§16. Integrated Modeling Study of Heat and Particle Control

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The magnetic confinement device of fusion plasmas, such as tokamaks and helical devices, generally consists of a closed and an open system. In the closed system, the magnetic field forms nested flux surfaces and confines the core plasma. The open system with the peripheral plasma surrounds the closed one and both ends of the magnetic field line contact with divertor plates. Although core and peripheral plasmas naturally interact with each other, the integrated modeling of both plasmas and the understanding of the interaction have not yet accomplished so far. The integrated models and the understanding of the interaction by using the integrated models help to establish efficient methods of heat and particle control in magnetic fusion devices. From the above points of view, we have done some works to develop the integrated modeling and to study their interaction by the integrated simulation. We here pick up the following two works.

(1) ELM energy loss and cycle

An integrated code TOPICS-IB has been developed on the basis of the 1.5-dimensional core transport code TOPICS extended to the integrated simulation for burning plasmas. In the TOPICS-IB, a dynamic five-point model of the peripheral plasma (scrape-off-layer (SOL) and divertor plasmas) is coupled with TOPICS. Up to now, we applied the TOPICS-IB to the study of the energy loss caused by edge localized modes (ELMs) in tokamaks. The TOPICS-IB successfully simulated a series of transient behaviors of an H-mode plasma; the pedestal growth and an ELM crash. The experimentally observed collisionality dependence was found to be caused by the bootstrap current, the SOL conductive heat transport and the equipartition effect. In these studies, however, only one ELM crash was examined. Thus, we here study the ELM cycle following the first ELM.

At first, we confirmed that the TOPICS-IB can reproduce a series of ELMs and the collisionality dependence of energy loss by each ELM is almost the same as that found in the first ELM. In an ELM cycle, there are two periods; one is the ELM phase where the energy, ΔW_{ELM}, is lost by the transport P_{trELM} and charge-exchange (CX) P_{CXELM} and the other is the inter-ELM phase where the heating recovers the stored energy depending on the loss powers, P_{trint} and P_{CXint}. The power balance of core plasma in the ELM cycle is approximately described by a time averaged equation, $\overline{P_{\mathrm{in}}} \approx \overline{P_{\mathrm{trint}}} + \overline{P_{\mathrm{CXint}}} + \overline{P_{\mathrm{ELM}}}$ where $\overline{P_{\mathrm{in}}}$ is the net heating power and the ELM loss power, $\overline{P_{\mathrm{ELM}}}$, is defined by $\overline{P_{\mathrm{ELM}}} = f_{\mathrm{ELM}} \Delta W_{\mathrm{ELM}}$. The ELM frequency f_{ELM} increases linearly with the input power $\overline{P_{\mathrm{in}}}$, as seen in experiments of type-I ELMs. Figure 1 shows the loss power ratio as a function of the normalized collisionality at the pedestal top ν^*_{ped}. As the collisionality decreases, the inter-ELM transport is reduced and the ELM loss power is enhanced, as found in experiments. In the TOPICS-IB, we apply a transport model where the transport is reduced to the ion neoclassical transport in the pedestal region. While the anomalous transport is prescribed, the neoclassical transport is calculated by the matrix inversion method. The pedestal neoclassical transport is connected to the SOL parallel transport. We found that this transport model reproduces the experimentally observed collisionality dependence of the inter-ELM transport [1].

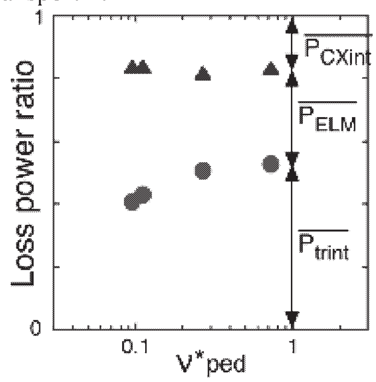

Fig.1 Dependence of $\overline{P_{\mathrm{trint}}}$, $\overline{P_{\mathrm{ELM}}}$ and $\overline{P_{\mathrm{CXint}}}$ normalized by $\overline{P_{\mathrm{in}}}$ on ν^*_{ped}.

(2) Flow pattern in the SOL plasma

The plasma flow in the SOL plays an important role for the particle control in magnetic fusion reactors. The flow is expected to expel Helium ashes and to retain impurities in the divertor region, if it is directed towards the divertor plate. It has been experimentally observed, however, that the flow direction is sometimes opposite; from the plate side to the SOL middle side in the outer SOL region of tokamaks. A full particle code, PARASOL, is applied to a tokamak plasma with the upper-null-point (UN) or lower-null-point (LN) divertor configuration for the downward ion grad-B drift. PARASOL simulations for the medium aspect ratio reveal the variation of the flow pattern: For the UN case, the flow velocity $V_{//}$ parallel to the magnetic field is directed to the diverter plate both in the inner and outer SOL regions and the stagnation point ($V_{//} = 0$) is located symmetrically at the bottom. On the other hand for the LN case, $V_{//}$ in the outer SOL region has a backward flow pattern. The stagnation point moves below the mid-plane of the outer SOL. These simulation results are very similar to the experimental results. Simulations are carried out by changing the aspect ratio and by artificially cutting the electric field. It is found that the banana motion of trapped ions is very important for the formation of the flow pattern in addition to the self-consistent electric field [2].

1) Hayashi, N. et al. : "Integrated Simulation of ELM Energy Loss and Cycle in Improved H-mode Plasmas", 22nd IAEA FEC 2008, IAEA Proceedings series (CD-ROM), submitted to Nucl. Fusion

2) T. Takizuka, et al. : "Two-dimensional Full Particle Simulation of the Flow Patterns in the Scrape-Off-layer Plasma for Upper- and Lower Null Point Divertor Configurations in Tokamaks", accepted in Nucl. Fusion