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Radial variations of the floating potential in front of the lower hybrid grill of the CASTOR tokamak

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Lower hybrid waves are currently used in tokamaks for non-inductive current drive. Interaction of LH waves with plasma exhibits series of specific features, some of them not fully described by theory up to now. The reasons are both the high level of plasma density fluctuations in tokamaks as well as the high fluxes of RF power used. One of manifestations of LHW-plasma interaction, observed in various tokamaks (Tore Supra, CASTOR, TdeV), is a thermal overloading of parts of limiters or divertor plates connected directly with the launching antenna by the magnetic field lines. Theory explains this undesirable phenomenon by acceleration of thermal edge electrons due to the trapping by the high spatial harmonics of the wave in a radially very narrow region just at the grill mouth. Ions may be also subsequently accelerated because of the charge separation field generated by the escaping accelerated electrons [1]. This acceleration can be further enhanced by spontaneous excitation of strong random electric fields in front of the grill. The energy of accelerated electrons (ions) can reach several hundreds of eV or, at high RF powers, even several keV [2].

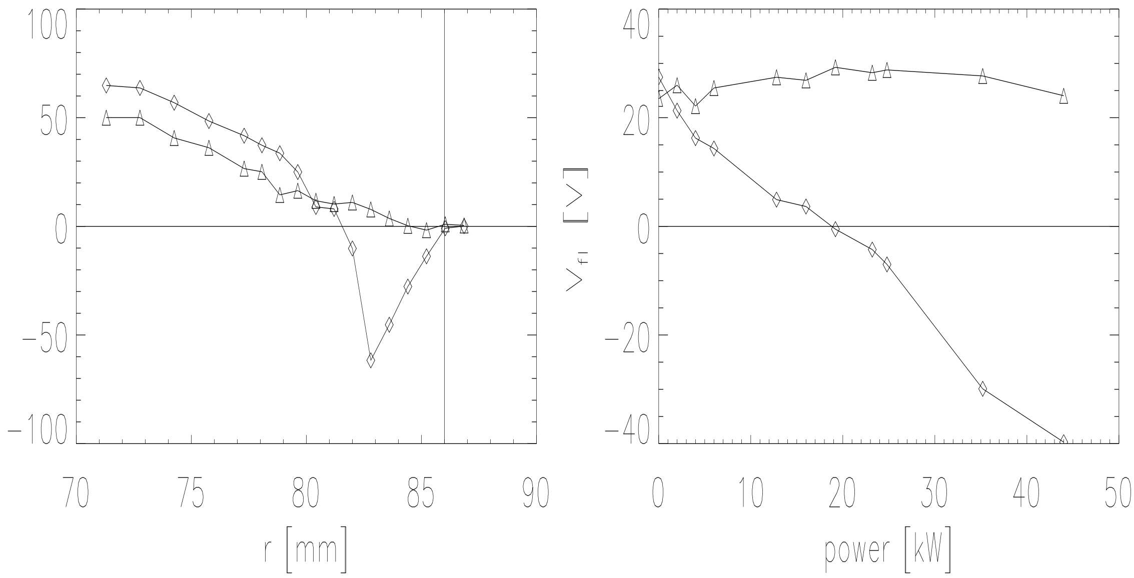
To check some theoretical conclusions concerning generation of fast particles, measurements of the floating potential just in front of the LH grill have been carried out on the tokamak CASTOR (Section 1). Simultaneously, numerical simulations of electron and ion acceleration in front of the CASTOR grill have been done using the 2d3v PIC code XPDP2 from Berkeley (Section 2).

1. Measurements on the CASTOR

Tokamak CASTOR is a small limiter tokamak with major radius $R = 0.4m$, wall radius $b = 0.1m$ and limiter radius $a = 0.085m$, plasma current up to $20kA$, toroidal magnetic field $B_t = 1T$ [3]. Three-waveguide multijunction grill (having the phase shift between adjacent waveguides 90^o) with a broad spectrum $1 \leq N_{||} \leq 5$ has been used as a launcher for the measurements of the electron acceleration effects. Output dimensions of the grill mouth are $160mm$ in the poloidal and $50mm$ in the toroidal directions. The grill is partially circularly shaped in the poloidal plane to follow magnetic surface at the radius $r = 86mm$. Magnetron generator with the power up to $P_{RF} = 50kW$ and frequency $f = 1.25GHz$ was used.

For the measurement of radial profile of floating potential V_{fl} just in front of the grill, a special Langmuir probe has been constructed. The probe is movable through the whole poloidal cross-section of tokamak CASTOR and due to the proper shaping of an insulated probe holder, even measurements inside the grill waveguide are possible. The probe itself is cylindrical, made from molybdenum and its measuring tip has diameter $1mm$ and length $0.5mm$ (to achieve a sufficient radial resolution). The probe signal has been sampled with a rate $0.2\mu s$ and averaged over 10^3 samples, i.e. $0.2ms$.

The measurements of the floating potential V_{fl} (with respect to the liner potential), presented in Fig.1 and 2 below, have been done in the poloidal plane of symmetry of the middle waveguide. Fig.1 shows comparison of V_{fl} radial profiles in front of the grill (position of the grill $r = 86mm$ is denoted by a vertical line in the figure) just before the application of LHW (triangles) and during the application of LHW (diamonds, $P_{RF} = 44kW$). It may be seen from the figure that a very narrow ($2 - 3mm$), radially localized layer of negative V_{fl} is formed just in front of the grill during the LH active phase. Fig.2 shows dependence of this phenomenon on LHW power used (again diamonds during the LHW pulse, triangles just before the LHW pulse). The probe has been placed at radius with a maximum V_{fl} drop for this measurement.



$Fig.1$. Radial profile of probe floating potential V_{fl}.
$Fig.2$. Power dependence of the floating potential drop.

The results obtained can be summarized as follows:
1. the probe floating potential V_{fl} exhibits a strong decrease during LHW application;
2. this decrease is radially localized in a very narrow layer, just in front of the grill;
3. depth of this potential "well" in the layer depends linearly on LHW power and it reaches value nearly 80V for the maximum power 50kW accessible on the CASTOR;
4. all these facts indicate the presence of accelerated electrons in this radially thin layer.

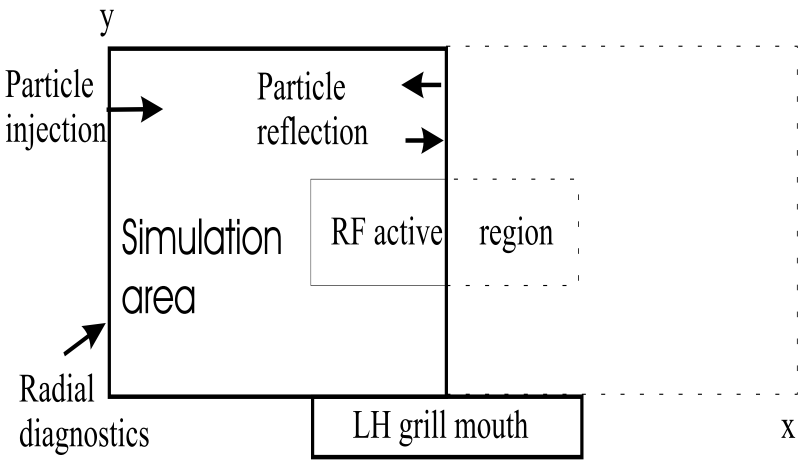
2. Description and results of the model used

We consider a two-dimensional plasma slab in front of the LH grill mouth for our PIC simulation, see Fig.3. In our model, the x and y axes correspond to the toroidal and radial directions, respectively. In the radial direction the boundary conditions are fully periodic.

The electron-wave interaction is modelled by a "ponderomotive" force which acts only on

electrons:
$F_{pond} = -e\partial_x U(x,y), \;\; U(x,y) = (U_o/2)(1 + cos(\pi(L_x - x)/l_{RF,x}))exp(-|L_y/2 - y|/l_{RF,y}),$
where $2l_{RF,y}$ is the radial width of the RF active region, $2l_{RF,x}$ is toroidal length of the RF active region and $L_{x,y}$ are the dimensions of the simulation region.

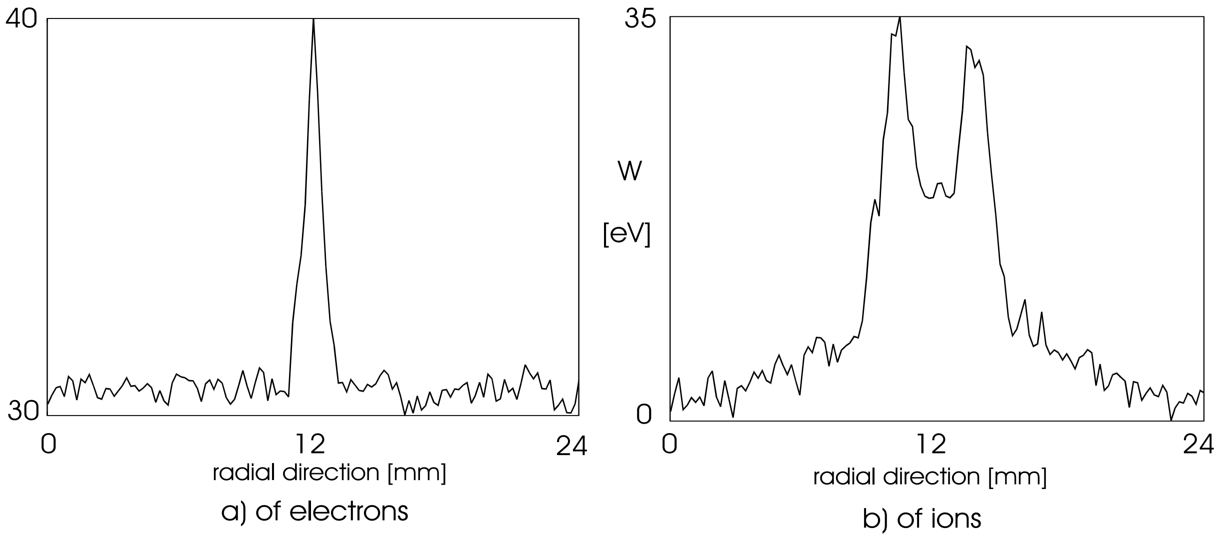
The large size of the plasma region under consideration (more than 10^3 Debye lengths in the toroidal direction), together with the requirement of long runs (more than 4×10^5 time steps), does not allow us to simulate the real CASTOR size system. Hence, we have simulated a system four times smaller. In order to have a correct analogy with the real system, we increased the magnetic field and the diffusion by a factor of four. The simulation parameters are therefore following: plasma density $n_o = 3 \times 10^{17} m^{-3}$ and temperatures $T_e = 3Ti = 15eV$, however, magnetic field strength $B = 3.2T$ and the ambipolar particle source in the RF active region $D = 12m^2/s$.



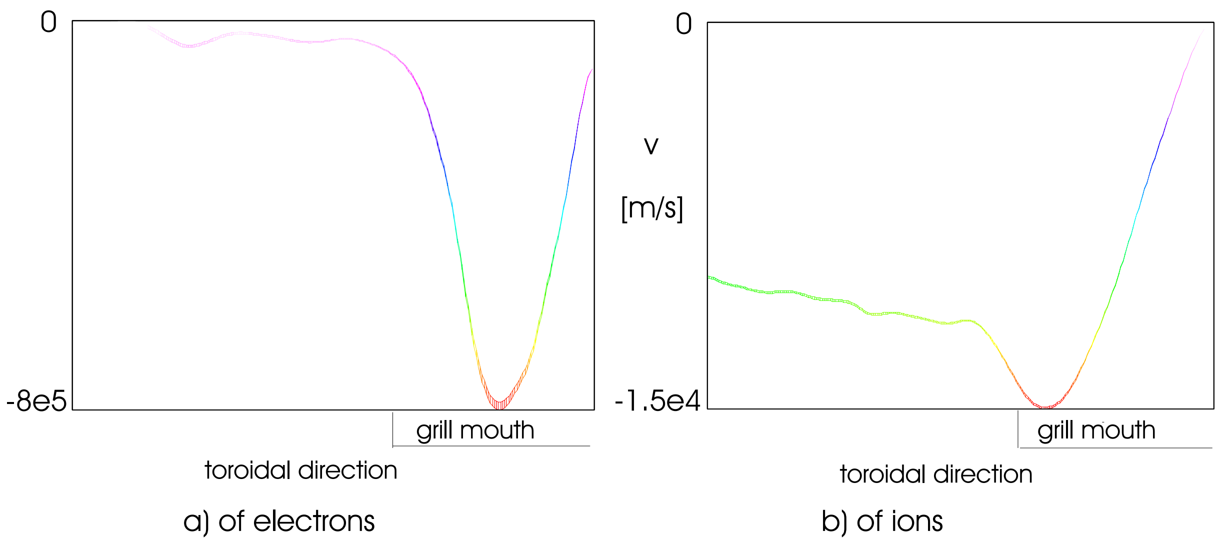
$Fig.3$. Simulation geometry.

We ran the simulation up to the stationary state. The main results of the simulation are given in Figs.4,5. Fig.4 gives the radial profiles of the average energy of the particles crossing the simulation region (propagating into the plasma), Fig.5 toroidal profile of the averaged toroidal velocity of particles (in the center of the active region). These results can be summarized as follows:
1. Both the electrons and the ions are accelerated in the RF active region (while the electrons are accelerated by the "ponderomotive" force, ions are accelerated by the electrostatic field arising due to the charge separation).
2. In the region which is magnetically connected to the RF active region, the average particle energy is seen to exceed $1.3\times$ for electrons and $3\times$ for ions the thermal value $(2T)$. Correspondingly, energy fluxes are $0.5MW/m^2$ for electrons and $0.03MW/m^2$ for ions.
3. The highly energetic electron beam has the same radial width as the RF active region $(2mm)$, whereas the ion beam width is four times larger $(8mm)$.
4. A strong radial electric field in the RF active region, $|E_y| \approx 2 \times 10^4 V/m$, can cause poloidal rotation of the plasma.
5. Inside the RF active region, the particle average velocity is of the order of the thermal velocity.
6. Using these simulation results we can estimate the radial drop in floating potential for a probe

inserted at the center of the RF active region. Namely, by calculating the electron current to the probe and by equating it to the ion current under condition that the electron distribution is close to a shifted Maxwellian with the shift velocity $v_o = 8 \times 10^5 m/s$, we obtain the potential drop ϕ across the probe sheath $\phi \approx 3.8T_e/e$ instead of $\phi_o \approx 2.7T_e/e$ outside the RF active region. The difference $\Delta\phi \approx |\phi - \phi_o| \approx 17V$ is in a qualitative agreement with the experiment.



$Fig.4$. Radial profiles of the average particle energy W.



$Fig.5$. Toroidal profiles of the particles toroidal velocity v in the center of the system.

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References

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