Optik 154 (2018) 83–92

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Full length article

Impacts of orbital elements of space-based laser station on small scale space debris removal

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ARTICLE INFO

Article history:
Received 23 June 2017
Accepted 2 October 2017

Keywords:
Space debris
Space-based laser
Impulse coupling
Orbit modification

ABSTRACT

This paper investigated the impacts of orbital elements of space-based laser station on small scale space debris removal by numerical simulation. The orbital momentum models of small scale space debris and space-based laser station were established. The velocity variation of the space debris ablating by the space-based laser station was analyzed, and the orbit maneuver of the space debris irradiated by laser station was modeled and studied. The variations of orbital parameters of the space debris orbit respectively without and with irradiation of high-power pulsed laser were simulated and analyzed, and the impacts of the inclination and right ascension of ascending node (RAAN) of the space-based laser station on debris removal were analyzed and discussed. The simulation results show that, debris removal is affected by inclination and RAAN, and laser station with the same inclination and RAAN as debris has the highest removal efficiency. It provides necessary theoretical basis for the deployment of space-based laser station and the further application of space debris removal by using space-based laser.

1. Introduction

A great deal of space debris has been produced from frequent space activities since human beings come into space age in 1957, which has seriously polluted the space environment. The increasing number of space debris poses a considerable danger to orbiting satellites, humans in space and further space exploration activities. Space debris is mainly distributed in range from 400 km to 2000 km of Low Earth Orbit (LEO), where the small scale space debris with 1 cm to 10 cm order size can be neither monitored and tracked, nor shielded from orbiting spacecraft, posing a significant hazard for its large kinetic energy [1–3]. Hence, the small scale space debris is considered as the most dangerous debris. It is urgent to remove small scale space debris in LEO actively to guarantee space environment security [4–6]. At present, the proposed solutions of space debris active removal mainly include chasing and grappling the objects, deploying nets to capture objects, attaching an electrodynamics tether and pulsed laser orbiting debris removal [7–9]. Pulsed laser orbiting debris removal has advantages such as simple operation, short response time, low cost, repeated use, and capable of both monitor and track activities. Therefore, it is considered as the most promising approach and is the focus of current research [10,11].

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https://doi.org/10.1016/j.ijleo.2017.10.008
0030-4026/

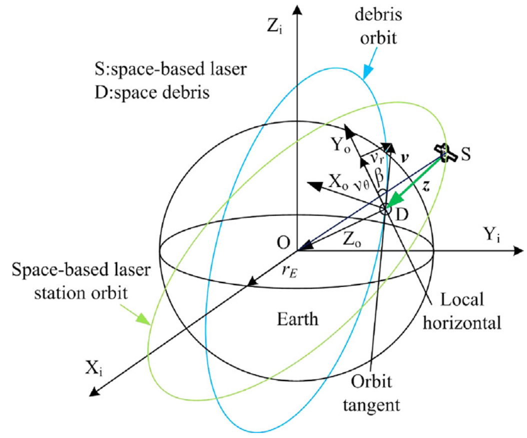

Fig. 1. Schematic of removal scheme of orbiting space debris by using space-based laser.

Over the past few years, laser debris removal is subject to a majority of studies all over the world. Moreover, plenty of researches project on laser removal of space debris have been proposed, such as the ORION project of USA [12] and the CLEANSPACE project of EU [4]. C. Phipps proposed the approach of using a high power pulsed laser system on the Earth to remove debris, suggesting that laser orbital debris removal is the most cost-effective way to mitigate the debris problem [13]. W. Schall performed a discussion on the feasibility and basic principle for cleaning space debris in LEO by laser irradiation [14]. X. Jin et al. have researched laser removal method of elliptic orbital debris, indicating that the high power pulsed laser is a feasible method to remove debris [15]. S. Shen et al. proposed a project of a space-based laser system, and the simulation results shown the space-based laser system can successfully protect the space station from the collision of debris [16]. Recently, C. Phipps presented a completely new proposal of a space borne ultraviolet laser system for space debris clearing and gave an estimated cost of removal [17]. The previous researches are mainly in ground-based laser debris removal, in which relevant research institutions have made some progress. However, the operating space of the ground-based laser is very limited due to its geographical location and distance. With the development of laser technology, the space-based laser debris removal has become a new solution to space debris removal for it can capture and monitor debris more conveniently and flexibly and hardly be affected by atmospheric. At present, researches on laser debris removal concentrate on the ground-based laser debris removal and involved less in the space-based laser debris removal. The action mechanism of space-based laser debris removal still lacks of further research at present. Hence, it is necessary to study the basic principle and feasibility of space-based laser debris removal.

In this paper, we discuss the variations of the orbital parameters of the small scale space debris repspectively without and with the irradiation of high-power pulsed laser by simulating ten passes of space-based laser station. In addition, the impacts of orbital elements of space-based laser station are concentrated on by numerical simulations.

2. Model descriptions

2.1. Exposition of elimination process

As shown in Fig. 1, space-based laser station is arranged in outer space, assuming that both space debris and space-based laser station run in a circular orbit. We assume that 200 km is the maximum of the space-based laser operating range in consequence of constraint on volume power consumption of space-based laser [18].

When the range between debris and space-based laser (operating range) is below 200 km and the angle between debris velocity and laser irradiation velocity increment (irradiation angle) is over 90°, which means debris runs into the elimination window of the space-based laser station, pulsed laser starts to irradiate debris. Afterwards, space debris obtains a laser irradiation velocity increment instantaneously, making debris orbit modified and the perigee decline [19]. When the debris runs over the elimination window, space-based laser stops working. The laser goes on to irradiate when debris runs into the next elimination window. The 200-km altitude is considered as the threshold for successful removal where debris is burned down owing to the aerodynamic heating effect [20].

2.2. Momentum transfer model of space debris orbit

The ECI (Earth Centered Inertial) O-$X_iY_iZ_i$ is used to describe the motion of space debris and space-based laser station in this model as shown in Fig. 1, where D is space debris, S is the space-based laser station. The initial orbital elements of space