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NEW LIGHT-GAS GUNS FOR THE HIGH-VELOCITY THROWING OF MECHANICAL PARTICLES

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ABSTRACT

The paper describes the three new light-gas guns for the high-velocity throwing of mechanical particles: an upgraded two-stage light-gas gun and single- and three-stage compressed gas guns. The paper also provides the schemes, pictures and characteristics of light-gas guns.

Keywords: light-gas gun accelerator, two-stage light-gas gun, three-stage light-gas gun.

INTRODUCTION

Space debris and flows of natural particles (meteoroids) create a fragmental and meteoroidal environment that poses a danger to spacecrafts. Therefore, one of the tasks concerning the development of designs for space rocketry is to provide the fracture resistance during a high-velocity impact of mechanical particles. Various particle acceleration methods including light-gas guns (LGG) which occupy a leading position are widely used and improved to study experimentally the strength characteristics of materials and structural elements [1-4]. The two- and three-stage light-gas guns are used for the high-velocity (2-8 km/s and higher) throwing of mechanical particles with a mass from the fractions of a gram to a kilogram and more [5-8]. Experimental results on the high-velocity interaction of particles with targets are required to develop mathematical models and conduct numerical studies of high-velocity impact phenomena [9-12].

This paper describes the three new light-gas guns which differ in the use of different energy sources such as powder charge and compressed air.

UPGRADED TWO-STAGE GUN

The results of experimental studies and tests of LGGs with a light piston [5-7], and the RF patent [8] that offers several original design solutions to increase the survivability of guns and the stability of throwing parameters were used for the development of the upgraded «classical» light-gas gun PPKh50/18. The scheme of this light-gas gun is shown in Figure-1.

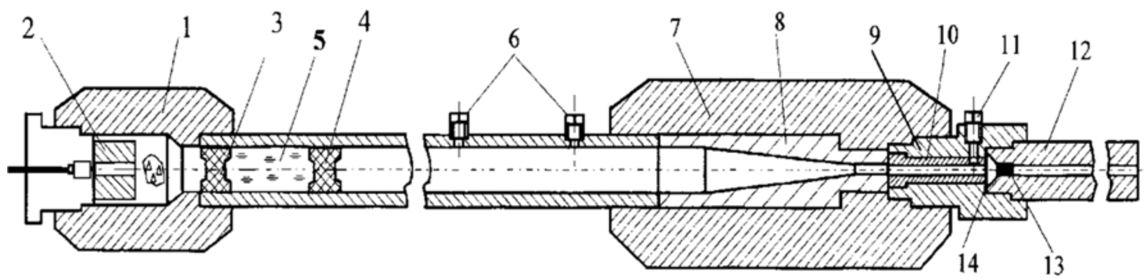

Figure-1. Upgraded two-stage light-gas gun.

1 is the powder chamber; 2 is the ring insert; 3, 4 are the obturators; 5 is the gel-like filler; 6 is the pressure sensors T-6000; 7 is the conical adapter; 8 is the gun liner (tungsten heavy alloy); 9 is the measuring adapter; 10 is the gun liner (tungsten heavy alloy); 11 is the pressure sensor T-10000; 12 is the barrel; 13 is the thrown element; 14 is the diaphragm.

The upgraded light-gas gun PPKh50/18 includes an electric priming plug that can use conventional electric cartridge primers (ECP), double-wire ECP, etc. In order to provide the stable ignition and combustion of powder charge, the internal volume of the powder chamber can be changed [8]. To increase the survivability of a conical adapter, its maximal length is selected in view of technological solutions [5, 8]. In addition, the original design of a piston [5, 8] is used with two obturators and gel-like filler. The upgraded light-gas gun includes a measuring adapter that reduces the wear of a ballistic barrel [5] and also allows a throwing mode to be implemented without a diaphragm and a free throwing mode to be implemented without a pallet. The light-gas gun is designed to obtain the velocities of projectiles up to 8 km/s with a mass of 5-10 g. Figure-2a shows the assembly drawing of the light-gas gun, and Figure-2b shows the light-gas gun.

The upgraded light-gas gun was mounted in the laboratory ballistic test room of the department for impact strength at the Central Research Institute of Machine

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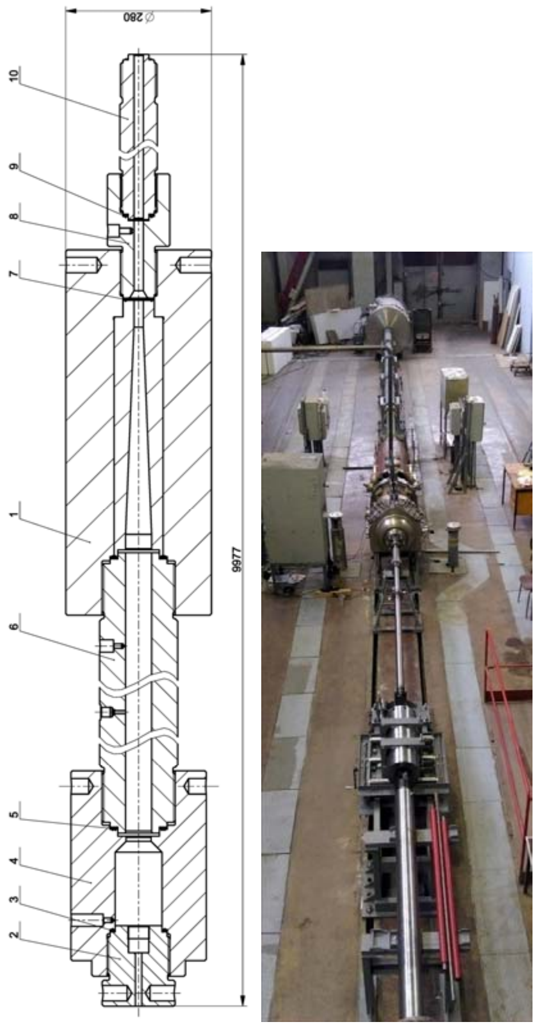
Building (Korolev, Moscow Oblast, Russia), which is the Institute of the Aeronautics and Space Agency and specializes in the development of long range ballistic missiles, air defense missiles, and propulsion units for defense sectors. The tests confirmed the efficiency of all units and the light-gas gun.



(a) (b)

Figure-2. Assembly drawing of the upgraded two-stage light-gas gun PPKh50/18 (a); the upgraded light-gas gun in the laboratory room. 1 is the adapter, 2 is the plug, 3 is the gasket, 4 is the powder chamber, 5 is the gasket, 6 is the pipe, 7 is the diaphragm, 8 is the measuring adapter, 9 is the gasket, 10 is the barrel.

SINGLE-STAGE COMPRESSED GAS GUN

The use of powder charge as the original source of energy for LGGs creates certain difficulties for operation with a light-gas gun. A laboratory that plans to use a light-gas gun should obtain a license for operation with explosives and organize their utilization (accounting, storage, transportation, usage, etc.). The ballistic test room should be equipped with appropriate safety equipment. Increased requirements are also imposed on the personnel for operation with a light-gas gun. All this significantly complicates the use of such installations in experimental studies.

The paper represents a review and preliminary analysis of some possible LGG designs with a source of energy alternative to the powder charge, in particular, a three-stage LGG, the first stage of which uses compressed gas.

To obtain supersonic velocities, a single-stage light-gas gun was developed, in which a projectile was accelerated by compressed gas (helium) supplied from a standard gas vessel (maximum initial pressure is 15 MPa). This installation provides a velocity of 400-700 m/s for projectiles with a mass of 0.5-1 g for the case when the caliber of a barrel is 8 mm and the volume of a chamber is 20 cm^3.

The repetition of the experiments is provided by the initial pressure in the chamber that is covered with a multilayer diaphragm made of the X-ray film. At the certain moment of time, the film is broken by a special needle when the rod built-in in the lock unit is rotated. The single-stage LGG is shown in Figure-3.

The calculations show that when compressed gas is used as an origin energy source for a two-stage LGG, then throwing velocities are about 1.5-2 km/s. In this case, the gas pressure should be much higher and, consequently, metal diaphragms should be used. A double-diaphragm unit shown in Figure-4 can be used for the operation of this installation at a certain pressure P_0.

The operation of a two-stage LGG is as follows. The breakout pressure of the diaphragms P_f is selected according to the condition P_f = 0,7P_0, and pressure equal to 0,5P_0 is supplied in the volume between the diaphragms.

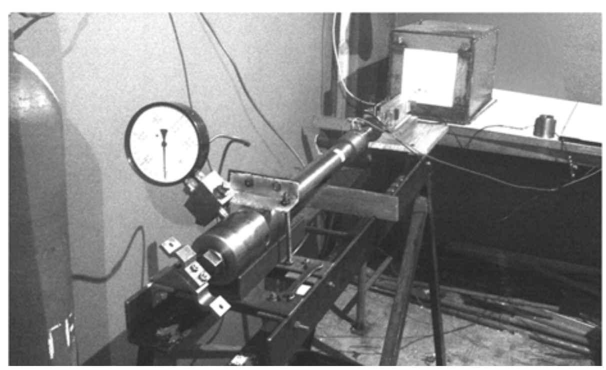


Figure-3. Single-stage compressed gas LGG.

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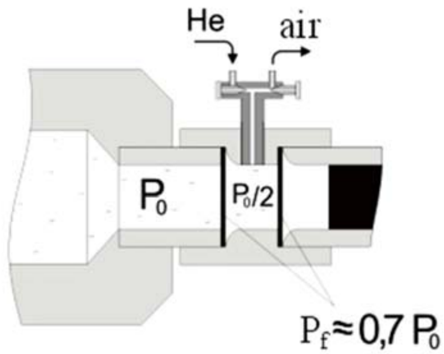

Figure-4. Scheme of a double-diaphragm unit.

After that, the chamber is filled with compressed gas at the required pressure P_0. At the certain moment of time, the gas is released from the volume between the diaphragms, the pressure drop at the first diaphragm exceeds P_f and the diaphragm is broken. After that the second diaphragm is also broken.

THREE-STAGE COMPRESSED GAS GUN

The further development of the approach described above is the creation of a light-gas gun to obtain ultrahigh (8 km/s and higher) throwing velocities. The preliminary analysis showed that there was a need to create a three-stage LGG. The scheme of such a LGG is shown in Figure-5.

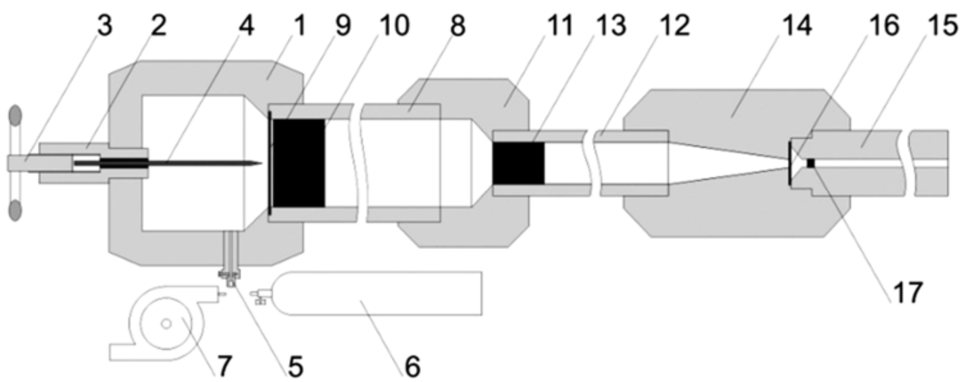

Figure-5. Three-stage compressed gas gun.

The three-stage compressed gas gun (Figure-5) includes a gas (pneumatic) chamber (1), in the bottom of which a diaphragm breakout device consisting of a body (2), a pusher screw (3) and a movable needle (4) is mounted. In addition, a gas valve (5) is mounted in the wall of the gas chamber to fill it with light gas from the gas vessel (6) or with compressed air through the compressor (7). The first stage barrel (8) filled with light gas and separated from the gas chamber by the diaphragm (9) is connected with the gas chamber. The first stage piston (10) is placed in the entry section of the barrel (8) behind the diaphragm (9). Another end of the barrel is connected through a conical adapter (11) with the second stage barrel (12) also filled with light gas.

In the entry section of the second stage barrel there is a deformable second stage piston (13) that separates the internal volumes of the barrels. A high-pressure chamber (14) is connected with another end of the second stage barrel. A ballistic barrel (15), the internal volume of which is separated from the internal volume of the second stage barrel grooved by a metal notched diaphragm (16) is attached to the entry section of the high-pressure chamber. A projectile (17) is placed in the entry section of the barrel behind the diaphragm.

This installation operates as follows. The gas chamber (1) is filled with light gas or air up to the required (calculated) pressure by using a gas vessel (6) or a compressor (7) through a gas valve (5). During rotation, the pusher screw (3) pushes the movable needle (4) into the gas chamber to break the diaphragm (9). After that, the piston (10) subjected to compressed gas starts moving along the first stage barrel (8) and compresses the light gas. When the first stage pressure in the barrel exceeds the frictional force between the second stage piston (13) and the barrel, the second stage piston starts moving along the second stage barrel (12) by compressing the gas in the second stage barrel and in the high pressure chamber (14). When the pressure in the high-pressure chamber exceeds the breakout pressure of the diaphragm (16), the diaphragm is broken, and the compressed light gas starts accelerating the projectile (17) along the ballistic barrel (15). When the deformable piston enters the conical compression chamber, its front end accelerates generating an additional compression wave in the acceleration gas, which leads to an additional acceleration of the projectile (so-called hydrodynamic effect). The RF patent was obtained for this installation [13].

The design of the three-stage LGG [13] was developed on the basis of the LGG with a cylinder-conical compression chamber TPKh34/23/8 [14] (Figure-6) that uses a pneumatic chamber instead of the powder stage. The installation includes the two piston barrels 34 and 23 mm in caliber, as well as a ballistic barrel 8 mm in caliber. The installation is designed to obtain projectile velocities up to 5-8 km/s with a mass of 0.3-1 g, as well as a flow of submicron particles. The pneumatic stage with a compressor and gas vessels is shown in Figure-7.

Figure-6. Three-stage LGG.

Figure-7. Pneumatic stage.

This LGG is the basis for the stand designed to study the high-velocity impact of small particles with a target. The stand [15] was developed for modeling the high-velocity interactions of small different particles with the samples of structural materials used in space rocketry to develop means for protecting glass elements of spacecraft (illuminators, optical lens, etc.) against micrometeoroids and cosmic dust [16].

CONCLUSIONS

The paper describes the three new light-gas guns for the high-velocity throwing of mechanical particles: an upgraded two-stage light-gas gun and single- and three-stage compressed gas guns.

The upgraded two-stage light-gas gun (PPKh50/18) is presented, which provides the throwing of projectiles with a mass of 5-10 g at a velocity of up to 8 km/s. A single-stage compressed gas gun provides a velocity of 400-700 m/s for projectiles with a mass of 0.5-1 g and can be used for the training of students at universities. A three-stage compressed gas gun is designed to obtain a projectile velocity up to 5-8 km/s with a mass of 0.3-1 g, as well as a flow of submicron particles.

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