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Contribution of Suprathermal Electrons to Cyclotron Radiation Transport in Hot Toroidal Plasmas

K.V. Cherepanov, A.B. Kukushkin,

NFI RRC "Kurchatov Institute", Moscow, 123182, Russia

1. Introduction. The transport of electron cyclotron radiation (ECR) in hot (T_e > 10 keV) toroidal plasmas confined by a strong magnetic field (B_T > 5 T) is known, for highly reflecting walls, to exhibit the following features [1,2(A),3]: (1) the escaping radiation spectrum is dominated by the high harmonics of fundamental cyclotron frequency; (2) peripheral plasma appears to be a net absorber of the ECR, thus attenuating the radiation emitted by the hot core; (3) spatial profile of the net radiated power density, $P_{EC}(r)$, strongly depends on temperature and density profiles; (4) concentration of $P_{EC}(r)$ in the core (i.e. the peaked profile) may influence the ignition conditions even for not so large *total* ECR power loss.

Here we report on numerical studies of the contribution of suprathermal electrons to $P_{EC}(r)$ in toroidal magnetically confined plasmas. The respective code is based on the approach [2] which allowed, via extending the *escape probability* methods developed in the theory of nonlocal transport, to solve semi-analytically the transport problem in the case of a strong enough reflection of EM waves from the wall. The code was tested [2(A)] against the numerical (Monte Carlo) and semi-analytical results [1] (as well as against the (benchmark) numerical results, and respective analytic fit [4], for *total* ECR power loss for *maxwellian* plasmas of *homogeneous* profiles of temperature and density).

2. Profile effects in non-maxwellian tokamak plasma. An analysis of $P_{EC}(r)$ is carried out for a model bi-maxwellian electron velocity distribution function which qualitatively describes the presence of suprathermal electron under condition of auxiliary heating (either central or off-axis ones):

$$f_e(p,r) = n_{e0}(r)\left\{\left[1-\delta_{ne}(r)\right] f_{MAXW}(p,T_e(r)) + \delta_{ne}(r) f_{MAXW}(p,T_e^{(hot)}(r))\right\}, \qquad (1)$$

$$\delta_{ne}(\rho) \equiv n_e^{(hot)}/n_e = (\delta_{ne})_{\max} EXP\left[-(\rho-\rho_0)^2/(\Delta\rho)^2\right] \qquad (2)$$

$$T_e^{(hot)}(\rho)) = (T_e^{(hot)})_{\max} EXP\left[-(\rho-\rho_0)^2/(\Delta\rho)^2\right] \qquad (3)$$

where ρ = r/a is the normalized radial coordinate in the reduced 1D problem [1] for ECR transport in a non-circular toroidal plasma; relativistic Maxwellian distribution f_{MAXW} is normalized in momentum space; other parameters in Eqs. (2),(3) characterize the density and temperature of suprathermal electrons, and the location and width of their spatial distribution. The profiles of background plasma (Fig. 1) were taken close to those for one of ITER-FEAT regimes predicted by the ASTRA code simulations [5] (see Table 1 in [5]).

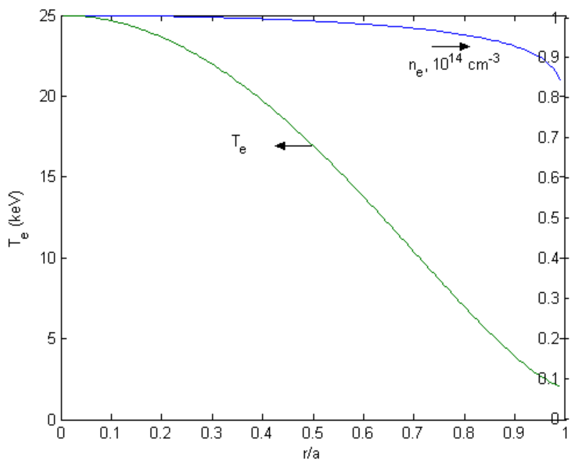

Fig. 1. Electron temperature and density profiles of background maxwellian plasma.

The profiles of $P_{EC}(r)$ and the respective spectral intensity of the ECR escaping from plasma column, (i.e. yet inside the chamber) for the case of non-perturbed (maxwellian) background plasma are shown in Figs. 2,3 for various values of the wall reflection coefficient R_W. The jumps in the curves stem from the calculation procedure (these illustrate the accuracy of calculation procedure's transition from optically thick core to optically thin periphery in the frequency-radius space) and have to be smoothed.

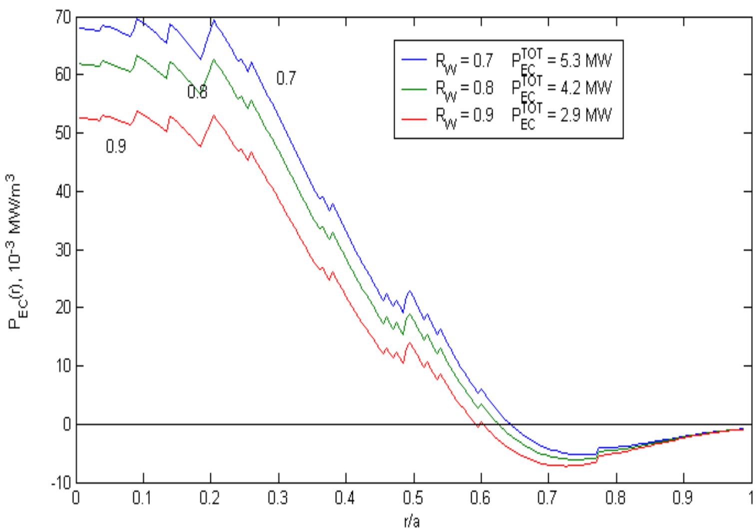

Fig. 2. Radial profile of net ECR power loss for various values of the wall reflection coefficient R_W. The respective values of total (i.e. volume integrated) power loss are indicated.

The spectral distribution in Fig. 3 illustrates the role of high harmonics of fundamental cyclotron frequency in the EC transport.

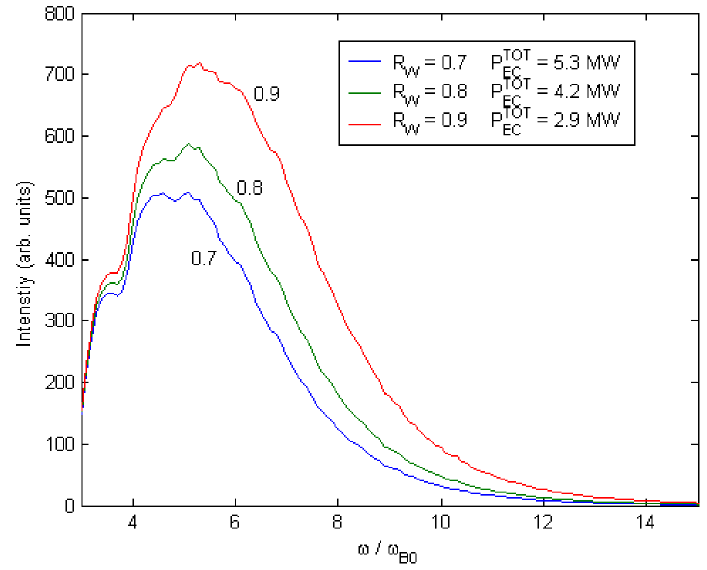

Fig. 3. Spectral distribution EC radiation escaping the plasma column for various values of the wall reflection coefficient R_W . The respective values of total (i.e. volume integrated) power loss are indicated. (The frequency is given in the units of fundamental cyclotron frequency.)

The results of calculations for two types of suprathermal electron velocity distrubution are given in Figs. 4,5 in comparison with the case of waxmellian background plasma only. These two regimes are described by the following set of parameters (cf. Eqs. (2), (3)):

"bi-maxwellian core": $\rho_0 = 0$, $\Delta\rho = 0.2$, $(\delta_{ne})_{max} = 0.1$, $(T_e^{(hot)})_{max} = 50$ keV, (4)

"bi-maxwellian off-axis": $\rho_0 = 0.5$, $\Delta\rho = 0.1$, $(\delta_{ne})_{max} = 0.1$, $(T_e^{(hot)})_{max} = 30$ keV, (5)

These regimes correspond to local enhancement of temperature by a factor of 2 for a small enough fraction of electrons. We chose parameters (4), (5) to illustrate profile effects for those deviations from electron local thermal equilibrium, which practically do not disturb total EC power loss.

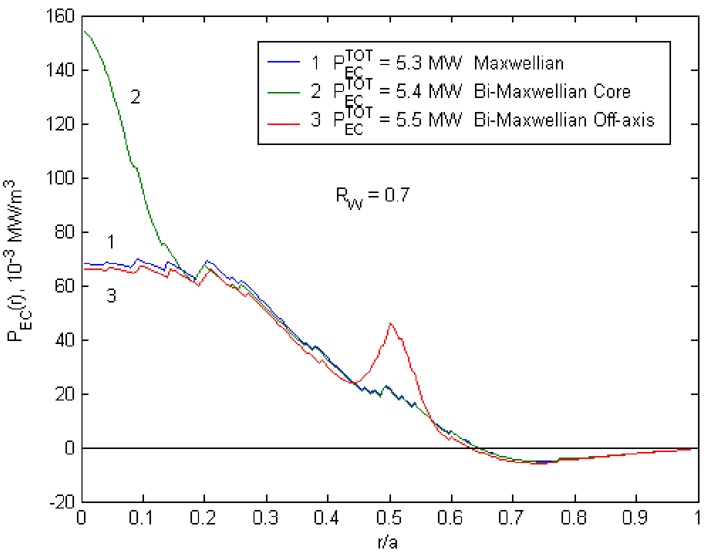

Fig. 4. Comparison of radial profiles of net ECR power loss for (i) two regimes (4),(5) with bi-maxwellian electrons and (ii) maxwellian background plasma, which give almost the same value of total ECR power loss, for wall reflection coefficient $R_W = 0.7$.

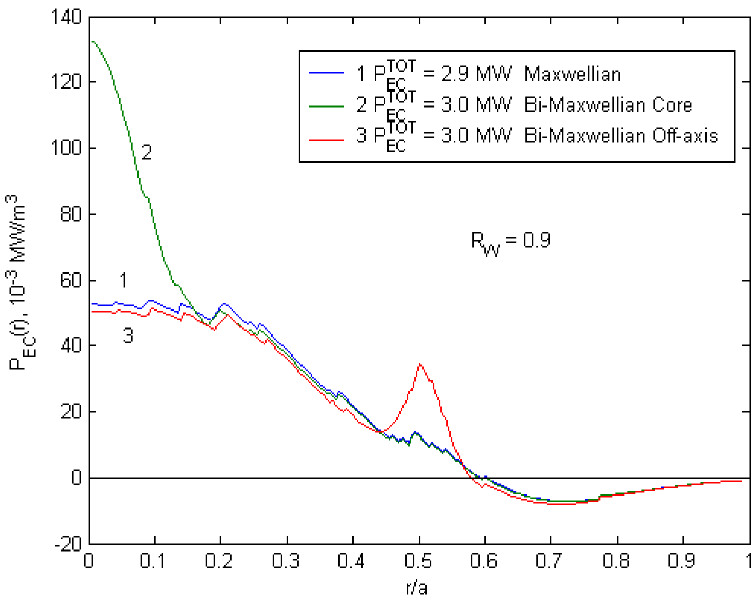

Fig. 5. The profiles similar to those in Fig. 4, for wall reflection coefficient $R_W = 0.9$.

3. Conclusions. Comparison of profiles in Figs. 4 and 5 suggest the following conclusions relevant to the studies of the role of suprathermal electrons in ITER-like tokamak. (1) Strong absorption of ECR in the relatively cold and dense peripheral plasma (cf. Fig. 1) is capable of compensating the enhancement of ECR source due to suprathermal electrons -- both in the core and off-axis regions – to give almost the same value of total (i.e. volume-integrated) ECR power loss. (2) The local rise of the net ECR power loss caused by the suprathermal electrons may approach the allowable limits for local radiation power loss. (3) The revealed sensitivity of $P_{EC}(r)$ to suprathermal electrons suggests the necessity of a self-consistent treatment of (i) plasma electron kinetics and (ii) ECR transport problem (similarly, e.g., to self-consistent treatment applied [2(A)] to the case of the dominance of ECR losses in tokamaks with $B_T \sim 10$ T (APOLLO, IGNITOR)).

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