§23. MHD Computational Study on Pellet Injection

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It has been pointed out that tritium and deuterium fueling could be a problem in toroidal fusion reactors. In the present experiments, there are two ways for the particle supply to keep or increase the plasma density. One is neutral gas puffing, which is a standard method used as a particle source from the edge region of the plasma column. The other is pellet injection, which has mainly been used to obtain high density plasmas. The latter approach to fueling may work even in fusion reactors in which the pellet velocity exceeds several km/s.

A theoretical analysis of pellet injection into magnetically confined plasmas was started by Rose [1]. After this work several ablation models for the pellet based on different physics were developed. One of the models established is the neutral cloud shielding model set up by Parks and Turnbull [2]. In this model, it is assumed that a pellet is shielded from the incident electron heat flux by a surrounding neutral cloud ablated from the pellet surface. However, the ablation model dose not include the effects that the neutral cloud is distorted by interacting with plasma, and the fuel is diffused along magnetic field lines. The temporal behavior of plasma and magnetic surface induced by those effects is thus not clear. Therefore, we will develop 3D-MHD code to investigate the dynamic behavior of the magnetically confined plasma caused by the pellet injection without any ablation model, in which the pellet is treated as an incompressible fluid. The hydrodynamic calculation includes equation of state (EOS) expressing the solid matter. In general, the numerical scheme for incompressible fluid (pellet) is different from one for compressible fluid (neutral cloud and plasma). We thus need a scheme to treat both compressible and incompressible fluids simultaneously in one program to simulate the interaction of pellet with plasma. For this purpose, we must treat compressible fluid by non-conservative equations and treat incompressible fluid by the same equation without imposing any condition such as divergence-free. Then, we use the Cubic-Interpolated Pseudoparticle (CIP) method [3] that can treat both fluids.

Fully hydrodynamic equations for both compressible and incompressible fluids can be written in the form:

$$\frac{\partial \mathbf{f}}{\partial t} + \mathbf{u} \cdot \nabla \mathbf{f} = \mathbf{g} \qquad (1)$$

The CIP method solves equations like Eq. (1) by dividing them into non-advection and advection phases. These are symbolically written as:

$$\frac{\partial \mathbf{f}}{\partial t} = \mathbf{g} \quad \text{(non-advection phase)} \qquad (2)$$

$$\frac{d\mathbf{f}}{dt} = 0 \quad \text{(advection phase)} \qquad (3)$$

The non-advection phase can be solved with the finite difference or finite volume method. Then, a cubic-interpolated profile is shifted in space according to Eq. (3). In determining this profile, we use **f** and spatial derivatives of **f** as independent variables. An interpolation of this kind is sometimes called Hermite spline. However, the key issue of the CIP scheme is in the way of determining the time evolution of spatial derivatives. They are determined from spatial derivatives of Eq. (1). Therefore, the profile is totally determined to be consistent with the equations without any artificial constraint such as smoothness that is frequently used in conventional spline. By a simple extension, the CIP can be used for both compressible and incompressible fluids. Namely, the pellet, neutral cloud, and plasma can be treated simultaneously. We will develop 3D-MHD code by using the CIP method, and investigate the behavior of the magnetically confined plasma induced by pellet injection.

Reference

[1] Rose, D. J., Culham Laboratory Technical Division Memorandum No. 82 (1968).

[2] Parks, P. B. *et al.*, Nucl. Fusion **17** (1977) 539.

[3] Takewaki, H. *et al.*, J. Comput. Phys. **61** (1985) 261.