Yu. M. Holdshtein, O. A. Fokov

Optimization of transfers between low orbits with significantly different longitudes of ascending nodes

Institute of Technical Mechanics
of the National Academy of Sciences of Ukraine and the State Space Agency of Ukraine
15 Leshko-Popel St., Dnipro 49005, Ukraine; e-mail: jura_gold@meta.ua

At present, satellite systems, each comprising hundreds of satellites, are, and are to be, deployed in low orbits. In addition, existing satellite systems are replenished. There has appeared a trend towards the development of modular satellites, which will lead to the development of easy-to-maintain spacecraft consisting of many small structural modules with standardized interface mechanisms. To extend the life of all these systems and reduce their maintenance cost, it is advisable to develop a system for their maintenance. Despite the relatively large number of works on the rendezvous problem, this problem is considered in a somewhat simplified formulation, which is not sufficient for spacecraft servicing in low orbits. As a rule, the consideration is limited to coplanar rendezvous problems in an impulse formulation. In real conditions, rendezvous maneuvers in low orbits are nontrivial. As is known, the orbital parameters of low-orbit spacecraft may differ significantly: the difference in the longitude of ascending nodes (LAN) may reach tens and even hundreds of degrees. Because of this, the energy consumption for an orbital plane change becomes unacceptably high for modern service spacecraft. This energy consumption can be reduced by using the precession of the line of nodes due to the non-centrality of the Earth's gravitational field. A waiting maneuver of a service spacecraft in a well-chosen orbit makes it possible to eliminate the mismatch between the LANs of the service spacecraft's parking and destination orbits, thus significantly reducing the orbital transfer energy consumption. However, the long wait time of the service spacecraft in its parking orbit significantly increases the total orbital transfer time. The aim of this article is to develop a mathematical model of bicriteria optimization of a transfer of a service spacecraft with a low constant thrust engine between low near-circular orbits with significantly different LANs. This problem is solved by averaging the service spacecraft's dynamics equations over a fast parameter and using a genetic algorithm of global Pareto optimization. The novelty of the results obtained lies in a formulation of a bicriteria optimization problem and the development of a mathematical model for choosing an optimal service spacecraft parking orbit. The mathematical model developed may be used in planning service spacecraft transfers between low near-circular orbits with significantly different LANs.

Keywords: optimization, parking orbit, Pareto front, on-orbit servicing, low thrust, averaging method.

1. Marec J. P. Optimal Space Trajectories. Elsevier, 2012. 356 pp.

2. Razoumny Yu. N., Razoumny V. Yu., Spencer D.B. et al. The concept of on-orbit-servicing for next generation space system development and its key technologies. Proceedings of the 68th International Astronautical Congress IAC. 2017. V. 16. Pp. 10486-10499.

3. lpatov A. P., Holdstein Y. M. On the choice of the ballistic parameters of an on-orbit service spacecraft. Teh. Meh. 2019. No. 1. Pp. 25-37.
https://doi.org/10.15407/itm2019.01.025

4. Cerf M. Low-thrust transfer between circular orbits using natural precession. J. Guid. Contr. Dynam. 2016. V. 39. No. 10. Pp. 232-239.
https://doi.org/10.2514/1.G001331

5. Zhang S., Han C., Sun X. New solution for rendezvous between geosynchronous satellites using low thrust. J. Guid. Contr. Dynam. 2018. V. 41. No. 3. Pp.1-10.
https://doi.org/10.2514/1.G003270

6. Labourdette P. A software for rendezvous between near-circular orbits with large initial ascending node difference. Proceedings of the 17th International symposium on space flight dynamics. 2003. Pp. 130-142.

7. Chen H., Ho K. Integrated space logistics mission planning and spacecraft design with Mixed-Integer Nonlinear Programming. Journal of Spacecraft and Rockets. 2018. V. 55. No. 2. Pp. 365-381.
https://doi.org/10.2514/1.A33905

8. Legge Jr. Optimization and valuation of recongurable satellite constellations under uncertainty. PhD thesis, Massachusetts Institute of Technology, 2014.

9. Li H., Chen S., Baoyin H., J2-perturbed multitarget rendezvous optimization with low thrust. J. Guid. Control Dyn. 2018. V. 41. No. 3. Pp.802-808.
https://doi.org/10.2514/1.G002889

10. Holdshtein Yu. M. On the choice of a parking orbit for a service spacecraft. Teh. Meh. 2020. No. 3. Pp. 30 - 38. (in Ukrainian).
https://doi.org/10.15407/itm2020.03.030

11. Popovici N. Pareto reducible multicriteria optimization problems. A Journal of Mathematical Programming and Operations Research. 2005. V. 54. Iss. 3. Pp. 253-263.
https://doi.org/10.1080/02331930500096213

12. Kim I. Y., de Weck O. L. Adaptive weighted-sum method for bi-objective optimization: Pareto front generation. Structural and Multidisciplinary Optimization. 2005. V. 29. Pp. 149-158.
https://doi.org/10.1007/s00158-004-0465-1