ON THE PLASMA EC-HEATING IN TOKAMAKS AT VERTICAL EC-WAVES LAUNCH

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The development of large tokamaks (major radius $8-10$ m) projects during the last years requires more accurate methods of calculation of RF fields in plasma. Some diffraction effects, which have never been considered before, become an object of active theoretical investigations. In particular, the most essential influence of diffraction may take place at the "vertical" propagation of EC-waves in a toroidal installation because of the increase of the length of ray trajectories along the resonance layer.

In the present work, we propose to consider some effects taking place at the EC-waves absorption at vertical launch in the plane of torus-reactor poloidal cross-section [1,2]. The minimum size of the energy absorption zone corresponds to this geometry of EC waves interaction with plasma in toroidal systems, which is quite essential for MHD-instabillities supression. Here, a situation when electromagnetic waves are propagating alongside the quite narrow gyroresonance layer (practically corresponding with the caustic field limits), is possible and consequently, the geometrical optics description is inappropriate. To solve this boundary problem we have developed a quite simple model for the description of EC-waves dissipation in the caustic zone, which made it possible to find an analytical solution of the Helmholtz equation (though with some limitations), and also to perform numerical computations in a general case.

We considered a flat layer with the "longitudinal" dielectrical permitivity $\varepsilon_{zz}(x)$ depending on the coordinate x (the magnetic field is directed along the z-axis, $n_z \ll 1$). A flat wave with the "ordinary" polarization falls to the layer:

$$\mathbf{E} \approx \mathbf{z}_o E(x) exp(ik_o(n_y y + n_z z) - i\omega t), \quad k_o = \frac{\omega}{c}. \tag{1}$$

The dielectrical permitivity in the Helmholtz equation is being represented by the following model

$$\varepsilon_e = \frac{x_e - x}{a} + i\sigma, \ \sigma = \begin{cases} \alpha(x-x_c)^{3/2}, & \text{if} \quad x > x_c \\ 0, & \text{if} \quad x < x_c \end{cases}. \tag{2}$$

Here, x_e is the geometrical optics reflection point, a is the scale of the plasma density inhomogeneity, the parameter α depends on the magnetic field inhomogeneity scale, plasma density and the structure of the moments of the electron distribution function.

In case of the "boundary" variant ($x_e \simeq x_c$), the expression for the function $\varepsilon_e(x)$ may be simplified as follows:

$$\varepsilon_e(x) = \begin{cases} (x_e - x)/a, & x < x_e \approx x_c \\ i\alpha(x - x_c)^{3/2}, & x > x_e \approx x_c \end{cases} .$$

In this case, the solution may be found analytically through Bessel and Neumann functions of fractional argument [3]. Using that $E(x \to \infty) \to 0$ and continuity condition of both E and $\partial E/\partial x$ at the limit $x = x_e$, the power reflection coefficient $R = |A/B|^2$ is easily found:

$$R = \left| \frac{1 - 6\beta/7}{1 + 6\beta/7} \right|^2 ,$$

where β is the small parameter.

So we may draw a conclusion: at the concentration of dissipation in the caustic zone, a strong EC-waves reflection will take place (it is quite comprehensible if one takes into account that the conditions of the problem are very similar to the skin-layer problem ones).

In the intermediate region of parameters $|\beta| \simeq 1$, numerical calculation of Helmholtz equation has been performed (using the expression (2)). With respect to the results, the dependence of R on the dismatch of x_e and x_c has the following character: R is nearly zero when $x_e \gg x_c$ – all power absorbed before reflection; when the point x_e approaches (from the side of dissipation) the limit of the absorption layer (line x_c), the coefficient R increases – R is about 1 when $x_e \ll x_c$; near the caustic zone, where geometrical optics description is inappropriate we found, in particular, that at $x_e = x_c$, the RF-power reflection from the resonance zone consists about 60 % at any geometrical parameters of the installation.

References

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