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About possibilities of clearing near-Earth space from dangerous debris by a spaceborne laser system with an autonomous cw chemical HF laser

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Abstract. **The possibility of clearing hazardous near-Earth space debris using a spaceborne laser station with a large autonomous cw chemical HF laser is substantiated and the requirements to its characteristics (i.e., power and divergence of laser radiation, pulse duration in the repetitively pulsed regime, repetition rate and total time of laser action on space debris, necessary to remove them from the orbits of the protected spacecrafts) are determined. The possibility of launching the proposed spaceborne laser station to the orbit with the help of a 'Proton-M' carrier rocket is considered.**

Keywords: *spaceborne laser station, autonomous cw chemical laser, space debris, ablation regime, repetitively pulsed lasing.*

1. Introduction

Nowadays great attention is paid to the study related to the possibility of using lasers for clearing the near-Earth space from space debris fragments (SDFs) that present a considerable threat for spacecrafts. Objects with a diameter less than 1 cm are not dangerous for the existing spacecrafts, because the latter are equipped with passive construction protection, although it makes the spacecraft noticeably heavier. Large SDFs having the diameter greater than 10 cm are detected by the modern facilities and recorded in special catalogues. The most efficient protection against them is the debris avoidance manoeuvre. The most dangerous SDFs for the spacecrafts are those with the diameter from 1 to 10 cm. An aluminium SDF having the dimensions 1×5 cm (mass ~13.5 g) and the impact velocity ~2.5 km s^{-1} possesses the energy, equivalent to that of the directed explosion of 10 g of TNT [1]. Avoiding the collision with such a SDF by manoeuvring is not possible, since it is not seen on the radar monitor, and the required degree of passive protection cannot be provided because its weight becomes too high. At present the number of such SDFs amounts to ~6×10^5 [2].

At low orbits under the action of the atmosphere the self-removal of SDFs occurs rather quickly. For example, the lifetime of a SDF at ~200-km orbits is about one week [3]. At higher orbits (with the altitude 600 km) the SDF self-removal may take 25–30 years, and at the altitude ~1000 km – two thousand years [3]. It was shown in Ref. [4] that the probability of a collision of a spacecraft having the diameter 10 m with a SDF of the size 2–4 cm during one year of exploitation is 0.45×10^{-2}. For SDFs with the size 1–10 cm this probability increases up to ~2×10^{-2}. Therefore, the removal of SDFs from the orbit of a protected spacecraft is a rather urgent problem.

To remove a SDF from the orbit, it is possible to decrease the velocity of its motion, e.g., by means of pulsed irradiation of the SDF, so that the plasma, arising at its surface and creating the recoil momentum, could scatter before the arrival of the next radiation pulse. In the most probable scenario of the approaching process, when the SDF overtakes the spacecraft, after the action of a laser radiation pulse on the SDF its velocity v_0 decreases by the quantity Δv, as a result of which the SDF will start to move towards the centre of the Earth with the acceleration a_n, and after the time t the radius of the SDF orbit will be reduced by the quantity

$$\Delta H = \frac{a_n t^2}{2} = \frac{\Delta v(\Delta v - 2v_0)}{R_E + H} t^2, \qquad (1)$$

where R_E is the Earth radius, H is the altitude of the SDF flight above the Earth surface. If the quantity ΔH is greater than the spacecraft dimensions, the SDF will not hit the spacecraft.

Using the action of laser radiation, it is also possible to solve another problem, i.e., to produce such recoil momentum at the SDF surface, that the altitude of its orbit will be reduced to 200 km. Then, in the course of deceleration in the atmosphere, the SDF will burn rather quickly, i.e., the spacecrafts with a laser station will serve as 'cleaners' of the most used orbits. The dependence of the required reduction of the SDF velocity in the apogee of an elliptical orbit on the altitude of the initial circular orbit is presented in Fig. 1. A similar dependence was reported in [5]. One can see from Fig. 1 that a SDF, occupying initially the ~400-km orbit, will descend down to 200 km, if its velocity is reduced by only 60 m s^{-1}.

In the present work we consider the possibility of spacecraft protection and scheduled orbit clearing from dangerous SDFs having the diameter 1–10 cm by means of a spaceborne laser station (SBLS) equipped with a large-scale autonomous cw chemical HF laser (HF-CWCL) with the radiation power up to 400 W, manufactured at the NPO Energomash Co. (the length of the active medium, 135 cm; the height, 40 cm) [6].

In a number of papers (see, e.g., [7, 8]) it is proposed to use ground-based lasers for clearing the space; however, such a scheme suffers from serious disadvantages, related to passing high-power radiation through the atmosphere, which may lead

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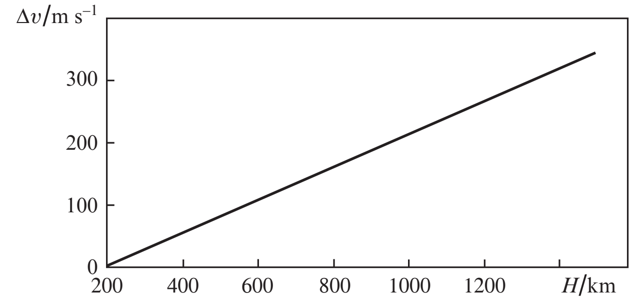

Figure 1. Reduction of the SDF velocity Δv, required for transition of an SDF from the initial circular orbit with the altitude H to the orbit with the altitude 200 km with respect to the Earth surface.

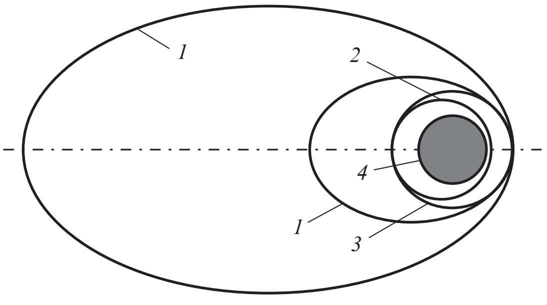

Figure 2. Coplanar orbits: the elliptical orbits with apogee height greater than that of the circular orbit and the perigee height equal to that of the circular orbit (*1*), the elliptical orbit with the apogee height, equal to that of the circular orbit and the perigee height smaller than that of the circular orbit (*2*), the circular orbit (*3*) and the Earth (*4*) [10].

to the loss of the optical quality of the beam and the appearance of nonlinear effects. Moreover, ground-based lasers cannot be used in cloudy weather because they have low mobility, etc. And, finally, the main problem is that the required laser power is essentially higher because the distance from the Earth surface to the SDF becomes longer. For these reasons the most rational is to place the laser station directly in the space. With already available values of the radiation power and specific energy parameters taken into account, the autonomous HF-CWCL is suitable for this goal. As shown in [9], this laser is able to provide sufficiently high energy characteristics of a short radiation pulse with the duration ~10 ns in the repetitively pulsed regime.

2. Methods of calculation

The authors of paper [10] analysed possible scenarios of approaching different spacecrafts, moving along circular orbits with the altitude 200, 400 and 700 km (research satellites, satellites of meteorological monitoring and distant probing, e.g., 'Kosmos', 'Molniya', 'Prognoz') to SDFs, that, as a rule, move along elliptical orbits. Two of these scenarios appeared the worst, namely, when the spacecraft moves along the circular orbit 400 km high and the SDF moves along elliptical orbits with the apogee height H_{a1} = 2000 km or H_{a2} = 4000 km. In these cases near the perigee the regions exist, where the orbital planes of the SDF and the spacecraft coincide and the approach velocity is maximal, the velocity of the spacecraft being exactly antiparallel to that of the SDF (Fig. 2), so that the laser action cannot impart a transverse velocity component to the SDF, as in the more favourable case of the orbits, inclined with respect to each other. The maximal closing-in velocities, calculated in [10], for these two cases turned out to be 395 m s^{-1} for H_{a1} and 2463 m s^{-1} for H_{a2}. For SDFs moving along circular orbits with the altitude 200, 400, and 700 km the calculated velocities of approaching the spacecraft do not exceed 343 m s^{-1}, and, therefore, these cases may be neglected.

The reduction of the approach velocity Δv (in cm s^{-1}) due to the recoil momentum produced by a single laser radiation pulse with the energy density E (in J cm^{-2}) acting on a SDF is determined from the following expression [5]:

$$\Delta v = C_m ES/m, \tag{2}$$

where $S = S_{\text{f}}$ (in cm^2) is the area of the focal spot, if it is smaller than the cross section of the SDF and $S = S_{\text{FSG}}$, if the total cross section area of the SDF is irradiated; m (in g) is the mass of the SDF; C_m (in din s J^{-1}) is the proportionality coefficient, depending on the SDF type. The characteristics of the most common SDFs are presented in Table 1 [5].

The authors of [5] demonstrated that the optimal relation between the energy density and the pulse duration (Fig. 3) exists when the coefficient C_m (see Table 1) takes the optimal value C_m^{opt} at the optimal relation between the pulse energy density E_{opt} and its intensity I_{opt}. From the analysis of the results of 48 experiments for different spectral regions, pre-

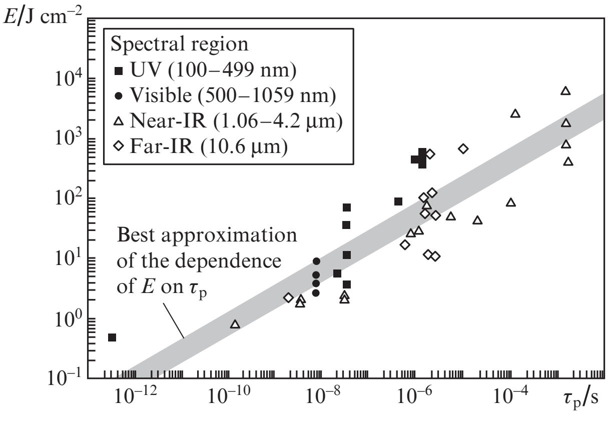

Figure 3. The energy density required for optimal conditions of laser action versus the pulse duration [5].

Table 1. Characteristics of the most common SDFs [5].

Type of space debris	Orbit inclination/deg	Apogee/ km	Perigee/ km	S/m/ cm^2 g^{-1}	Size/ cm	Albedo	C_m^{opt}/ din s J^{-1}
Na (K) spheroids	65	930	870	1.75	1.0	0.4	6 ± 2
Carbon-phenolic debris	87	1190	610	0.7	1×5	0.02	7.5 ± 2
Plastic–aluminium fragments	99	1020	725	2.5	0.05×30	0.05/0.7	5.5 ± 2
Aluminium debris	30	800	520	0.37	1×5	0.05/0.7	4 ± 1.5
Steel tank spacers	82	1500	820	0.15	1×10	0.5	4 ± 1.5

sented in Fig. 3, and five materials, indicated in Table 1, it follows that the reduction of the pulse duration (within reasonable limits) provides the optimal coupling coefficient $C_m^{\rm opt}$ at lower energy density. For example, the pulse duration $\tau_{\rm p}$ = 10 ns in the near-IR range corresponds to the optimal values of the energy density $E_{\rm opt}$ =2 J cm^{-2} and the intensity $I_{\rm opt} \approx 2\times10^8$ W cm^{-2}.

The authors of paper [9] calculated the characteristics of repetitively pulsed lasing for a large-dimension Q-switched HF-CWCL. This calculation showed that it is possible to obtain the peak radiation power density $\sim$50 kW cm^{-2} and the pulse energy density $\sim$0.5 mJ cm^{-2} from a unit area of the nozzle array exit plane at a pulse duration of $\sim$10 ns. The pulse repetition rate f is determined by the rate of restoration of the population inversion in the active medium of the HF-CWCL and is nearly $\sim10^5$ Hz [11]. Since the plasma of the ablation plume flies away with the velocity 3–5 km s^{-1}, it will have time to expand during the time between the pulses (10^{-5} s) and will not shield the radiation of the next pulse. The area of the nozzle array exit plane of the considered HF-CWCL is equal to 5400 cm^2; therefore, the pulse energy of the output radiation will be $\sim$2.7 J, and the power of the pulse may approach $P_{\rm m} = 2.7\times10^8$ W. For the telescope diameter 1 m and the realistic divergence, equal to two diffraction limits, the area of the focal spot $S_{\rm f}$ at the initial 1.7-km distance of the effective action of pulsed radiation (as will be shown below) will be $\sim$4.4 cm^2, and the intensity of radiation $I = P_{\rm m}/S_{\rm f}$ will equal $\sim0.6\times10^8$ W cm^{-2} (and, correspondingly, $E \approx 0.6$ J cm^{-2}). Therefore, the radiation intensity in the focal spot at the distance 1.7 km is smaller than the optimal intensity values by the factor of 3.3. At smaller distances, starting from 1 km, the radiation parameters in the focal spot may attain the optimal values. To take this circumstance into account, one has to know the dependence of the coupling coefficient C_m on the laser pulse intensity.

It was found in paper [5] that the coupling coefficient C_m very weakly depends on the pulse intensity at $C_m \sim C_m^{\rm opt}$, i.e., this dependence possesses a broad maximum. Similar broad maximum was obtained for millisecond (Fig. 4) [11] and femtosecond (Fig. 5) [12] pulses. As follows from Fig. 4, the dependence of the coefficient C_m on the laser pulse intensity for nonmetallic SDFs is much weaker than for metallic ones.

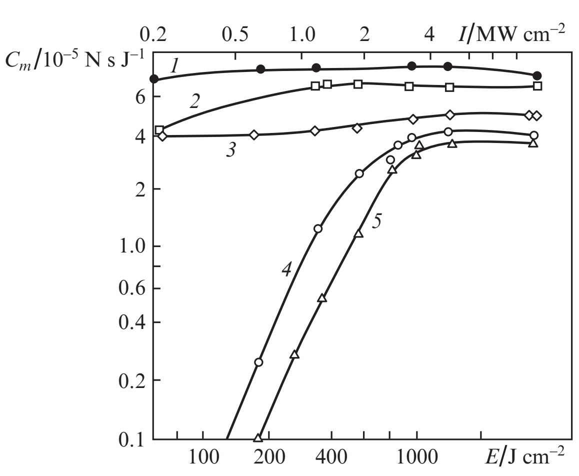

Figure 4. Dependence of the coefficient C_m on the energy density in the focal spot E for the action of 0.3-ms neodymium laser pulses in vacuum on different construction materials: the heat-protective coating (*1*), organic plastic (*2*), carbon plastic (*3*), alloys of titanium (*4*) and aluminium (*5*) [10].

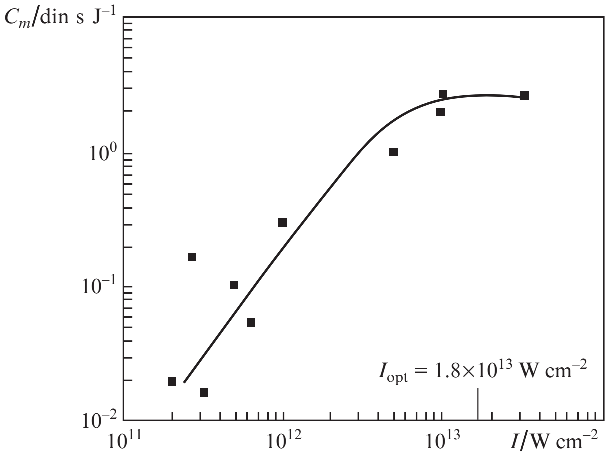

Figure 5. Dependences of the coefficient C_m on the energy density in the focal spot E for tungsten under the action of $\sim$100-fs neodymium laser pulses [12].

For more precise calculations at large closing-in velocities one has to take into account the dynamics of variation in Δv and the current distance between the SDF particle and the spacecraft after the action of each pulse in the course of repetitively pulsed irradiation of the SDF. For this goal a system of Eqns (1) and (2) was formed accounting for the relations for the energy density of a single pulse $E = I\tau_{\rm p}$, the radiation intensity in the focal spot $I = P_{\rm m}/S_{\rm f}$, the focal spot area $S_{\rm f} = \pi d^2/4$, the spot diameter $d = \theta L$ when focusing the beam at the distance L (in km), and the divergence of the laser beam $\theta = k\theta_{\rm dif}$. Here $\theta_{\rm dif} = 2.44\lambda/D$ is the diffraction divergence of the laser radiation, k is the ratio of actual divergence to the diffraction one, D = 1 m is the diameter of the main mirror of the output telescope. The dependence of C_m on E for a metallic particle is taken following [10, 12] as C_m = 3.8 din s J^{-1} for $E > 1$ J cm^{-2}, $C_m = 5.1E - 1.3$ for $0.4 < E < 1$ J cm^{-2}, $C_m = 1.85E$ for $0.025 < E < 0.4$ J cm^{-2}, and $C_m = 0$ for $E < 0.025$ J cm^{-2}. For a nonmetallic particle the coupling coefficient C_m is assumed to be constant and equal to 6 din s J^{-1}.

Using this system of equations, the software was developed for calculating the influence of repetitively pulsed laser radiation on the dynamics of the SDF-to-spacecraft approach, allowing the possibility to vary a number of parameters: the initial $L_{\rm b}$ and final $L_{\rm e}$ distances, characterising the region of action of the repetitively pulsed radiation on a SDF, the material of the SDF (metal or nonmetal), the size and the mass of the SDF, the initial SDF-to-spacecraft approach velocity, and the orbit altitude above the Earth surface. Using these data the influence of each single laser pulse on the change in the velocity and altitude of the SDF flight was calculated. At each step of the iteration procedure, the influence of the next pulse on the current variables that were obtained after the previous steps was calculated. A parallel calculation yielded the current values of the distance between the SDF and the spacecraft, the diameter and the area of the focal spot in the course of focusing. The values of C_m were analysed at each step of integration and, depending on the material taken, the corresponding value of C_m was chosen, following the dependence of C_m on the energy density of the laser pulse, defined above (it was assumed that the character of this dependence does not change in the case of nanosecond pulses). After finishing the calculations, the final number of pulses and the total time of laser action on the SDF were determined.

3. The calculation results

First let us consider the variation of Δv in dependence of the distance between the SDF and the spacecraft, when the SDF is irradiated by a repetitively pulsed laser at the distance L_b =10 km (Fig. 6). The initial data were taken as follows: the SDF approach velocity (the worst case) v_{apr} = 2463 m s^{-1}, the orbit altitude H = 400 km, the ratio S/m = 0.3 cm^2 g^{-1} and 1.6 cm^2 g^{-1} for metallic (aluminium) and nonmetallic SDFs, respectively (see Table 1), the SDF size 1.5 cm, the diameter of the main mirror of beam-forming telescope D = 1 m, the divergence of the beam is twice the diffraction limit. One can see from Fig. 6 [curve (*1*)] that for metallic SDFs the noticeable reduction of the approach velocity begins at the distance $L_e \approx 3$ km, and at L_e = 200 m the velocity decreases by ~1600 m s^{-1}; the total time of repetitively pulsed lasing is ~3.2 s. According to Fig. 1, this value is quite sufficient to transfer the SDF from the orbit 1000 km high to an elliptical orbit with the perigee located in the dense layers of the atmosphere, which means that the SDF will be finally burned.

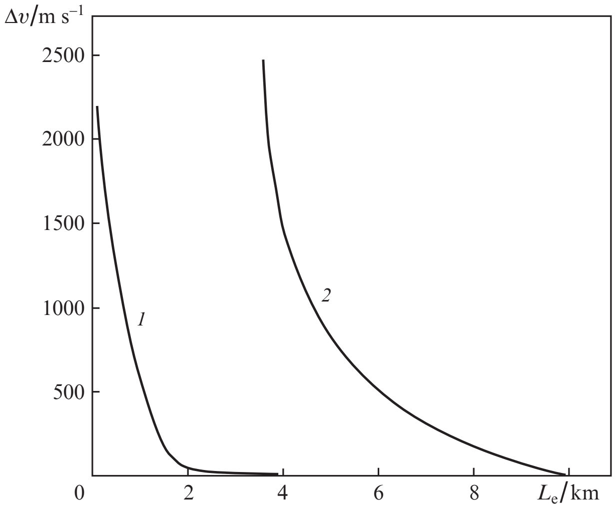

Figure 6. Dependences of Δv on the distance L_e, at which the laser action is terminated for metallic (*1*) and nonmetallic (*2*) SDFs, provided that the action begins at the distance L_b = 10 km and the initial closing-up velocity 2.5 km s^{-1} between the spacecraft and SDF.

In the case when a nonmetallic SDF is exposed to laser radiation [Fig. 6, curve (*2*)], the noticeable reduction of the approach velocity begins immediately (starting from the distance 10 km), and at L_e = 3.5 km the velocity will be reduced by ~2500 m s^{-1}, i.e., the SDF will stop approaching the spacecraft. This is caused by a significantly smaller volume density of nonmetallic SDFs and much greater value of C_m at a lower laser intensity. The total time of irradiation in this case is ~3.5 s. The same value of Δv under irradiation of the considered SDF can be achieved starting the irradiation at the distance L_b = 750 m and finishing at the distance L_e = 500 m. In this case the total time of irradiation will be reduced by ~20 times and will be equal to ~0.15 s.

Consider now the possibility of safe avoidance of the spacecraft impact with the SDF, if the SDF overtakes the spacecraft. Figure 7 shows the orbit descend for metallic and nonmetallic SDFs versus the distance, at which the laser action on these SDFs is stopped, provided that L_b = 10 km. It is seen that for metallic SDFs and L_e = 200 m, first, the orbit altitude decreases by 15 m (which can be considered sufficient for the SDF to avoid the impact with the spacecraft), and, second, the orbit descend, as well as the reduction of approach velocity, begins only from the distance ~3 km. Therefore, the pulsed laser action on metallic SDFs should be started just at this distance, and not at 10 km. The total time of laser action will be ~1.8 s.

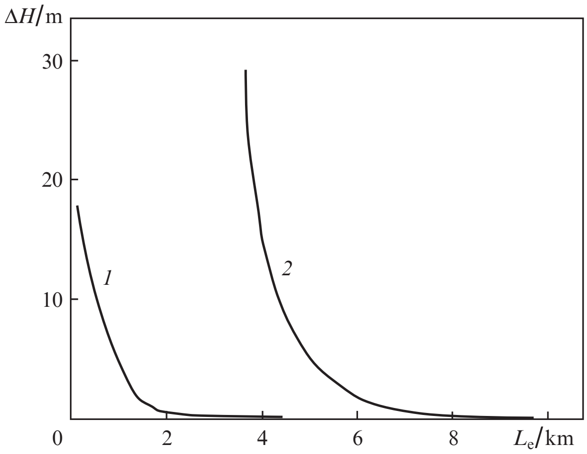

Figure 7. Dependences of the reduction of the orbit height ΔH for metallic (*1*) and nonmetallic (*2*) SDFs on the distance L_e, at which the laser action is terminated, provided that the action begins at the distance L_b = 10 km and the initial closing-up velocity 2.5 km s^{-1} between the spacecraft and SDF.

For nonmetallic SDFs a noticeable change in the orbit altitude H begins from the distance ~8 km, and already at the distance $L_e \approx 4$ km the altitude reduces by $\Delta H \approx 20$ m, which ensures avoiding the collision of the spacecraft with this SDF. The total time of laser action in this case is equal to ~3 s. The fact that the efficiency of laser pulse action on nonmetallic SDFs appears much higher than for metallic ones motivated the search for the possibility to reduce the SBLS power, required for acting on such SDFs. It was found possible to reduce the orbit altitude of these SDFs by $\Delta H \approx 20$ m upon irradiation at the distance from L_b = 8 km to L_e = 200 m with the HF-laser energy 8–10 times lower, which offers considerable economy of laser fuel components. For essential reduction of the HF-CWCL radiation power it is reasonable to use the module design [13], where the active medium generator consists of several modules, mounted in sequence within the joint optical scheme. Then the required laser power is obtained by simple variation in the number of modules.

The results presented above concern the SDFs with the diameter 1.5 cm. Let us briefly describe the results of calculations for SDFs of greater size. As an example of such SDF we took a 1×5 cm fragment of aluminium (see Table 1) having the mass ~13.5 g. In the calculations of the SDF–spacecraft approaching dynamics we took into account the change in the area, exposed to a focused laser beam with the circular focal beam spot, on the surface of the rectangular fragment. The initial data were taken as follows: v_{apr} = 2463 m s^{-1}, H = 400 km, L_b = 3.5 km. The calculation has shown that the orbit descend for such SDF at the distance $L_e \approx 200$ m is rather small ($\Delta H \approx 6$ m), provided that the reduction of its velocity Δv is ~ 500 m s^{-1}. The total laser action time in this case is ~ 1.6 s.

However, one should take into account that a part of the SDF mass is evaporated under the laser irradiation, and the remaining mass of the SDF is calculated as $m = m_0 - \sum_i mE$ [14], where m_0 is the initial SDF mass; i is the number of the pulse; μ is the evaporation coefficient, which is accepted to be zero at $E < 1$ J cm^{-2}, and at $E \geqslant 1$ J cm^{-2} to equal 8×10^{-8} kg J^{-1} for a metallic particle and 1.25×10^{-8} kg J^{-1} for a nonmetallic one [15]. The calculation with the SDF mass variation due to partial evaporation properly taken into account shows that the efficient evaporation process begins at the distance ~ 1300 m and in the case of aluminium SDF with the dimensions 1×5 cm the mass of the evaporated material will amount to 4.5 g at $L_{\rm e} = 800$ m and 11 g at $L_{\rm e} = 300$ m, i.e. 80% of the SDF mass will be evaporated and the remaining mass will be 2.5 g. The velocity reduction in this case will amount to $\Delta v = 2463$ m s^{-1}, i.e., the SDF-to-spacecraft approaching will be stopped. With the mass reduction due to evaporation taken into account, a metallic SDF with the size 1.5 cm (~ 5.5 g) appears to be totally evaporated at the distance $L_{\rm e} = 800$ m.

The calculation of the approaching dynamics for the largest of hazardous SDFs with the size 1×10 cm, consisting of steel [$S/m = 0.15$ cm^2 g^{-1}, $m \approx 70$ g (see Table 1)] at $v_{\rm apr} = 2463$ m s^{-1}, $H = 400$ km, $L_{\rm b} = 3.5$ km, and $L_{\rm e} \approx 200$ m has shown that the mass of the evaporated fraction of the SDF amounts to ~ 22 g, $\Delta v \approx 210$ m s^{-1}, and $\Delta H \approx 1.1$ m. Note, that such SDFs are already detectable by radar facilities.

The efficiency of SDF removal from the spacecraft trajectory may be significantly increased by using an intermediate mirror, located at a considerable distance from the SBLS (10–20 km), as proposed in [14].

4. Analysis of the possibility of mounting the SBLS on board a spacecraft

In the present work we also estimated the mass of the SBLS components to evaluate the possibility of launching such a station using the 'Proton-M' carrier rocket, which, being launched from the "Baikonur" cosmodrome, can put into the orbit ~ 350 km high inclined at $\sim 50°$ a spacecraft with the total mass of useful load ~ 20 t. The proposed SBLS can be placed in the unpressurized pallet of a nonrecoverable spacecraft. To provide the exploitation at the orbit during a half-year, the estimate of the mass of the spacecraft (without the laser station) was made following the procedure of 'relative mass indices', recommended by [16, 17], where a similar problem was considered for Earth surface monitoring ('Resurs-F2', 'Kuban'), communication, and TV-broadcasting spacecrafts. The estimated mass of the empty spacecraft, including the system of orientation and orbit correction on the base of liquid-propellant rocket engines, appears to be ~ 6 t. Then the mass of the laser station should not exceed ~ 14 t, which is ~ 70% of the total mass of the loaded spacecraft.

To estimate the total time of the SBLS laser action, using the data [9], the total mass consumption of laser fuel components, providing the achievement of the laser radiation pulse parameters, used in Section 2, at the mole composition of the fuel components $CS_2:NF_3:He:H_2 = 1:7:40:40$ and the pressure of the active medium 3.5 Torr, was estimated as ~ 1.9 kg s^{-1}. To prolong the total time of laser action it is proposed to store the components of the laser fuel on board in liquid state, particularly, NF_3, He, and H_2 should be stored at cryogenic temperatures in low-pressure tanks (~ 1 atm) with screen vacuum thermal insulation and compensation of incoming heat flow from the environment by using cryogenic cooling machines, power-supplied from solar batteries.

The gasification of the cryogenic liquids is also supposed to be implemented using the energy from solar batteries, accumulated in electric storage cells having the capacity, sufficient for 10 s of the SBLS operation. In the total balance of the system of storage and supply of the laser fuel components the required mass of the electric storage cells (lithium-ion, 160 W h kg^{-1} [18]) is taken into account and appears to be a small quantity of ~ 100 kg.

The estimated masses of components of the spacecraft and the SBLS described above are the following:

Construction of the spacecraft with the life support system/kg	6000
Construction of SBLS/kg	2000
System of radiation beam formation and targeting/kg	1000
System of storage and supply of the laser fuel components (not filled)/kg	7500
Laser fuel components/kg	3500

The average consumed power from the solar batteries, necessary for providing the operation of the system of storage and supply of laser fuel components and determined mainly by the laser system, does not exceed 5 kW, and the total time of laser action is ~ 30 min. Similar estimates for cw operation of the HF-CWCL, providing 40-kW radiation power, yield the total lasing time 300 min (~ 5 h).

Thus, the described SBLS can protect a spacecraft from collision with a few tens of thousands of dangerous SDFs and clear from them the most used orbits.

5. Conclusions

The principle possibility is demonstrated to use SBLS equipped with the HF-CWCL (NPO Energomash, Russia) having the radiation power in the cw regime up to 400 kW, for removing the most dangerous SDFs, having the size 1–10 cm, from the orbits of protected spacecrafts. To achieve high efficiency of the laser radiation action on the incident SDFs, we prove the advantage of using a repetitively pulsed laser with the pulse duration of ~ 10 ns and repetition rate of 10^5 Hz. This rate is determined by the time, required to restore the population inversion in the active medium, which should be shorter than the pause between the adjacent pulses. In this regime the calculated peak power of the laser radiation pulse $\sim 2.7\times10^8$ W is sufficient to produce the recoil momentum due to the ablation plasma plume, formed in the focal spot of laser radiation on the surface of the SDF.

We have considered the possible application of the laser station not only for removing SDFs from the orbit of a particular spacecraft, but also for scheduled clearing of the most exploited orbits, when this system will play the role of the 'orbit cleaner'. For this goal it is necessary to push the SDF onto an elliptical orbit with the perigee located in the dense layers of the atmosphere, where the SDF must burn. The dependence of the required reduction of the SDF velocity on the altitude above the Earth surface is presented.

We have demonstrated the possibility of launching the station together with the system of storage and supply of laser fuel components under the nose cone of the heavy-lift launch 'Proton-M' vehicle (the acceptable overall dimensions of the spacecraft and the mass of the useful load are $\varnothing 3000\times10500$ mm and ~20 tons, respectively). It is shown, that such a station is able to protect a spacecraft from tens of thousands of dangerous SDFs per one loading with the laser fuel components. If necessary, the time of the station operation may be prolonged by orbital refill of the fuel components storage systems.

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