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OBSERVATION OF CURRENTS DRIVEN BY RF WAVES AT THE ELECTRON CYCLOTRON RESONANCE IN THE CULHAM LEVITRON

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ABSTRACT

An observation of current generated by RF waves at the electron cyclotron resonance is reported. The current is found to flow in opposite directions on opposite sides of the non-Doppler shifted resonance position confirming that the current is driven by asymmetric heating of the electron distribution function by Doppler shifted waves. Scaling measurements show that the current (∿30mA/W) is directly proportional to both the microwave power and electron temperature and inversely proportional to the density.

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INTRODUCTION During the last few years there has been growing interest in the possibility of driving the plasma current in a tokamak reactor continuously using RF waves. In 1980 Fisch and Boozer[1] proposed a scheme which relies on creating an asymmetric plasma resistivity. In this scheme an electron cyclotron wave, for example, is used to increase the perpendicular energy of resonant electrons moving in a particular direction along the magnetic field lines. The reduced collisionality of these electrons leads to an asymmetry of the electron distribution function which manifests itself as a current. The present experiments were designed to search for such a current.

EXPERIMENTAL METHOD AND RESULTS The experiments were carried out using the Culham Levitron which is an axisymmetric toroidal system with a levitated superconducting ring of major radius 30cm and minor radius 4.5cm[2]. The ring current was 120kA and the current through the centre column providing the toroidal field was 65kA. The helium plasma was produced by ECRH using a 10GHz microwave source. Power levels of up to 120watts were used to form plasmas with temperatures

(T_e) and densities (n_e) in the range $1\text{x}10^{11} < n_e < 3\text{x}10^{11}$ cm^{-3} and $3\text{eV}<T_e<18\text{eV}$. For each set of conditions the profiles of T_e and n_e were measured using a swept double probe. The microwave power was 100% square wave modulated at 2.88kHz and the total oscillating current flowing in the plasma was detected through the voltage induced in a 40 turn coil which looped the plasma in the poloidal direction. The coil signal was recorded digitally as was the signal from the microwave power monitor. The 2.88kHz component of each signal was then extracted by Fourier analysis. The observed coil signal consisted of a component due to the current flowing parallel to the field and a component arising from the modulation of the perpendicular diamagnetic current due to modulation of T_e and n_e. The diamagnetic component (∿15% of the parallel current) was eliminated by making measurements with 'normal' and 'reversed' toroidal fields and averaging the results. Typical signals from the coil are displayed in the inset of Fig.1 showing that the current rises in about 15μs after the microwave power onset. This fast rise shows that the current is not carried by runaway electrons and is consistent with the skin-time of the plasma. The upper and lower coil signals show the reversal of the current when the poloidal direction of the microwave input power is reversed. Note that the principal field is the poloidal field in the Levitron.

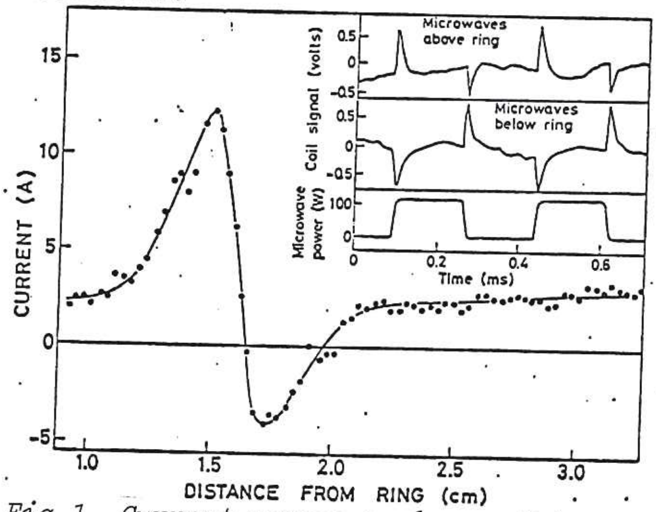

Fig.1 Current versus probe position
The inset shows the coil signal for microwave input above and below the ring.

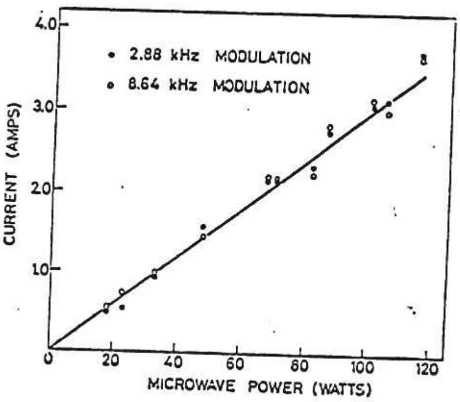

Fig.2 Current versus microwave power.

The radial position of the current was located using a floating probe which intercepted 3mm of the plasma in minor radius and 5cm in the toroidal direction and which served to inhibit the current. (The probe adjusts its floating potential to draw an essentially randomly directed current from the background plasma to cancel the intercepted wave driven current). Figure 1 shows the 2.88kHz component of the coil signal as a function of the probe position in minor radius. The electron cyclotron resonance is 1.55cm from the ring. The data are averaged over 'normal' and 'reversed' toroidal field conditions. As the probe moves inwards the current is unaffected until the resonance region is approached. At 2.1cm the net current begins to fall and reverses sign until the resonance is reached. At this point the net current swings positive again as the probe moves closer to the ring. Although the probe produces a large perturbation of n_e and T_e as it passes through the resonance region the results in Fig.1 clearly demonstrate that the current flows close to the electron cyclotron resonance and in opposite directions on either side of it. This behaviour is precisely that predicted by the current drive scheme based on asymmetric heating by a Doppler shifted wave[3].

The current was found to vary linearly with microwave power as shown in Fig.2. Inductive corrections for plasma-skin-time effects of typically 4% and 30% were made for the 2.88kHz and 8.64kHz data respectively. For these experiments a target plasma was formed using 63watts of unmodulated 10GHz microwave power in order to maintain T_e(7.5eV) and n_e ($2.9\times10^{11}cm^{-3}$) constant as the modulated power was increased. The solid line is a least-squares fit giving a current drive efficiency of 30mA/watt.

In Fig.3 the current per unit power times n_e is plotted against T_e. The observed linear dependence of the current per unit power on the ratio T_e/n_e is universally predicted by wave driven current theory provided the effective wave phase velocity (v_o) normalised to the electron thermal velocity (v_e) is constant. There is some evidence from numerical studies of the direct absorption of electron cyclotron waves that this is indeed the case and that v_o/v_e is close to unity[4]. However initial calculations suggest that direct ECRH by the Extraordinary wave is insufficient to explain the magnitude of the observed current. A more probable explanation is that the Extraordinary wave is first converted, at the upper hybrid resonance, to a Bernstein plasma wave which then propagates to, and is absorbed at, the electron cyclotron resonance.

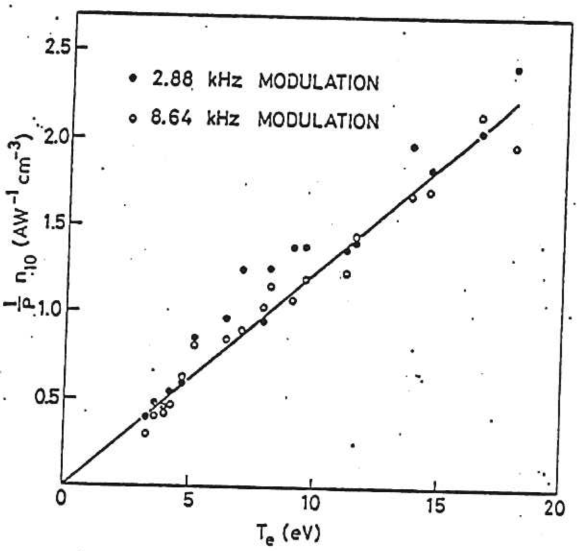

Fig.3 Current per unit power times density versus electron temperature.

SUMMARY We have observed currents of a few tens of milliamps per watt which are driven by the absorption of RF waves at the electron cyclotron resonance. The direction of the current was found to reverse on reversal of the microwave propagation direction. The currents on opposite sides of the resonance were found to flow in opposite directions consistent with the current being driven by asymmetric heating of the electrons by Doppler shifted waves. The current varies linearly both with microwave power and T_e/n_e. The latter result agrees with the general prediction of wave-driven current theory for constant ratio of wave phase velocity to electron thermal velocity.

REFERENCES

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