POWDER PARTICLE FLOW ACCELERATION METHODS FOR SIMULATION OF INTERACTION WITH MATERIALS USED IN SPACECRAFTS

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Introduction

In recent decades, the role of satellites for monitoring the condition of agricultural land and forests, as well as in the study of natural resources, has especially increased. The amount of debris in near-Earth space is constantly increasing, which creates a real danger to the operation of satellites and other flying objects. The failures of satellites and spacecrafts increase the cost of their production and inhibit the development of the industry, lead to pollution of near-earth space by space debris.

For a long time, all attention in the development of protective shells is paid to space debris ranging in size between millimetres to meters. However, in the last decade, researches have shown that the influence of space dust (micron-sized) dust has been seriously underestimated. The recent experiments suggested that when microparticles collide with a spacecraft shield, it may cause not only a mechanical damage, but also causes an occurrence of plasma, which in turn leads to the appearance of electromagnetic radiation capable of disabling nearby electrical equipment (Fletcher and Close 2017; Maki et al. 2004). Other research has shown that the flow of high-speed dust particles penetrates into metal barriers to depths up to centimetres (Aleksentseva and Krivchenko 1998; Krestelev 2014; Qi and Chen 2014). Therefore, the existing protective shields of spacecraft do not provide reliable protection. Development of additional protection is required. An additional challenge is the carrying out full-scale tests to measure protective properties of various materials. Providing such experiments on spacecraft is costly and complex, so the computer simulation is often used, which is not always able to ensure full compliance.

The effect of super-deep penetration (SDP), demonstrating the possibility of penetration of high-speed flows of powder particles into barriers to depths of tens of centimeters, is capable of creating a ground-based method for testing the protective properties of materials. For this reason, it is necessary to analyze the capabilities of various particle acceleration methods.

Super-deep penetration method

Super-deep penetration (SDP) is a complex physical phenomenon, when in a split second bunch of powder particles with a fraction less than 200 microns, accelerated to speeds of 700-3,000 m s^{-1}, penetrates into the solid metal body at depth in tens, hundreds mm. At the same time the high and ultra-high pressure (0.2-20 GPa), intensive deformation, local heating, friction are occurred (Kheifets et al. 2004; Owsik et al. 2008). This physical phenomenon occurs only in a closed system.

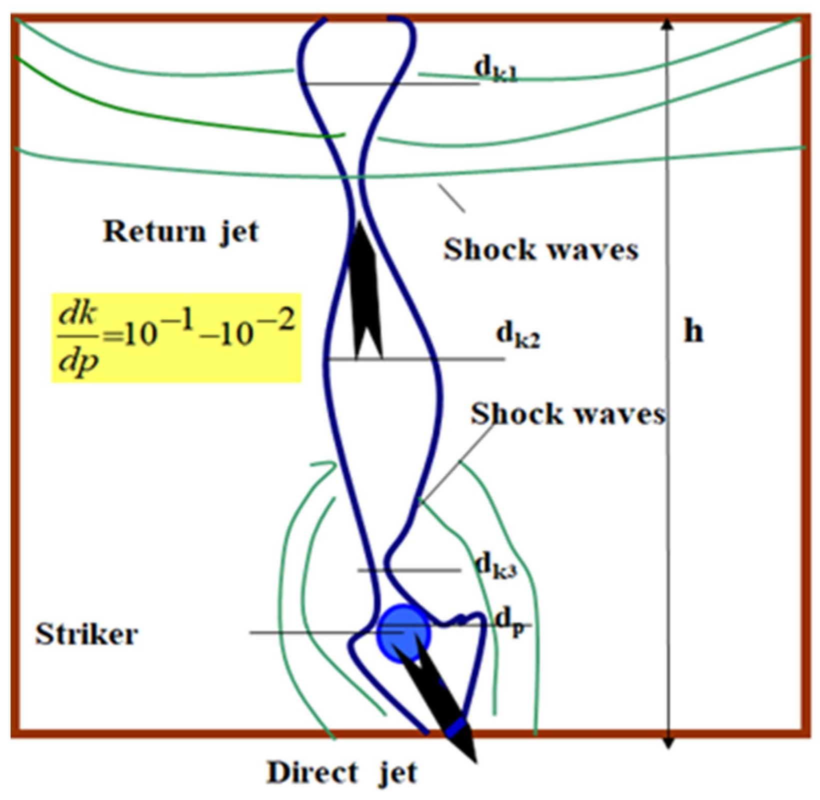


Figure 1. Scheme of channel element (dp – diameter of a striker (particle) , dk – diameter of a channel, and h – channel depth)

Penetration depths depend on the material of obstacle as well as on the parameters of a dust cluster. Pressure level in zones of particles motion ensures dynamic phase transition. Material in a solid phase undergoes a transition into a quasi-liquid (dense plasma) state. Due to pulsation of channel elements (in a direction perpendicular to particle motion), plasma jets of opposite directions are formed in channel areas. Jets move inside a shell and ejected from it (Fig.1). Intense interaction of dust clusters with a protective shell material leads in a closed volume to strong electric effects, which can initiate magnetic field oscillations.

Powder particles acceleration methods

The magnetic-pulse method is widely used for throwing bodies with a mass of 0.1–500 g at speeds of 30–1,000 m s^{-1} (Mironov and Viba 2007; Mironovs et al. 2013). The technology of magnetic-pulse processing of materials (MPPM) uses the principle of converting electrical energy stored in a storage device into a powerful pulsed magnetic field that affects the material being processed in a strictly metered form (Gafri et al. 2006; Mironov et al. 2019). At the heart of the principle of magnetic pulse accelerator (Fig. 2) is used the method of direct conversion of electrical energy stored by the energy storage device into the electromagnetic field arising in the inductor.

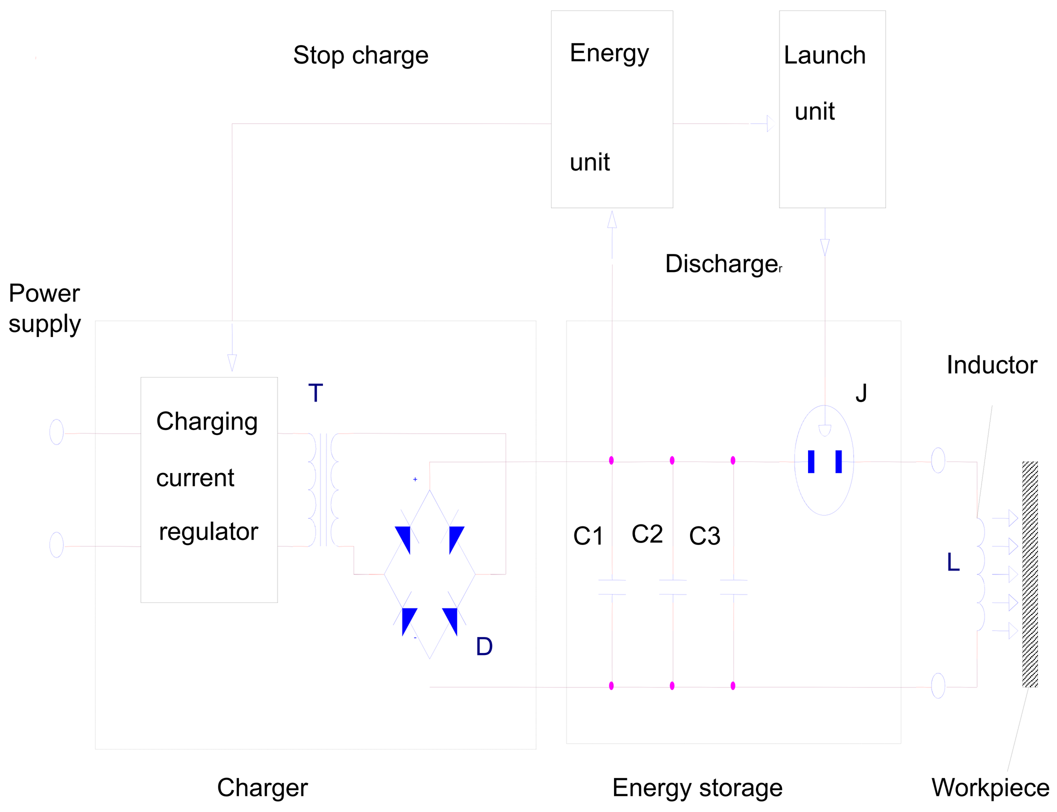


Figure 3. Block diagram of the magnetic pulse accelerator

The processes of charge and discharge of energy storage in MPU are automated. The technique features the use of capacitor banks with stored energy from 1 up to 100 kJ. The discharge of capacitors to the coil (working tool) initiates short pulsed electromagnetic field with intensity of 50-200 A m^{-1} and duration of few milliseconds(Fig.3).The interaction time of flow of particles with a surface of the workpiece is about 2-6 μs. (Fig. 4).

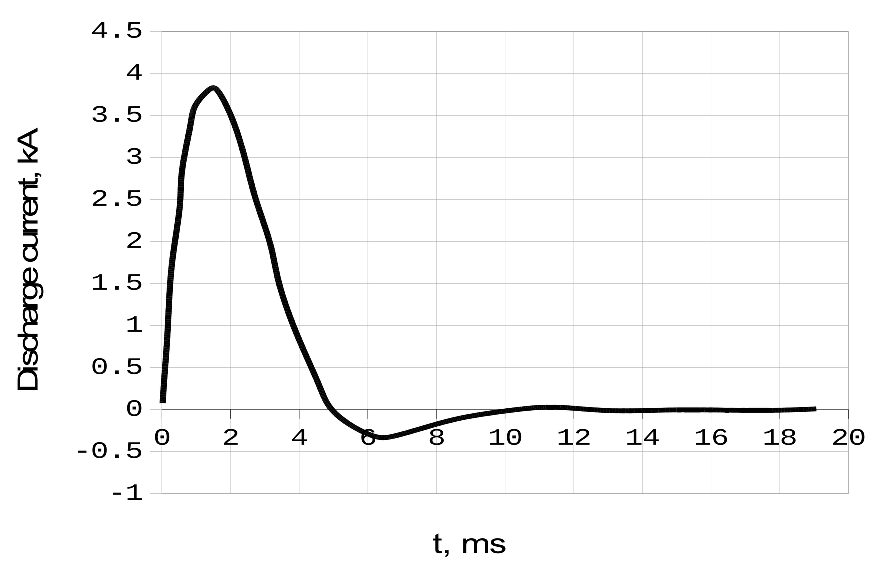


Figure 4. A typical impulse shape generated by impulse current source

Explosive Accelerators

The speed range of explosive combustion is about 3-4.5 km s^{-1}, up to 9 km s-1. The pressure at the front of P ″ can be 1–10 GPa. Explosive combustion is realized by initiating of the propelling charges of gunpowder, high-energy rocket fuels. Explosive methods are the most effective, providing acceleration of bodies due to the initiation of explosives with a detonation velocity D=5–9 km $^{-1}$ s and pressure P=10–100 GPa (Huneault et al. 2011).

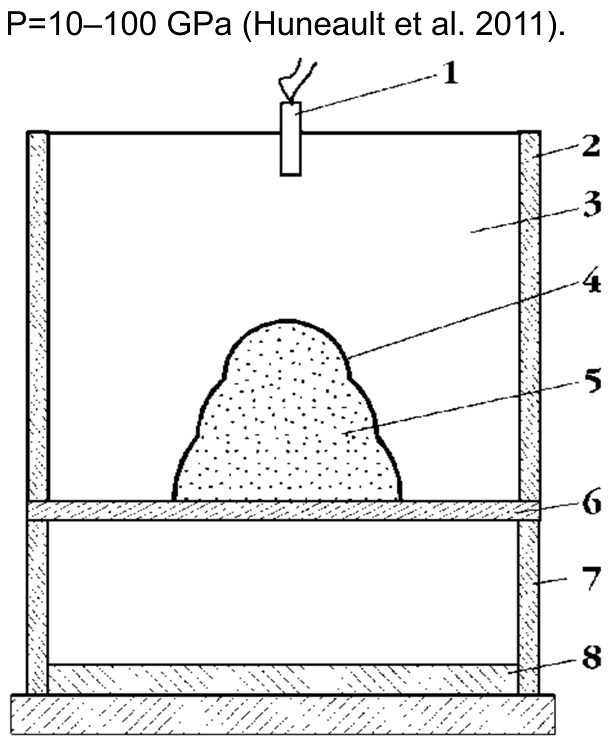


Figure 5. Outdoor explosive accelerator 1– initiator; 2 – facing; 3 – charge; 4 – cumulative lens; 5 – powder mixture 6 – plate-cartridge base; 7 – adjusting support; 8 – obstacle;

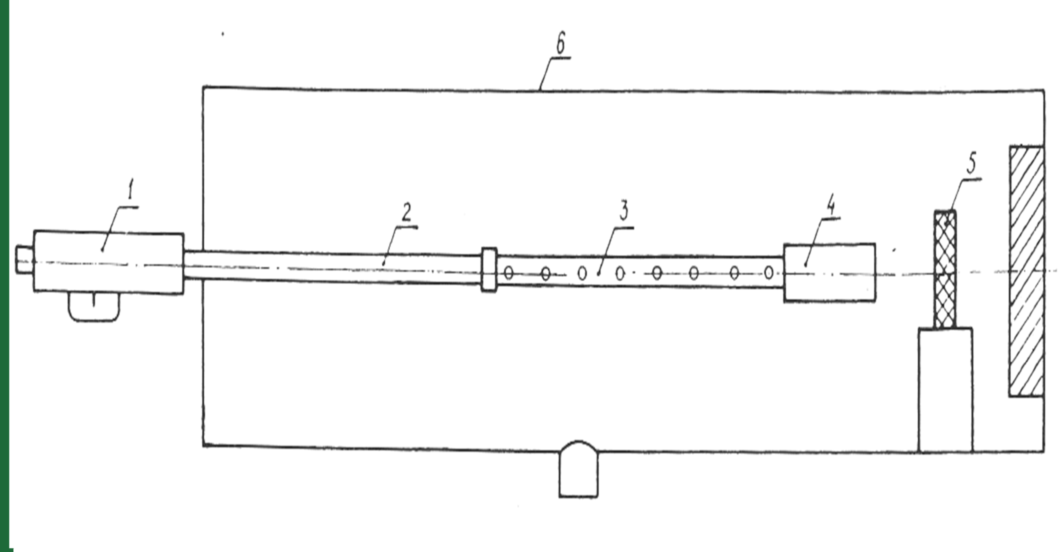
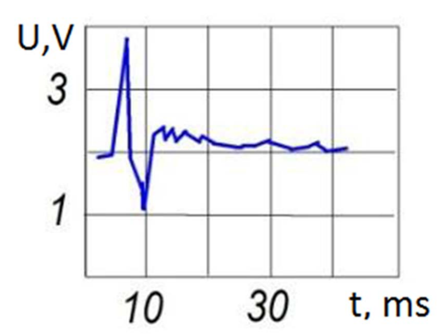


Figure 6. Ballistic accelerator. 1 - charging chamber; 2 - barrel with a diameter of 16 mm; 3 - chamber for depressurization of powder gases; 4 - speed meter; 5 - sample holder; 6 - vacuum chamber



The exposure time of the powder flow with the workpiece was determined (Fig. 7).

Figure 7. The type of pulse from the pressure sensor when exposed to flow on the workpiece

Table 1. Parameters of powder particles accelerators

Type of Accelerator	Amount of energy applied to the accelerated material, (kJ kg^{-1})	Size of the moved particles (mm)	Distance of movement (m)	Velocity of movement (m s^{-1})	Number of pulses (min)
Explosive	150 - 3,000	0.001-0.5	0.01-0.2	300-3000	1
Magnetic pulse	2-20	0.001-10.0	0.01-2.0	10-1000	1-200

Conclusions

Failures of satellites and spacecrafts increase costs of their production and inhibits the development of the industry, lead to pollution of near-earth space by space debris. The lack of a test method does not allow to solve the problem.

Thus, the investigation of the interaction of high-speed flows of powder particles with a barrier is topical. Using the method of dynamic material loading with a high-speed flow of powder particles will provide an easy and effective way of testing the protective properties of materials and electronic systems in ground-based conditions.

SDP method ensures the penetration of powder particles in metal obstacles to depths of 60-300 mm. It exceeds the thickness of the protective shields of spacecraft. Ground-based materials testing technology developed on the basis of the SDP effect will allow to perform tests of protective properties of various materials using destructive testing tools.

The most promising methods of acceleration in the SDP mode are the magnetic-pulse and explosive methods. Explosive methods of acceleration in SDP mode in order to ensure throwing velocities in 1-3.5 km s^{-1} are the most acceptable for industrial technologies, and magnetic-pulse methods provide greater safety for the staff in laboratory conditions.

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