SELF-CONSISTENT CALCULATIONS OF THE POWER DEPOSITION AND VELOCITY DISTRIBUTION DURING ICRH INCLUDING FINITE ORBIT WIDTHS, SPATIAL RF-INDUCED DRIFT AND DIFFUSION.

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Abstract

SELF-CONSISTENT CALCULATIONS OF THE POWER DEPOSITION AND VELOCITY DISTRIBUTION DURING ICRH INCLUDING FINITE ORBIT WIDTHS, SPATIAL RF-INDUCED DRIFT AND DIFFUSION.

Self-consistent calculations of ICRH for toroidally directed wave spectrum have revealed the importance of including finite orbit width and RF-induced spatial transport. This is in particular important for heating at higher harmonics in which case the cyclotron absorption depends strongly on the details of the distribution function.

1. INTRODUCTION

Heating with waves in the Ion Cyclotron Range of Frequencies, ICRF, results in ion and electron absorption, Further ion or electron currents can be driven by launching toroidally directed waves. If the power density is sufficiently strong, the velocity distributions of the heated ion species become anisotropic and non-Maxwellian, which may affect the power deposition profiles and the partition of the absorbed power between the different plasma species as well as the collisional power transfer. This becomes particularly important for scenarii with moderate or weak single pass absorption, in which case the evolution of the velocity distributions can significantly change the power partition and power deposition profiles. For such cases the velocity distribution and power deposition have to be calculated self-consistently. For asymmetric wave spectra or high power densities in medium sized machines, RF-induced spatial transport and finite orbit width effects become important. A quasi-linear theory for general wave-particle interactions in a toroidal plasma including these effects had been derived in Ref. [1] and one specialised for ICRH [2]. A code SELFO, calculating self-consistently the power deposition and velocity distribution, including these effects has been developed [3]. In the code it is done by iteratively computing the velocity distribution in a toroidal geometry with the Monte Carlo code FIDO [4] and the wave field with the global wave code LION [5, 6] or the $\alpha\kappa$-wave field model [7]. In order to self-consistently include the effects of the non-Maxwellian ion distribution function on the wave absorption the dielectric tensor is constructed from the calculated 3D-distribution function in the torus.

The FIDO code calculates the distribution function of the heated ion species in a toroidal plasma with a Monte Carlo method. The distribution function is given in terms of invariants of the equation of motion for unperturbed orbits (E, P_ϕ, Λ), where E is the energy, $P_\phi = Rmv_\phi + eZ\psi(r)$ is the canonical angular momentum and $\Lambda = B_0\mu/E$ is an adiabatic invariant, defined by the ratio between the magnetic moment and energy normalised with the respect to the magnetic field at the magnetic axis. Since there is not a unique relationship between these invariants and the orbits; the same triple may describe different types of orbits. A label σ is introduced to distinguish between them.

The $\alpha\kappa$-wave field model is based on the assumption that the wave field can be described as a superposition of two wave fields one for weak and one for strong damping. The wave field for strong damping is computed with ray tracing. The wave field for weak damping is given in terms of eigenfunctions of a circular cylinder [7]. The model allows for including the upshift of the parallel wave number due to the finite poloidal magnetic field.

To include the contribution to the dielectric tensor from the distribution function of the heated ion species calculated with the Monte Carlo-code FIDO, which gives the distribution function as a set of orbit invariants, the local velocity distribution function $f(v_\perp, v_\parallel)$ is constructed, which is then used for calculating the susceptibility for plane waves propagating in a quasi-homogeneous plasma expressed in a local orthogonal coordinate system (x, y, z), where z is along the magnetic field and y chosen so that $k_y = 0$ [8].

2. MINORITY ION CURRENT DRIVE

Minority ion current drive including finite orbit width effects and RF-induced spatial transport has been studied in Ref. [9, 10]. In a standard ITER like plasma reversed shear can be achieved by on-axis heating of α-particles with a toroidally directed waves parallel with the plasma current, here represented by a single toroidal mode number $n_\phi = -42$. The inward RF-induced spatial drift accumulates α-particles with non-standard trapped orbits near the magnetic axis. These orbits produce a centrally peaked ion current parallel with the plasma current [11, 12]. The back current caused by collisions with electrons and background plasma species produce a resulting anti-parallel current (assuming $Z_{eff} < 2$). Also the current produced by TTMP and ELD is strongly peaked on axis due to the trapping and is anti-parallel to the plasma current as shown in Fig. 1. [10]. For these calculations the power partition between the plasma species was kept fixed to 42% on the α-particles, 56% on the electrons and the remaining 2% on the other species, according to the initial power partition as calculated with the LION-code.

3. FAST WAVE CURRENT DRIVE IN THE PRESENCE OF PARASITIC ION ABSORPTION

The tail formation during fast wave electron current drive at the third harmonic of the deuterium cyclotron resonance has been studied [3, 13]. The absorption by the ions at $\omega = 3\omega_{CD}$, which is here a parasitic absorption mechanism, increases rapidly with perpendicular velocity $\propto v_\perp^4$. If the tail ions are confined to the region where the power absorption is strong, the formation of the tail significantly reduces the current drive efficiency, whereas if the tail formation is curtailed by removing fast ions from this region by an RF-induced pinch, the ion absorption is then reduced.

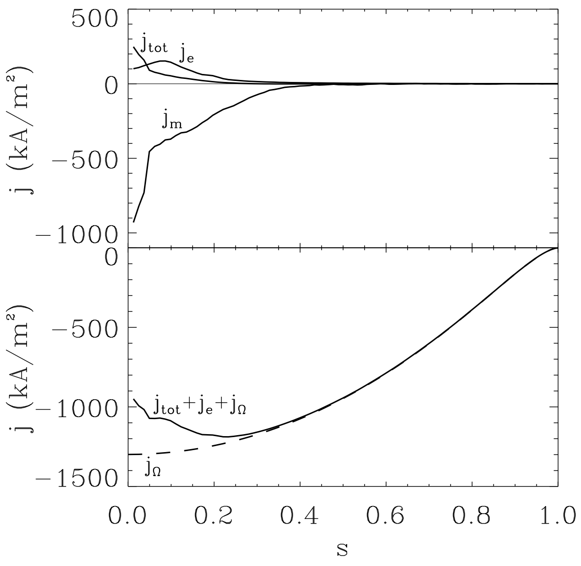

Fig. 1. *Driven current in an ITER-like plasma with on axis heating of α-particles at the fundamental frequency, n_ϕ = -42, j_m is the α-minority ion current, j_{tot} is j_m minus the back current, j_e is the electron current driven by TTMP and ELD. Total heated power 50 MW.*

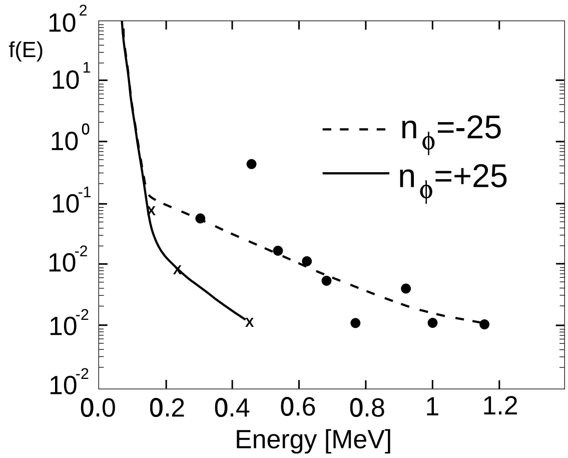

Fig. 2. Energy distribution of deuterium during third harmonic heating for different phasings: n_ϕ = 25 (full) and n_ϕ = -25 (dotted).

These findings are in agreement with those observed in JET, where high energy ions are formed resulting in dominating ion absorption and little direct electron heating [13]. However, in Tore Supra electron current drive is observed [14]. In order to illustrate the effects of the different phasings we have used the following parameters B_0=2.08T, R_0=2.28m, a=0.75m, I_p=0.75MA, P=5MW, $n_D=4\times10^{19}m^{-3}$, $n=n_0\times(1-0.95\times(r/a)^2)^{1/2}$, $T_D=T_e$=5keV, n_ϕ=25 and n_ϕ=-25. For a wave propagating in the opposite direction of the plasma current the fast ions are removed from the centre as they start increasing their energy and absorb power, whereas for a wave directed parallel to the plasma current the RF-drift is directed towards the magnetic axis acting as an inward pinch; the high energy ions are then well confined and a high energy tail builds up as can be seen in Fig. 2. The presence of a tail enhances the single pass damping resulting in a change of the wave field from that of a weak damping scenario to that of strong one as can be seen in Fig. 3. In the absence of a tail only 10% of the power is absorbed by $\omega = 3\omega_{CD}$ and in the presence of a tail the absorption increases to 50% for the case the wave propagates opposite to the plasma current and 80% when it propagates parallel. The corresponding fast wave driven currents become 98kA and 16kA, respectively. By replacing the deuterium with Helium, the tail formation is reduced as well as the asymmetry, with similar plasma parameters but with half of the ion density we found driven currents of 110kA and 30kA. Similar asymmetries and driven currents have been found in Tore Supra [14]. However, in Tore Supra no high energy tails have been detected.

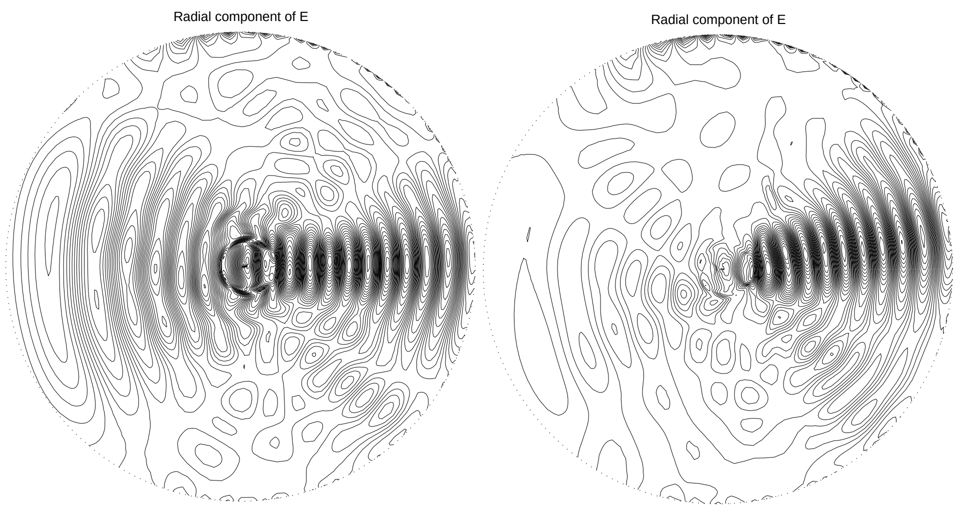

Fig. 3. The electric field component E_r for n_ϕ = -25 in the absence of a tail, to the left, and during steady state in the presence of a tail arising from 5 MW of total coupled power to the right.

4. CONCLUSIONS

For heating and/or current drive with a toroidally directed wave spectrum the RF-induced spatial transport and finite orbit width have an important effect on the formation of the high energy tail, which will affect the power partition, the structure of the wave field and the current drive efficiency. Similar asymmetries and driven currents have been found in Tore Supra [14] as obtained from the self-consistent computations with the SELFO-code.

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