Investigation of Current Drive Possibilities with the present ICRH system in Wendelstein VII-AS

S.C. Chiu*)

IPP 4/241 January 1990

MAX-PLANCK-INSTITUT FÜR PLASMAPHYSIK

8046 GARCHING BEI MÜNCHEN

MAX-PLANCK-INSTITUT FÜR PLASMAPHYSIK

GARCHING BEI MÜNCHEN

Investigation of Current Drive Possibilities with the present ICRH system in Wendelstein VII-AS

S.C. Chiu*)

IPP 4/241 January 1990

---

*) Permanent address:
General Atomics, P.O. Box 85 608
San Diego, Ca. 92138

14/49

Die nachstehende Arbeit wurde im Rahmen des Vertrages zwischen dem Max-Planck-Institut für Plasmaphysik und der Europäischen Atomgemeinschaft über die Zusammenarbeit auf dem Gebiete der Plasmaphysik durchgeführt.

S.C. Chiu

IPP 4/241

Investigation of Current Drive Possibilities with the present ICRH system in Wendelstein VII-AS

January 1990

Abstract

With the double antenna configuration, designed for first heating tests on W VII-AS, a maximum driven current of 390 A/MWcoupled can be expected when using a frequency of 75 MHz and a phasing of $\pi/2$.

Current drive with ICRH can be most easily investigated in a stellarator since any effect should readily show up in the otherwise currentless stellarator. For optimal current drive antenna arrays with good directivity are required. This work estimates the amount of current that could be driven using the present configuration with only two antennas, designed for first heating tests.

The possibility of current drive depends on whether power can be deposited on the electrons in a preferential direction. This depends on the spectrum of the antenna, the absorption by electrons and ions in that spectrum, and, of course, the current drive efficiency.

(A) Spectrum

Wendelstein has a pair of antennas, which can be arbitrarily phased. It then gives the possibility of asymmetry in the spectrum.

Consider two current strips (Fig. 1) separated by a distance L each of width W, and excited with a relative phasing of $\Delta\phi$. The toroidal wave number (assumed to be approximately the parallel wave number) is

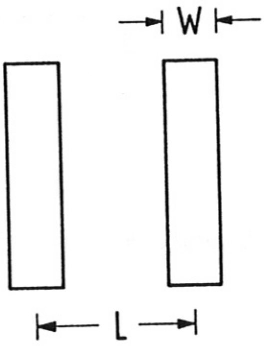

Figure 1

$k_{\parallel} = n/R_o$, R_o = major radius, approximately a constant. The spectrum of current excited is

$$|J_n|^2 \propto 1/2 \left[1+\cos\left(\frac{nL}{R_o} + \Delta\phi\right)\right] \left(\frac{\sin \frac{nW}{2R_o}}{\frac{nL}{2R_o}}\right)^2 = f(n,\Delta\phi)\ (g/n,W)$$

$(f/n,\Delta\phi)$ is sinusoidal whose peaks are shifted by $-\Delta\phi$.

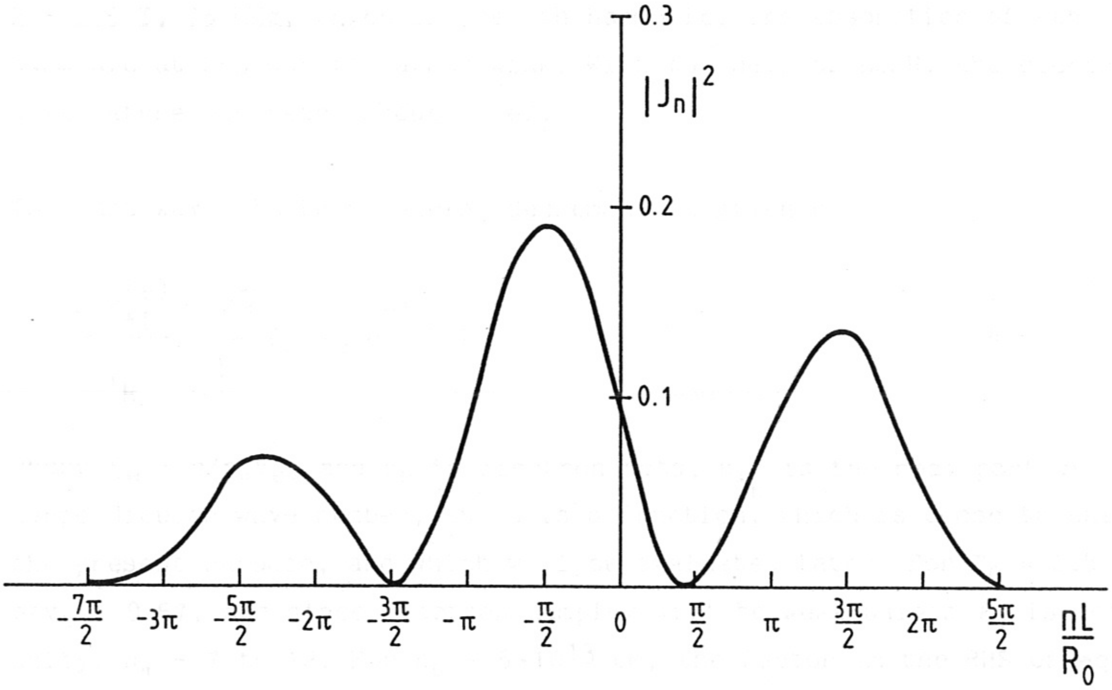

Figure 2

The envelope function g determines the relative amplitudes at the peaks $nL/R_o = -\Delta\phi + 2m\pi$, $m = 0, \pm 1, \pm 2$ .... The spectrum for the case for $\Delta\phi = \pi/2$ is plotted in Fig. 2. The spectrum of actual power coupled to the plasma is somewhat different because of the dependence of coupling on $n_{\parallel}$. At f = 75 MHz, the three peaks correspond to $n_{\parallel} = -2.2$, 6.67 and 11.11. The power in the peak at $n_{\parallel} = -11.11$ is considerably smaller than that in n'' =

6.67. The power in the peaks at $n_{\parallel} = -2.2$ and 6.67 are comparable but the absorption mechanisms are different. At $n_{\parallel} = -2.2$, ion damping should dominate, while at the other peaks, electron damping dominate. We thus have a certain degree of asymmetry of absorption.

(B) Electron Absorption

The absorption mechanism of fast waves by electrons is a rather weak mechanism in ICRF. We have to avoid strong ion damping. Take deuterium, B = 2.5 T, 75 MHz, which is the 4th harmonic. The absorption of 4th harmonic at 2-3 keV is rather weak. With the help of ECRH, the electron temperature can reach about 3 keV.

The fast wave electron damping decrement is given by

$$\frac{2\, k_{\perp I}^{(e)}}{k_{\perp_R}} = \frac{\sqrt{\pi}}{2}\, \beta_e\, \xi_e\, e^{-\xi_e^2}\, G\ , \qquad (4)$$

where $\xi_e = c/n_{\parallel}V_e$, and β_e is electron beta, $k_{\perp_R}$ is the real part of perpendicular wave number, and G is a function, which is close to unity for the present purpose, and which will be evaluated later. For $T_e = 2.8$ keV, $c/v_e \sim 9.57$, and since electron damping will be weak unless ξ_e is near unity, $n_{\parallel} \sim 7$ to 12. For $n_e \sim 6 \cdot 10^{13}$ cm, the factor on the RHS of eq. (4) is about $1.62 \cdot 10^{-3}$ for $n_{\parallel} \sim 6.67$ and 3.64×10^{-3} for $n_{\parallel} \sim -11.11$. For the $n_{\parallel} \sim -2.2$ peak, this factor is about $3.25 \cdot 10^{-10}$, so the power in this part of the spectrum will not go to electrons if there is some deuterium 4th harmonic damping or parametric decay.

The single pass absorption is approprimately $4k_{\perp I}^{(e)}\, \bar{a}$, where $\bar{a}$ is an average minor radius which is taken to be 15 cm. The value of $k_{\perp R}$ may be estimated from the dispersion relation

$$n_\perp^2 = \frac{(s-n_\parallel^2)^2-D^2}{S-n_\parallel^2} \qquad (5)$$

where

$$S = 1 - \sum_i \frac{\omega_{pi}^2}{\omega^2-\Omega_i^2} \simeq - \frac{\omega_{pi}^2}{\Omega_i^2}\,\frac{1}{l_c^2-1},$$

$$\omega = l_c\Omega_i,$$

$$D = \frac{l_c^2}{l_c^2-1}\,\frac{\omega_{pe}^2}{\omega\Omega_e}\ .$$

Thus, taking $l_c \simeq 4$, and $\omega/V_A \simeq 1.45\ \mathrm{cm}^{-1}$, $\frac{\omega_{pi}^2}{\Omega_i^2} \simeq 3636$ for deuterium,

$$k_\perp \simeq 1.45\ \left[\ -\left(6.67\cdot 10^{-2} + \frac{n_\parallel^2}{3636}\right) + \frac{1.07}{1+\frac{15}{3636}\,n_\parallel^2}\ \right]^{1/2}$$

The values for the three $n_\parallel$ values are given in Table I.

$n_\parallel$	$k_\perp$	G	$k_\perp G$	$4k_{\perp I}^{(e)}\ \bar{a}$
- 2.2	1.45	-	-	-
6.67	1.32	1.15	1.52	.074
-11.1	1.09	1.24	1.35	.147

Table I.

The expression for G is given in Ref. (1). They are evaluated and shown, together with single pass damping decrements in Table I. As can be seen, we have an unhappy situation that although the peak at $n_\parallel = 6.67$ is twice as large as that at $n_\parallel = -11.1$, the later is almost twice absorptive. We cannot count on multiple pass because the directionality of the waves is not clear after one bounce in the stellarator geometry. We may hope that because of edge evanescence, the large $n_\parallel$ peaks are weaker, but this cannot be ascertained unless a coupling calculation is made. One may finally hope that the difference of J/Pd may give some uncancelled current drive. Unfortunately, the J/Pd is rather flat in the region $0.7 < \xi_e < 1.4$ (a difference of about 10 %). Thus we cannot confidently conclude that there will be current drive with $\pi/2$ phasing. The situation will not be much better in other phasings because for $\Delta\phi > \pi/2$, the absorption at the second peak will decrease while for $\Delta\phi < \pi/2$, the amplitude and coupling of the second peak will decrease and approach that of the third peak.

The present conclusion for prospect of current drive with the existing antenna configuration (which were designed for first heating tests) is not very optimistic. The efficiency of current drive for the individual peaks at $n_\parallel = 6.67$ and 11.1 is around .05 - .06 A/W absorbed. Assuming there is 20 % power coupled in $n_\parallel \sim 6.67$, 5 % power coupled in $n_\parallel \sim 11.1$, the single pass absorbed power in $n_\parallel \sim 6.67$ is about 15 $kW/MW_{coupled}$, in $n_\parallel \sim 11.1$ is about 13 $kW/MW_{coupled}$ the current driven for the two peaks together is about 390 $A/MW_{coupled}$.
For current drive purposes, it would be worthwhile to maximize the asymmetry of the spectrum. Without drastic change of hardware, one can possibly increase the asymmetry by increasing the ratio W/L. This is because the envelope function $g = \sin^2 \frac{nW}{2R_o} / (\frac{nL}{2R_o})^2$ is a function of W/L at the peaks of the spectrum. Assuming W = 20 cm, the ratio of the second and third peaks increase from 2.1 to 2.8 when L is changed from 45 cm to 40 cm.

References

(1) S.C. Chiu, V.S.Chan, R.W. Harvey, M.Porkolab, GA-A19534, to be published in Nuclear Fusion.