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Numerical Investigations of Plasma Parameters in COMPASS Tokamak

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Abstract

A numerical investigation of plasma parameters in COMPASS tokamak is presented. The plasma parameters in the device are analyzed in the frame of the self-consistent model of central plasma and edge region. The possibility of achieving high recycling and detached regimes in COMPASS divertor is discussed.

1. Introduction

Presently, the transfer of the COMPASS tokamak from UKAEA to IPP Prague is in progress. During reinstallation auxiliary systems will be developed, basic diagnostics will be installed and the COMPASS tokamak will be put in routine operation in the Ohmic regime with toroidal magnetic field up to 1.2 T. In the second step the installation of the NBI system (2 x 300 kW) will be done together with the re-deployment of the existing LH system (400 kW) and the toroidal magnetic field will be increased up to 2.1 T [1].

In order to analyze plasma parameters in the COMPASS device under different operating scenarios a modelling activity has been undertaken. The plasma performance in the COMPASS tokamak has been analyzed in the frame of self-consistent treatment of the core and edge plasma. The issue of such global simulations is to assess the expected range of plasma parameters in the device as well as to determine plasma conditions when the high recycling or detached regimes would develop in the divertor of the COMPASS tokamak.

2. Description of the model

The self-consistent description of the core and edge plasma is based on 0D model of the plasma transport in the centre and 1D model of plasma dynamics in the scrape-off layer. Detailed description of the physical model is given in [2]. A similar model was applied to the FTU tokamak poloidal limiter configuration and it was verified by comparison with experiment [3].

Core region. The plasma parameters in the core (plasma temperature T, ion density and plasma current) are assumed to have profiles in the form of generalized parabolas [2] with exponents consistent with the old COMPASS experimental profiles [1]. The profile of impurities is prescribed as $n_z = (n_e/n_{es})^{\alpha_z} n_{zs}$ with $\alpha_z = 0.5$ corresponding to a flat profile of effective charge Z_{eff}. The plasma parameters at separatrix (index s), which result from the SOL model, are required as input data to this part of the model. The plasma temperature in the centre is calculated from the energy balance equation $3\langle n_e T\rangle/\tau_E = P_{aux} + P_{OH} - f_{rad}P_{lin} \equiv P_{core}$, where P_{core} is the total power in the core composed of auxiliary heating power P_{aux}, ohmic power P_{OH} and line radiation power P_{lin}. The energy confinement time τ_E corresponds to ITER98(y2)-ELMy H mode scaling law [4]. The coefficient f_{rad} is the ratio between power radiated in the core and the total radiated power. Power flowing to the SOL is defined as $P_{inp} \equiv P_{aux} + P_{OH} - P_{lin}$.

Boundary region. Simulation of plasma behavior in the scrape-off layer is based on standard two-point model [5]. The energy balance in the SOL defines the equation for the temperature at the target plate (index p) $P_{plate}(T_p) = P_{inp}(T_p) - P_{rad}^{SOL}(T_p)$, where P_{rad}^{SOL} is the line radiation in the SOL and the power flowing to the SOL P_{inp} is calculated in the core part of the model. Plasma density at the plate and plasma temperature and density at the separatrix are evaluated according to expressions corresponding to the two-point model [2, 5]. Impurity model includes both sputtered and additional impurities and it is described in [2] in more detail. The radiation losses in the core and the SOL regions are calculated assuming corona equilibrium [6].

3. Results

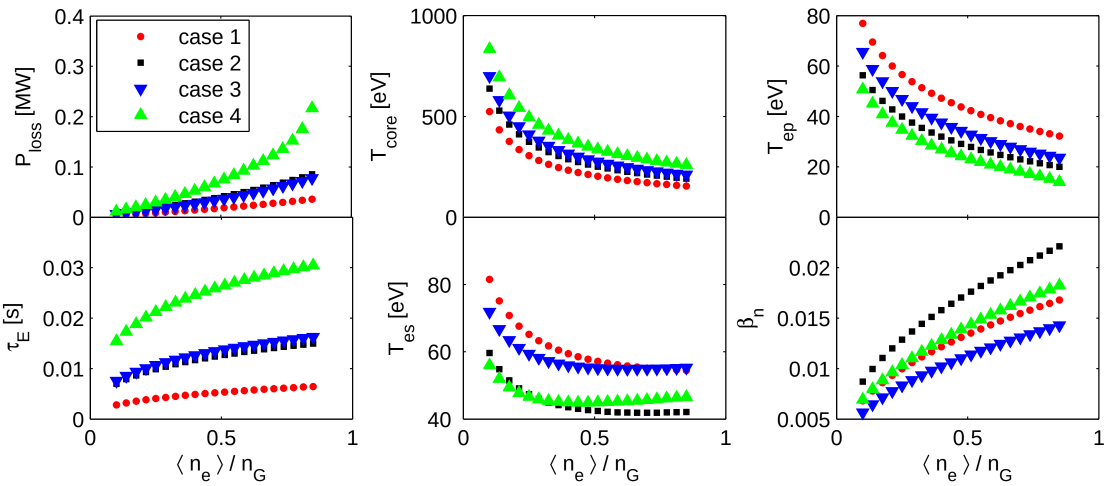

Figure 1: Total energy losses P_{loss}, energy confinement time τ_E, average plasma temperature T_{core}, plasma temperature at the LCMS T_{es}, plasma temperature at the plate T_{ep} and normalized parameter β_n as functions of normalized volume average density $\langle n_e\rangle/n_G$ for different configurations. Scaling (B).

We use following device parameters in simulation: toroidal radius $R_T = 0.56$ m, poloidal radius $R_p = 0.21$ m, elongation $\kappa = 1.8$, auxiliary heating power $P_{aux} = 0.7$ MW. We assume that the anomalous radial diffusion is of the order of Bohm diffusion ($D_\perp = \frac{1}{3}D_{Bohm}$) and we take $R = 0.975$ as the recycling coefficient in the SOL. In the model we have assumed carbon as the sputtered impurity, taking into account the physical as well as the chemical sputtering. In some simulations neon has been considered as an additional (injected) impurity. We have investigated operation regimes with toroidal magnetic field $B_T = 1.2$ T as well as higher magnetic field $B_T = 2$ T which is predicted for the future upgrade of the COMPASS device [1]. For every magnetic field two plasma currents I_p are considered: case 1: B_T = 1.2 T, I_p = 100 kA, case 2: B_T = 1.2 T, I_p = 200 kA, case 3: B_T = 2 T, I_p = 200 kA, case 4: B_T = 2 T, I_p = 350 kA. Greenwald densities n_G corresponding to cases specified above are: 0.72, 1.44, 1.44 and 2.53 (in $[10^{20}\mathrm{m}^{-3}]$), respectively. First, we analyze the global plasma parameters in the COMPASS by changing the average plasma density $\langle n_e \rangle$ in the device in the range $0.1n_G \leq \langle n_e \rangle \leq 0.85n_G$. Since the scaling for the edge plasma density n_{es} for COMPASS tokamak is not available, we have considered three different expressions in our simulations: $n_{es}/\langle n_e \rangle$ = $\frac{1}{2}$ (A), $\frac{1}{3}$ (B) and $\frac{1}{4}$ (C). The results of simulations for medium scaling of the edge density (B) and four cases specified above are shown in Fig. 1. It can be seen that with increasing plasma density the confinement time increases (according to the energy scaling law) and the plasma temperature in the core decreases, however the normalized beta β_n increases. Since the Ohmic heating is small the changes to the heating power are weak and the same refers to the power transmitted to the divertor plates. It should be noted that plasma radiation losses are relatively small even for the highest plasma densities. In fact, the edge plasma parameters correspond to the simple SOL picture [5] with weak temperature and density gradients. For the highest edge densities the plate temperature is well above the 5 eV level, at which we can expect the development of detached regimes in the divertor. Very similar picture is obtained for scaling (C) with lower edge plasma densities. In the case of high edge densities (scaling (A)) a new regime could develop in the SOL if the plasma density was large enough (cases 2 and 4) as it can be seen in Fig. 2 a). If the plasma density exceeds some threshold density then the temperature at the plate drops below 5 eV, the high density plasma is formed in the divertor and energy losses due

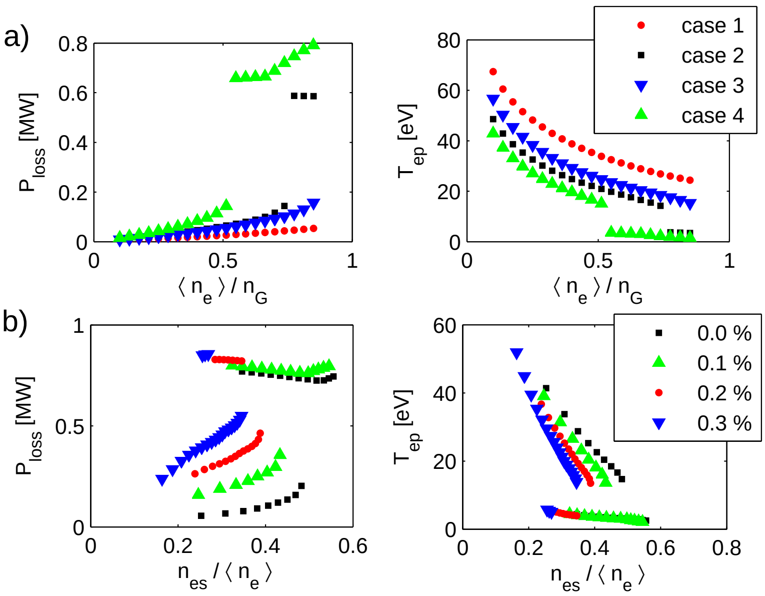

Figure 2: Total energy losses P_{loss} and plasma temperature at the plate T_{ep} a) versus normalized volume average density $\langle n_e \rangle / n_G$ for different configurations and for scaling (A). b) versus normalized plasma density at the LCMS $n_{es}/\langle n_e \rangle$ for different concentrations of additional impurities.

to impurity radiation are significant. We note that the core parameters are almost not affected by the transition to the detached mode. It should be remarked that such desirable strongly radiating regime develops only at high plasma densities. In real device it could be very difficult to operate with so large separatrix density n_{es}. However, it appears that the access threshold to the detached regime could be lowered by introducing additional impurities. It comes out from the simulations that the achievement of detached regime depends strongly on plasma density and impurity concentration. The results show that for lower plasma density ($\langle n_e \rangle \lesssim 0.5 n_G$) it is impossible to achieve the detached regime independently of the edge plasma density as well as the impurity concentration, however the transition appears for higher density ($\langle n_e \rangle \gtrsim 0.5 n_G$) for relatively large range of edge plasma densities. In order to investigate the effect of additional impurities we show the results of simulations for the same case (case 4, $\langle n_e \rangle = 0.7 n_G$), but for different concentrations of neon (Fig. 2 b)). Two branches of solution corresponding to attached and detached plasma are clearly seen in the Fig. 2 b). It is interesting to point out that in the detached regime, the plasma parameters are almost independent on the edge density and impurity concentration. The threshold density is reduced when the concentration of neon increases. It should be mentioned that in the detached regime, there is a significant production of carbon due to the chemical sputtering while for attached regimes, physical sputtering is responsible for the carbon release.

4. Conclusions

We have investigated plasma parameters in the COMPASS tokamak by means of self-consistent core-edge model. Different operating scenarios of the COMPASS device have been analyzed in order to estimate conditions for developing the high recycling and detached regimes. It has been found that the operational space of the tokamak is relatively broad in terms of available plasma densities, plasma currents and magnetic fields. It appears that the detached conditions in the divertor can be created only if the plasma density is high enough and/or if additional (injected) impurity is present.

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