PROJECTILE ACCELERATION AIMING AT VELOCITIES ABOVE 9 km/s BY A COMPACT GAS GUN

Tatsumi Moritoh, Nobuaki Kawai, Kazutaka G. Nakamura and Ken-ichi Kondo

Abstract. Optimization conditions were studied for the conventional two-stage light-gas gun, which is a part of a three-stage light-gas gun having a preheating and filling stage. A firing test achieved a velocity of 6.2 km/s using helium as driver gas with a projectile weighing 0.6 gram. In the case of firing test using hydrogen with the same projectile mass and a piston weighing 430 gram, a velocity of 8.1 km/s was obtained. Moreover, it was found that higher velocity can be achieved using a lighter piston to increase the piston velocity. A velocity of 8.9 km/s was achieved using a piston weighing 290 gram.

INTRODUCTION

A two-stage light-gas gun is one of the most important tools for shock compression studies because of its abilities to generate plane shock-waves. However, conventional two-stage light-gas guns are limited to launch heavy projectile at velocities of 7-8 km/s. In order to perform shock compression studies in the region of terapascals pressure by using this gun, a projectile velocity more than 9 km/s is necessary even for a symmetric impact of platinum. Recent developments of laser-shock technologies have made it possible to generate pressures above terapascals. However, a gas gun launching at low acceleration without changing the initial state of flyer materials will be required even in future. In 1995, we proposed a non-destructive type of three-stage light-gas gun having an additional preheating and filling stage which allows us to regulate initial temperature of driver gas in order to obtain higher projectile velocities. In preliminary tests, helium and hydrogen were preheated to 1080 K and 500 K, respectively by using a 9-kg pre-pump piston. In order to examine effects of preheating on projectile velocity, it is necessary to determine the performance of this gun as a normal two-stage light gas gun and to know the relationship among operating parameters in the non-destructive experiments. In this paper, we report optimization
TABLE 1. Specification of The Compact Two-Stage Light-Gas Gun Used In This Work as Compared With Those of NASA Gun and LLNL Gun.

<table>
<thead>
<tr>
<th></th>
<th>LLNL gun</th>
<th>NASA gun</th>
<th>TITECH gun</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pump tube length (m)</td>
<td>10</td>
<td>15.18</td>
<td>4.2</td>
</tr>
<tr>
<td>Accelerating reservoir length (mm)</td>
<td>445</td>
<td>343</td>
<td>370</td>
</tr>
<tr>
<td>Launch tube length (m)</td>
<td>9</td>
<td>3.87</td>
<td>3.58</td>
</tr>
<tr>
<td>Pump tube diameter (mm)</td>
<td>90</td>
<td>64.4</td>
<td>50</td>
</tr>
<tr>
<td>Launch tube diameter (mm)</td>
<td>28</td>
<td>12.7</td>
<td>11.8</td>
</tr>
<tr>
<td>Piston mass (g)</td>
<td>4540</td>
<td>888</td>
<td>290,430</td>
</tr>
</tbody>
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studies of the compact two-stage light-gas gun which is a part of the three-stage light-gas gun. We examined the following five operating parameters: (1) powder mass, (2) kinds of light gas used as driver gas, (3) initial pressure of driver gas, (4) projectile mass, (5) piston mass. In particular, this paper describes effects of piston mass on projectile velocities and importance of optimizing initial gas pressure.

EXPERIMENTAL

Specifications of the compact two-stage light-gas gun developed in this work are given in Table 1 as compared with those of NASA gun and LLNL gun. All the units of the gun are mounted on a considerably heavy steel base (10.5-m long and 0.9-m wide). This gun is very compact for a two-stage light-gas gun, which can be placed in a small experimental room. In particular, the length of the pump tube is much less than the others listed in Table 1, so that the purpose of this experiment is to raise the temperature of driver gas in such a short pump tube. Pistons are made of high-density polyethylene, having a diameter of 50-mm. Two types of piston with different weights were examined: one was 430 g with a 200 mm length, and the other was 290 g and 165 mm length. Smokeless powder (Nippon Oil & Fat Co, NY-500) was used as propellant for driving the piston. Projectile velocity was measured by Magnetoflyer method. Polycarbonate was used as the sabot material, and a small magnet was embedded in the sabot for projectile velocity measurement. The sabot is 11.85 mm in diameter, and its mass was varied from 0.6 to 2.6 g by varying its length from 4 mm to 12 mm, respectively.

RESULTS AND DISCUSSION

Firing Tests Using Hydrogen As A Driver Gas

The maximum velocity achieved in tests using helium as a driver gas was 6.2 km/s, but erosion of the gun barrel was so severe. In order to obtain higher projectile velocities, we performed firing tests using hydrogen, whose sound velocity is higher than that of helium at the same temperature. Initial pressure of hydrogen was initially fixed at 5 atm, and mass of powder was increased gradually from 40 g to prevent the apparatus from being damaged. A firing test achieved a velocity of 6.6 km/s using a projectile weighing 0.8 g and 95 g of powder. This velocity is higher than the maximum velocity in the case of helium, and gun erosion was not detected.

Consequently, we performed tests to obtain higher velocities by changing initial gas pressure and powder mass, monitoring projectile velocity and energy efficiency (E), which is the ratio of kinematic energy of projectile to combustion energy of the powder.
\[
E = \frac{1}{2} \frac{M_{\text{pro}} v^2}{M_{\text{pow}} Q},
\]

where \(M_{\text{pro}}, M_{\text{pow}}, Q,\) and \(v\) are projectile mass (kg), powder mass (kg), combustion energy per unit mass of powder \((3.38 \times 10^6 \text{ J/kg})\), and projectile velocity (m/s), respectively.

Results of the firing test using hydrogen at a piston weight of 430 g are shown in Fig. 1. Energy efficiency was better at the condition of lower gas pressure. Although the projectile velocity is higher than that of heavy projectiles, energy efficiency decreases in the case of a light projectile. In these tests, a projectile velocity of 8.1 km/s was achieved by optimization to an initial hydrogen pressure with a 0.6 g projectile.

When changing powder mass and initial gas pressure, we were careful to prevent the piston from invading into the launch tube in all firing tests by checking the stop position of the piston after firing. The stop position after the firing test that we obtained a velocity of 8.1 km/s was so close to the launch tube that we chose to stop increasing powder or decreasing initial gas pressure, in order to prevent excess momentum of the piston resulting in damage to the launch tube.

**Effect of Piston Mass on Velocities of Projectile**

In order to decrease the momentum of the piston but increase the kinetic energy of the piston, we carried out several firing tests using a lighter piston to optimize both powder mass and initial gas pressure. Pistons weighing 290 g were also prepared. Piston velocities were measured by three strain gauges fixed on the outside wall of the pump tube at the same intervals, as shown in Fig. 2. Figure 2 shows that the rise in the velocities of 290 g pistons is much greater than those of 430 g pistons. Figure 3 shows energy efficiency as a function of

**FIGURE 1.** Changes in energy efficiency at three different projectiles vs initial hydrogen pressure. Projectile velocities are also shown in the figure.

**FIGURE 2.** Piston velocities measured vs powder mass as a function of piston mass.

**FIGURE 3.** Energy efficiency vs initial hydrogen pressure as a function of piston mass. Powder mass, projectile mass, and projectile velocity are shown from the top to the bottom in the vicinity of each symbol, respectively.
hydrogen pressure and piston mass. It was possible to use a larger powder mass than those for a 430 g piston without any damage. When the initial gas pressure was lower, energy efficiency increased with 290 g pistons. Moreover, higher velocities were achieved under conditions of lower initial gas pressure and energy efficiency was better. It is necessary to decrease the initial pressure of driver gas in order to accelerate the projectile efficiently in the case of a light piston. The maximum projectile velocity achieved so far was 8.9 km/s using piston weighing 290 g.

SUMMARY

We performed optimization studies on the compact two-stage light-gas gun having a short pump tube. It was found that velocities up to 8.9 km/s were obtained by using hydrogen as driver gas and a light piston for such a short launcher. The use of a light piston makes it possible to increase powder mass without any damage of apparatus. The projectile is accelerated efficiently to higher velocities. We believe that this is because the lighter piston with higher velocity creates stronger shock-waves in the driver gas, resulting in higher gas temperature. It is necessary to optimize initial gas pressure, which strongly affects the energy efficiency. It will be possible to achieve higher velocities by further optimization of parameters such as thickness of the diaphragm and inner diameter of the launcher.

ACKNOWLEDGEMENT

This work has been supported by CREST (Core Research for Evolutilional Science and Technology) program organized by Japan Science and Technology Corporation (JST). We thank M. Hasegawa for his experimental help.

REFERENCES