

### §34. MHD Computational Study on Pellet Injection

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In the experiments, there are two ways for the particle supply to keep or increase the plasma density, neutral gas puffing and pellet injection. The pellet injection may work even in fusion reactors in which the pellet velocity exceeds several km/s. A theoretical analysis of pellet injection into magnetically confined plasma was started by Rose [1]. After this work, several ablation models for the pellet based on different physics were developed. One of the established models is the neutral gas shielding (NGS) 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 does not include the effects that the pellet and neutral cloud are distorted by interacting with plasma, and the fuel is diffused only along magnetic field lines. The temporal behavior of plasma and magnetic surface induced by those effects is thus not clear. Therefore, we would develop three dimensional fluid code to investigate the dynamic behavior of the magnetically confined plasma caused by the pellet injection. Since we have to treat a contact surface between the pellet and plasma and a shock wave driven by ablation, the Cubic-Interpolated Pseudoparticle (CIP) method [3] is used in the code.

In order to simulate the pellet ablation, we consider the following equations:

$$\frac{d\rho}{dt} = -\rho \nabla \cdot \mathbf{u}, \quad (1)$$

$$\rho \frac{d\mathbf{u}}{dt} = -\nabla \cdot \mathbf{P}, \quad (2)$$

$$\rho C \frac{dT}{dt} = -\mathbf{P} : \nabla \mathbf{u} + H, \quad (3)$$

where  $\rho$  is the density,  $\mathbf{u}$  the velocity,  $\mathbf{P}$  the pressure tensor including an artificial viscosity,  $T$  the temperature,  $C$  the specific heat, and  $H$  the heat source. Since the primary energy carriers is the electron in the plasma,  $H$  is represented by the following equations:

$$H = Q \frac{dq}{dl} = Q \frac{\rho}{m} q \Lambda(E), \quad \frac{dE}{dl} = \frac{\rho L(E)}{m \langle \cos \theta \rangle}, \quad (4)$$

where  $Q$  is the fraction,  $q$  the incident electron energy flux,  $l$  the distance,  $m$  the average mass,  $E$  the average electron energy,  $\Lambda$  the energy flux cross section,  $L$  the electron loss function,  $\langle \cos \theta \rangle$  the average pitch angle of electrons with respect to the magnetic field. For simplicity, we consider two dimensional code with rectangular coordinates in which the plasma heat flux propagates along the magnetic field ( $y$ ) into the ablation cloud, namely,  $l = y$  and  $\langle \cos \theta \rangle = 1$ . On the other hand, the heat flux in the NGS model is assumed to be uniform in direction, namely,  $l = r = \sqrt{x^2 + y^2}$  and  $\langle \cos \theta \rangle = 1/2$  [2].

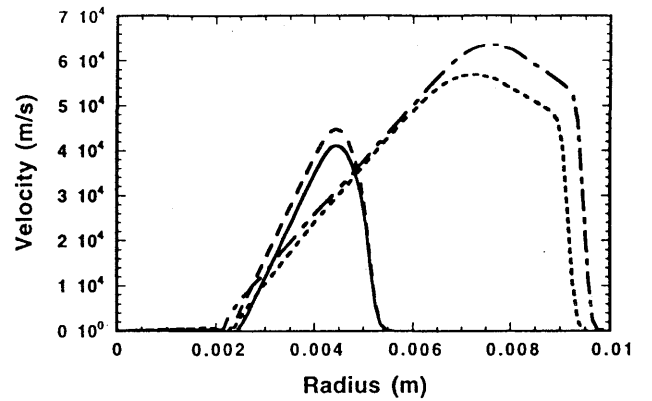


Fig. 1: Velocity,  $u$ , as a function of radius,  $r$ . Solid and dashed lines show  $x$ - and  $y$ -velocities, respectively, at  $t = 0.6 \times 10^{-7}$  s. Dot and dot-dashed lines show  $x$ - and  $y$ -velocities, respectively, at  $t = 1.2 \times 10^{-7}$  s.

Initially, a cylindrical pellet with the number density  $n = 10^{20} \text{ m}^{-3}$ , temperature  $T = 0.1 \text{ eV}$ , and radius  $r = 0.0025 \text{ m}$  is assumed to be in the plasma with the electron density  $n_e = 10^{20} \text{ m}^{-3}$  and temperature  $T_e = 10 \text{ keV}$ . Figure 1 shows the special profiles of the velocity obtained by 2D simulation. A solid and dashed lines show  $x$ - and  $y$ -velocities, respectively, at  $t = 0.6 \times 10^{-7}$  s. A dot and dot-dashed lines show  $x$ - and  $y$ -velocities, respectively, at  $t = 1.2 \times 10^{-7}$  s. We have found that the ablation structure is constructed within  $0.002 \text{ m} \lesssim x \lesssim 0.004 \text{ m}$  at  $t = 0.6 \times 10^{-7}$  s and  $0.002 \text{ m} \lesssim x \lesssim 0.007 \text{ m}$  at  $t = 1.2 \times 10^{-7}$  s, respectively. The profiles have jump structures around  $r \sim 0.005 \text{ m}$  and  $0.0095 \text{ m}$  at  $t = 0.6 \times 10^{-7}$  s and  $1.2 \times 10^{-7}$  s, respectively, that express shock waves. The shock is driven out of the pellet because the expansion speed caused by the ablation is larger than the sound speed. It should be noted that the position of the shock front in  $y$ -direction is more outward than one in  $x$ -direction while the position of the the ablation front in  $y$ -direction is more inward than one in  $x$ -direction. This is due to the fact that since the pellet is mainly heated in  $y$ -direction because of the heat flux along the magnetic field, the neutral gas is expanded and the pellet is evaporated in  $y$ -direction rather than in  $x$ -direction.

A fluid code has been developed to investigate physics on the pellet injection. The CIP method is used in this code in order to treat a shock wave and contact surface with a sharp discontinuity. We show the geometrical effects caused by the heat flux propagating along the magnetic field with the code. In the future work, we extend this code to the fluid code with a neutral fluid and MHD plasma and compare with the ablation model and experimental results.

#### References

- [1] D. J. Rose, Culham Laboratory Technical Division Memorandum, No. 82 (1968).
- [2] P. B. Parks *et al.*, Nucl. Fusion **17**, 539 (1977).
- [3] H. Takewaki *et al.*, J. Comput. Phys. **61**, 261 (1985).