§3. Extension of Ideal Gun Theory Taking into Account Shock Wave

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A Pellet injection is one of the main candidates in the refuel to magnetic confined fusion plasmas because it can supply fuel particles directly to core plasma. In order to supply a fuel effectively, a high speed pellet is injected by a pneumatic pipe-gun injector. The injection mechanism of a pellet is investigated for the optimization of a pellet speed.

In a pneumatic pipe-gun injector, the pellet is accelerated by applying a high-pressure propellant gas from a breech. The pellet propellant property is calculated by the ideal gun theory (IGT), which is described by one-dimensional rarefaction wave propagation in an unbounded tube. In the IGT assumes the pellet velocity is equivalent to the gas velocity, the pellet velocity, *u(t)* ,is given by

$$u(t)=\frac{2a}{\gamma-1}\left\{1-\left[1+\frac{(\gamma+1)A_{proj}}{2ma}p_i t\right]^{-\left(\frac{\gamma-1}{\gamma+1}\right)}\right\} \qquad (1)$$

where a is the initial sound velocity of propellant gas, γ is the specific heat ratio, A_{proj} is the projected base area, m is the projectile mass and p_i is propellants pressure, respectively [1]. Propellant gas pressure dependence of pellet velocity is shown in Fig. 2. Solid line and closed circle indicates the calculated and measured pellet velocity. The measured pellet velocities decreases by 30% compared with the IGT predictions. We try to find reason for the difference between the IGT and experiment.

There is finite space with low pressure saturated gas between a pellet and propellant gas before injector as shown in Fig. 1(a) ① while the IGT neglect the space for simplicity. This low pressure space lead to generation a shock wave and propagated in region ① before propagation of propellant gas pressure. We take into account the shock wave effect on pellet acceleration. The pressure behind shock wave (region ②) p_2 is expressed using the ratio of the propellant gas pressure p_4 to the saturated gas pressure p_1 as follows.

$$\frac{p_4}{p_1}=\frac{p_2}{p_1}\left\{1-\frac{(\gamma-1)\frac{a_1}{a_4}\left(\frac{p_2}{p_1}-1\right)}{\left[2\gamma\left(2\gamma+(\gamma+1)\left(\frac{p_2}{p_1}-1\right)\right)^{1/2}\right]}\right\}^{\frac{-2\gamma}{\gamma-1}} \qquad (2)$$

If the pellet does not be moved by the incident shock, the shock is reflected as shown in Fig. 1(c) ⑤. The pressure behind reflected shock wave p_5 is given by

$$p_5=\left[\frac{2\gamma M_s^2-(\gamma-1)}{\gamma+1}\right]\left[\frac{(3\gamma-1)M_s^2-2(\gamma-1)}{(\gamma-1)M_s^2+2}\right]P_1 \qquad (3)$$

where M_s is shock wave Mach number[2].

Pellet velocity range, which consider the shock wave effect by substituting p_2 and p_5 for p_i in equation (1), are shown by hatched area in Fig. 2. The lower and upper limits temperature at the region ① T_1 are 13.8K (hydrogen triple point temperature) and room temperature, respectively. Experimental results are in the range of the calculated pellet velocity is driven by a reflected shock wave.

The reflected shock wave may be related to the pellet injection mechanism. We do not take into account the deceleration effects of fluid viscosity and friction with wall, and do not consider the pellet velocity which is driven by a multiple reflected shock in this calculation. Further calculation that takes into account these effects is required.

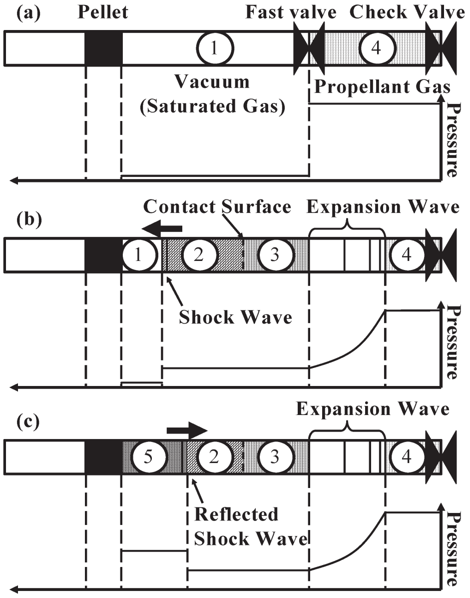

Fig. 1 Schematic diagram of shock wave drive.

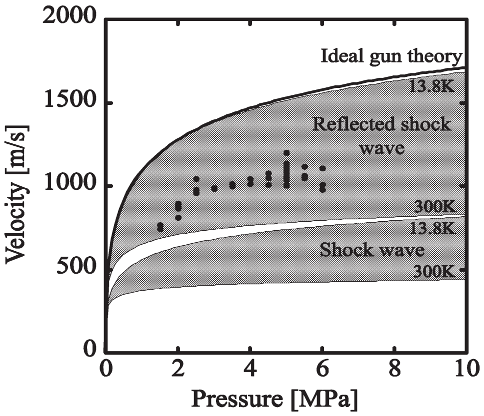

Fig. 2 Pellet velocity driven by shock wave. The broken curves are the ideal gun theory calculations.

Reference

1) L.D.Landau, E.M.Lifshiz, *Fluid mechanics* (Pergamon Press,1987).
2) Kii, T., *Compressible fluid dynamics* (Rikougakusya,1996).