Dc Electric Field and Finite Confinement Time Effects On LH Heated Fast Electrons

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1-Introduction

Tokamak is much more attractive when it is run in steady state. This can be accomplished with an efficient source of continuous toroidal current. The kinetic theory of current drive by high-phase Lower Hybrid Waves (LHW) based on the flattening of the electron distribution function is considered as away to achieve the steady state. This process is studied by numerically solving the two dimensional quasi-linear Fokker–Planck equation. The motivation of our work is to study the influence of the dc electric field and to take into account a finite time life of the superthermal electrons.

2-Statement of the problem

The time evolution of the velocity distribution function of collisional electrons in the presence of LHW, having a finite confinement time, in the presence of a dc electric field is given by the kinetic equation

$$\left(\frac{\partial f}{\partial \tau}\right)=\left(\frac{\partial f}{\partial \tau}\right)_{lh}+\left(\frac{\partial f}{\partial \tau}\right)_{col}+\left(\frac{\partial f}{\partial \tau}\right)_{dc}+\left(\frac{\partial f}{\partial \tau}\right)_{loss}$$

where $f = f(\tau, r, v_\perp, v_{//})$ is the electron distribution function, τ is the normalized time, r is the normalized radial position in the plasma slab, $v_\perp, v_{//}$ are the normalized components of $\vec{v} = \frac{\vec{p}}{(m_e T_{e0})^{\frac{1}{2}}}$ respectively perpendicular and parallel to the confining magnetic field $\vec{B}_0$ and $\vec{p}$ the electron momentum.

The term of LH waves appearing in the above kinetic equation is explicitly written as [1]

$$\left(\frac{\partial f}{\partial \tau}\right)_{lh}=\left(\mu\frac{\partial}{\partial v}+\frac{1-\mu^2}{v}\frac{\partial}{\partial \mu}\right)\left(D_{lh}(v_{//})\left(\mu\frac{\partial f}{\partial v}+\frac{1-\mu^2}{v}\frac{\partial f}{\partial \mu}\right)\right)$$

In [2], it was assumed that the effect of the LHW is appreciable in the plasma core within a cylinder of radius r_{lh} ππ a, a is the plasma radius, where the electron density and temperature are homogeneous so that the quasi-linear diffusion coefficient is also homogeneous within r_{lh}. $D_{lh}(v_{//})$ is given by the following expression

$$D_{lh}(v_{//}) = \frac{4\pi}{e^2 n_{e0}\Omega \ln\Lambda |v_{//}|}\left(\left|\frac{B}{A}\right|\frac{\left|D_{11}D_{22}-|D_{12}|^2\right|}{\left|\frac{\partial D}{\partial \vec{n}}\right|}S(n_{//})\right)_{n_{//}=\frac{\mu^{\frac{1}{2}}}{v_{//}}}$$

where $\mu = \dfrac{m_e c^2}{T_{e0}}$, Ω is the LH wave frequency, $D_{ij} = n_i n_j - n^2\delta_{ij} - \varepsilon_{ij}^c$ and the explicit expressions of $A, B, D, S(n_{//})$ can be found in [2].

The collision operator and the dc electric field terms are given by the expressions

$$\left(\frac{\partial f}{\partial \tau}\right)_{col} = \frac{2}{v^2}\left(\frac{1}{v}\frac{\partial f}{\partial v} + f\right) + \frac{1+Z_i}{v^3}\frac{\partial}{\partial \mu}\left((1-\mu^2)\frac{\partial f}{\partial \mu}\right)$$

$$\left(\frac{\partial f}{\partial \tau}\right)_{dc} = \frac{E_{//}}{E_c}\left(\mu\frac{\partial f}{\partial v} + \frac{1-\mu^2}{v}\frac{\partial f}{\partial \mu}\right)$$

Z_i is the ion charge, $E_c = \dfrac{2\pi n_{e0} e^3 \ln\Lambda}{T_{e0}}$ is the Dreicer electric field

The last term is given by [3] $\left(\dfrac{\partial f}{\partial \tau}\right)_{loss} = \dfrac{1}{v^2}\dfrac{\partial}{\partial v}\left(\dfrac{v^3 f}{2 t_0 v_{e0}}\right)$ where t_0 is the *ad hoc* energy confinement time for the energetic electrons, and v_{e0} is the electron collision frequency.

3-**Numerical results**

In each plasma slab position, we have numerically integrated the basic kinetic equation using a suitable Alternating Direction Implicit (A.D.I) method. The various derivatives of f are approximated by finite differences at each point of the grid (v, μ) using appropriate boundary conditions. We then obtain at each time step a tridiagonal system we solve using a vectorized Gauss elimination technique.

At $\tau = 0$, the form of the electron distribution function is chosen maxwellian. We have investigated the time evolution of the electron distribution function with the following parameters:

$Z_i = 1, n_{e0} = 3.10^{13} cm^{-3}, T_{e0} = 4Kev, v_{1lh} = 3, v_{2lh} = 5, r_{lh} = 0.4, a = 40cm, B_0 = 30KG$

$R_0 = 150cm, f_{lh} = 1.5GHz, S_{lh} = 15Kw/cm^2, v = 0 \to 10, \mu = -1 \to 1, r = -1 \to 1$

In the case where $\left(\frac{\partial f}{\partial \tau}\right)_{loss} = \left(\frac{\partial f}{\partial \tau}\right)_{dc} = 0$, the steady state is achieved at $\tau = 100$ as an equilibrium between collisions and quasi-linear diffusion. In fig.1 we have depicted the parallel distribution function versus $v_{//}$ at $r = 0$ defined by $f(v_{//}) = 2\pi \int_0^\infty v_\perp f(v_\perp, v_{//}) dv_\perp$ which exhibits a plateau in the resonant region with LH waves. A significant population of energetic electrons is created. Fig.2 shows the perpendicular temperature versus $v_{//}$ at $r = 0$, defined as $T_{perp}(v_{//}) = \frac{2\pi T_{e0}}{f(v_{//})} \int_0^\infty \frac{v_\perp^2}{2} v_\perp f(v_\perp, v_{//}) dv_\perp$. Throughout the resonance region, the electrons are at a perpendicular temperature greater than the bulk temperature of the background plasma electrons. The dc electric field has a detrimental effect on the parallel velocity distribution plateau: when fast electrons are diffused in the parallel direction of the magnetic field $\vec{B}_0$ the dc electric field has a role to slow-down these electrons. The increase of the dc electric field is associated to a significant depletion of the resonant plateau and a net decrease of the perpendicular electron temperature as depicted respectively in (fig.3) and (fig.4), at the same plasma position (r=0). Taking into account the effect of the confinement time, numerical results show a significant impact only on the electrons of the distribution tail. As expected, the decrease of t_0 induces quite the same effects found when increasing the amplitude of the dc electric field (figs.5,6). So the experimental improvement of t_0 will have an advantageous effect on the LHW heating efficiency.

4-**Conclusion**

We have numerically investigated the time evolution of the electron distribution function under the combined effects of collisions and LHW using an A.D.I scheme. We have presented the interesting features of the resonant electrons and shown that the dc electric field and the confinement time play an important role on the resonant electrons. The developed Code is now fruitfully used for including the Electron Cyclotron Wave effects to investigate the induced spatial diffusion. However, there is a serious restriction on the use of the Code because calculations are very time consuming for a good accuracy of the computations. The work is in progress and will be reported in a forthcoming paper.

Acknowledgements: The authors are grateful to Dr Paulo R da S Rosa for fruitful suggestions.

References

1- Paulo R da S Rosa, Luiz F Ziebell Plasma Phys. Control. Fusion 38(1996)375
2- I. Fidone, G. Girruzi, G. Granata, R. L. Meyer Phys. Fluids27(1984)2468
3- G. Giruzzi, and al Plasma Phys and control Fusion 27(1985)1151

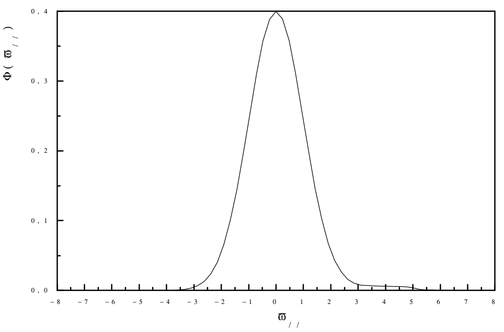


Fig-1-

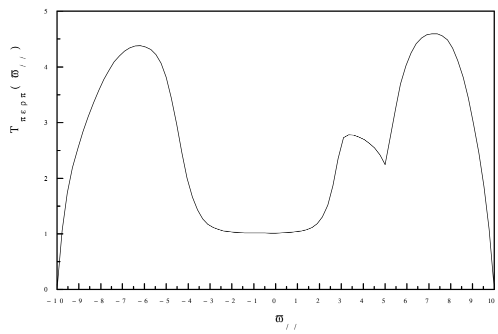
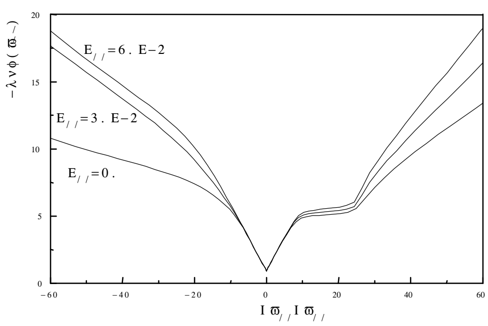


fig-2-



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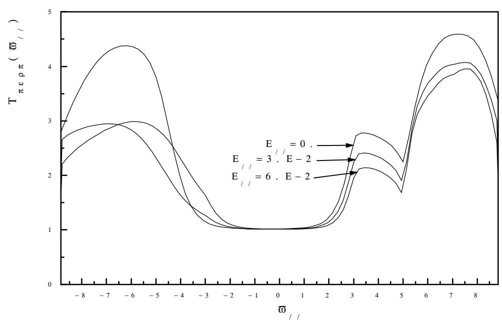

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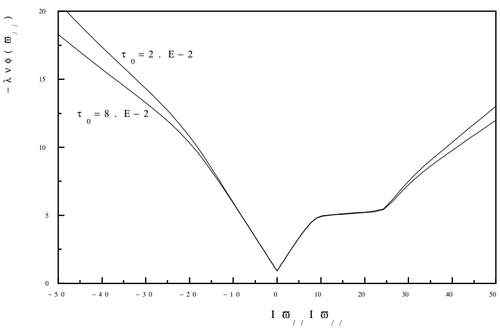
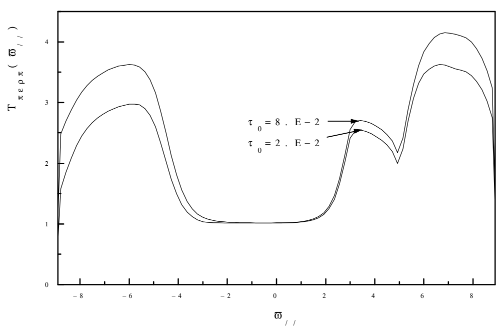


Fig-5-



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