ITER plasma sheath characteristics during ELMs

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Introduction

In the future tokamak fusion devices such as ITER, the Edge Localized Mode (ELM) [1] induced transient heat loads are of a significant importance and represent one of the largest threats to the divertor target lifetime. Quantitative description and prediction of the expected ELM behavior are currently possible only through numerical modelling. That approach is often used by fluid plasma boundary modelling codes, such as SOLPS, in which the ELM is crudely approximated. The approximation is set as a fixed increase in anomalous cross-filled transport coefficients for particles and heat for a short duration with a specified total energy loss ΔW_{ELM}. However, one of the issues of this approach is that while the fixed kinetic heat flux limiters are regularly applied in the fluid codes, the boundary conditions at the target sheath interface are expected to strongly vary in time through the ELM transient. The main goal of this work is to address this issue and obtain the first set of theoretical results for ITER simulations with high performance computing using the 1D3V electrostatic parallel Particle-in-Cell (PIC) code BIT1 to provide the kinetic target sheath heat transmission factors (SHTF) [2]. The obtained results will be then used as boundary conditions for the ELM target heat loads calculations using the SOLPS-ITER code [3].

Boundary conditions at stationary state

The first and most challenging step is to establish the starting point for the BIT1 simulations of the stationary parallel transport in the inter-ELM scrape-off layer (SOL). The BIT1 simulations were performed for burning plasma conditions corresponding to the ITER $Q = 10$, 15 MA baseline at $q_{95} = 3$, for which the poloidal length of the 1D SOL is $\sim 20\ m$ from inner to outer target. Typical upstream separatrix parameters of $n_e \sim 3-6 \cdot 10^{19}\ m^{-3}$, $T_e \sim 100-200\ eV$ and $T_i \sim 200-300\ eV$ are assumed, guided by SOLPS-ITER code runs. Inclined magnetic fields at the targets ($\sim 5^\circ$) are included, as are particle collisions, with a total of $3.4 \cdot 10^5$ poloidal grid cells giving shortening factors of 20. Secondary electron emission at the tungsten targets is neglected. Also the neutrals and impurities are not included in this run. In the first instance, a SOL flux tube just outside the separatrix is considered.

On this basis the ELM transient is then launched by injecting an ambipolar, Maxwellian source of particles, distributed around the midpoint, between the two targets and at the $T_{i,ped}$, $T_{e,ped}$, $n_{e,ped}$ characteristic of the H-mode pedestal. The duration of the ELM pulse is set to be between 100-400 μs with ΔW_{ELM} in the range between $0.1-1.0\ MJ$.

A standard BIT1 simulation runs for about 60 days in a parallel computing mode on 1152-2304 computer cores.The results, electron and ion densities, electron and ion temperatures, plasma potential and electron and ion parallel velocity in stationary state depending of the poloidal length, obtained from the BIT1 code simulations are shown in artciles [4, 5].

To obtained the plasma sheath [6, 7], was used density profile from the previus simulations. The length of the PWT is from $4.2\cdot10^{-4}$ m to $1\cdot10^{-2}$ m. DS point is $4.2\cdot10^{-4}$ m, MP $2.3\cdot10^{-3}$ m and CP $1\cdot10^{-2}$ m, so the length of the plasma sheath is $2.3\cdot10^{-3}$ m or $4.5\rho_i$, where ρ_i is ion gyroradius. The plasma at MP and CP is quasineutral, while at the DS, the electric field is so strong that plasma becomes non-neutral. The boundary conditions (BCs) are formulated at the boundary between the magnetic and collisional presheaths, named sheath edge (SE) [6, 7]. The BCs targets at the SE used in this paper are based on a classical sheath model. The main parameters needed for BCs at the MP entrance are as follows: the potential drop between the MP entrance and the wall ($\Delta\phi$), the ion fluid velocity component $\left(V_{\parallel}^{i}\right)$, and the electron and ion energy fluxes $\left(Q_{sh}^{e,i}\right)$. Those quantities are calculated from a set of equations (1) [6]:

$$M=\frac{V_{\parallel}^{i}}{C_s};\quad \gamma^{e,i}=\frac{Q_{sh}^{e,i}}{\Gamma^{e,i}\cdot T^{e,i}};\quad \varphi=\frac{e\Delta\phi}{T^{e}}; \tag{1}$$

where M, $C_s=\sqrt{\frac{Te+\delta_i T_i}{m_i}}$, $\gamma^{e,i}$, $\Gamma^{e,i}$ and φ are the Mach number, the ion-sound speed, the electron and ion sheath heat transmission factor, the electron and ion fluxes to the divertor, and the normalized potential drop, respectively. $m_{e,i}$ and $T_{e,i}$ are electron and ion masses and electron and ion temperature. Here δ_i (~ 1)is the polytrophic constant.

Time dependent BCs

The BIT1 code also can be used for obtaining time depending profiles during fixed point. We fixed the plasma sheath point and run the BIT1 simulation during $200\mu s$ at ELM-free and $400\mu s$ at Type I ELM. In previous works [4, 5] were presented the results durign ELM-free of the Mach number ($\sim$1), sheath transmission coefficients for the electrons ($\sim$2) and ions ($\sim$7), are constant and near to classical one. The normalized potential drop for inner and outer divertor that reduces proportionally. In this work for Type I ELM, Mach number is increasing during the time and the max value is 2, the sheath transmission coefficients for electrons and ions rapidly increase and reach the peak values, for electrons 3, for ions 9, then slightly decrease and vary the values during the time. At outer divertor SHTF have the same dependencies as in inner.

The normalized potential drops for inner and outer divertor at the same time where the SHTF for electrons and ions rapidly increase, rapidly decreases and then slightly increase. After $400\mu s$ from the graphs in 1 the values for Mach number, normalized potential drops and SHTF for electrons and ions start to decrease. This phase is called post-ELM.

The SHTF decreases, but are still in the range of classical value. The reasons of such behaviour is the extremely high pre-ELM divertor temperatures, due to the absence of plasma recycling and cooling impurity interactions.

Conclusion

Kinetic effects in the SOL play an important role for the future fusion devices: they strongly affect plasma and power loads to the plasma facing components (PFC). As a results kinetic effects in the SOL influence the lifetime of the PFC. Therefore, kinetic study of the SOL has become one of the most challenging topics in fusion plasma research. For systematic kinetic study of SOL, in this work, was used the worldwide unique PIC/MC code BIT1. The BIT1 code contains all the range of SOL kinetic parameters. That are needed for performing the set of 1D SOL simulations. The model of SOL in the fluid codes required artificial ad-hoc parameters. These

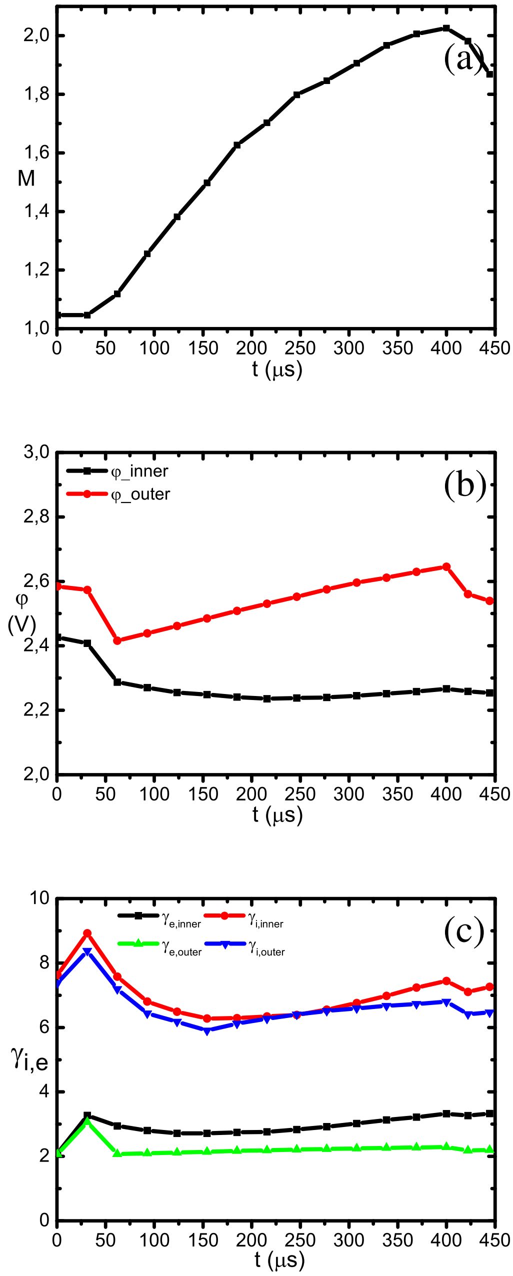

Figure 1: Time dependent BCs for Type I ELM (a)-Mach number, (b)-normalized potential drop for inner and outer divertor, (c) - Sheath transmission coefficients for electron and ion on the wall at inner and outer divertor

kinetic parameters were obtained in this work experimentally and during time for Type I ELM. From the simulation results, the BCs at the point of plasma sheath, in ELM-free SOL are near to the classical and in Type I ELM are changed during time. This work is to be further continued by investigating the classical BCs for ELMs.

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