*35th EPS Conference on Plasma Phys. Hersonissos, 9 - 13 June 2008 ECA Vol.**32D**, P-1.016 (2008)*

Similarity of Spatial Distributions of Net Electron Cyclotron Power Losses in Fusion Plasmas

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1. Introduction. Recently a comparison [1] of numeric codes SNECTR [2], CYTRAN [3], CYNEQ [4] and EXACTEC [5] for calculating the 1D distribution, over magnetic flux surfaces, of the net electron cyclotron (EC) wave power density, $P_{EC}(\rho)$, emitted for different electron temperature profiles and average temperatures of relevance for fusion reactor-grade magnetoplasmas, was carried out in view of the potential importance of EC wave emission in the local electron power balance for ITER and tokamak-reactor steady-state operation [6]. A comparison of results for the following tasks was made:

(A) *specular* reflection of the EC waves from the wall of the vacuum vessel, a *cylinder* with *circular* cross-section (EXACTEC and SNECTR),

(B) (i) *diffuse* reflection in a *circular cylinder* (SNECTR),

(ii) *diffuse* reflection in *any* geometry or *any* reflection in a *noncircular toroid* (CYTRAN and CYNEQ, based on the assumption [3] of the angle isotropy of the radiation intensity, which has been suggested by the results from SNECTR for these cases, especially for diffuse reflection in noncircular toroids [2]),

and has shown good agreement of results within tasks A and B. The results [1] have confirmed the expectation that for large enough reflectivity of the vacuum vessel wall, R_w (>~0.5), the cases A and B provide, respectively, the lower and upper bounds for $P_{EC}(\rho)$, including that for the modulus of $P_{EC}(\rho)$, inverted in sign in the plasma column periphery because of net self-heating of plasma by EC waves in the periphery. This expectation was based on the fact that either the diffuse reflection or the noncircular toroidal geometry make (*) the trajectories of the waves distributed more homogeneously over the plasma volume and (**) the radiation intensity more isotropic in wave direction angles, as compared with the case of specular reflection in a circular cylinder. The above homogenization and isotropisation of radiation intensity are valid for radiation frequencies for which the mean free path of the waves is comparable with, or exceeds, the plasma column diameter, while these frequencies appear to be responsible for the dominant contribution to $P_{EC}(\rho)$ for large enough R_w (see [2-5]). In the case A, the radiation from the hot plasma core is reflected from the wall back and, hence, its re-absorption in the core is higher, as compared with the case B. In the latter case, the radiation from the hot plasma core travels longer in a colder periphery and is absorbed there stronger, giving a stronger reversal of $P_{EC}(\rho)$.

Here we extend the analysis [1] to show the universal character of the above-mentioned features, via analyzing the shape of the $P_{EC}(\rho)$ profiles for the data from CYNEQ, for temperature profiles with the *same* shape and substantially *different* volume-averaged values.

2. Similarity of normalized spatial profiles of EC power loss. The shape of the $P_{EC}(\rho)$ profiles is defined as a normalized profile, $P_{norm}(\rho) \equiv P_{EC}(\rho)/P_{tot}$, where P_{tot} is the volume-integrated EC power loss, while the shapes of electron density and temperature profiles are defined, respectively, as $n_e(\rho)/\langle n_e \rangle$ and $T_e(\rho)/\langle T_e \rangle$, where <> denotes volume-averaging.

Figures 1-4 give a comparison of the $P_{norm}(\rho)$ profiles for three different shapes of temperature profile (parabolic, "advanced" and "peaked") and two very close density profiles. Also, for the parabolic T_e profile, a comparison for three values of reflectivity (R_w = 0.6, 0.8, 0.9) is presented by Figs. 1,2.

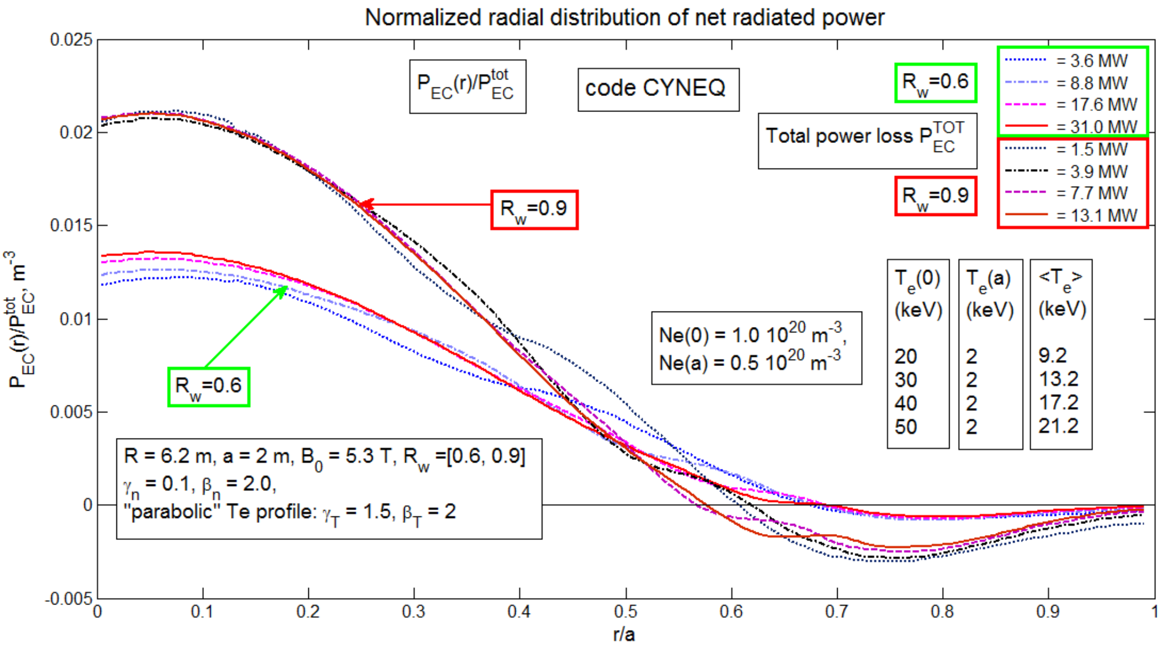

Fig. 1. The normalized profile of the net radiated power, $P_{EC}(\rho)/P_{tot}$, for different values of central temperature, $T_e(0)$, (and different values of volume-averaged temperature, $\langle T_e \rangle$) and the same shape of temperature profile, $T_e(\rho)/\langle T_e \rangle$ (specifically, for β_T =2 and γ_T =1.5 in the profile $T_e(\rho) = T_e(a) + (T_e(0) - T_e(a))\left[1-\rho^{\beta_T}\right]^{\gamma_T}$ with $T_e(a)$=2 keV). The density profile is described by similar formula with β_n =2 and γ_n =0.1. Other parameters (major/minor radii, wall reflection coefficient R_w) are taken close to ITER case (except elongation, which is taken k=1). The profile of *total* magnetic field, averaged over magnetic surfaces, is taken flat (that, e.g., for ITER "inductive" regime is accurate to <20% [7]): $B_{tot}(\rho)=B_T(0)$=5.3 T.

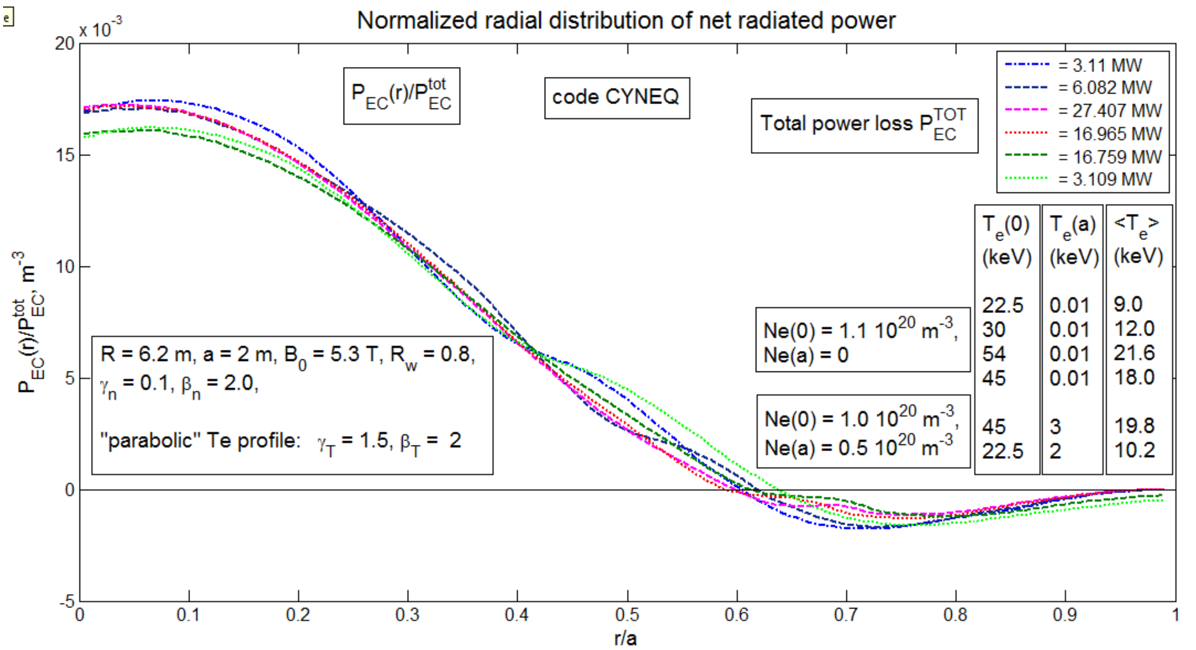

Fig. 2. The same as in Fig. 1 but for wall reflection coefficient R_w=0.8 and T_e profile without pedestal. Also, two curves are given for slightly different density profile and T_e profile with a pedestal. The volume-averaged density <n_e> = 1 and $0.95 \cdot 10^{20} m^{-3}$.

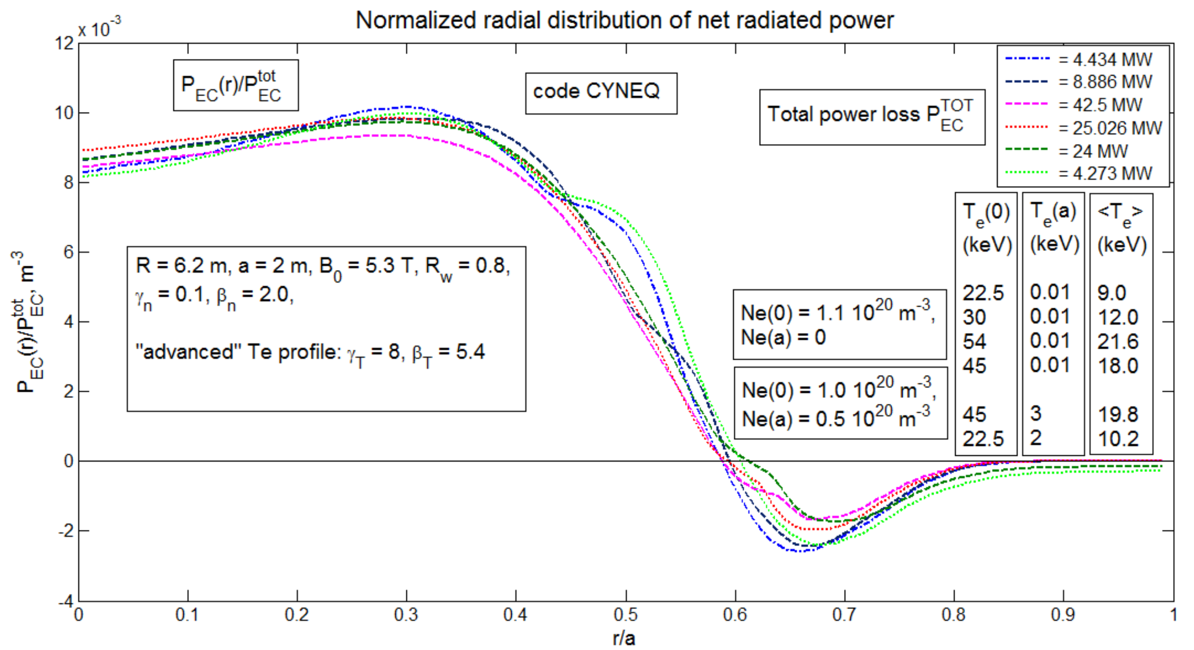

Fig. 3. The same as in Fig. 2 but for the “advanced” temperature profile (β_T =2 and γ_T =1.5).

The degree of similarity of normalized profiles appears to quantify the accuracy of basic approximations used in CYNEQ because these (namely, isotropy of the radiation intensity, spatial homogeneity of intensity in the optically thin (outer) region, rather weak sensitivity of $P_{EC}(\rho)$ to the definition of the boundary of this region in the $\{\rho,\omega\}$-space) work better for higher R_w and not so steep profiles of plasma temperature and density. It is seen that in the center the similarity is better for higher R_w, whereas in the transient region (e.g., ρ=0.3-0.7 in Fig. 1), where CYNEQ is less accurate, the similarity is worse for all the values of R_w.

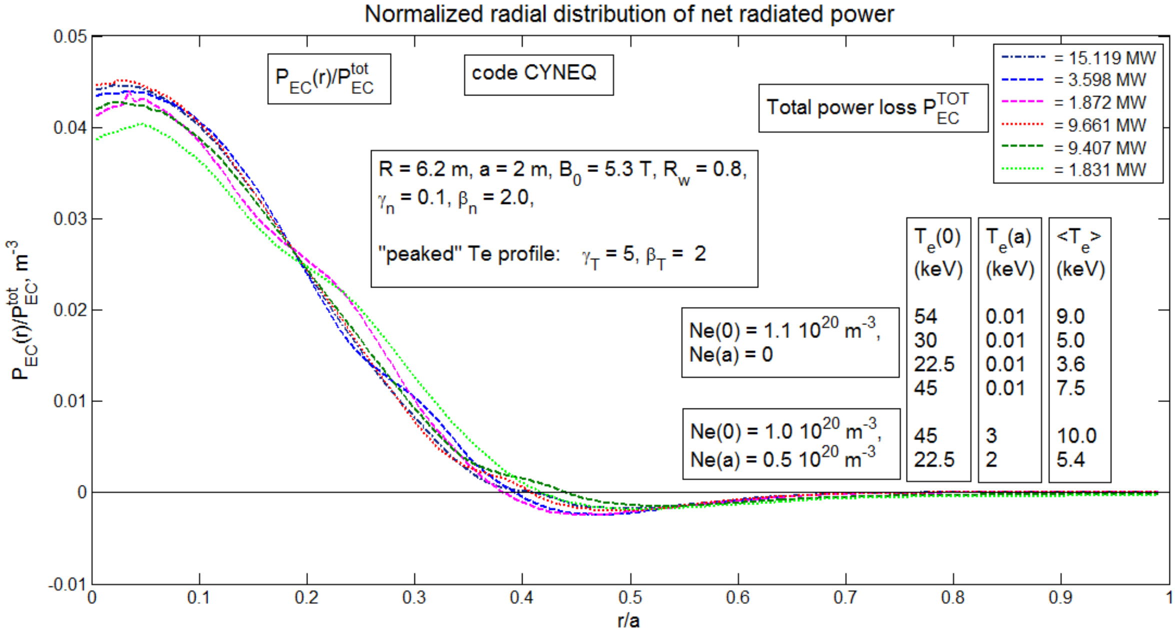

Fig. 4. The same as in Fig. 3 but for the “peaked” temperature profile (β_T =2 and γ_T =5).

3. Conclusions.

(a) The normalized profiles, $P_{EC}(\rho)/P_{tot}$ (where P_{tot} is the volume-integrated EC power loss), appear to be close enough for the same normalized temperature and density profiles, $T_e(\rho)/\langle T_e\rangle$ and $n_e(\rho)/\langle n_e\rangle$, and substantially different values of volume-averaged temperature, $\langle T_e\rangle$.

(b) The degree of similarity of normalized profiles, $P_{EC}(\rho)/P_{tot}$, may quantify the accuracy of various numeric codes.

Acknowledgments. A part of the work by A.B. Kukushkin was supported by the Cariplo Foundation (the Landau Network-Centro Volta).

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