Space mini-vehicle with the laser propulsion system

Yuri A. Rezunkov

Ltd "Research Institute for OptoElectronic Engineering" (NII OEP),
Sosnovy Bor, Leningrad region, 188540, Russia.

Abstract.

Application of high-power lasers to explore a space is discussed for a long time, starting from the pioneer papers published by Arthur Kantrowitz [1] in 1972 and A.M. Prokhorov [2] in 1976. A number of theoretical and experimental studies on laser propulsion are performed during the past years in Russia, USA, Germany, Japan, China, Brazil, and Australia. Various models of laser propulsion engines were developed and experimentally tested since this time [3]. One of the most remarkable technological projections of beamed energy propulsion has been made by Prof. Leik Myrabo as applied to space flights by using Lightcraft technology [4]. Lighcraft is designed self-empirically for suborbital missions of a man in a near-Earth space basing on radio-wave radiation propulsion. In the presentation, we consider a creation of a space mini-vehicle with laser propulsion system, called like a Space Laser Cleaner - SLC. The vehicle is assumed to be used to remove space debris out off Low Earth Orbits, to monitor a large-size space station during its inter-orbital missions, to monitor the near-Earth space, and so on. In all cases, there is a necessity of using a small mobile spacecraft without the fuel and power great consumption.

The SLC optical system is designed to fulfill the following conditions defined by its functional capabilities.
1. Independence of the vehicle orbital movements on a direction to laser power source. The aerospace laser propulsion engine (ASLPE) developed earlier [5] is suggested to be used to produce a thrust. Such auxiliary optical units as the optical turret and hinges, satisfying this condition completely, are designed for the vehicle.
2. Efficient collection of laser power by a receiver telescope. The efficient delivery of laser power from a laser to the vehicle depends on matching of transmitter-receiver telescopes apertures, laser radiation wavelength, and on distance between them.
3. There is a basic optical axis at which both spatial orientation system of the vehicle and receiver telescope axis are referred to.
4. High production efficiency of laser propulsion at ASLPE, being no less than the efficiency of conventional rocket engines (~ 70 %).

The last condition is a principal one for space application of the laser propulsion engine because the engine efficiency, which is defined as a momentum coupling coefficient C_m [6] being a ratio of a produced thrust to incoming laser power, characterizes low limits on the laser power to be used. C_m gives the thrust magnitude at a given laser power. For the example, to maneuver a spacecraft promptly with a mass of 100 kg, the thrust of 10 N has to be produced, which results in $C_m \sim 10^{-2}$ N/W at a laser power of 1 kW. The value of the coupling coefficient is large enough and it requires the development of a new method of laser propulsion production at space conditions.

To the present time, a few laser propulsion mechanisms are examined at a subsonic mode, including: a) laser breakdown of gases running with a production of blast waves (shock waves), b) laser ablation of solid materials, c) laser detonation of energetic materials, running with a liberation of internal energy of the material under the action of laser pulse. The laser breakdown of gases seems also to be the most attractive for laser propulsion application in the atmosphere, when the air may be used as a propellant producing a thrust.

Well less attention have been paid at a supersonic mode of the laser propulsion running in supersonic flows. The point is that the processes of gas discharge action with supersonic flow are discriminated by an instability and complexity of gas dynamic phenomena accompanying the laser propulsion production. To stabilize production modes and to increase the production efficiency of laser propulsion at space conditions, we suggest using a laser ablation jet being formed at interaction of laser radiation with walls of a supersonic nozzle. The laser ablation jet has some specific features, which allow extra accelerating of supersonic flows [7].

First, the jet is directed perpendicular to a solid wall independently on an incident angle of incoming laser beam. Secondly, the jet velocity and mass rate, determining the jet power, depend both on laser power and on efficiency of the power absorption by wall materials, temperature of the material vapor, and so on. Thirdly, there is a bow shock wave in the region in front of an ablation area, just as in the case of a supersonic flow in front of solid body. It is shown theoretically that an extra acceleration of the supersonic flow is achieved behind the ablation area.
It is also shown the momentum coupling coefficient of 10^{-2} N/W can be provided by this method. To increase the coupling coefficient greater, such energetic propellants of CHO-chemical composition as a polyoxyethylene ([-CH_2O-]$_n$) is suggested to be used.

References

[1] Arthur Kantrowitz. 1972. Propulsion to orbit by ground-based lasers. *Aeronautics Astronautics*, Vol. 10, № 5, pp. 40-42
[2] Bunkin F.B. Prokhorov A.M. 1976. The application of laser power to produce a thrust. *Progress in physics sciences*. Vol. 119, No 3, , pp. 425-446
[3] Yu.A. Rezunkov. Laser propulsion: the review of researches. 2007. *Journal of Optical Technology*, Vol. 74, No 8, pp 20-32
[4] *Leik N. Myrabo, John S. Lewis*. 2009. LIGHTCRAFT, Flight handbook. USA, Apogee Books
[5] A.A. Ageichik, M.S. Egorov, Yu.A. Rezunkov, A.L. Safronov, V.V. Stepanov. Aerospace laser propulsion engine. Russian patent № 2266420, 08 October 2003
[6] *John D.G. Rather*. 2003. Ground to space laser power beaming: mission, technologies, and economic advantages. *Beamed Energy Propulsion, AIP Conference Proceedings*. Vol.664, pp.37-48
[7] Yu.A. Rezunkov, A.A. Schmidt. High-power laser propulsion. Laser Optics 2012, Saint-Petersburg, 25-29 June, 2012. Technical program.