24C06

Analysis of Partially Detached Divertor Plasmas with Multi-Layer 1D Model
多層型一次元モデルを用いた部分非接触ダイバータプラズマ解析

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We have developed a "multi-layer (ML)" 1D model for investigating behaviors of partially detached divertor (PDD) plasmas. The basic idea is to put the detached and attached flux tubes adjacent each other, so that PDD plasmas that are multi-dimensional phenomena can be represented in one-dimensional results. Cross-field transport terms are evaluated as source terms in each partial differential equation. We show the contents of the ML 1D model and explain briefly the role of each section. We also show some results of preliminary simulations that insure the validity of the code.

1. Introduction

Reduction of the divertor heat load is one of the crucial issues in designing the next generation tokamaks such as ITER and DEMO. In order to resolve this issue, operating under partially detached divertor (PDD) plasmas is considered to be essential [1]. It has been shown by experiments that PDD plasmas are preferred to fully detached divertor plasmas with respect to thermal stability [2], so that PDD plasmas have been adopted for ITER operation scenarios [3].

In order to model PDD plasmas, many two-dimensional codes have been developed. It is considered, however, that somewhat simpler codes such as one-dimensional codes [4, 5] are adequate to gaining physical insight of PDD plasmas because 2D codes are computationally massive and sometimes inconsistency with experimental results was found [6]. While 1D codes are useful and comprehensible because of its simplicity, they are essentially unable to model PDD plasmas due to their multi-dimensionality.

The ‘multi-Layer (ML)’ 1D model we propose here has been developed for the purpose of solving this dimensional problem by treating cross-field transport terms as source terms in each partial differential equation. Detached and attached flux tubes are put adjacent to each other as shown in Fig.1, so that interactions between these tubes can be evaluated. In addition, the particle and energy transport to the first wall can be taken into account. We make brief explanation of this model and show some results of preliminary simulations.

2. Model

2.1 Plasma fluid model

The 1D transport equations are given as follows [7];

$$\frac{\partial(mn)}{\partial t}+\frac{\partial(mnv)}{\partial x}=mS \tag{1}$$

$$\frac{\partial(mnv)}{\partial t}+\frac{\partial\left(mnv^2+P\right)}{\partial x}=M \tag{2}$$

$$\frac{\partial}{\partial t}\left(\frac{1}{2}mnv^2+3nT\right)+\frac{\partial}{\partial x}\left\{\left(\frac{1}{2}mnv^2+5nT\right)v-\kappa_e\frac{\partial T}{\partial x}\right\}=Q \tag{3}$$

Here, the density n, the flow velocity v, the temperature T of ions and electrons are assumed to be equal, respectively. $P(=2nT)$ is the plasma pressure and κ_e is the parallel electron heat conductivity.

At the stagnation point (x=0), we use the following symmetric boundary conditions:

$$\frac{\partial n}{\partial x}=0,\ v=0,\ \frac{\partial T}{\partial x}=0 \tag{4}$$

At the divertor target (x=L), we use the following boundary conditions:

$$M_s=\frac{v}{c_s}=1 \tag{5}$$

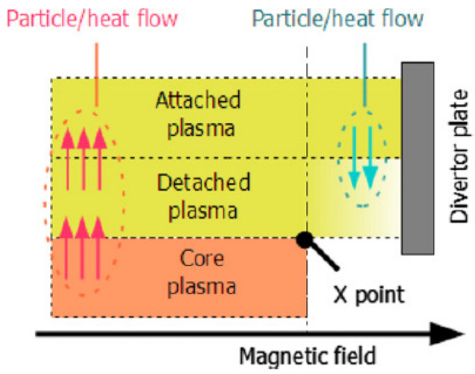

Fig.1. Schematic picture of the multi-layer 1D model.

$$q_{heat} = \left(5nT + \frac{1}{2}mnv^2\right)v - \kappa_e \frac{\partial T}{\partial x} = \gamma nTc_s \qquad (6)$$

Here, M_s is the Mach number, c_s is the sound speed, q_{heat} is the heat flux and $\gamma(\approx 6.5)$ is the sheath energy transmission factor. These boundary conditions are the same as B2 code.

2.2 Neutral diffusion model

We use the simple 1D neutral diffusion model:

$$(n_n v_n)_{j-1/2} = (n_n v_n)_{j+1/2} \exp\left(-\frac{ds}{\lambda_{ion,j}}\right) \qquad (7)$$

Here, s is the coordinate along the poloidal direction and λ_{ion} is the mean free path of ionization.

At the divertor target, we use the following condition:

$$(n_n v_n)_{div} = \eta_{trap}(nv)_{div} \sin\theta \qquad (8)$$

Here, η_{trap} is the recycling rate and θ is the pitch of the magnetic field.

3. Results

Prior to simulation studies using the ML 1D model, we checked validity of the ML1D plasma fluid code. In this simulation, ASDEX-like plasma parameters are assumed. The particle and heat flux from core plasma are set to be 6.0×10^{21} [s^{-1}] and 4.0MW, respectively. The pitch of magnetic field is fixed at 2.0 degrees. The calculated density, temperature and output flux amplitude factor as functions of the input flux amplitude factor $R_{in}\left(=1/(1-\eta_{trap})\right)$ are shown in Fig.2.

The output flux amplitude factor is consistent with the input flux amplitude factor. The correlation between plasma parameters and R_{in} is also consistent with that of two-point model [8].

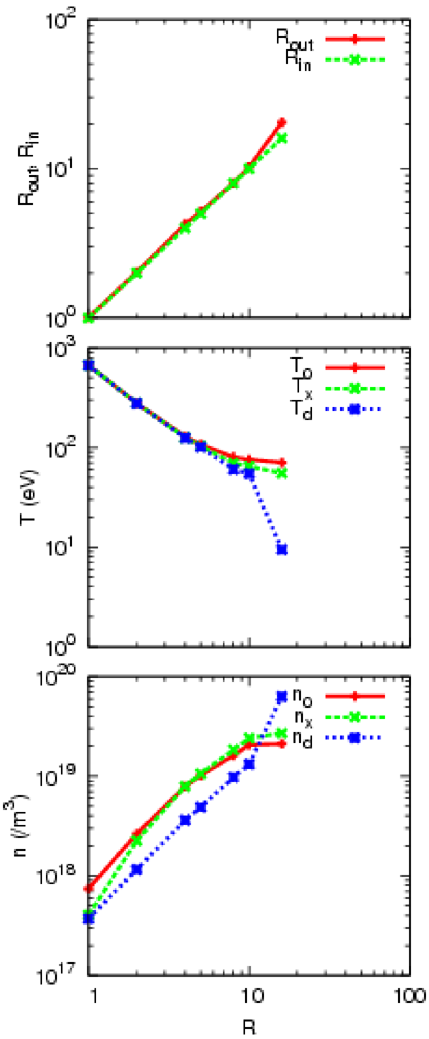

Fig.2. Correlation between plasma parameters and input flux amplitude factor R_{in}. The subscripts '0', 'x', 'd' represent the stagnation point, the X-point, the divertor plate, respectively.

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