Fast electron generation by LH waves scattered on ponderomotive density modulations in front of LH grills

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Lower hybrid (LH) wave scattering on self-consistent plasma density modulations produced by ponderomotive forces is explored, using the model developed in [1]. A long grill in the poloidal (y) and toroidal (z) directions is assumed; only the hasic mode is considered in waveguides with thin walls. For simplicity, we choose a step and ramp profile for the unperturbed plasma density, $n_0(r) = n_b+n_c\, r/L_n$, where n_b is the boundary density and n_c is the cut-off density (for which the plasma frequency equals the frequency of the LH wave). In the presence of LH power, the density $n_0(r)$ is modified and reads $n(r,z) = n_0(r)\exp(-\delta(r,z))$, $\delta(r,z) = \varepsilon_0\, |E|^2 / 4n_cT$, ε_0 being the permittivity of the vacuum, E is the electric field of the wave and $T = T_e+T_i$ is the temperature. Computed $\delta(r,z)$ and n(r,z) in front of the grill for typical Tore Supra parameters are shown in Fig.1 and 2.

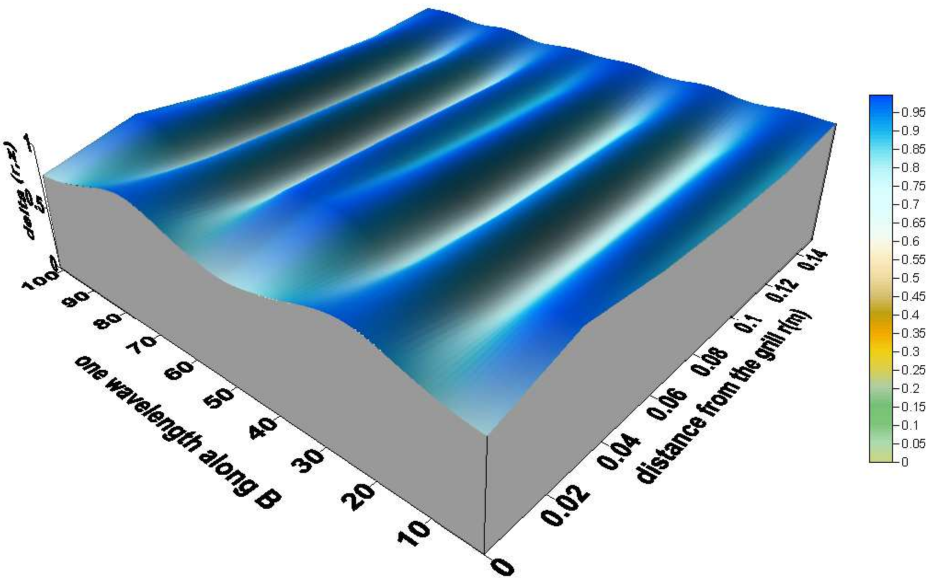

Fig. 1. Graph of $\delta(r,z)$ for the LH power flux = 1.86 kW/cm^2 (corresponds to 1.5 MW on C2), L_T=3 cm, Ln=1cm, T=20 eV, n_b=2.4 x 10^{17} m-3.

The electric field of the wave is assumed to be in the form $E_z(r,z) = \Sigma_s\, (E_s^+(r)\exp(isk_zz)+E_s^-(r)\exp(-isk_zz))$. The individual Fourier components create standing waves. The launched wave then scatters on the density ripple, which it produces. The equations for

$E_s^+(r)$ and $E_s^-(r)$ are solved numerically with the following boundary conditions: for the first harmonic, the value of the field and its derivative is chosen deep enough inside the plasma where the ponderomotive effects are negligible.

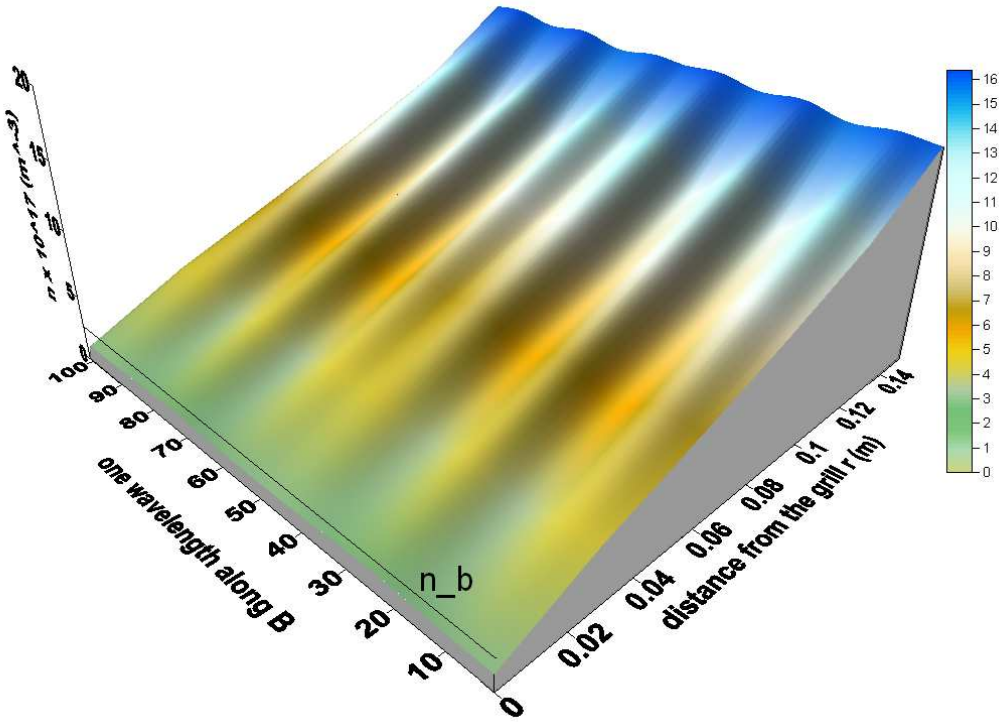

Fig. 2. Graph of n(r,z) for the LH power flux = 1.86 kW/cm^2 (corresponds to 1.5 MW on C2), L_T=3 cm, Ln=1cm, T=20 eV, n_b=2.4 x 10^{17} m-3.

Because of the higher temperature there, ponderomotive forces can be neglected and the wave propagation is described by the linear theory. For higher harmonics, the first boundary condition is the radiation condition inside the plasma. As we want to explore higher harmonics generation from the main wave, so as the second condition it is assumed that no higher harmonics are radiated by the grill. The detailed numerical procedure is described in [1]. The energy flux in the k-th harmonics is proportional to $1/k^2$. The LH wave frequency, the LH power density and plasma parameters correspond to the Tore Supra C2 and C3 launchers. Amplitudes of higher spatial harmonics of the scattered wave, which higher harmonics can produce the electron acceleration near the grill mouth [2], are derived up to the 25th harmonics. It is shown that the SOL (Scrape-off-layer) electrons with velocities along the magnetic field higher or equal to the velocity corresponding to energy of about 80 eV can be accelerated in the field of the scattered

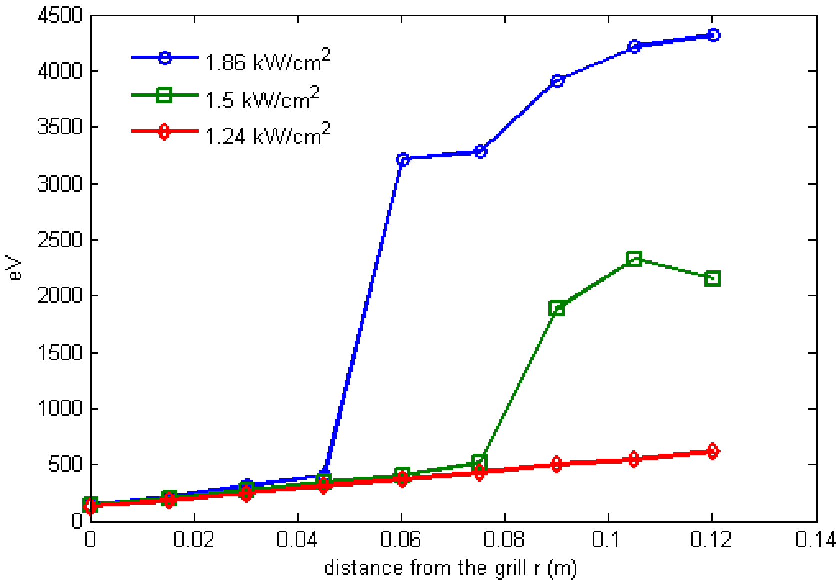

Fig. 3. Acceleration of electrons in the scattered field as a function of radius for varying LH power flux from 1.24 to 1.86 kW/cm^2 (corresponds to 1 - 1.5 MW on C2), L_T=3 cm, Ln=1cm, T=20 eV, n_b=2.4 x 10^{17} m^{-3}, the initial electron energy is 80 eV.

wave up to an energy of several keV, cf. Fig 3 and 4. The radial width of the accelerating region can be several cm as observed [3], however only electrons at the distance larger than about 4 cm radially from the grill mouth can be accelerated in our model.

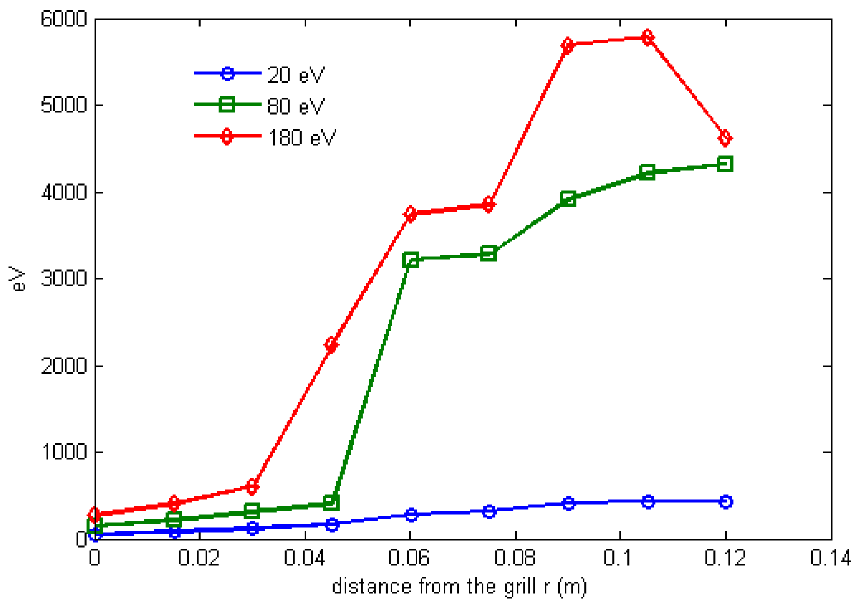

Fig. 4. Acceleration of electrons in the scattered field as a function of radius for the LH power 1.86 kW/cm^2 (corresponds to 1.5 MW on C2), and varying initial electron energy from 20 to 180 eV.

The maximum amplitude of the higher harmonic waves peaks at a certain radial distance from the grill mouth, cf. Fig.5, and therefore the maximum energy and number of the accelerated electrons also peaks several cm from the grill mouth, depending on the LH wave power density and other parameters.

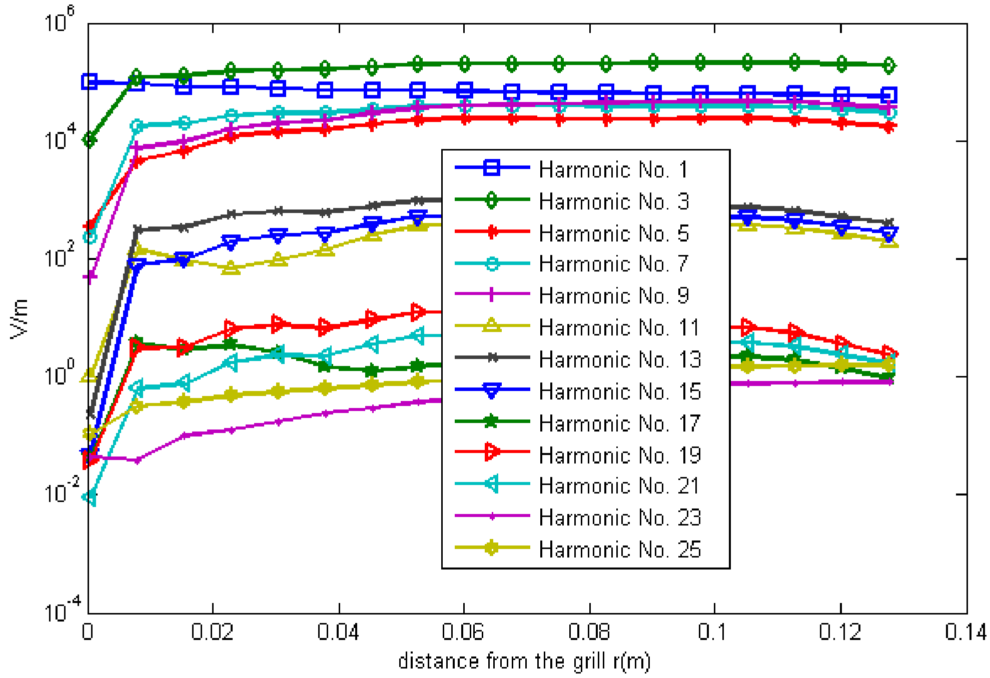

Fig. 5. The radial profile of higher spatial harmonics of the scattered field, propagating in the + direction, for the LH power 1.24 kW/cm^2 (corresponds to 1 MW on C2).

Let us note that the above described wave scattering and resulting electron acceleration process can possibly be at play in producing fast electrons observed experimentally at a distance of several cm from the grill mouth [3]. The higher harmonics launched by the grill and generating accelerated electrons in the SOL [2] are dissipated in a few mm distance from the grill mouth [4], and their presence can not explain the observed [3] radially several cm wide fast electron layer. However, for a detailed comparison with experiment, the launched grill field and its nonlinear modification should be accounted for much more precisely, e.g. by a 3D coupling code, which would be able to take into account the toroidal density ripple.

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