P05

レーザーアブレーション反力による衛星回転の制御の可能性

Suppression of Satellite Rotation by the Reaction Force by Laser Ablation

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宇宙デブリは宇宙開発にとって大きな課題になりつつある。運用を停止した衛星は、衛星同士の衝突による宇宙デブリの増加を抑制するために、初期軌道から外して地球に再突入させるか、衛星の存在密度が小さい軌道に再投入する必要がある。すでに運用を停止し姿勢制御を長期に起こっていない衛星は、様々な理由により回転していると考えられている。この回転を止めないと再捕獲して、新しい軌道に投入したり、新たにスラスタやテザーを取り付けることが困難である。本論文では、近距離から高輝度パルスレーザーを照射して、アブレーションプラズマの反力で回転を抑える可能性について検討する。

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Space debris becomes one of the major risks for space development. Non-operating satellites have to be de-orbited to reentry to the Earth or to the orbits where the satellite density is small in order to suppress the debris creation by the collisions. The satellite, however, may have a rotation of the order of one rotation per minutes, long after the stopping its operation. This rotation prevents us to recapture them to attach a thruster or tether for the de-orbit operations. In the present paper, we seek the possibility to use intense pulsed laser to control the rotation of the satellites. The reaction force due to the plasma ablation due to the focused intense laser beam is calculated as:

$$f_L = C_m E_d R = 1.0 \times 10^{-4} \left(\frac{C_m}{10^{-4} N/W}\right) \left(\frac{E_p}{10mJ}\right) \left(\frac{R}{10^2 Hz}\right) N,$$

where C_m is the reaction force coefficient, E_p the pulse energy, R the repetition rate.

The mass of the 1 m cube satellite is calculated as:

$$M = 10^3 \left(\frac{\rho}{10^3 kg/m^3}\right) \left(\frac{a}{1m}\right)^3 kg$$

and the moment of inertia as *2/3 Ma²*. A significant change in the angular momentum of the satellite can be achieved within:

$$\tau = \frac{I\omega}{a f_L} = 7.8 \left(\frac{a}{1m}\right) \left(\frac{M}{10^3 kg}\right) \left(\frac{f_L}{10^{-4} N}\right)^{-1} \left(\frac{\omega}{0.1Hz}\right) days,$$

when we exert the force f_L on the point separated a from the centre of mass of the satellite. Here, ω is the angular velocity of the satellite. The fluence of the laser beam on the target is as high as:

$$I = \frac{4E_p}{\pi a^2} = 1.3 \times 10^4 \left(\frac{E_p}{10mJ}\right) \left(\frac{a}{10^{-3} m}\right)^{-2} W m^{-2},$$

which is well above the ablation threshold of 3×10^4 W m^{-2}, where n_p is the pulse duration and a the beam spot diameter on the satellite. The spot diameter of 10^{-3} m is feasible from the operation from 100 m distance, since the diffraction limited beam size is as small as 0.3×10^{-3} m for the case that the steering optics of 0.3 m and the distance of 100 m, assuming the wavelength of the laser photons to be 1 μm. A laser system with an average power of 1 W can stop the rotation of one-ton class satellite with the size of 1 m within a month.

Figure 3 shows the results of the vacuum thermal test of the laser system (Figure 4) in Photonics Control Technology Team, RIKEN in collaboration with JAXA. The power above 1 W was maintained for four days in the vacuum environment between -40°C and 60°C. The conduction cooling system shown in Figures 5 was proven to work in 1 W average power operation in vacuum.

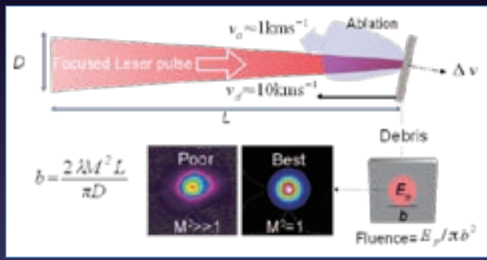

Figure 1: Concept of the propulsion by laser ablation. Ablated material is ejected as ablation plasma by the velocity of v_a.

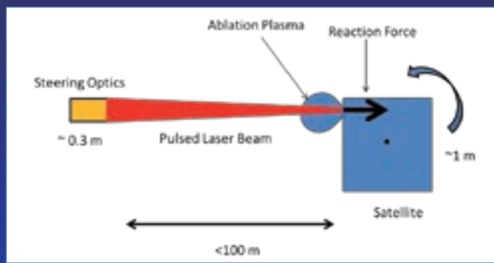

Figure 2: The concept of the laser suppression of the rotation of a satellite.

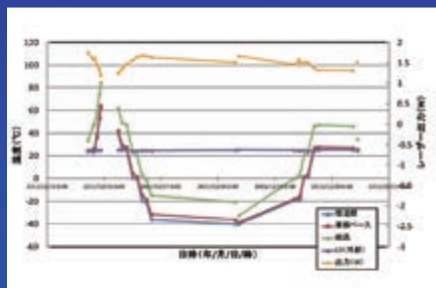

Figure 3: The result of vacuum-thermal test on the laser system. The power above 1 W was maintained for four days in the vacuum environment between -40°C and 60°C.

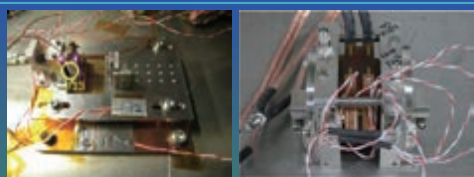

Figure 4: The laser system overlook and the laser system used in the vacuum thermal test.

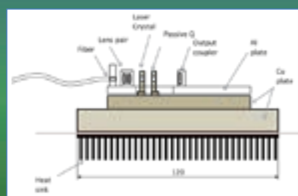

Figure 5: The laser system is cooled by only conduction by Al and Cu plate with a heat sink.