ICRF HEATING AND CURRENT DRIVE FOR TFTR AND ADVANCED TOKAMAKS

J.E. Scharer and R.S. Sund

Electrical and Computer Engineering Department
University of Wisconsin-Madison, Madison, WI, USA 53706

Abstract

Comparison with experimental results and methods for utilizing ion cyclotron range of frequencies power to provide the heating and current profile control for TFTR and moderate beta operation of advanced tokamaks are considered. Mode conversion current drive in TFTR and the large aspect ratio, high beta machine LCT-2 (ETX) are considered. Minority heating for startup from ohmic conditions is considered for the ETX machine as well. The results presented show that ion cyclotron range of frequency methods are attractive for use in advanced tokamak regimes.

1. Mode Conversion Current Drive in D-T in TFTR

We consider the experiments for D-T supershots in which lithium-7 pellets have been replaced by lithium-6 for wall conditioning. We utilize the nonlocal large gyro-radius code SEMAL [1] which solves an integrodifferential equation for global wave fields and incorporates large ion gyroradii. We have previously found that small fractions of ^{7}Li (0.5-0.7%) have given rise to strong absorption due to the D-^{7}Li two-ion resonance lying on the low field side of the D-T two-ion resonance for 30 MHz mode conversion experiments on TFTR. This greatly reduced the mode conversion efficiency for coupling to electrons. The use of ^{6}Li changes this process so that much more power is available to couple to the electrons in moderate temperature TFTR plasmas.

We consider the supershot series of D-T experiments on TFTR and the role of the alphas, tritium, deuterium and electron absorption on the mode conversion efficiency. We have considered T_{i0} = 30-10 keV with parabolic squared temperature and parabolic density profiles. The alphas are modelled by equivalent Maxwellians whose profiles are parabolic to the fourth power for density and parabolic for temperature.

The equivalent Maxwellian temperature is $T_{\alpha 0}$ = 800 keV and the peak alpha density for T_{i0} = 30 keV is taken to be $n_{\alpha 0}$ = 0.2% to illustrate alpha particle absorption effects. Figure 1 illustrates one of the runs for $k_z = 8\ m^{-1}$, T_e = 6.5 keV, $n_{e0} = 4.5 \times 10^{19}/m^3$, $n_D = 0.4\ n_e$, $n_T = 0.32\ n_e$, $n_H = 0.1\ n_e$ and $n_C = 0.03\ n_e$, R_0 = 2.62 and B_0 = 5.1 T. The code is a global wave code such that reflections from the high field side are taken into account in the total absorption. Note that the integrated tritium absorption at these high temperatures is 58%, the electrons 17%, the alpha particles 15% and the deuterium absorption is 9%. It is interesting to note that for these parameters, the alpha absorption is competitive with the electrons and the tritium ion absorption is substantial. When the ion temperatures are reduced to 20 or 10 keV corresponding to some of the shots, the fractional tritium absorption is reduced and the electron fraction is increased.

A series of runs for TFTR mode conversion cases which are close to experimental conditions is shown in Table I. Note that at shorter wavelengths corresponding to k_z=8m^{-1} and lower ion temperatures of 10 keV, the absence of tritium beam fractions and alphas allows a substantial fraction of electron absorption, leading to efficient current drive. However, when appreciable fractions of tritium beam distributions are present as in case t24.1, the electron absorption fraction decreases at the expense of tritium beam absorption. As the tritium bulk ion temperature is increased further to 30 keV, the electron absorption is further reduced resulting in lower current drive efficiency. Finally, when alpha particles are introduced, they also absorb a small fraction of the wave power with the tritium beams dominating the wave absorption.

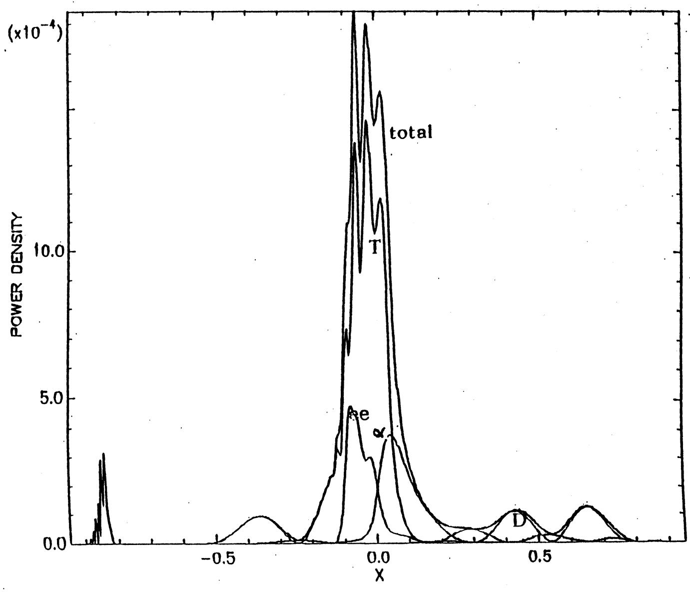

Fig. 1. D-T mode conversion current drive for TFTR

Table I. TFTR Mode Conversion Current Drive Simulations

For all runs:	R_0 = 2.62	B_0 = 5.1 T	T_e = 6.5 keV
	f = 30 MHz	$n_e = 4.5\ e^{19}/m^3$	$n_D = .4\ n_e$
	$n_T = .32\ n_e$	$n_H = .1\ n_e$	$n_C = .03\ n_e$
	T_{tbeam} = 56 keV	n = parabolic	T = $(\text{parabolic})^2$

Run #	T_i (keV)	k_z (m-1)	n_{Tb}/n_T	P_e	P_{Tb}	P_T	P_D (%)
t1.15:	10	8	0	97.2	0	1.4	1.4
t24.1:	10	8	0.2	24.5	72.6	1.9	1
t78.3:	30	8	0	21.0	0	71.7	7.3
t78.4:	30	8	0.2	9.1	53.2	31.6	6.1
t24.10:	30	5	0.1	37.7	18.7	38.0	5.6

For the following runs, alphas have been added, $n_\alpha = 9 \times 10^{16}\ (1 - (r/a)^2)^4/m^3$ approximated by a Maxwellian with $T_\alpha = 800\ (1 - (r/a)^2)$ keV.

Run #	T_i (keV)	k_z (m-1)	n_{Tb}/n_T	P_e	P_{Tb}	P_α	P_T	P_D
t30.2:	10	8	0.2	20.9	63.6	1.8	1.4	13.2

2. LCT-2 High Aspect Ratio, High Beta Tokamak

We have considered radiofrequency antenna coupling, heating, current drive and plasma rotation concepts and analyses for the LCT-2 large aspect ratio tokamak which is under construction at UCLA [2]. This machine has several features which make it attractive for high beta research. Since it is a large aspect ratio machine with a large plasma size, antennas can be mounted on the high field side or the low field side. The large surface access available for antennas permits a low coupled rf power density and the potential for good spectrum control using antenna array factors. The magnetic field line curvature is also reduced compared to the low aspect ratio machines allowing a 1-D nonlocal description of the wave heating and current drive scenarios. Our research has explored low and high field side antenna coupling, plasma heating at lower ohmic densities and magnetic fields, concepts for localized current drive for profile control (including two-ion mode conversion schemes with the wave launched from the high field side) and high harmonic current drive. We have also examined concepts and Fokker-Planck calculations for plasma minority ion ejection to produce a radial electric field which drives plasma rotation and can produce classical ion transport and stabilize MHD ballooning and kink instabilities.

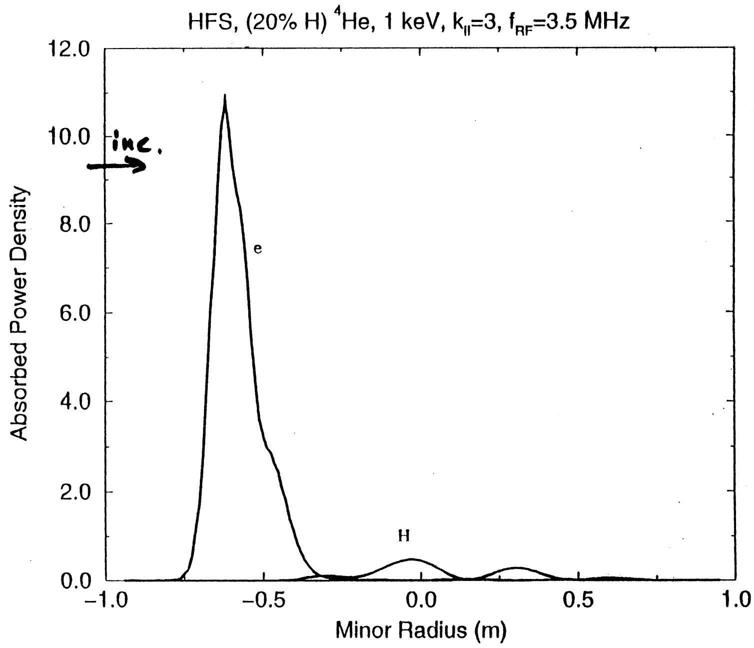

Fig. 2. High beta mode conversion

To illustrate some of the results for this machine, we consider the generation of localized radiofrequency non-inductive electron currents needed for profile control. We considered a high field current drive launch scenario with 20% hydrogen in a ^{4}He high beta ($T = 1$ keV, $n = 1 \times 10^{13}/\mathrm{cm}^3$) plasma at 0.25 T and a launched frequency of 3.5 MHz with a $k_{||} = 3$ m^{-1}. Figure 2 illustrates the results of the run utilizing SEMAL which solves an integro-differential equation for the wave fields and incorporates large ion gyroradii. It illustrates that electron current drive via mode conversion which is localized in a 15 cm half-width can be produced with a small amount of hydrogen heating. This method produces the localized current drive required for profile control during the transition from moderate to high beta conditions.

Acknowledgments

The authors thank Drs. R. Majeski, C. Phillips, G. Shilling, R. Wilson, and R. Taylor for many stimulating discussions on ICRF heating and current drive issues. This research was supported in part by DOE.

References

[1] O. Sauter and J. Vaclavik: Nucl. Fus. **32**, 1455 (1992).
[2] R. Taylor, et al.: “High Beta Tokamak LCT-2 proposal”, *private communication,* (1997).