ION'S FORMATION AND PHOTO ISSUE AT INTERACTION OF HIGH-SPEED DUST PARTICLES WITH OPTICAL GLASS

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ABSTRACT

One of the factors influencing on a resource of open elements of designs of space vehicles, is micro meteoric particles and space dust influence. The installation is developed for experimental simulation of particle's influence in a range of weights and speed accordingly $10^{-13} \div 10^{-14}$ g ton $1 \div 12$ km·s^{-1} on a surface of optical glass, allowing following problem saving:

– Ion's formation and photo issue from a glass surface;

– Definition of degradation of a surface and dependence of optical characteristics of glass on size of a stream of particles.

The device containing the receiver of ions with a high transparency for particles, the photo electronic multiplier established from the party to blow is with that end in view developed.

Forward of the ion's receiver two Faraday's cylinders for measurement charge and speed of a particle are established.

As a source of particles the electrodynamics accelerator with an acceleration direction 0,8 MV was used. The exit of ions and photo issue as functions of parameters particles are experimentally investigated. By means of an electronic microscope the element structure of substance of a particle and glass on a structure of craters in investigated.

1. INTRODUCTION

To simulate the processes of high-speed interaction of particles with materials, various types of accelerators are used [1,2,3]. In order to control and repeat experiments it is necessary to measure the parameters of accelerated particles. This problem can be solved if the accelerated particles bear electric charge. However, the measurement of parameters of high-speed neutral particles is possible through evaluation of secondary effects that arise in their collision with the target. This article provides a description of multi-detector of high-speed dust particles, as well as the results of experiments aimed at assessing their parameters.

2. METHODS OF EXPERIMENTS

To study the processes of high-speed interaction of particles with different materials and degradation of structural elements of spacecraft, a detector and the method of experimentation with the use of an electrodynamics accelerator [4] were developed. The detector is a device that consists of three different types of sensors: inductive, photoelectric and ionization. The structure of the sensor is shown in Figure 1.

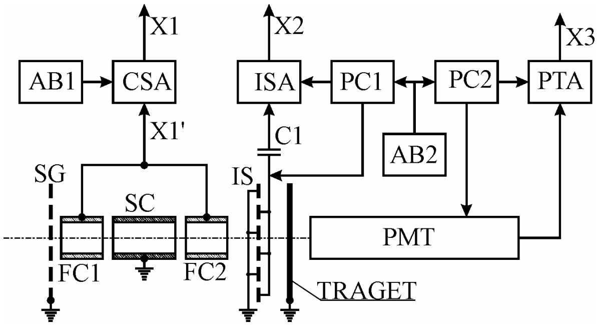

Figure 1 - Structure of multi-sensor of high-speed particles.

In Figure 1, the following abbreviations are used: AB1, AB2 - batteries; CSA – charge-sensitive amplifier; ISA - ionization sensor amplifier; PTA - photomultiplier tube amplifier; PC1, PC2 - power converters; SG - shielding grid; SC - shield cylinder; FC1,FC2 - Faraday cup; IS -ionization sensor; C1 - condenser; PMT - photoelectron multiplier.

The induction sensor consists of two Faraday rings, 100 mm apart from each other. Between the Faraday cups a shielding cylinder (SC) with a length of 60 mm is placed which provides better pulse separation at the output of the inductive sensor (X1). The amplification coefficient of the charge-sensitive amplifier (CSA) equals 1000.

The receiver ionization sensor is made of two grids with the transparency coefficient equal to 0,95. As the target, quartz optical glass and tantalum were used. The target is located at 12 mm from the receiver ionization sensor. PMT is set immediately behind the target.

For the experimental study of the detector, an electromagnetic accelerator with an effective accelerating voltage of ~ 800 kV [4] was used. The particles in the accelerator are accelerated one by one, their frequency, which is 1 particle per second, is governed. A dual channel oscilloscope Velleman PCS-500 was attached to the computer-based accelerator which allows recording incoming signals and link them to the internal time clock

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of the computer hard drive with the help of developed Velleman PCS software. The oscillogram of the voltage at the terminals "X1" and "X2" are shown in Figure 2.

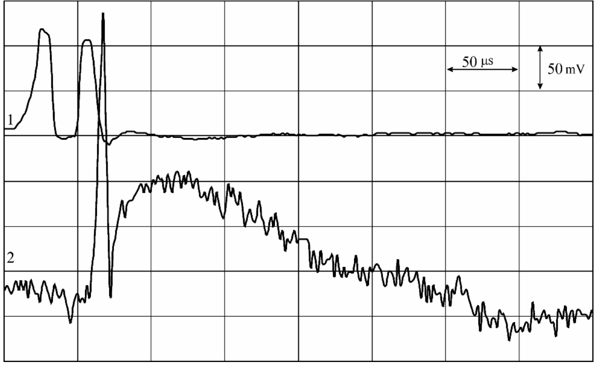


Figure 2 - Oscillogram with outputs X1 and X2 sensor.

The first channel records the signal from the inductive sensor, which is a pair of bell-shaped pulses, resulting from the movement of particles inside the first and second Faraday rings. The second channel records the signal directly from the receiver grid of the ionization sensor. The first short pulse (channel 2) is caused by charge induced on the grid during the flight of particles through the receiver.

The velocity of the particles is determined by the signals from the output charge-sensitive amplifier (the first channel in Figure 2). Methods of determining the parameters of particles, accelerated in an electrodynamics accelerator is described in [4,5].

The total charge of ions, arising from a particle strike on a target is proportional to the square of ion momentum:

$$Q^{+}=\int_{0}^{\tau} i(t)dt=\frac{1}{R_{In}}\times\int_{0}^{\tau} U(t)dt=\frac{1}{R_{In}}\times\sum_{i=N_1}^{N_2} U[i]\cdot(T[i+1]-T[i]) \quad (1)$$

where Q^+ - total charge of ions, R_{In} - amplifier input impedance, U(t) –time dependence of voltage on the grid of the ionization sensor, U(i) - value of the voltage on the grid of the ionization sensor at the time moment T[i], N_1 - number of reference corresponding to the beginning of the ion pulse, N_2 - number of reference corresponding to the end of ion pulse, τ - length of ion pulse.

Specific charge of particles according to the known velocity of the particle before and after a linear electrostatic accelerator is determined by the [4,5]:

$$\frac{Q}{m}=\frac{V_2^2-V_1^2}{2U_0}=\frac{\left(L/\Delta T_2\right)^2-\left(L/\Delta T_1\right)^2}{2U_0} \quad (2)$$

where V_1, V_2 - velocity of the particle before and after a linear electrostatic accelerator, respectively, L - distance between the Faraday rings and accelerator (base ring), ΔT_1,ΔT_2 - measured time periods, U_0 - effectively accelerating voltage of linear electrostatic accelerator. Specific charge of the particle is determined according to the measured value of the amplitude of the Faraday cup:

$$Q=CU_A \quad (3)$$

where Q - charge of the particle, C - capacity of Faraday cup (11 pF), U_A - amplitude of the signal.

The most likely surface density of electric field on the surface is $2\cdot10^9$ V/m. Thus, the mass of the particle can be determined by the formula:

$$m=\rho\cdot\frac{4}{3}\pi\cdot r^3=\rho\cdot\frac{4}{3}\pi\cdot\left(\frac{3\cdot\varepsilon\cdot\varepsilon_0\cdot E_{\Pi}}{\rho\cdot Q/m}\right)^3 \quad (4)$$

ρ - density of particles material, ε - dielectric constant.

To research the release of ions from the surface of optical glass and to study the impact flash, the glass target was installed in front of the input window of photomultiplier tube (Figure 1). The diameter of the optical glass was 15 mm, and it was equal to the diameter of the input window of the photomultiplier tube.

Percussion outbreaks were recorded with the photomultiplier tube in short pulse voltage.

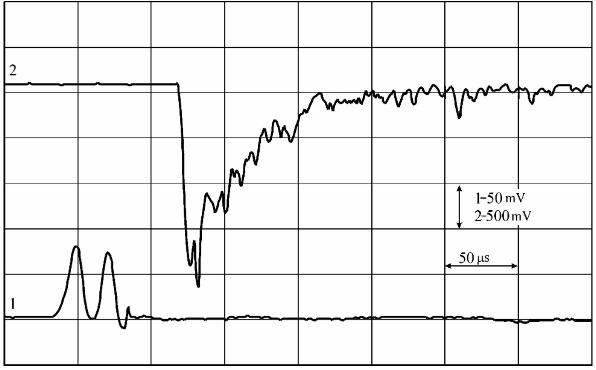


Figure 3 - Oscillogram outputs X1 and X2 of multi-detector.

Figure 3, as well as in Figure 2, show that in the first channel, the signal is recorded from the charge-sensitive amplifier, while the second channel impulse is recorded with the photomultiplier tube amplifier.

3. RESULTS OF EXPERIMENT

The analysis of the results obtained during the study of secondary charged particles at high-speed collision of particles with optical glass and tantalite (Fig. 4) shows the considerable variation of data Q + / m in the range of low speed of 3 km / sec. The difference of glass and tantalum density (which is about 6 times) allows determining the influence of the target density on the processes of generation and scattering of ions at the impact.

With the particles speeds up to 1 km / s the main contribution to ion generation is made by micro-charge between the particle and the target. The mechanism of emission from the micro-charge can be quite effective, and the value of nk + ions of the cathode and anode Na + are consistent with the experimental data [6], when the values of ionic charge $5\cdot10^{-15}$C÷ $5\cdot10^{-16}$C for particles at the speed of less than 1 km were observed The relative role of each mechanism of ion generation at different velocities of particles is determined by the ratio of kinetic energy (W_K), potential energy (W_P) and the conversion efficiency of any energy in the process of interaction of particles with the target:

$$\frac{W_K}{W_P} = \frac{\rho}{3\varepsilon_0}\left(\frac{V}{E_S^{MAX}}\right)^2 \qquad (5)$$

where V - velocity of particle, E_S^{MAX} - maximum value of field strength at the surface of particles

To determine the time dependence of scattering shock plasma as a function of particle velocity, particle and target density in the oscillogram (Fig. 2), the leading edge of rise time of ion momentum were measured. The formula for the time of rise of the leading edge of ion momentum was obtained on the basis of processing experimental data:

$$\tau_F = \frac{L}{V}\left(1 + \sqrt{a}\right) \qquad (6)$$

where L - effective distance between the receiver and the target (calculated on the basis of the distribution of ions in the plane of the receiver for the device L = 0,023 m),

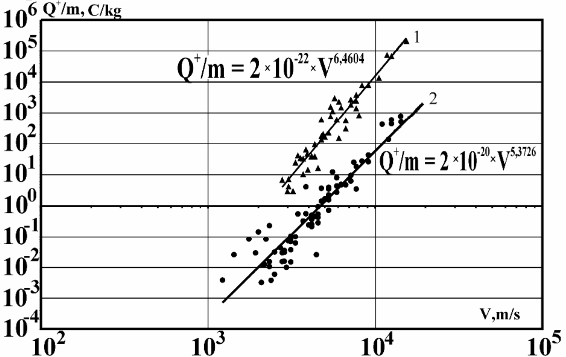


Figure 4 - Dependence Q^+/m from speed of a particle

Figure 4 triangles show experimental data for the impact of aluminum particles with a target of tantalum, and the points - for the target of optical glass. Lines 1 and 2 are the interpolation lines for these experiments. Experimental dependence of the leading edge of the ion pulse velocity of particles is shown in Figure 5.

In Figure 5 the triangles show experimentally measured length of the leading edge of ion momentum for the target of tantalum, and circles - for optical glass. Lines 1 and 2 are theoretical plots for the target of optical glass (1) and tantalum (2), constructed by formula (6). Figure 5 demonstrates that the theoretical data agree well with the experiment.

With known particles density according to the measured value τ_F rate is determined by the particle, the velocity dispersion equal to plasma, as a reciprocal of τ_F:

$$U_F = (0,2 \div 0,6) \cdot V \qquad (7)$$

Under a=1 plasma, the dispersion velocity is minimal, but when a<<1 it is maximal, it can be seen in Figure 5 (experimental points for the optical glass target are placed over the experimental points for the target of tantalum). Great variation in the range of speed of 1÷3 km / s is due to the influence of micro-charges as well as to the shape of particles which is not ideal. The total charge of ions in high-speed collision of solid bodies is determined in accordance with a well-known parametric expression [6]:

$$Q^+ = c \cdot m^\alpha \cdot V^\beta \qquad (8)$$

where – c - coefficient of proportionality; β, α - coefficients obtained experimentally

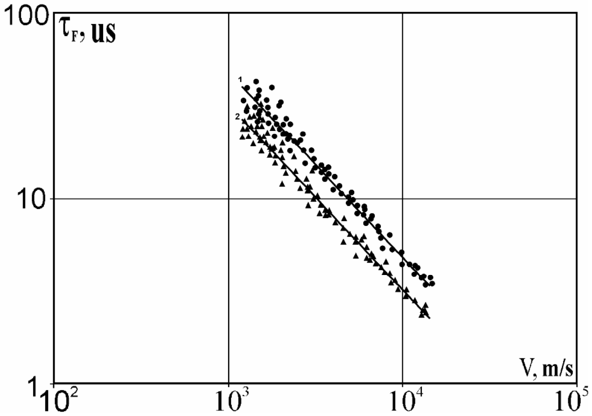


Figure 5 - Dependence of the duration of the leading edge of the ion pulse velocity particles

Negative impulses obtained with the photomultiplier tube (Fig. 3), are characterized by the intensity J and the total light energy E; in accordance with Stefan-Boltzman's law, radiation intensity can be written as:

$$J = \sigma \cdot T_0^4(t) \cdot S_0(t), \qquad (9)$$

and the total light energy:

$$E = \int_{t_0}^{\infty} J(t)dt \qquad (10)$$

where σ - Boltzman constant, T_0 - initial temperature of radiating plasma, $S_0(t)$ - total area of radiating surface, where G_0 - coefficient of proportionality.

For example, if T_0 = 3000 ÷1000 °C, which corresponds to the range of particles velocities of 1 ÷ 6 km/s and at S_0 =3 microns, the intensity is in the range of $10^{-7} \div 10^{-6}$W.

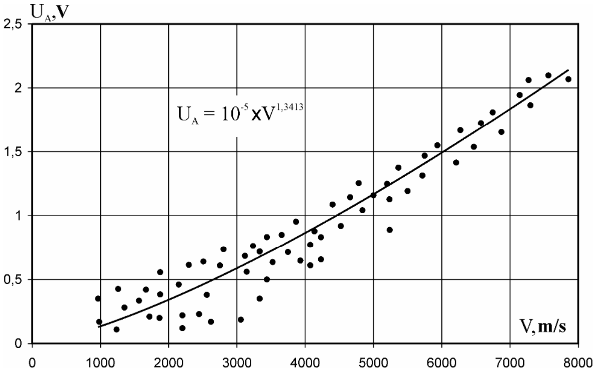


Figure 6 - Dependence of pulse amplitude with a photomultiplier tube on the velocity of particles

Figure 6 shows the experimental data in points and a continuous line demonstrates interpolation curve. In addition, the dependence of transmission coefficient of optical glass before and after the interaction with around 3000 particles (Fig. 7) was measured with the help of a spectrophotometer.

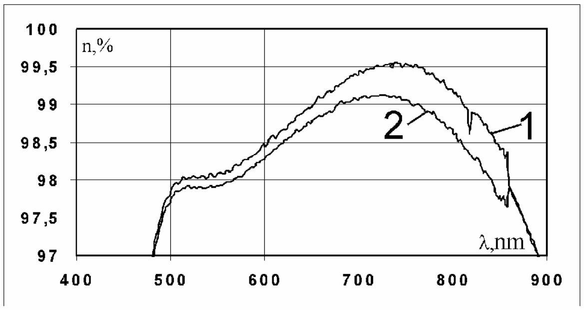
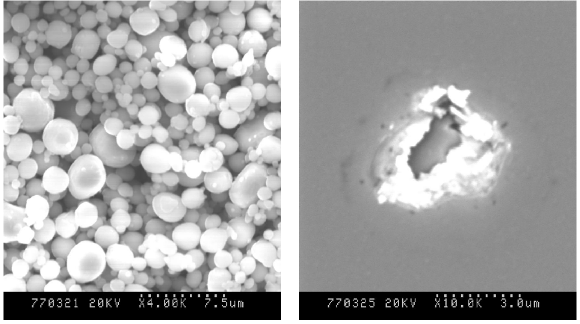


Figure 7 - Dependence of optical glass transmission on the wavelength

Figure 7 demonstrates that in the wavelength range from 500 to 870 nm a decrease in the transmission coefficient of approximately 0.7% is observed.

Figure 8a shows a picture of aluminum particles from an electron microscope, while in Figure 8b a photo of a typical crater on the optical glass surface is shown.



a. *b.*

Figure 8 - Photos of particles (8a) and crater (8b).

4. CONCLUSIONS

1. The proposed methodology and technology of experiments makes it possible to improve the quality and reliability of the results.
2. Using the developed instrument for the registration of high-speed dust particles, the research into the structural elements of spacecraft under the conditions of streams of dust particles can be conducted, as well as the calibration of various detectors of micrometeorites and space debris can be made.
3. Controllable parameters of particles at all stages of acceleration and automation of the experiment allow its rapid and effective implementation.

5. REFERENCES

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