§24. Hybrid Simulation of Neutralization Processes in an Accelerated Compact Torus Plasma

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The CT Injection method [1] was proposed as a fuel-injection method for large-scale power generation plasmas such as the ITER. However, its feasibility is still unclear because of the difficulty concerning the translation process of a plasmoid across the vertical magnetic field of the fuel injection target. To solve this problem, the CT Neutralization Fuel Injection method was proposed [2].

In this study, we run a computer simulation on the neutralization process inside the “CT Neutralization Fuel Injection” device. In our calculations, we focus on the plasmoid itself moving through the cell. The plasmoid is treated as a stationary target with which the neutral gas particles of the cell collide and charge exchang. The collision processes are reproduced by using rate-coefficients. The calculation determines the plasmoid’s degree of neutralization, and as a result minimum cell length is found.

The hybrid simulation model takes into account the neutralization process to investigate an electromagnetic behavior inside the neutralization cell. In particular, it should be clarified if the magnetic flux would decay with the plasma current and associated radial expansion of the plasma would cause the imbalance of the radial force, or not. We also study the influence of the axial electric field generated by the friction force between electrons in the moving plasmoid and slow ions.

In our calculations, slowing-down collisions and pitch-angle scattering are considered. Slowing-down collisions are the ion’s drag against electrons, causing deceleration. This term is used in the equation of motion by means of the slowing-down collision frequency, which is obtained from the Vlasov equations [3]. Next, pitch-angle scattering is the effect of the ions colliding with each other. The total energy of colliding ions remains unchanged, while the velocities are changed by the collision. The base pitch-angle is calculated and the collision frequency is used to determine the effective pitch-angle for each collision [4].

The charge exchange effect of the ions is created by reducing the weight of each super particle using the charge exchange rate coefficient. During the neutralization process, slow ions are generated by charge exchange in the neutralization cell. The slow ions are expected to ‘pull (decelerate)’ the CT by the friction force between electrons in the moving plasmoid and will create an axial electric field.

Figure 1 is the combined ion density time evolution result of our simulation. The Grad-Shafranov equilibrium of a CT in a ‘flux-conserved’ container was used for the initial CT state. The parameters listed in Table 1 were assumed in the simulation. These results are reasonable, since the front-end of the CT becomes neutralized faster than the rear sections in accordance with the typical reaction time $1/\left(n_n\langle\sigma v\rangle\right)$, which is about 1[μs]. Also, the simulation run time 10[μs] at a CT injection speed of 200[km/s] corresponds to a neutralizer penetration length of about 2[m].

From our results, the CT neutralization process is not affected overall from slow ions. Therefore, the CT was neutralized in a run length that collates to a neutral gas cell length of about 2 [m]. However, there are a lot of elements not considered yet in our simulation; such as electric field electron pressure gradients, charge re-exchanges, and also problems associated with numerical oscillation persists. Therefore, we plan to add and solve the above factors and improve our simulation to achieve a more accurate representation of the CT neutralization process.

Table 1. CT parameters.

Max Ion Density	7.0×10^{21}	[m^{-3}]
Ion Temperature	10	[eV]
CT Radius	5.0	[cm]
CT Length	7.5	[cm]
CT Elongation	1.5	[-]
CT Magnetic Field	0.2	[T]

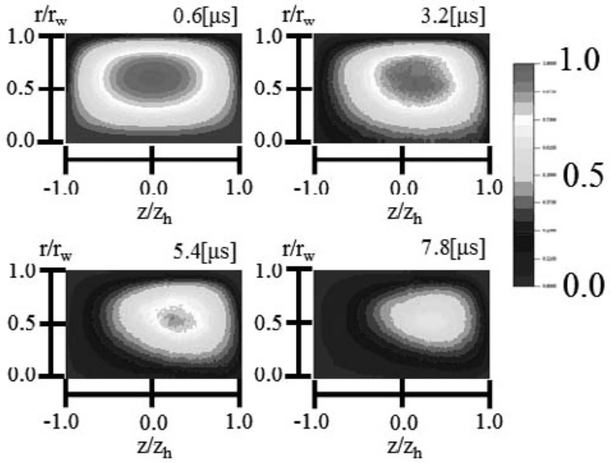

Fig. 1. Time evolution of CT ion density combined with the slow ion density.

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2) Fujii, S. et al. : IEEE Transactions on Plasma Science **38** (2010) 1473.
3) Helander, P. and Sigmar, D. J.: Collisional Transport in Magnetized Plasmas, CUP, (2002).
4) Boozer, A. H. and Petravic, G. K.: Phys. Fluids **24** (1981) 851.