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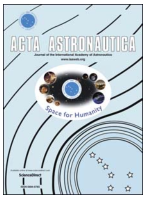

Numerical simulation and experimental study of explosive projectile devices

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ABSTRACT

A study of explosive-throwing device (ETD) was undertaken to simulate the hypervelocity impact of space debris fragments (SDF) and meteoroids with spacecrafts. The principle of operation of an ETD is based on the cumulative effect in combination with the cut-off head of the cumulative jet, which enables one to simulate a compact particle, such as a meteoroid or a fragment of space debris. Different design schemes of ETD with different composition explosive charge initiation schemes with notably low speeds of the jet cut-off are explored, and a method to control the particle velocity is proposed. Numerical simulation of device modes and basic technical characteristics of experimental testing are investigated.

1. Introduction

During the experimental development of resistance spacecraft constructions to impact space debris fragments (SDFs), the main problem is to provide a compact particle acceleration in a given range of mass and velocity. Space debris consists predominantly of aluminum particles with velocities of 1–16 km/s. According to the models of OKM distribution, the main danger for the long-term orbital stations and spacecraft are SDFs with sizes up to 10 mm [1–4]. Those impactors can cause serious damage to the spacecraft elements and containments [5–7]. When the ground-shock performance of the spacecraft and protective measures are applied, a two-stage light gas ballistic installation is commonly used, which provides a projectile speed range of 6–8 km/s, which is near the physical limit [8]. Increasing the speed is possible using blasting techniques in systems such as the cumulative system [9,10]. The main problem in this embodiment is the allocation of the cumulative jet compact warhead by a low-speed cut-off portion. This study examines the possibility of applying a cumulative scheme with the recess of "a hemisphere-cylinder" to throw the aluminum jets and a subsequent cut-off of the low-speed jet.

Currently, the charge with a cumulative hollow cylinder hemisphere is investigated to throw high-speed compact steel elements in RFNC VNIIEF. In the BMSTU studies, compact cumulative facings were applied in the form of a truncated sphere or ellipsoid.

2. Statement of the problem

ETD (Fig. 1) is a high-explosive (HE) charge, which is enclosed in steel and a bimetal shaper to charge a hollow "hemisphere-cylinder". Initiation occurs in two manners: placing the detonation point at the center of the ring and knocking on the outer surface of the charge. Because the process of forming a cumulative jet compact particle search is complex, the ETD scheme was performed in conjunction with an experimental study of a numerical simulation of the process. The particle formation was modeled based on the equations of dynamics of a continuous medium in terms of Euler variables [11,12]. The material properties (equation of state and conditions of strength and fracture) were selected based on known experimental data [13]. The Euler field set includes the explosive and a body shaper with bimetallic recess "hemisphere-cylinder". The area consists of 720,000 cells with a size of 0,05 h 0,05 mm mesh. (See Fig. 1). On the outer surfaces of the Euler field conditions are free streaming, on the medium surface section are formulated conditions of kinematic and power contacts.

The metal elements of the device is physically modeled based on the equation of state of Mi-Grüneisen.

To describe the plastic flow model, Steinberg-Guiana is used, considering the change in shear modulus and yield stress during the deformation:

For explosives, the equation of state is represented in JWL form.

The software package ANSYS/AUTODYN was used for the calculation.

3. Effect of the ETD design parameters on the speed and nature of the projectile element

We investigated the following ETD design parameters:

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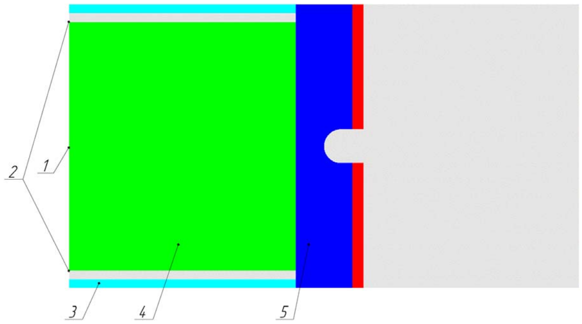

Fig. 1. Calculation scheme: 1 – point detonation, 2 – ring detonation, 3 – shell, 4 – explosive, 5 – shaper.

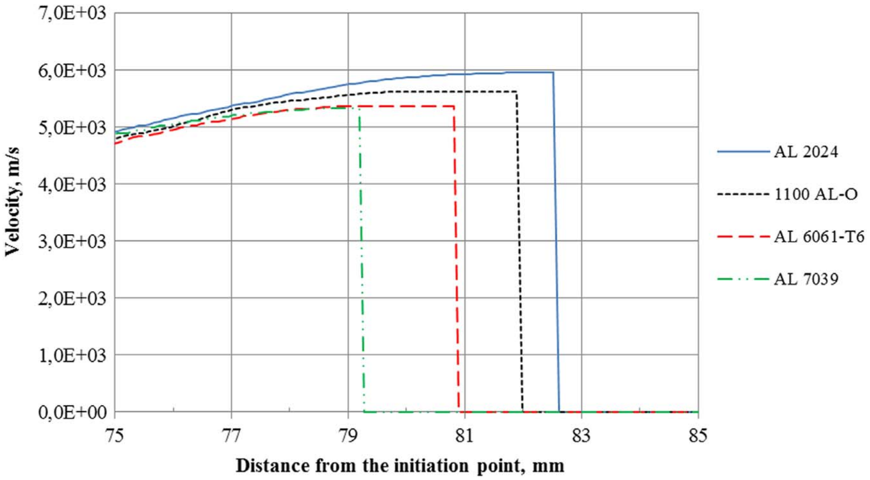

Fig. 2. Effect of the driver material on the final throwing velocity and education gradientless site – particles.

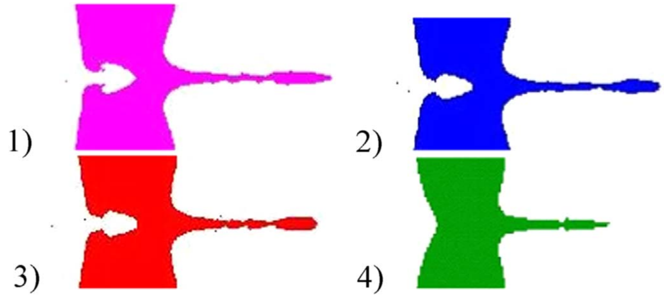

Fig. 3. Operation of the shaper of different materials at t=13 ms: 1) 1100 AL-O; 2) 1100 AL-O; 3) AL 6061-T6; 4) AL 7039.

A. Shaper material (1100 AL-O, AL 6061-T6, AL 2024, AL 7039). The best alloy is AL 6061-T6 because the shaped-charge jet propelling element is more compact and has a more regular shape (see Figs. 2 and 3).

B. HE type. (El-506C, TNT, PBX-9404-03, HMX, C4). When the experimental developments El-506C and PBX-9404-03 are used: the El-506C speed to throw the element was 5–7 km/s. In the case of PBX-9404-03, the speed increased to 11 km/s (Fig. 4).

C. Method to initiate the explosive charge (point detonation and ring detonation). Due to the convergence of a detonation wave to the charge symmetry axis when the ring detonation occurs pressurized Mach wave formation and its irregular reflection, it leads to increased throwing speed (Fig. 5). The pressure in front of the detonation wave for the point and ring initiations varies significantly (Fig. 6).

D. Thickness of the shaper. The thickness of the shaper must be sufficiently large to prevent the breakthrough products of the detonation from flying after the compact metatemym element. An increase in thickness reduces the throwing speed (Fig. 7).

E. Radius cumulative recess in the shaper. According to the calculation results (Fig. 8), the radius of the best cumulative recesses is 0.136 of the explosive charge radius.

F. Length of the cylindrical part of the recess in the cumulative shaper. The most stable formation of a compact propellant element in proximity radius cumulative recess and the length of its cylindrical part (Fig. 9).

Case thickness. According to the calculation results (Fig. 10), the body thickness does not significantly affect the characteristics of the compact projectile element.

G. Thickness of the lining under the charge. To change the throwing speed of the charge generator, a gasket with material density less than the density of the explosives can be used, e.g., plexiglass. By increasing the thickness of the gasket by 1 mm, the particle-throwing speed is reduced to approximately 500 m/s (Fig. 11).

H. Overall dimensions of the ETD. Calculations with dimensions of charges: 25×30 mm, 50×60 mm, 75×90 mm, 100×120 mm, 200×240 mm and 400 h480 mm. When resizing, the throwing speed is practically constant. The size of the compact particle changes according to the change in charge size (Table 1).