas has indicated that a high field side fast wave launch is necessary to efficiently access the mode conversion surface. It appears possible that the present NCSX modular magnetic field coil design will permit installation of a high field side "combline" antenna [6].

The METS 95 code, a 1-D hot plasma full-wave code which has been extensively benchmarked during mode conversion heating experiments in TFTR and C-MOD, has been employed to model mode conversion in NCSX. Mode conversion scenarios for NCSX have now been identified for D-H and D-^{3}He plasmas. Either ion or electron heating can be selected through an appropriate choice of the species mix, magnetic field, and launched wavenumber.

Mode conversion in D-H

The results of modeling D-H mode conversion are shown in Fig. 1 (a &b). Figure 1(a) is a plot of the dispersion relation for 10% H in a D majority plasma, with a central magnetic field of 1.6 T, a central electron density of 5×10^{19} m^{-3} (parabolic profile), for a fast wave excited on the high field side at 20 MHz with a wavenumber of 9 m^{-1}. As is well-known, a fast wave launched from the high field side has direct access to the IBW branch of the dispersion. Minimization of tunneling to the low field side of the mode conversion region is assured by choosing a wavenumber and species mix which results in a wide evanescent layer, as shown in Figure 1(a).

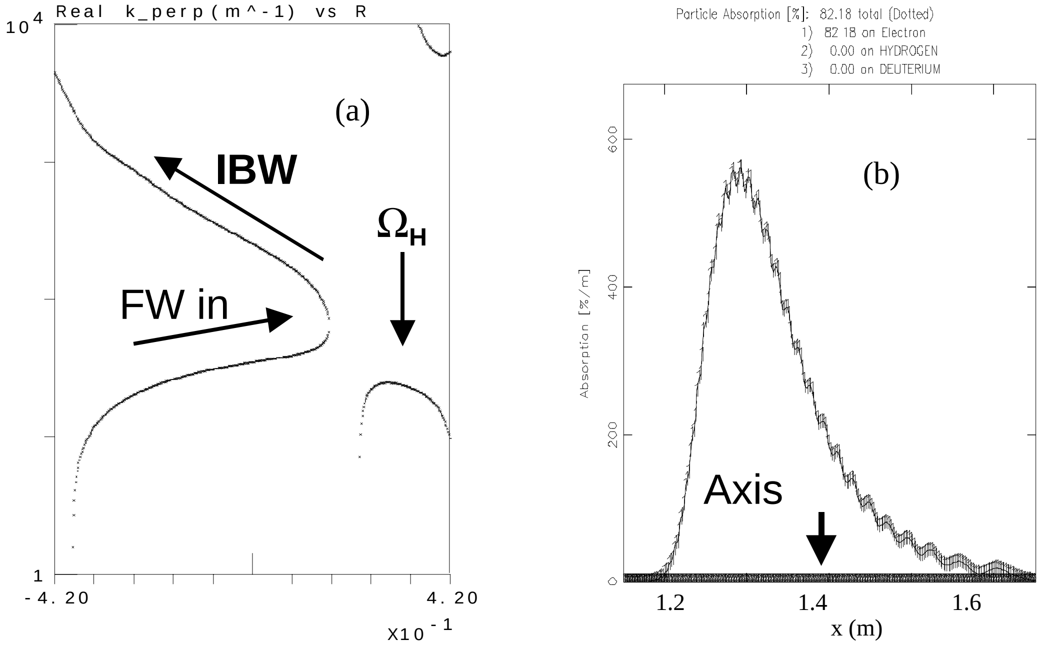

Figure 1. Dispersion relation for mode conversion in 10% H/90% D in NCSX (a), and power deposition profile (b). 82% of the launched power is deposited on electrons within the simulation window, with a full-width at half-max of ~15 cm. Central density for the simulation was 5×10^{19} m^{-3} (parabolic profile), central $T_e = T_i = 1$ keV, 1.6 T, with a launched frequency of 20 MHz and wavenumber of 9 m^{-1}.

For the ion and electron temperatures chosen (T_e=T_i= 1 keV), METS 95 indicates that majority D/minority H mode conversion will produce relatively weak absorption, with a broad deposition profile on the electrons. Absorption occurs to the high field side of the hydrogen cyclotron layer, so that for near-axis electron absorption the Ω_H layer must be located well to the low field side of the axis. Still lower hydrogen concentrations (~5%) would allow experiments in conventional light ion minority heating, although fast ion tail populations are not expected to be well confined in NCSX.

Mode conversion in H-^{3}He

The most promising and flexible ion system for mode conversion heating in NCSX is H - ^{3}He, which should permit localized ion or electron heating (or electron current drive), either on or off axis. With a transmitter frequency of 20 MHz (the lowest practical frequency for the existing PPPL sources), on axis heating can be obtained at central magnetic fields as low as 1.3T. Localized electron heating can be produced in H-^{3}He for a wide range of species mixes and wavenumbers. However, ion heating is predicted for low concentrations of either hydrogen (light ion minority) or helium (heavy ion minority). In Figure 2 (a - c) power deposition profiles for mode conversion in varying H-^{3}He mixes are shown. Fig. 2(a) shows the results of METS 95 modeling for 10% H in ^{03}He. At high launched wavenumber (12 m^{-1}) ion heating is predicted. Ion tail formation will be lessened due to the high hydrogen concentration. If a lower launched wavenumber or a higher hydrogen concentration is chosen, then localized electron heating rather than ion heating is predicted. Note that the deposition profile is very narrow, with a FWHM of approximately *2 cm.* 3D effects will likely broaden the deposition profile, but insofar as the mod-B surfaces lie on flux surfaces very narrow power deposition profiles are likely.

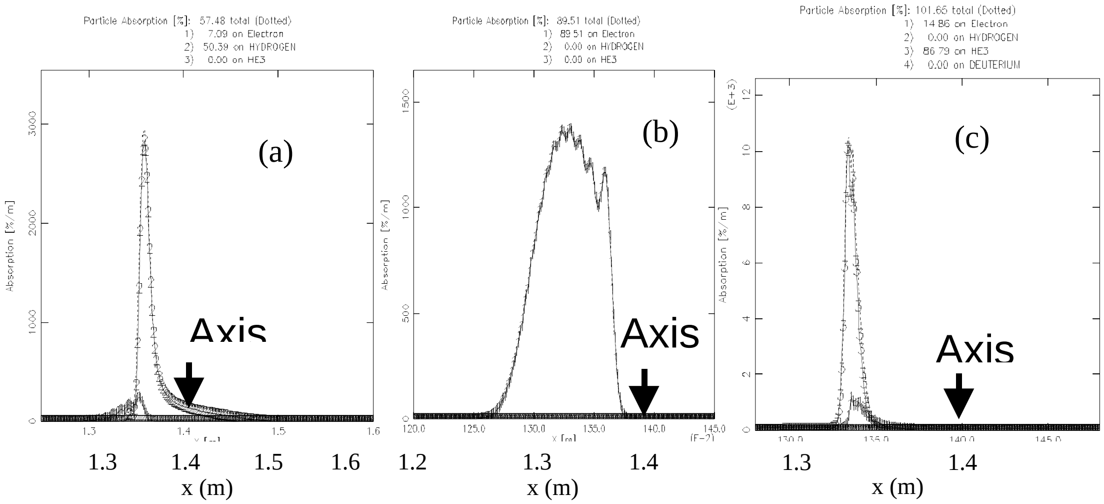

Figure 2. Power deposition profiles with increasing fractions of H in ^{3}He for mode conversion at 20 MHz in NCSX. (a) Hydrogen heating, 12 m^{-1}, 10% H in ^{3}He, 1.3T. (b) Electron heating, 6 m^{-1}, 25% (n_i/n_e) ^{3}He in H, 1.5T. (c) ^{3}He heating, 4 m^{-1}, 10% ^{3}He in H, 1.8T.

At higher ^{3}He fractions electron heating is predicted to dominate, for a wide range of launched wavenumbers. In Figure 2(b) is shown the modeled power deposition profile for 25% ^{3}He concentration, at 1.5T. 90% of the power is deposited on electrons. In Figure 2(c) a predicted deposition profile for 10% ^{3}He in H is shown, at 1.8T. Deposition at large minor radius may be interesting here, since this case corresponds to IBW ion damping near a cyclotron resonance, which is desirable for rf shear flow generation. Operation at 1.5T would result in power deposition at r/a ~ 2/3. Note that the deposition layer (in this 1-D model) is very narrow, with a FWHM of about 1 cm.

These capabilities (localized or broad electron heating, localized current drive or current profile control, localized ion heating, possible rf shear flow drive) combine to make mode conversion heating an attractive physics tool for NCSX.

RF systems and antennas for mode conversion

As stated earlier, the most attractive antenna for a high field side launch in NCSX is probably the combline [6], which utilizes "passive" excitation of a wide array of current straps. In order to provide the required 6 MW of RF heating, three antennas could be installed in NCSX, on the high field side of the device, with each antenna centered about the "bullet" plasma cross section.

The existing PPPL FMIT units could be used for mode conversion in NCSX, in a time-sharing arrangement with NSTX. An engineering study has determined that operation of four of the FMIT sources over the frequency range of 20 - 30 MHz is feasible; this would provide 6-8 MW of rf source power. Although the sharing of sources precludes simultaneous RF heating of NSTX and NCSX, the transmitter modifications proposed would require minimal down time to change frequencies.

Conclusion

Modeling with a 1-D full wave code indicates that mode conversion heating is feasible for NCSX, provided the device design can accommodate a high-field side antenna.

Acknowledgements

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