§21. Study of Pellet Injection for Efficient Core Plasma Fuelling in Heliotron J

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The possible application of the formation by an in-situ technique and pneumatic acceleration of solid hydrogen pellets, which are reliable techniques and already adopted in the pellet injection system of LHD, has been studied to shape the smaller size (0.8 mm) and velocity (300 m/s-500 m/s) of pellets required in Heliotron J device. By using ideal gun theory (IGT), pellets could be injected with the speed of 590 m/s-760 m/s by these techniques when the barrel length is optimally minimized. Although the velocity might be still higher and the effect of pellet on plasma core should be taken into account, these techniques seems to be a good candidate for Heliotron J.

The theoretical velocity of the pneumatically accelerated pellet can be described by a propagation of one-dimensional rarefaction wave[1)], which is known from the ideal gun theory:

$$\frac{M}{A_p}\frac{\mathrm{d}U(t)}{\mathrm{d}t} = \frac{2}{3}d\rho_s\frac{\mathrm{d}U(t)}{\mathrm{d}t} = P_0(1-\frac{1}{2}\frac{(\gamma-1)U(t)}{C_0})^{\frac{2\gamma}{\gamma-1}},$$

where $U(t), d, M, A_\mathrm{p}, P_0, \gamma, \rho_\mathrm{s}$ and C_0 denote the pellet velocity, pellet diameter, pellet mass, projected area of a pellet, initial pressure of propellant gas, specific heat ratio of propellant gas, solid hydrogen density and sound. The pellet velocity as a function of a propellant gas pressure is obtained by solving the above differential equation.

The variation of the pellet speed with the propellant gas pressure is shown in Fig. 1. Some species of propellant gases such as He, N_2, Ar are assumed. Here, barrel length is fixed as 0.1 m. N_2 or Ar seems suitable for the slower speed as required in Heliotron J. However, they can not be adopted since they become solid state in cryogenic components, resulting that they are injected into plasma as an impurity pellet. By using He inevitably, the pellet speed with 700m/s-900m/s, which is 70-90% of the speed predicted by IGT, is probably reached at 1 MPa of gas pressure. Here, the result that the measured velocities decreased by 10-30% compared with the IGT due to the conflict, heat transfer and viscosity between pellet and barrel was reported[2)].

The pellet speed could be controlled by adjusting the barrel length. Figure 2 shows the pellet velocity as a function of gas pressure. Attained pellet velocity is reduced with decreasing the barrel length. If the barrel length is assumed to be 0.05 m, the pellet velocity is 840 m/s at 1 MPa of gas pressure by using IGT and actual pellet speed is predicted to be between 590 and 760 m/s. In this case, the penetration depth is $0 < r/a < 0.2$, and the pellet might be marginally injected into the plasma core. However, if the electron temperature of background plasma more than 1 keV is achieved, the pellet penetration would not affect the plasma core.

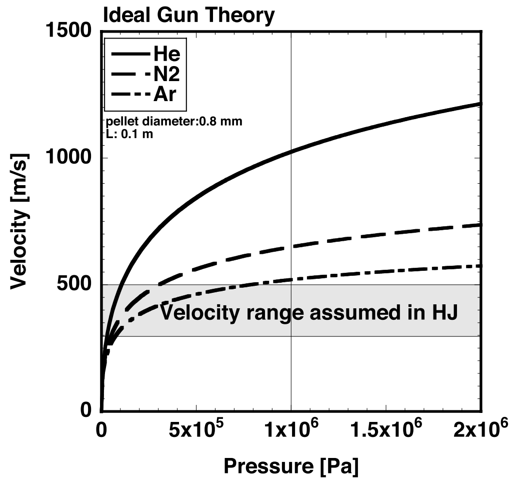

Fig. 1: Pellet velocity as a function of propellant gas pressure. Barrel length is assumed to be 0.1 m.

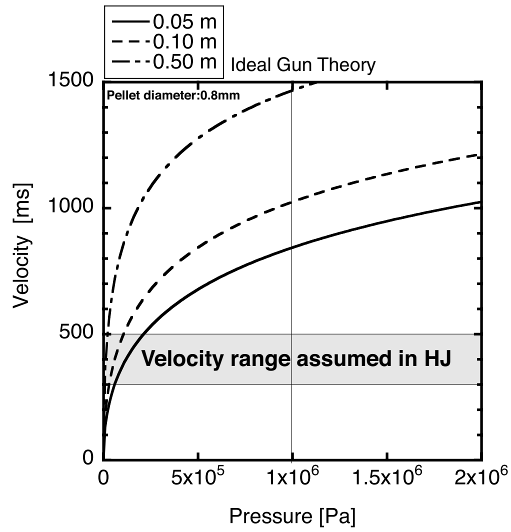

Fig. 2: Variation in the pellet velocity against barrel length of 0.05, 0.10 and 0.50 m.

1) L.D. Landau, E.M. Lifshitz, Fluid mechanics (Pergamon Pres, 1987).

2) K. Kumagai et al., Annual report of NIFS 2007, p. 91.