PROSPECTS OF USING LASERS AND MILITARY SPACE TECHNOLOGY FOR SPACE DEBRIS REMOVAL

S.G. Bondarenko, S.F. Lyagushin

Dniepropetrovsk State University, Naukovy Lane 13,
320625 Dniepropetrovsk, Ukraine

G.A. Shifrin

Ukrainian Youth Aerospace Association «Suzir'ya», Lenin Str.14,
320070 Dniepropetrovsk, Ukraine

ABSTRACT

Technologies developed in the framework of SDI and similar programmes can be applied for space debris removal. Laser weapons have the best prospects of such applications. Mechanical impacts of pulsed lasers can clean up the «graveyards» in the geostationary orbit and the whole orbit. Some characteristic features of mechanical impact and rational types and ranges of laser plants are analyzed in the paper. The project of a space laser sweeper using Nd laser is proposed, the laser plant being installed on board a space vehicle with powerful solar plant and electric thrusters. The programme of successive operations of the space vehicle in the GSO zone is put forward with further dispatching it to the Sun.

1. INTRODUCTION

Near-Earth space pollution with space debris was begun with the first artificial satellite launch when the last stage of the launcher was put into orbit. During the following years more then 20,000 artificial space objects with dimensions more then 10 cm were observed in Earth orbits. Only about 5% of observable space objects are functioning ones, and registered objects make only a small part (0.2%) of the total quantity of artificial space fragments. An extrapolation based on modern models shows that the quantity of fragments with dimensions 1-10 cm makes hundreds thousands, and that of smaller objects equals to millions (Ref. 1).

Space debris is especially dangerous in the geostationary orbit (GSO) in view of the narrowness of the intensively used zone. An operating satellite position in GSO is maintained through active correction with the accuracy of $\pm 0.1°$ in longitude and latitude that means deviations ±75 km and with the accuracy of about 25 km in height. Space debris drift can result in its approach to operating objects causing faults of communication means and even in impacts in future. Satellites in GSO drift along their orbits after the end of their service life coming to the so called «potential holes» where satellites may remain forever. These regions of «graveyards» for stationary satellites approximately coincide with the small axis of the equatorial section of the Earth and have the longitudes of 75° east and 150° west, i.e. over the Indian and Pacific oceans (Ref. 2).

The problem of cleaning the GSO seems to be the most urgent because of the great prospects of using this orbit for space power and communication systems and the process of self-cleaning of low orbits. Military space technology was developed for fighting the objects in low Earth orbits, and its application for space debris removal from the GSO demands a certain analysis. We shall concentrate just on it.

2. SDI TECHNOLOGY IN SPACE DEBRIS PROBLEM ASPECT

In the framework of the Strategic Defense Initiative some damaging means were considered: 1) laser weapon; 2) beam weapon; 3) kinetic weapon; 4) electromagnetic pulses (EMP- weapon). We are interested in the possibility of using the above mentioned weapons for such peaceful purpose as space debris removal. Different kinds of weapons have rather different prospects in this direction.

EMP-weapon acts with a beam of the microwave range like an electromagnetic pulse caused by a nuclear explosion. Being intended for destroying electronic apparatus of missiles, it is entirely useless for solving the problem of space debris.

Kinetic weapon, i.e. projectiles destroying a target mechanically, needs great power outlay. It may be applied against a large object in a low orbit in the situation resembling its military employment. But using the projectiles in the GSO zone is pointless because it results in space debris quantity growth.

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Beam weapon uses accelerated particles for directed power transfer to the target substance . The low intensity of particle fluxes does not allow to destroy large -scale space objects. Small fragments can be damaged by beam weapon at distances not exceeding 250 km (Ref.3.). The operation of a beam plant in the GSO zone seems to be inexpedient.

Thus, only laser fighting plants have clear prospects of conversion application. The laser weapon provides directed power transfer with energy evolution in the surface layer of target. One should differ two basic types of lasers: continuous wave and pulsed lasers. Both types are capable of fighting military space objects. Continuous wave lasers with adequate tracking system can damage warheads. Pulsed lasers can provide not only thermal destruction of important units and shells, but also considerable changes of mechanical momentum. Both thermal and mechanical impact may be of use for solving the problem of space debris.

Thermal impact can be applied for: a) heating space vehicles with nuclear power sources with the purpose of full evaporation of radioactive substances; b) heat striking small debris in congestions in GSO or libration points for full or partial evaporation; c) destroying thermal protection of large fragments for further natural sublimation (the velocity of carrying away the mass of Zn bodies reaches 1 mm/year at the temperature of 180°C which may be caused by solar radiation).

Mechanical impact can be used for: a) deceleration of large-scale fragments without radioactive materials in low orbits for further burning out in the atmosphere; b) braking of small debris (with dimensions > 10 cm) in low Earth orbits; c) trajectory changes of large space debris for moving it into an orbit-storage.

Very thorough research of the possibility of active shielding and prospects of cleaning low Earth orbits with the aid of a special space vehicle equipped with a laser plant was presented in Ref. 4. Chemical HF laser was considered as the best choice for the mentioned purposes.

3. CHANGING AN ORBIT BY LASER PULSES

We regard orbit changes as the most important feature of fighting space debris in GSO since large-scale fragment utilization is more preferable than its evaporation from the point of view of space industrialization prospects. So we should examine laser mechanical impact in detail. Even laser pulses of very high energy carry small mechanical momenta because of extremely high light velocity, and their own momenta may be neglected. Therefore the mechanical impact is due to jet forces caused by evaporated matter spreading into space. Space debris rotation is an additional factor accounting for the necessity of short pulse impact (Ref. 4).

The order of magnitude of a momentum transferred by escaping gases can be estimated by the formula

$$P \sim (E\ \delta\ S)^{1/2} \qquad (1)$$

where E is a light pulse energy, δ is effective thickness of the absorption zone, S is a laser spot area (Ref. 3).

Eq. 1 was obtained with supposing that the matter in the thin layer is fully evaporated and heated to high temperatures. This supposition should be tested without fail. Such approach results in the fact that the transferred momentum grows with the area S increasing. Thus, the most efficient momentum transfer takes place when the beam section coincides with a target area. These considerations must be taken into account while analyzing the range of laser plant action.

Further estimates require the determination of a laser type. In SDI programme eximer lasers and free electron lasers of terrestrial basing with a mirror system in space were considered. Their great mass (with power sources) exclude them from our versions. X-ray lasers are attractive due to their great range, but the necessity of nuclear explosion pumping makes us to reject this type of lasers. Chemical lasers require great «fuel» expenditure (about two tons for one shot of HF laser) and so have pure prospects of using in GSO.

We shall suppose that solid state pulsed laser with light pumping is employed for the task under consideration. In the former Soviet Union a neodymium laser with pulse power 100 TW and pulse duration 10^{-6} s was elaborated (Ref. 5). In neodymium lasers glass with neodymium admixture is active medium, glass playing the role of matrix while ions Nd^{3+} are active centres. Laser rods are 40-50 mm in diameter and 5-6 m in length. Energy for pumping can be accumulated in a power storage system with using solar power plant as a primary power source.

For such a laser E makes 10^8 J. According to Ref. 3, the effective absorption zone thickness may be estimated from the correlation

$$\delta = (\kappa\tau)^{1/2} \qquad (2)$$

where κ is a temperature conductivity coefficient and τ is pulse duration.
For usual aluminium alloys we obtain $\delta \approx 3 \cdot 10^{-2}$ kg/m^2
If the spot area is about 1 m^2, the momentum transfer calculated from Eq. 1 will reach $2 \cdot 10^3$ N·s, i.e. about 1% of the fragment momentum.

4. SPACE LASER PLANT AND AUXILIARY TECHNOLOGIES

A laser plant assigned for cleaning GSO should be installed on board a special space vehicle equipped with a powerful solar arrays and electric thrusters providing orbital transfers, orbit corrections and orientation. The Ukrainian project of a solar power satellite of small power performing power supply for space vehicles (Ref. 6) may be taken as a prototype of space laser sweeper. In Refs. 6, 7 the possibility of using laser power transmission in such a power supplying system was analyzed. Thus, the only problem of the development of the proposed system for space debris removal is to co-ordinate the power satellite parameters with the laser plant described above. Liquid propulsion may be also used for cruise purposes, but calculations show (Ref. 8) that putting apparatus for mission purpose into the GSO with the aid of electric thrusters is much more efficient. In Dniepropetrovsk University a multifunction electric propulsion plant for this mission has been elaborated. It provides putting a satellite with a powerful solar plant from an intermediate orbit to the geostationary one in a year term and further orbital manoeuvres.

The proposed transport system uses solar arrays of 30 kW power. Neodymium laser efficiency can be raised to 8% if liquid nitrogen is used as cooler. Such a power-propulsion complex has to accumulate energy for about 10 hours for one laser shot.

It is necessary to use telescope optical system at the outlet of the laser system in order to overcome the problem of laser beam divergence connected with diffraction. If we apply an approximate formula for the range of effective power transmission L (Refs. 4, 9) which is well known in space power sphere

$$L \approx 0.7\, d\, D/\lambda\,, \qquad (3)$$

where d and D are apertures of transmitting and receiving systems, correspondingly, and λ is an applied wavelength, we come to a conclusion that for the neodymium laser (λ = 1.03 μm), impacting the space debris with dimensions of about 1 m, the range of effective using makes up 300 km if d is raised to 0.5 m.

Our space laser sweeper should carry a laser leading locator giving accurate data for the control system of the main laser.

Lamps of multimegawatt power must be available for laser pumping. Such lamps manufactured by the technology of Vortek Industries (Canada) can meet the requirements of our system (Ref. 10). Moreover, the lamps may be used for direct thermal impact on space debris. Their well focused radiation causes rapid evaporation of a substance absorbing white light better than laser emission. Such operation may be put into life under the condition of bringing our space vehicle and a space fragment close together.

The debris matter may be evaporated also by concentrated solar flux. In Chicago University a solar concentrator providing very high concentration degree and temperatures has been created (Ref. 11). Heating space debris by a concentrator requires their nearness also. Solar concentrators can be a source of light pumping for lasers, but this technique does not provide great energy of a pulse.

5. OPERATION ORBITS OF SPACE LASER PLANT

The initial orbit of the space laser plant should give the possibility of removal of space debris concentrated in the «graveyards» mentioned in Introduction. We propose to use an elliptic orbit with small eccentricity passing the perigee and apogee near the «graveyards». This orbit should lie in the equatorial plane.

After the cleaning of the «graveyards» (where 60% of space vehicles after the end of service life are situated) the system will move along the geostationary orbit performing simple manoeuvres and removing other space fragments from the GSO. Hypothetical duration of the whole work in the GSO is several years. The main part of space debris of this zone will be removed to the orbits which are higher to 100-200 km. After this mission the space vehicle with laser sweeper should be taken off from the geostationary orbit. We suggest to put it into a heliocentric orbit with using the electric propulsion plant and solar arrays still providing considerable power output.

The crucial problem is sufficient propellant reserves after many orbital manoeuvres. If such reserves are available, the space laser plant can be dispatched to the Sun. Power expenses may be reduced to 7.5 - 7.8 km/s in terms of velocity increment by using a trajectory with gravitational flying round the Jupiter (Ref. 12). Electric thrusters can provide such result in two years of operation with high accuracy and controllability.

6. REFERENCES

1. Borodenkov, A.M., Zavalishin, A.P., Negoda, A.A., Aerospace Needs a «Refuse Collector» Now, *Space and Terrestrial Orbits of Yu.V.Kondratyuk*, Dniepropetrovsk, Sich, 1996 (in Russian).

2. Burdakov, V.P., *Electric Energy from Space*, Moscow, Energoatomizdat, 1991 (in Russian).

3. *Space Weapons: Dilemma of Security*, Editors E.P.Velikhov, R.Z.Sagdeyev, A.A.Kokoshin, Moscow, Mir, 1986 (in Russian).

4. Schall, W.O., Active Shielding and Reduction of the Number of Small Debris with High-Power Lasers, *Proc. 1st European Conference on Space Debris*, 465-470, Darmstadt, Germany, April 5-7, 1993.

5. Gerchanovskaya, V.P., Ipatov, E.F., Malova, A.P., *New Professions of Light*, Kiev, Tekhnika, 1989 (in Russian).

6. Prisniakov, V.F., Lyagushin, S.F., Statsenko, I.N., Dranovsky, V.I., On the Way to Creating a System of Distant Power Supply for Space Vehicles, *Solar Energy*, Vol. 56, No. 1, 97-109, 1996.

7. Prisniakov, V.F., Lyagushin, S.F., Possibilities of Laser Power Transmission in an Energy Supply System for Space Vehicles, *45th Congress of IAF*, IAF-94-R.3.382, Jerusalem, Israel, Oct. 9-14, 1994.

8. Prisniakov, V.F., Lyagushin, S.F., Statsenko, I.N., Konyukhov, S.N., Gorbulin, V.P., Power-Propulsion Complex for Putting Space Vehicles into High Orbits, *45th Congress of IAF*, IAF-94-V.5.557, Jerusalem, Israel, Oct. 9-14, 1994.

9. Toussaint, M., Energy Transmission in Space: an Enabler Technology, *2nd Int. Symposium «Power from Space» SPS 91*, 285-292, Paris/Gif-sur-Yvette, August 27-30, 1991.

10. Million Watts Lamp, *Scientific American*, Vol. 263, No. 5, 50-51, Nov. 1990.

11. Solar Energy Amplifier, *Scientific American*, Vol. 261, No. 2, 83, August 1989.

12. Mukhametzhanov, M.Zh., Chekalin, S.V., Prospects of Space Isolation of Especially Dangerous Waste of Nuclear Energetics, *Space and Ecology (Collection of Papers), New in Life, Science, and Technology, Cosmonautics and Astronomy*, No. 7, 42-53, 1991 (in Russian).