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Removal of Space Debris Using Laser

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Abstract

For several decades Space debris has become identified as a serious concern. It is highly risky for the future space missions mainly, in low earth orbits and geostationary orbit. This space debris are nothing but the rocket bodies, objects released from spacecraft, refuse from human missions and break ups of satellite such as dead batteries, unused fuels, etc. There are different types of debris like fragmentation debris, mission related debris and non functional aircraft. Among all these, fragmentation debris accounts to 42% in quantity. There is wide range of techniques involved in active debris removal. Some of them are laser, electrostatic tractor and ionic engine plume pressure. These techniques have no contact with the debris. Other than this, there are many techniques like, contact but no control on debris and contact and control on debris. These techniques help in reducing the velocity of debris, since the removal of large potential colliders does not seem feasible because of operational and programmatic constrains. There are two types of laser technique, ground air based laser and space based laser. Laser technique provide very high power and will be able to track and target debris with a much larger field of view. The heat from the laser has to be targeted on the small objects, so that it would vaporize a small part of the junk. This heat would create that targeted junk, into the fuel for the small missions which are sent to push the debris out of orbit. There are two types of laser, continuous wave laser and pulsed lasers. The pulsed lasers nowadays are being used to have only thermal destruction of many units and shells. Our presentation is the modified pulsed laser which has both thermal and mechanical momentum, because both thermal and mechanical impact may be used for solving the space debris problem.

Keywords: Space Debris, Ionic engine, Modified pulsed laser, Plume pressure, Potential collider.

1. Introduction

Near-Earth space pollution with space debris has begun with artificial satellite launch when the last stage of the launcher was put into orbit. During the following years more than 20,000 artificial space objects with dimensions more than 10c were observed in the 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 (GEO) in view of the narrowness of the intensively used zone. An operating satellite position in GEO is maintained through active correction with the accuracy of 0.1^o in longitudinal and latitude that means deviations 75 km and with the accuracy of about 25km 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 GEO drift along 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^o east and 150^o west i.e over the Indian and pacific oceans (Ref 2).

2. Sections

2.1 Space Laser Plant:

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. Liquid propulsions may be also used for cruise purposes, but calculations show (ref 3) that putting apparatus for machine purpose into the GSO with the aid of electric thrusters is much more efficient . It provides putting a satellite with a powerful solar plant from an intermediate orbit to the Geo-stationary one in a year term and further orbital manoeuvres . Lamps of multi-megawatt power must be focused radiation causes rapid evaporation of the substance absorbing white light better than laser emission .Such operation may be put into life under the condition of bringing our space vehicle and fragment close together.

3. Changing an Orbit by LASER:

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 moments 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.

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

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

Where E is the light pulse energy, δ is the effective thickness of the absorption zone, S is a laser spot area .

The above equation 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 the target area. These 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 light pumping is employed for the task under consideration. In the former Soviet Union a neodymium Laser with pulse power 10 TW and pulse duration of 10^{-6} s was elaborated. In neodymium laser glass with neodymium mixture, is the active medium, glass playing the role of matrix while ions Nd^{3+} are active centers .Laser rods are 40-50 mm in diameter and 5-6 mm 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 laser E makes 10^8 J. The effective absorption zone thickness may be estimated from the correlation

$$\delta =(\ kt)^{1/2}$$

Where K is a temperature conductivity coefficient and t is pulse duration. For usual aluminium alloys we obtain $\delta = 3*10^{-2}$ kg/m^2. If the spot area is about 1 m^2, the momentum transfer calculated from eq 1 will reach $2*10^3$ n.s, i.e. about 1% of the fragment momentum.

3.1 Modification for Pulsed LASER:

It is therefore easy to see that power scaling methods which conserve the beam quality are highly desirable. For beam combining with multiple lasers, the beams need to be superimposed so that a single output beam with similar parameters is obtained. For just two beams, having well-defined polarization states, a simple polarizer (e.g. a polarizing cube) could be sufficient (→ polarization beam combining), but this method cannot be repeated because it leads to an unpolarized beam. For large numbers of combined beams, there are various methods:

If the beams have different wavelengths, spectral beam combining can be used. The outputs of single-frequency lasers can be coherently combined e.g. with ordinary beam splitters, if the relative phase of the beams can be stabilized, and the beams are polarized. Alternatively, beams with a transverse displacement can be combined to form a single beam with larger area but smaller beam divergence, thus also preserving the beam quality. Such methods are currently being explored both with bulk and fibre lasers.

Coherent beam combining does not always require single-frequency operation; there are certain optical feedback techniques which work with multimode lasers.

Such methods make it possible to scale the output power without degrading the beam quality, but still at the cost of increasing the number of components. Other power scaling methods operate on the design of a single high-power laser. Not every type of laser, however, is suitable for true power scaling. For example, a simple end-pumped or side-pumped rod laser will exhibit increasingly severe thermal effects if the pump power is increased. Modifying the mode area does in this case not help: while a larger pump beam reduces the focusing power of the thermal lens, a larger laser mode is more sensitive to lensing, so that the beam quality and eventually also the power efficiency is compromised. A good example of a power-scalable laser design is that of a thin-disk laser. Here, power scalability arises from the special geometry with a longitudinal heat flow. Within a large range of output powers, power scaling is possible just by increasing the mode area in the gain medium (the thin disk) in proportion to the pump and output power. If this scaling procedure is applied, the maximum temperature excursion in the disk is not significantly increased, as the cooled area increases in proportion to the power. Moreover, the focusing power of the thermal lens resulting from the transverse temperature gradient is even reduced for models with higher powers; this just compensates for the fact that a larger laser mode is more sensitive to lensing. The output power can therefore be increased until other effects limit the performance – for example, effects related to mechanical stress in the disk, which increases with increased powers, or to amplified spontaneous emission in the transverse direction, which will eventually limit the power achievable from a single disk. Such effects can be substantially mitigated e.g. by using a composite (doped/un-doped) disk. Slab lasers have also been proposed as a power-scalable technology. In a similar fashion as for thin-disk lasers, the cooled area of a laser slab is scaled up for higher powers, so that the temperature rise, temperature gradient and induced stress do not have to be increased for higher powers. However, efficient power extraction with high beam quality is a challenge. Close to diffraction-limited operation will be more and more difficult to achieve as the powers are scaled up. An intermediate scaling method, also sometimes used, increases the number of laser heads, but uses those in a single laser resonator. The combined effect of beam distortions in the laser heads may be expected to soon spoil the beam quality, but there are so-called periodic resonator where this is not the case. Nevertheless, the number of usable laser heads will normally be fairly limited by practical factor.

4. Conclusion

It is clear and evident that space debris has become one of the major problems during space expeditions, leading to disasters. At the same time we are able to see that this debris can be also used in an effective manner by converting them into useful fuel for smaller space expeditions. Thus we can foresee a technique that will help us removing the debris as well as using them very effectively.

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