Study of electron cyclotron heating efficiency during tokamak plasma start-up with use of DINA and OGRAY codes

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1. INTRODUCTION

Fundamental O-mode resonance electron cyclotron heating (ECH) provides a reliable plasma initiation and start-up in many tokamaks [1, 2] and it is planned to be used for ITER. In accordance with [3] approximately 2 MW of absorbed ECH power is necessary to assist the ITER plasma initiation and to support impurity burn-through in the initial plasma current ramp-up phase. Burn-through occurs when the electron temperature becomes sufficiently high (more than 100 eV) so that low *Z* impurity charge states are no longer produce a large fraction of the power radiated from plasma and the plasma is transferred to the low-resistance state such that the applied electric field leads to efficient current ramp-up. On the other hand, the value of the absorbed fundamental O-mode ECH power injected into the plasma during the burn-through stage is quite sensitive to the electron temperature and density and can be very *small* [4]. This paper presents the modeling results of the absorption efficiency of ECH power in ITER tokamak plasma with scan of the plasma electron temperature and density values, which correspond to the burn-through phase and scan of the angle between the ray-tracing direction and the tangent to the magnetic surface at the point of magnetic resonance. Interaction of electron cyclotron (EC) wave with plasma is analyzed with use of OGRAY code [5] for 2D plasma equilibrium obtained by use of DINA code [6].

2. PHYSICAL MODEL AND MODELING SCHEME

Study considered in this paper includes the modeling analysis of ECH power absorption as a result of single pass ECH power damping in electron cyclotron resonance (ECR) zone during EC wave propagation through the ITER plasma during time period of inboard plasma initiation. In Fig. 1 an ITER plasma free boundary equilibrium obtained by means of DINA code and used for such analysis is shown. This equilibrium corresponds to the starting point of the ITER plasma current ramp-up phase with plasma current value equal to 0.1 MA. Position of ECR is specified, which corresponds to the toroidal magnetic field B_Θ = 5.3 T in R = 6.2 m and gyrotron frequency 190 GHz (vertical green line in Fig. 1). Plasma parameters (electron density and temperature) are specified also. For scoping study the electron temperature T_e is varied from 5 to 1000 eV together with varying of electron density

n_e from 0.1 to $1.0{\cdot}10^{19}$ m^{-3}. These parameter regions assume to cover the plasma initiation and burn-through range.

In Fig. 1 the footprints in poloidal section of EC wave ray tracing trajectories along geometrical path "*s*" are shown. The point "1" denotes a beginning of trajectory in plasma area and the point "2" denotes an exit from the plasma correspondingly. The value of *s*=0 corresponds to enter in the vacuum vessel. Red, black and blue lines show the trajectories, which have the 80^0, 70^0 and 60^0 angle between the ray tracing direction and the normal the tangent to the magnetic surface at the resonance point. The input EC power before the point "1" is assumed to be equal $P_0 = 4$ MW.

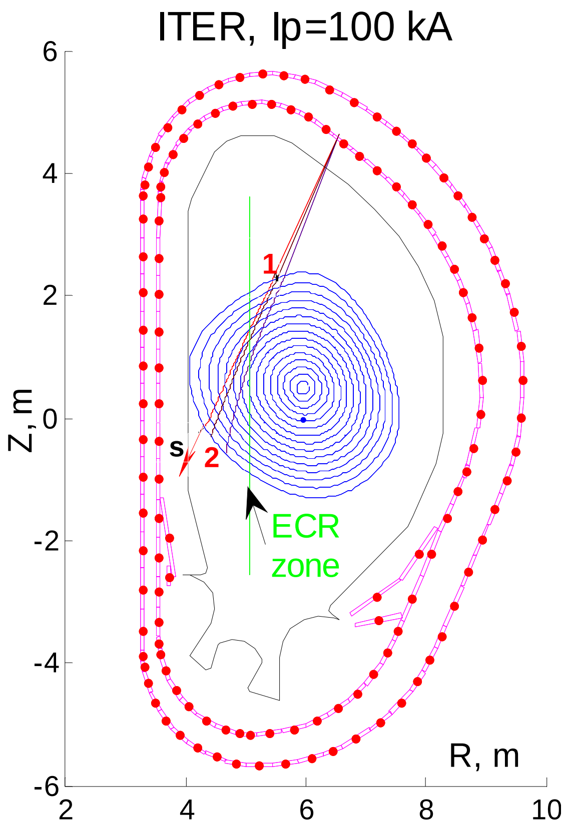

FIG. 1. Equilibrium in starting point of the ITER plasma current ramp-up phase with plasma current value 0.1 MA

Modeling of EC wave propagation within the plasma is based on the model of Gaussian beam optics [5], which is operating the cold plasma approximation for the ray tracing in OGRAY code. Absorption rate $\frac{dP}{ds}$ is calculated with approximation of Maxwellian function for equilibrium particle distribution [7].

3. SIMULATION RESULTS

Here we present the results of scoping study simulations of EC wave propagation, poloidal section footprints of the trajectories are shown in Fig. 1. The corresponding toroidal section footprints are presented in Fig. 2. Efficiency of ECH power absorption can be calculated as $\gamma_{ab} = \frac{\int_0^{V_0} \left(\frac{dP}{ds} \frac{ds}{dV} \right) dV}{P_0}$, where *P* is the absorbed power in plasma as function of *s*; V_0 is the full plasma volume. Scoping study kinetic plasma parameters cover the burn-through region in tokamak plasma. Power absorption is calculated as a result of single pass wave damping in the ECR region. Fig. 3 presents the *P*(*s*) functions for 80^0, 70^0 and 60^0

values of angle α between the ray tracing direction and the normal the tangent to the magnetic surface at the resonance point for the case T_e = 100 eV and $n_e = 0.1\cdot10^{19}$m^{-3} in plasma. The

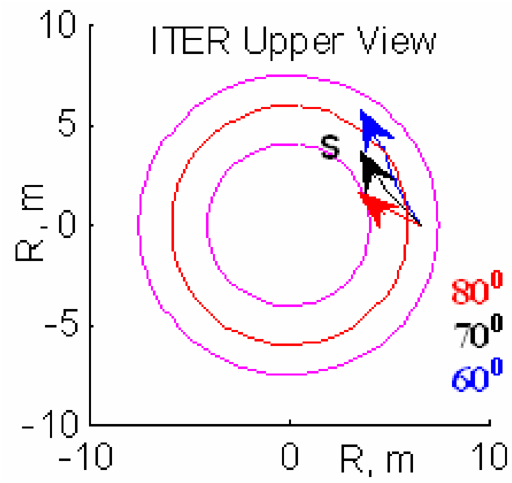

FIG. 2. Toroidal section footprints of EC wave trajectories

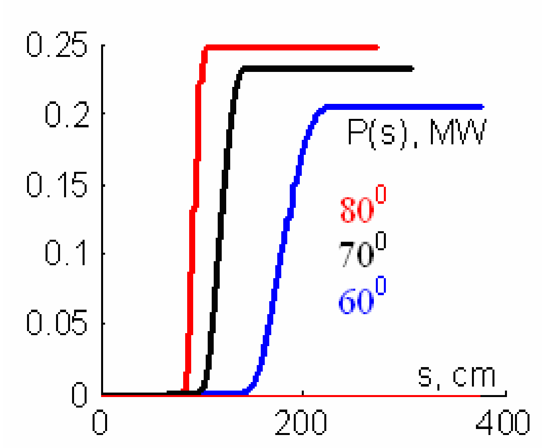

FIG. 3. $P(s)$ as function on angle between ray tracing direction and normal to tangent to the magnetic surface at the resonance point for T_e = 100 eV and $n_e = 0.1\cdot10^{19}$m^{-3}

corresponding $P(R)$ functions are shown in Fig. 4. Results presented in Figs. 3, 4 show that the absorbed power value is decreasing with α decrease but not strongly. Results of scoping study of dependence of fundamental ECH power absorption (as a result of *single pass damping*) efficiency γ_{ab} from the plasma parameters are shown in Fig. 5. All considered cases correspond to the value of α equal 80^0. The plasma parameters T_e and n_e are assumed to be uniform along the plasma cross section. Presented results in Fig. 5 show the extremely low absorption efficiency value within burn-through plasma parameter region. One can see that for $n_e < 0.1\cdot10^{19}$m^{-3} and $T_e < 80$ eV the efficiency of the fundamental wave absorption is less than 5 % as a result of single pass damping through the EC area. Such low level of γ_{ab} is confirmed by analytical analysis [8] and conclusion about ~ linear dependence of the $\gamma_{ab} \propto n_e T_e$ in considered region of plasma parameters. Practically the assessment of γ_{ab} value may be even lower if to consider non-uniform distribution of the plasma parameters T_e and n_e.

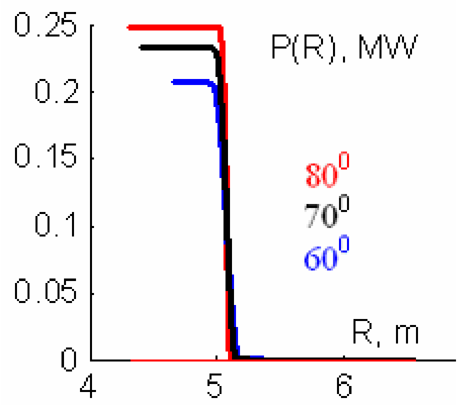

FIG. 4. $P(R)$ as function on angle between ray tracing direction and normal to tangent to the magnetic surface at the resonance point for T_e = 100 eV and $n_e = 0.1\cdot10^{19}$m^{-3}

It means that extrapolation from the *absorbed* power requirement to the *launched* can be an important problem. In connection with this the convertion of the O-mode to the X-mode migth be suggested for ITER [3] to have possibility to absorb EC wave as electron Bernstein waves, which has been carried out in JT-60U plasma during plasma initiation [9] .

4. CONCLUSION

OGRAY code scoping analysis of O-mode EC wave single pass damping absorption in ECR zone of ITER plasma (free boundary equilibrium is obtained with DINA code) performed with n_e and T_e scan show the extremely low efficiency (< 5 %) in burn-through region of the plasma parameters T_e and n_e. That creates the important problem between the absorbed power requirement and the launched one.

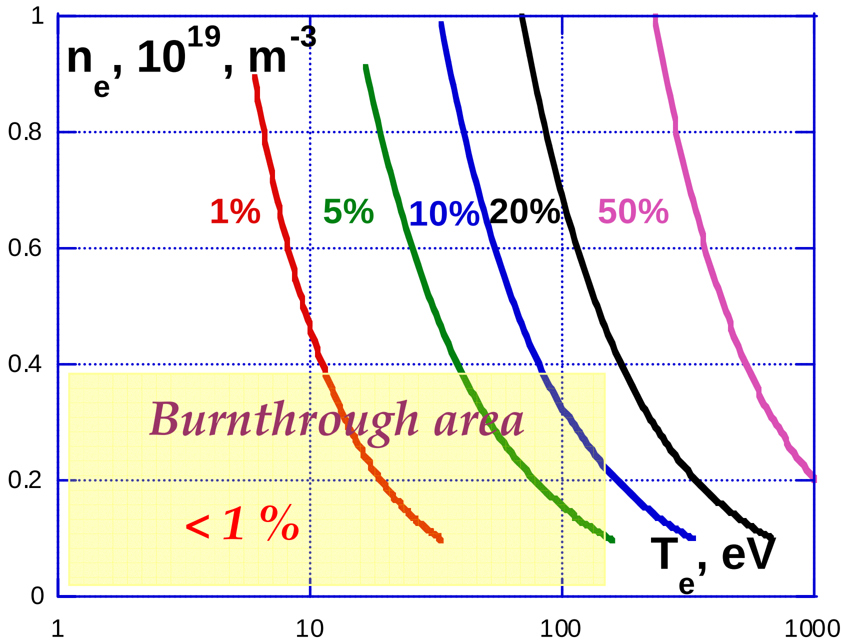

FIG. 5. Scoping study results of functional dependence of ECH power absorption efficiency γ_{ab} on the plasma parameters T_e and n_e

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