"Lovushka" sampler of biological particles in space

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A new sampler of biological particles and living organisms in the upper atmosphere and in space is described. While sampling, it smoothly decelerates particles down to a low speed, because collision of fast particles with sampler walls can not only inactivate, but also even destroy them. The sampler is based on a system of high-frequency resonators of an accelerator of neutral particles used for the deceleration of biological particles. In designing the sampler, we used experimental data on the behavior of biological particles (bacteria, cells, viruses) in a high-frequency electromagnetic field.

Introduction

Sampling of biological particles from spacecraft is complicated by the need to smoothly decelerate these particles in order to keep them alive. Collisions with hard walls are impermissible, since they can inactivate or even destroy particles.

In this paper we describe a sampler of biological particles to be operated in the open space and some aspects of its usage aboard a space station.

Using an accelerator of neutral particles[1–4,6] operating in the deceleration mode, can solve the above-mentioned problems. This operation mode allows the kinetic energy of an impinging particle to be decreased down to the nearly thermal energy. The accelerator of neutral particles can be built up around sequentially arranged resonators, in which a standing electromagnetic wave is induced. Inside each of the resonators, the electric component of the field strength E_x normal to the resonator axis and the magnetic component B_y are formed. The time dependence of their amplitudes is described by the following equations:

$$E_x = E_0 \sin \omega t; \quad B_y = B_0 \cos \omega t. \tag{1}$$

A particle caught in the resonator is polarized under the action of a high-frequency electric field. At interaction with the electric component of the field strength E_x, a dipole moment

$$d_x = \alpha \, \varepsilon_0 \, E_x = \alpha \, \varepsilon_0 \, E_0 \sin \omega t \tag{2}$$

is induced in the particle. In Eq. (2) α is the coefficient of polarizability of the particle,[5] ε_0 is the dielectric constant of vacuum.

The varying strength of the electric field induces the polarization current in the particle

$$j_x = \frac{1}{l} \frac{\mathrm{d}d_x}{\mathrm{d}t} = \frac{1}{l} \alpha \, \varepsilon_0 \, \omega \, E_0 \cos \omega t. \tag{3}$$

The polarization current interacts with the magnetic field of the resonator and thus decelerating force F_z appears with which the magnetic field acts on the particle:

$$F_z = j_x \, B_y \, l = \alpha \, \varepsilon_0 \, \omega \, E_0 \, B_0 \cos^2 \omega t, \tag{4}$$

where l is the particle length.

The mean is opposing to the particle motion and independent of the charge sign:

$$a_z = \frac{F_z}{m} = \frac{\alpha \, \varepsilon_0 \, \omega \, E_0 \, B_0}{2m}. \tag{5}$$

Let, for example, $\alpha = 10^{-18}$ m^3, $E_0 = 10^6$ V/m, $B_0 = 10^{-2}$ T, $m = 10^{-23}$ kg, $\omega = 10^9$. Having substituted these values in Eq. (5), we have $a_z = 5 \cdot 10^7$ m/s^2.

With this acceleration, the particle moving at a speed of 8 km/s slows down to low speed while traveling along the distance of 1 m. The slow particle is attracted to high-voltage electrodes without destruction.

Under conditions of space vacuum, the acceleration $a = 5 \cdot 10^7$ m/s^2 can be achieved by use of the accelerator of neutral particles with the high strength of a high-frequency electromagnetic field. At such values of the acceleration, particles less than $10^{-10} \times 10^{-10} \times 10^{-6}$ m are not destroyed. This size is supposedly characteristic of biological space particles (for example, DNA and RNA fragments).

Biological particles with the size less than 10^{-9} m slow down due to viscous friction in the atmosphere of the residual gas inside the "Lovushka" sampler. The density of the residue gas in "Lovushka" exceeds the density of gas in the ambient medium due to the pressure of the incoming flow and low temperature of the sampler. It is about 10^{-4} mm Hg.

Main parts of the "Lovushka" sampler

The "Lovushka" sampler consists of the following units:

1. A power supply consisting of a 1 W power adapter (U = 1 kV) and an ac generator with the voltage of 2 kV and power of 600 W in the continuous mode.
2. A resonator including two capacitor plates and a solenoid.
3. Two removable sampling collectors (upper and lower).

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4. A control unit and an ammeter based on high-voltage precipitators.

Brief description, size and mass of the units, power consumption

1. The power supply unit converts the direct current from an onboard power supply (40 A, 23–32 V; consumed power is about 800–900 W) to provide 1–2 kV dc voltage and 1–2 μA current and 1–2 kV ac voltage and the current of 0.8–0.4 A. The power supply is assembled using high-frequency transistors, a transformer, and high-voltage diodes. Its mass is about 1 kg; the dimensions are 100 × 100 × 100 mm.

2. The resonator is shown schematically in Fig. 1. Its dimensions (with removable collectors) are 300 × 550 × 1150 mm. The resonator is connected with the high-frequency terminal of the power supply. Because of a high Q-factor of the resonator ($Q = 600$), the voltage applied to the capacitor plates reaches 100 kV. The capacitor plates have the size $S = 500 \times 900$ mm and are spaced by the gap $d = 100$ mm. The capacitor has the capacity $C = \varepsilon_0 S/d = 8 \cdot 10^{-11}$ F. The resonator energy accumulated in the electric and magnetic fields is $W = C\,U^2/2 = V_c\,B^2/2m_0 = 0.4$ J. The inductance of solenoid is $L = 3 \cdot 10^{-4}$ Hn at 50 turns, and the cross size 200 × 1000 mm. Its length is 500 mm. The wire has the length of 120 m and the cross section of 8 mm^2. The active resistance of the solenoid is 0.25 Ω. The winding is made of copper, and its mass is 8.5 kg. If the aluminum solenoid is used, then the wire has the cross section of 13 mm^2 and the mass of 4.3 kg. The mass of the capacitor plates made of 1-mm thick aluminum sheet is 2.5 kg, and the mass of the resonator's side walls made of 2-mm thick Teflon is 1.5 kg.

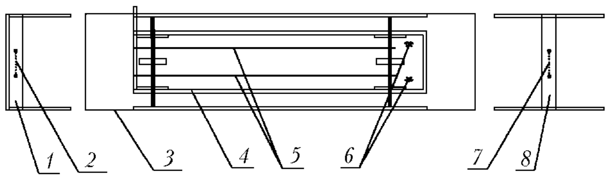

Fig. 1. Sampler Lovushka: lower removable sampling collector *1*, electrodes of the lower precipitator *2*, resonator body *3*, solenoid *4*, capacitor plates *5*, electron guns *6*, electrodes of the upper precipitator *7*, upper removable sampling collector *8*.

To provide for stable operation of the discharge chamber, a source of electrons with the energy of 1–2 keV and the current of 1 mA was used. For this purpose, an electron gun for a belt e-beam is set beyond the capacitor. The gun includes a cathode in the form of a filament with an oxide coating and an anode at the voltage of 1–2 kV.

Electrons arriving in the zone of the magnetic field $B = 0.58 \cdot 10^{-2}$ T rotate at a rate less than $\omega_B = e\,B/m_e = (1.6 \cdot 10^{-19})\,(0.58 \cdot 10^{-2})/(0.91 \cdot 10^{-30}) = 10^9$ along an orbit with the radius about

$$r = m\,v/(e\,B) = (0.91 \cdot 10^{-30})\,(2.65 \cdot 10^7)/(1.6 \times 10^{-19})\,(0.58 \cdot 10^{-2}) = 2.6 \text{ cm}.$$

Since electrons travel in the discharge chamber during a long time, they ionize molecules of the residual gas and impart the charge to particles that are to be trapped due to collisions with electrons and molecules of the residual gas.

3. Two removable sampling collectors (the upper and lower ones) serve to collect biological particles and transport them to the Earth. The samplers should be sterile and transported in a sterile pack with a molecular filter equalizing the pressures in the pack and in the ambient atmosphere to prevent mechanical damage and deformation because of the pressure difference. The collectors are removed from packs immediately before installation and are attached to the resonator body. Contacts from the source of high dc voltage ($U = 1$–2 kV, $I = 1$–2 μA) are connected to them. This voltage is applied to the electrodes of the precipitator. The collectors size is 50 × 100 × 500 mm (Fig. 2) in the ready-to-use state and 10 × 100 × 500 mm in the compact (transportable) state. The collector mass is 0.5 kg.

4. The control unit and the ammeter based on high-voltage precipitators are installed on the control desk in a pressurized compartment. The control unit is designed to connect (disconnect) the power supply to the onboard power system. It should provide commutating the current $I = 40$ A at the voltage $U = 32$ V. The ammeter based on the high-voltage electrodes of the precipitator determines the flux of particles deposited on the electrodes by using a conversion coefficient. The conversion coefficient for calculating the number of particles based on the charge they carry should be determined in ground-based experiments. The sensitivity of the ammeter should be within 1nA. The mass of the control unit is no more than 1 kg. The dimensions are roughly 100 × 100 × 100 mm. The mass of the ammeter is 0.2 kg, and its dimensions are 30 × 50 × 50 mm.

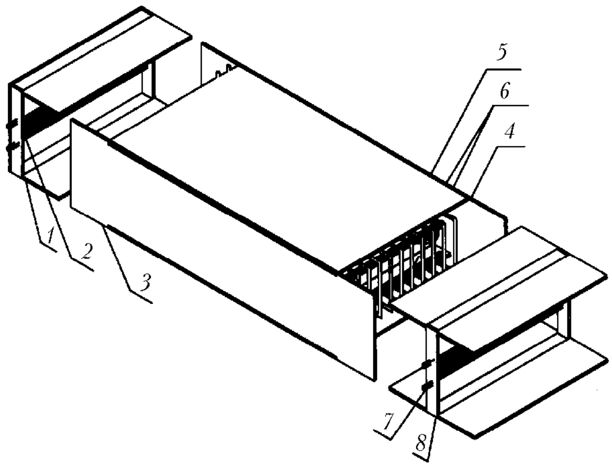

Fig. 2. The view of the sampler Lovushka. Designations are the same as in Fig. 1.

Brief description of the control unit, requirements to installation

The control unit includes a commutator of the onboard power line for feeding the power to the high-voltage adapter. The ammeter based on high-voltage precipitators is used as a device controlling Lovushka operation. It is desirable to install the control unit and the ammeter in a pressurized compartment on the control panel.

Power consumption cyclogram at operation in the periodic mode

The design of Lovushka sampler assumes it installation outside the station. The removable collectors are replaced periodically (annually). The collectors should be mounted and dismounted at the adapter being turned-off. The precipitators are supplied continuously, and their power consumption is 1 W.

The sampler Lovushka can be turned on in the mode of particle deceleration at the power consumption of 800 W for the period from fractions of a second to several days as long. The duration of operation periods should be recorded as it is used in the processing of experimental data when determining the density of biological particles in space. Lovushka may be turned on in the case that free power resources are available. Turning on of the device may be accompanied by electromagnetic noise in the communication blocks. Therefore, the resonator's adapter should be turned off during the communication sessions. The high-voltage adapter of the precipitator electrodes is low-powered (1 W), and it can be shielded to not introduce interference to communication, so it can be operated continuously.

Maintenance

When mounting and dismounting the collectors, the adapter should be turned off and its terminals should have electrical connection to provide the electrical safety of the crew. The crew taking part in the installation of the removable collectors should dismount a collector, fold it, and pack in a sterile pack equipped with a molecular filter for equalizing the pressure. Then a new collector should be taken out from a sterile pack, made serviceable, and installed. Then the contacts of the terminal of the high-voltage adapter should be connected with the contacts of the precipitator electrodes.

The means to control the collector filling-up and recording the particle trapping

To measure the amount of particles deposited on the electrodes, the data of the ammeter are converted using the conversion coefficient. The ammeter should have the scale about 1 μA. To determine the total amount of particles deposited during sampling time, the circuit measuring the total charge carried to the electrodes will be used. The coefficient of charge conversion to the amount of particles should be found in the ground-based experiments.

The volume productivity of sampling is 400 m^3/s. The sampling area is 0.05 m^2. According to the reference book,[7] the mass of the meteorite matter falling onto the Earth with particles less than 0.003 g in mass is $20 \cdot 10^6$ g/day. The total amount of the meteorite matter, including biological particles with mass $\approx 10^{-21}$ g collected in the resonator for a year will be from 0.7 to 700 μg depending on the sampling direction.

Requirements to the telemetry

The values of the current and the charge at the precipitator electrodes should be transmitted to the ground every day or two times a day through the telecommunication channels. The telemetric parameters should be recorded for the upper and lower collectors. This information can be used for analysis of particle fluxes at the sun-illuminated and shaded parts of the station orbit, for determination of the influence of solar activity on the particle flux, and for other purposes.

Requirements to orientation relative to the velocity vector of the space station and the Earth

The Lovushka sampler should be oriented accurately along the velocity vector of the space station. In this case, particles are slowed down most efficiently in the electromagnetic field of the resonator and in the atmosphere of the residual gas. If the resonator is directed normally to the station velocity vector and the Earth radius, particles moving toward the Earth are not trapped. The current measurements at such an orientation give the background value. If the resonator is oriented normally to the station velocity vector and along the Earth radius outward the Earth, only high-speed particles moving toward the Earth are trapped.

Tentative circuitry

The electric circuitry is shown in Fig. 3. The voltage is applied to the resonator from the high-voltage adapter to one of the solenoid turns. Because of a high Q-factor of the resonator, the voltage across the capacitor plates reaches 100 kV.

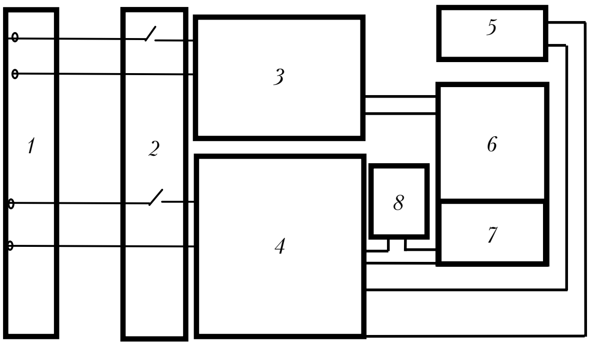

Fig. 3. Circuitry of the sampler Lovushka: the onboard power system (U = 27 V, I = 40 A) *1*, control unit *2*, high-voltage adapter for the resonator (U = 2 kV, I = 0.4 A, f = 1 MHz) *3*, high-voltage power adapter for the precipitator electrodes (U = 1 kV, I = 1 μA) *4*, upper collector *5*, resonator *6*, lower collector *7*, ammeter (I = 1 μA) *8*.

Crew duties

The crew will be responsible for mounting and dismounting the collectors once a year. During other days, the crew should control turning on and off the voltage to the high-voltage power adapter of the resonator.

Duration of a space mission

The time from the sampler installation to its dismounting should be ten years. Every year the collectors should be dismounted and delivered to a laboratory for separation and identification of biological particles collected in space. Particles are separated and identified according to their polarizability in an inhomogeneous alternating electric field and by the methods of polymer chain reaction.

Number of sessions

Supposedly, several space missions can take place. Every following mission could deliver the sampler improved with the allowance made for the data obtained in the preceding mission. The number of sessions can be corrected after first experiments with the sampler, because now it is unknown what is the concentration of biological particles on the orbit of a space station.

Conclusions

The sampler, which decelerates biological particles and thus prevents their destruction, is proposed.

The main requirements to the sampler orientation, telemetry, particle detectors, power consumption, and sampling duration are determined.

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