§8. Geometrical Effects on Pellet Ablation

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Refueling is one of essential methods in order to control plasma density and sustain steady state plasmas. A gas puffing has been successful for building and sustaining a plasma density in an experimental system of past generation. However, in a large scale experimental system, e.g., LHD, the plasma sources induced by the gas puffing are strongly localized near the plasma surface. Then, a pellet injection is placed as a fundamental tool and has been mainly used to obtain a high density plasma and control a density profile [1].

When a pellet is injected into torus plasma, it is essentially heated by electrons in the bulk plasma along B-field. Then, physics of the pellet ablation is different from one in so-called ablation models assuming isotropic heating [2]. In order to investigate such a geometrical effect, two dimensional simulation is carried out, where the cylindrical geometry (r, θ, z) is used. A spherical pellet is placed at the center of it and the plasma heat flux propagates along the magnetic field (z) to the pellet. Physical quantities are assumed to be uniform in the θ-direction. No effect of the magnetic field (except for setting the direction of the electron heat flux) is included.

Figure 1 reveals the essential dynamics of 2D pellet ablation. The parameters used as an initial condition are the pellet radius $r_p = 2$ mm, electron temperature $T_{e\infty} = 2$ keV and number density $n_{e\infty} = 10^{20}$ m^{-3} in the bulk plasma. $T_{e\infty}$ and $n_{e\infty}$ are assumed to be constant through the temporal evolution. It is seen that the 2D ablation rate versus time curve (thick solid line) increases at first, reaches a peak, and then falls to zero later on. It is due to the fact that the pellet is deformed like a disk shape by nonuniform ablation pressure on the pellet surface. The dashed line in Fig. 1 plots the ablation rate for the 1D spherically symmetric isotropic heating model used in the simulation. One of the key results of our study is that pellet deformation can shorten the life span of a pellet.

Notice that the pellet lifetime for the 1D isotropic heating simulation is 103 μs. The corresponding pellet lifetime predicted by the modified transonic-flow (TF) model [3] is 309 μs that is consistent with IPADBASE [4]. However, the 2D model predicts a pellet lifetime of 70 μs; a factor of 4 smaller than the modified TF model. Now according to Ref. [5], the 2D simulation of the hard pellet that is not allowed to make a deformation, would predict a pellet lifetime of ~103/0.54191 μs. Hence, there is a large difference–a factor of 2.7–in the lifetimes between hard and soft pellets. An obvious consideration is that we did not take into account electrostatic shielding. Electrostatic shielding cuts the ablation rate by a factor of 0.51–0.55 [3]. If we choose 0.53, the readjusted pellet

lifetimes for the three simulation cases become

$$t_p^{iso} = 191 \ \mu s, \tag{1}$$

$$t_p^{aniso/hard} = 360 \ \mu s, \tag{2}$$

$$t_p^{aniso/soft} = 132 \ \mu s, \tag{3}$$

$$t_p^{TF} = 309 \ \mu s. \tag{4}$$

Clearly the modified TF lifetime is intermediate between the soft and hard pellets lifetimes. This might suggest that the pellet undergoes deformation only in the beginning of ablation, when the surface pressure variation Δp is at a maximum, and $\Delta p > \sigma$ where σ is yield stress for material. Later on Δp diminishes due to the deformation, until at some point $\Delta p < \sigma$. Thereafter, the pellet would ablate as a rigid body, and consequently the lifetime would be extended.

Two dimensional fluid code treating with a neutral in various states of matter and plasma simultaneously, has been developed to investigate the pellet ablation. The pellet is deformed by nonuniform ablation pressure induced by the anisotropic heat flux along B-field, so that the pellet life time could be shorter than one in isotropic heating assumed in the ablation model.

REFERENCES

[1] L. R. Baylor et al., Nucl. Fusion **32**, 2177 (1992).

[2] P. B. Parks and R. J. Turnbull, Phys. Fluids **21**, 1735 (1978).

[3] P. B. Parks and M. N. Rosenbluth, Phys. Plasmas **5**, 1380 (1998).

[4] L. R. Baylor et al., Nucl. Fusion **37**, 445 (1997).
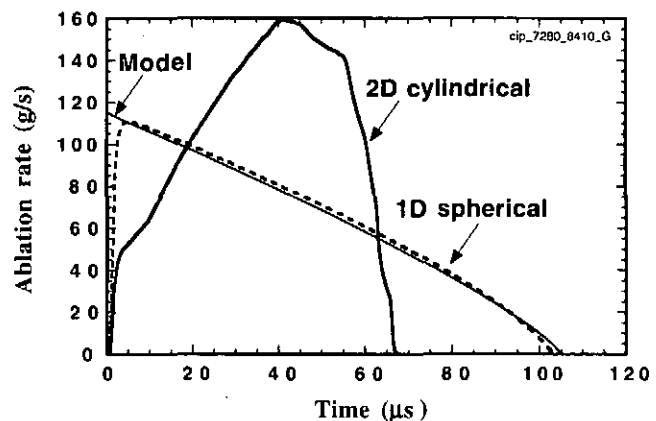
[5] R. Ishizaki et al., Phys. Plasmas (2004).

FIG. 1: Time dependence of the pellet ablation rate for a constant heat flux over the lifetime of the pellet. The solid curve pertains to 2D cylindrical axisymmetric geometry and the dashed curve is for the 1D spherically symmetric geometry. The thin solid line is the ablation rate from the transonic-flow model with the well-known scaling law $G \propto r_p^{4/3}$ [3].