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L/H transition simulation with integrated modelling of core and SOL/divertor transport
コアと周辺プラズマ輸送の統合モデルによるLH遷移のシミュレーション

Katsuhiro Shimizu [1], Tomonori Takizuka [1], Mitsuru Honda [1], Nobuhiko Hayashi [1], Kazuo Hoshino [2], Atsushi Fukuyama [3], Masatoshi Yagi [2,4]
清水勝宏 [1]，滝塚知典 [1]，本多充 [1]，林伸彦 [1]，
星野一生 [2]，福山淳 [3]，矢木雅敏 [2,4]
1 Japan Atomic Energy Agency, Mukouyama, Naka, Ibaraki 311-0193, Japan
2 Japan Atomic Energy Agency, Rokkasho-mura, Kamikita-gun, Aomori 039-3212, Japan
3 Graduate School of Engineering, Kyoto University, Sakyo-ku, Kyoto 606-8501, Japan
4 RIAM, Kyushu University, Kasuga, Fukuoka 816-8580, Japan
１日本原子力研究開発機構 〒039-3212 青森県上北郡六ヶ所村
２日本原子力研究開発機構 〒311-0193 茨城県那珂市向山
３京都大学 〒606-8501 京都府左京区
４RIAM 九州大学 〒816-8580 福岡県春日

We have developed a self-consistent integrated modelling of core and SOL/divertor transport, i.e. a 1.5D core code TOPICS-IB and a 2D divertor code SONIC have been successfully coupled. The dynamic simulations are carried out for JT-60SA with this integrated code including a CDBM transport model, where particle and heat transports are suppressed by the ExB shearing effect. The L/H transition is successfully demonstrated based on the turbulent suppression transport model and the self-consistent boundary condition. It is interesting to note that the fluctuating nature appears in the divertor plasma after the transition.

1. Introduction

Control of the power and particle exhaust is one of the most critical issues to achieve the fusion reactors, such as ITER and DEMO. To investigate the control method by the divertor, we have developed a 2D divertor code, SONIC [1]. In order to investigate the interactions between core and SOL/divertor transport, SONIC has been consistently coupled to a 1.5 D tokamak transport code (TOPICS-IB [2]). The predictive simulation studies were carried out for JT-60SA with this integrated code [3]. Dynamic change in particle and heat fluxes into the SOL region after an H-mode transition had a significant influence on the characteristics of divertor plasma. In these simulations, the timing of the H-mode transition and the anomalous heat diffusivities before and after the transition were specified as input data.

We have recently improved the core transport model based on the current-diffusive ballooning model (CDBM) [4]. Some parameters and the dependence of F(s,α) (see Eq.(1)) in the heat transport coefficient in the CDBM model were adjusted so that the transition threshold power and the energy confinement time were roughly equal to the values estimated from theirs scalings [5].

The dynamic simulations for the L/H transition in JT-60SA are carried out with the integrated code including the new tuned CDBM transport model, where particle and heat transports are suppressed by the ExB shearing effect. It should be noted that the L/H transition timing and the particle and heat transport coefficients before and after the transition are consistently determined, in contrast with the simulations carried out so far.

2. CDBM transport model

A heat transport coefficient based on the CDBM model is given as

$$\chi_{\rm CDBM} = |\alpha|^{3/2}\, F(s,\alpha)\, (c/\omega_{\rm pe})^2 (v_A/qR), \qquad (1)$$

with $\alpha = -q^2 R\,{\rm d}\beta/{\rm d}r$, where we assume $q = q_{\rm eng} = 2\pi\kappa r^2 B_t/\mu_0 R I(r)$ and $I(r)$ is the plasma current inside a minor radius r. The expression for F is modified and its value for the weak/negative shear regime is 2~3 times larger than original one. The suppression of transport by the E×B shear flow is introduced as

$$\chi_0 = \chi_{\rm CDBM}\, C_1/\{1 + (C_2\omega_{\rm EXB}/\gamma_{\rm CDBM})^K\} \qquad (2)$$

where $\gamma_{\rm CDBM} = |\alpha|^{1/2} F(s,\alpha)\, (v_A/qR)$ is the growth rate of CDBM and $\omega_{\rm EXB} = (RB_\theta/B_t)|{\rm d}/{\rm d}r(E_r/RB_\theta)|$ is the ExB shearing rate. The radial electric field E_r is simply assumed to balance with the ion pressure gradient

$$-dp_i/dr + en_i E_r = 0. \quad (3)$$

In Eq. (2), C_1 = 1.5 is selected by adjusting so that the HH factor ~ 0.5 in the L-mode phase, C_2 = 15 is selected by adjusting so that an L/H transition occurs at $P \sim P_{thr}$ anticipated from the threshold power scaling (P_{thr} ~ 5 MW). The power index K is chosen as 3 so that the pedestal profiles in the density and temperature are formed remarkably.

The ion heat diffusivity χ_i is given by the sum of χ_0 and χ_{NEO} (ion neoclassical diffusivity). We set for simplicity the electron heat diffusivity χ_e equal to χ_i. The particle diffusion coefficient is set by $D = \chi/3$. The particle pinch term is not included.

To validate the tuned CDBM model [5], the simulation of the L/H transition is carried out with the 1D core transport code (TOPICS-IB). The JT-60SA simulations are carried out for conditions of R = 3 m, a = 1.1 m, κ = 1.8, δ = 0.55, I_p = 4 MA, and B_t = 2.3 T. The simulation start with weak neutral beam heating (P_{NB} = 0.5 MW) and ohmic heating of P_{OH} = 3.1 MW and then neutral beam heating is increased up to P_{NB} = 8 MW at t = 3.0 s. Figure 1 shows the evolution of electron temperature profile Te, and heat diffusivity profile χ. An L/H transition occurs around t = 3.1 s. The χ is drastically dropped in the edge region and the pedestals are clearly formed on Te profiles. The HH factor is about 0.5 during L-mode phase and increases to ~0.85 at t = 4.0 s in the H-mode phase.

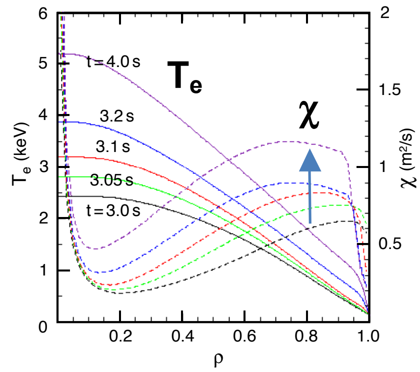

Fig. 1 Evolution of electron temperature profile and heat diffusivity profile.

3. Dynamics of the L/H transition in JT-60SA

The coupling between core transport code TOPICS-IB and SOL/divertor transport code SONIC are performed as follows. From the 1D core transport code the fluxes (Γ, Q_e, Q_i) at $\rho=\rho_c$ (= 0.82 for the present coupling) are sent to 2D SONIC code, while the plasma quantities (n_i, T_e, T_i) at the outer mid-plane are sent to the 1D core code from 2D SONIC code vice-versa. The edge region $\rho_c < \rho < 1$ is overlapped for both codes. The transport coefficients in the SOL/divertor region, χ_i, χ_e and D, are assumed uniform and their values are set equal to those at the separatrix boundary calculated by the CDBM model.

Figure 2 shows the time evolution of ion density and temperature (n_{id}, T_{ed}) at outer divertor strike point and ($n_{i,SOL}$, $T_{e,SOL}$) at the outer mid-plane through the L/H transition. The ion density at the strike point n_{id} drops rapidly from ~7x10^{19} m^{-3} to ~2x10^{19} m^{-3}, and the electron temperature T_{ed} increases from ~10 eV to ~50 eV. On the contrary at the mid-plane, the ion density $n_{i,SOL}$ is almost unchanged at ~1x10^{19} m^{-3}.

The L/H transition is successfully demonstrated based on the tuned CDBM model. Although results shown here are preliminary, it should be noted that the fluctuating nature appears in the divertor plasma after the transition. Further examination of the numerical accuracy and analysis on the physical mechanisms are required.

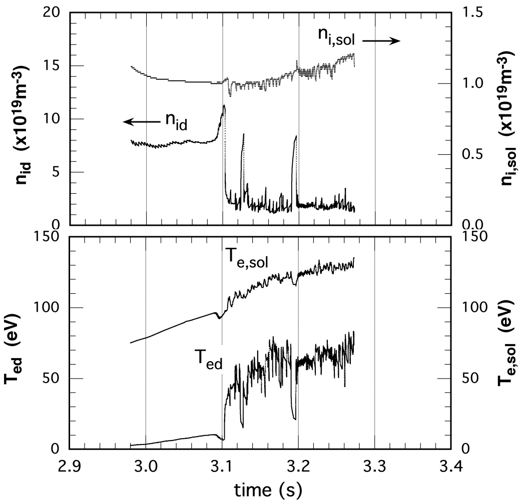

Fig. 2 Time evolution of electron density and temperature at outer divertor strike point and outer mid-plane through the L/H transition at t=3.1 s.

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