LABORATORY MODELLING OF SPACE PARTICLES IMPACT ON MATERIALS AND STRUCTURES

Novikov L.S.[1], Bednyakov S.A.[1], Soloviev G.G. [1], Ermolaev I.K. [2], Pilyugin N.N. [2]
[1] *Skobeltsyn Institute of Nuclear Physics Moscow State University, 119992 Moscow, Russia*
Email: novikov@sinp.msu.ru
[2] *Institute of Mechanics Moscow State University, 119992 Moscow, Russia*

ABSTRACT

Electrostatic accelerators of solid microparticles working in voltage range of 0.2-4.0 MV were used for laboratory modelling of space particles impact. The sizes of particles were 0.5-10 micrometers, velocity range was 0.1-30 km/s. Experiments on electrostatic acceleration of liquid microparticles were carried out, too. Laboratory experiments were done on light-gas gun allowing to accelerate particles of mass up to 1 g till the velocity ~6.5 km/s. Processes of interaction of high-velocity particles with solids were studied. Detectors for use in space experiments on registration of micrometeoroids and space debris dust were developed. Protective shields for spacecraft were tested. In the paper, description of the experimental equipment and techniques of researches is given, some examples of the research data are presented.

1. INTRODUCTION

Laboratory modelling of space particles impacts on spacecraft materials and equipment is necessary for examination of damages of the spacecraft outer surfaces and the open elements by meteoroids and space debris impacts, as far as for development of the particle detectors and for tests of various spacecraft protective shields. Also, laboratory experiments with the solid accelerated particles give a good opportunity to study the physical phenomena arising at high-velocity impact.

In the paper, experiments done on electrostatic accelerators of solid and liquid particles with the sizes ~1 – 10 micrometers (masses 10^{-12} - 10^{-8} g) and velocities 0.1 - 30 km/s, and on light-gas gun at velocities of 1.0 km/s and 6.5 km/s are presented. On the light-gas gun, single solids with diameter 8 mm and mass ~1 g, and the particle ensembles with sizes 0.2 – 1 mm were accelerated.

On electrostatic accelerators, following processes were studied: formation of craters and erosion of surface, breakdown of thin films, emission of charged particles, light flashes, initiation of electric breakdowns in vacuum and in charged irradiated dielectrics. On the basis of the physical phenomena above, development and calibrations of microparticle detectors were carried out. Also, damage of solar cells of solar areas caused by single impacts of solid particles was studied.

On the light-gas gun, punching of thick walls was explored, multilayered spacecraft protective shields were tested, and the detectors intended for registration of solid particles in space experiments were calibrated.

2. ACCELERATORS OF SOLID PARTICLES

2.1. Electrostatic accelerators in Skobeltsyn Institute of Nuclear Physics Moscow State University

In Skobeltsyn Institute of Nuclear Physics Moscow State University, electrostatic accelerators of three types: cascade generators with accelerating voltages U=0.2 MV and U =0.5 MV and Van de Graaff generator U=4.0 MV are used for acceleration of solid microparticles. Metal particles and the dielectric ones with conductive coatings of sizes 0.1 – 10 micrometers are accelerated up to velocities 0.1 – 30 km/s (Novikov L.S. et al., 1996; Novikov L.S., Voronov K.E. et al., 1997).

Electrostatic accelerators allow to carry out investigations of interaction of particles with target in high vacuum with precise measurement of mass and velocity of bombarding particles and good conditions for observation of processes on target.

Drawbacks of the electrostatic acceleration method are reduction of the particles velocity with magnification of their mass and wide distribution of particles over velocities on accelerator tube exit.

For elimination of the latter drawback, electrostatic accelerators in Skobeltsyn Institute of Nuclear Physics Moscow State University are supplied with high-speed selection system which allows to particle with velocities in the given interval to pass to the target (Novikov L.S. et al., 1996).

Also, the electrostatic accelerator of liquid microparticles (Novikov L.S., Soloviev G.G., et al., 2003) has been developed and tested. Both in case of solid particles, and in case of liquid particles, the particle gains an electric charge in special source on an electrode with voltage + (10 – 15) kV before acceleration. The analogy between cases of acceleration of solid particles and liquid ones is illustrated in fig. 1. In the case of acceleration of the liquid particles, there can be an electrostatic explosion of enough large drops during their motion in accelerating system.

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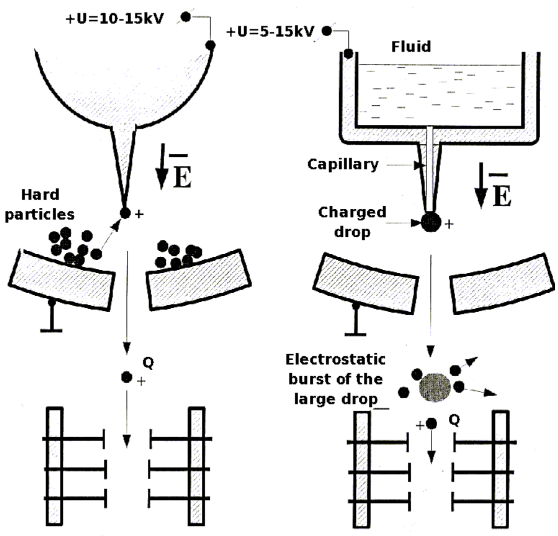


Figure 1. Analogy between cases of acceleration of solid and liquid particles

Difficulty of acceleration of the liquid particles is following: they can lose considerable portion of initial electric charge at flight in the accelerating system. It reduces the maximum velocity of the particles. The positive property of such accelerator is the opportunity to obtain particles of strictly identical sizes with an identical initial charge, and with identical velocity v consequently.

In fig. 2, the oscillogram of signals of contactless induction gauges of the particles parameters measuring system is shown. The amplitude of impulses corresponds to the particle charges. It is seen that charges of particles are identical, and frequency of following of particles is constant.

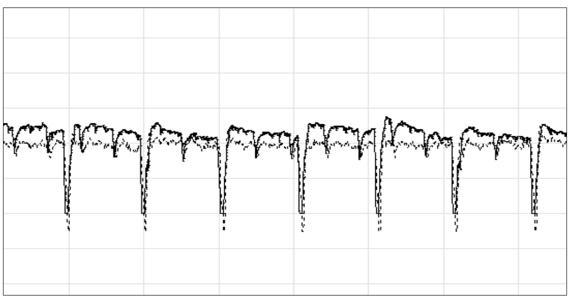


Figure 2. The oscillogram of signals of contactless induction gauges at acceleration of the liquid particles.

2.2. The light-gas gun of Institute of Mechanics Moscow State University

The block diagram of the light-gas gun of Institute of Mechanics Moscow State University is shown in fig. 3 (Pilyugin N.N., et al., 2001). The gun consists of combustor of gunpowder 1, piston trunk 2, high pressure chamber 3 and replaceable ballistic trunk 4. The charge of gunpowder 5 is disposed on an axis of the chamber 1 in sleeve 6 with holes. In the state part of the chamber 1, the shutter 7 with an electroigniter 8 is placed. The chamber 1 is joined to the piston trunk 2 which has length of 5 m. The input part of the trunk 2 is intended for arrangement of the piston 9. The chamber 3 has the conical channel 10 pairing cylindrical channels piston 11 and ballistic 12 trunks.

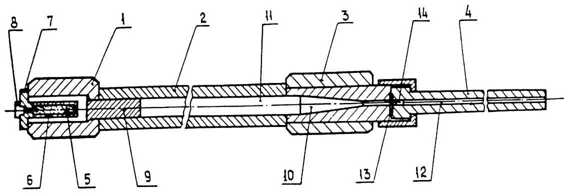


Figure 3. Block diagram of the light-gas gun .

The high pressure chamber 3 is designed for operation at pressure ~$2 \cdot 10^9$ N/m^2. On an exit from the chamber 3, the dividing membrane 13 disclosing at pressure $3 \cdot 10^7$ N/m^2 is placed. The ballistic trunk has length of 3.3 m at diameter of the channel of 12.7 mm. Special obturator 14 with accelerated particles is placed in the ballistic trunk 4 near to the membrane 13. The samples tested are disposed in the chamber on exit of the ballistic trunk 4.

For measurement of the accelerated bodies velocity in standard variant of the light-gas gun, the flight-time method implemented by means of two pairs of light-emitting diode - photodiode, generating signals at cross of the light beam by the accelerated body is used. Note, that this device, which has well proved at acceleration of enough large bodies (with mass ~1 g), has appeared unsuitable in case of acceleration of the small particles necessary for calibration of the detectors. In this connection, modernization of the velocities measurement system was required. In a variant, the scheme with induction contactless gauges similar to one used on Skobeltsyn Institute of Nuclear Physics Moscow State University electrostatic accelerators has been used on the given facility.

The facility above in which the gas compression is done by of the powder charge provides achievement of velocities of 6-7 km/s for the accelerated bodies with mass up to 1 g.

The basic mode of experiments on the light-gas gun is acceleration of individual solids with mass ~1 g up to velocity of ~6.5 km/s. In particular, the mode is used for tests of the spacecraft protective shields.

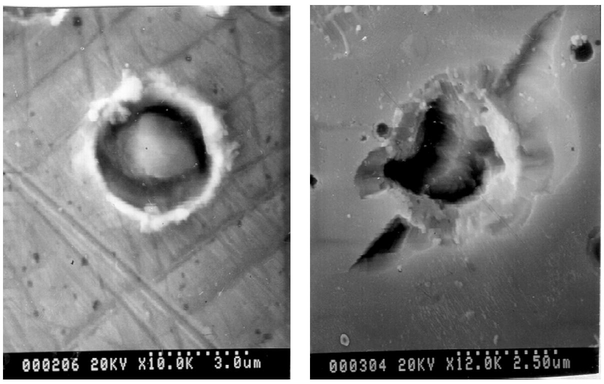
At the same time, at calibration of the detectors used in space experiments for recording of micrometeoroid particles and space debris, there is a necessity to accelerate particles with diameter ~0.1 – 1 mm up to velocity of 6.5 km/s on the light-gas gun. It is impossible to do on the electrostatic accelerators above. For solution of this problem, the special obturator in which accelerated particles are disposed has been designed. The obturator is stoped in the channel of the gun after acceleration, and particles are separated from it and continue flight to the target.

In experiments, the simplified variant of the light-gas gun without the gunpowder when the light gas (hydrogen) compression was carried out by delivery of heavy gas under high pressure in the channel has been used, also. In this case, the maximum velocity of the particles is ~1 km/s.

3. EXPERIMENTAL DATA

The basic directions of researches done on the described accelerating facilities have been specified above. Here we shall give some examples of the obtained results.

One of the important directions is study of crater formation in plastic materials and in fragile ones. Such researches are actual in connection with that the theoretical description of the crater parameters (especially for fragile materials) for fragile materials is correct insufficiently. In fig. 4, images of the craters obtained at impact of the 1 micrometer Ti particles with velocity ~5 km/s on copper target (fig. 4a) and on silicon target (fig. 4б) are presented.



a *b*

Figure 4. Craters in the Cu target and in the Si target.

In experiments on electrostatic accelerators, the major attention has been given to studying of emission of electrons and ions from area of the particle collision with the target. Results of these experiments were presented, in particular, in (Novikov L.S., Akishin A.I. et al., 1997). One of the important effects obtained in these experiments is finding-out of the role of the accelerated particle self charge played in emission at the low impact velocities. It has been shown, that at the impact velocities v <1 km/s emission from the impact area is determined by the electrical discharge which arises between the bombarding particle and the target at distance between them of order of the particle radius.

Also, examinations of the ionic composition of the positive charge emitted from the area of collision of the particle with the target have been carried out (Novikov L.S., Semkin N.D., et al. 2001).

The effect of the spacecraft solar cell damage was studied by single shocks of the solid particles. The physical mechanism of such damage consists in local fusion of p-n-transition of the solar cell due to the strong warming up of the semiconductor material by shock wave. The fused area has the reduced resistance which shunts p-n-transition of the solar cell. In fig. 5, variation of the solar cell I-V characteristics as the result of such damage is shown.

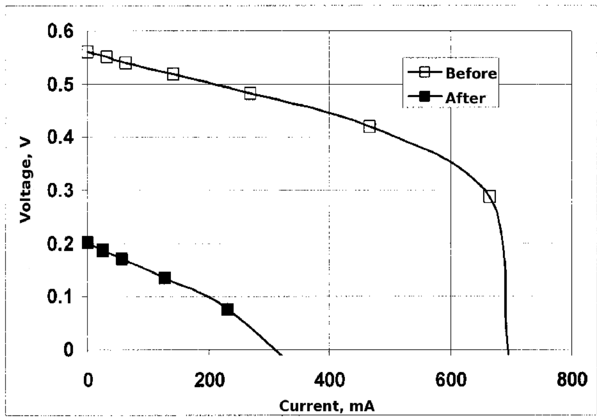


Figure 5. Variation of I-V characteristics of the solar cell as the result of single impact of the solid particle.

Tests of various spacecraft multilayered protective shields were done on the light-gas gun. As an example, the model of the combined multilayered protective shields after impact of the 1 g particle with velocity of ~6 km/s is shown in fig. 6. Here, the first screen is the double-layer construction consisting of steel leaf (thickness is about 1 mm) and small mesh metal net. The second screen is the metal net of the other structure.

The increasing of diameter of the hole in the second metal net in comparison with the first screen, and also expansion of the scattering area of fragments influencing the thick wall in which the central flow core, nevertheless, is maintained to be well visible.

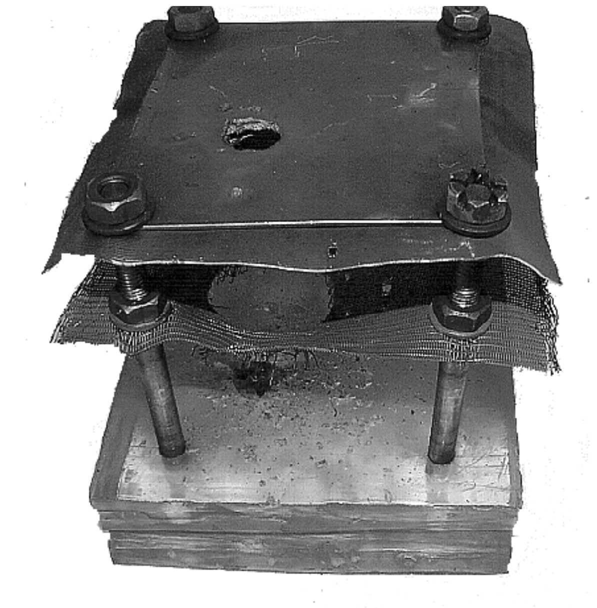


Figure 6. The model of the spacecraft multilayered protective shield after impact of the 1 g solid with velocity of ~6 km/s.

In fig. 7, craters in the thick PMMA plate obtained at conditions of impact similar to the previous case are shown.

Figure 7. Craters in the thick PMMA plate after impact of the 1 g solid with velocity of ~6 km/s.

Experiments without explosion of the gunpowder were conducted on the light-gas gun, also. In this case, the velocity of the solid was ~1 km/s. In fig. 8a, the image of the back side of the PMMA sample (thickness is 1.5 mm) which has been punched by impact of the 0.8 mm steel ball at velocity of 1 km/s is shown. After the punching, the ball has saved high enough energy and has got into a steel plug on depth of the order of its radius (fig. 8b).

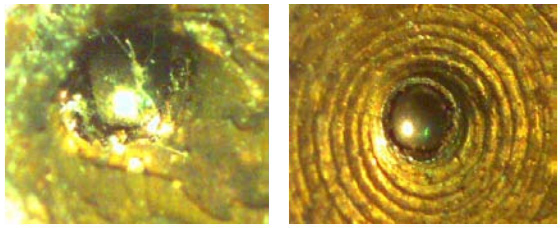


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Figure. 8. The back side of the PMMA sample after impact of steel ball (a) and the steel ball in the plug (b).

SUMMARY

1. Description of electrostatic accelerators of microparticles and of the light-gas gun which are used in Moscow State University for study of the high-velocity impact and for tests of the spacecraft equipment is given.
2. Examples of the results obtained are presented.

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