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ORIGINAL ARTICLE

Artificial frozen orbits around Mercury

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Abstract Orbits around Mercury are influenced by the strong elliptic third-body perturbation, especially for high eccentricity orbits, the periapsis altitude changes dramatically. Frozen orbits whose mean eccentricity and argument of perigee remain constants are obviously a good choice for space missions, but the forming conditions are too harsh to meet practical needs. To deal with this problem, a continuous control method that combines analytical theory and parameter optimization is proposed to build an artificial frozen orbit. The artificial frozen orbits are investigated on the basis of double averaged Hamiltonian, of which the second and third zonal harmonics and the perturbation of elliptic third-body gravity are considered. In this paper, coefficients of perturbations which satisfy the conditions of frozen orbits are involved as control parameters, and the relevant artificial perturbations are compensated by the control strategy. So probes around Mercury can be kept on frozen orbit under the influence of continuous control force. Then complex method of optimization is used to search for the energy optimized artificial frozen orbits. The choosing of optimal parameters, the objective function setting and other issues are also discussed in the study. Evolution of optimal control parameters are given in large ranges of semi-major axis and eccentricity, through the variation of these curves, the fuel efficiency is discussed. The result shows that the control method proposed in this paper can effectively maintain the eccentricity and argument of perigee frozen.

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1 Introduction

Mercury is one of four terrestrial planets. Explorations of Mercury not only give the knowledge of the planet itself but also have significance for researching on the origin and evolution of Solar System. Actually, although the rocket fuel to Mercury is much more than the fuel requirement of trips to other planets, Mercury mission have never been given up. In the 1970s, the space probe Mariner 10 succeeded in flying past Mercury three times and mapped 45 % of Mercury's surface. The second Mercury mission MESSENGER entered Mercury's orbit at 2011, this probe gave more significant data that people hadn't known before. BepiColombo is a new Mercury mission in the planning stage. This mission involves multiple components, which will explore the planet in more detail.

Probes around Mercury are perturbed by the non-spherical perturbation and the third-body gravitation from the Sun. Due to the close distance between Mercury and Sun, the third-body perturbation is relatively large, and the Kozai mechanism caused by the gravitation of the third-body may lead to an interchange between the eccentricity and inclination (Lidov 1962; Kozai 1962). In the case of MESSENGER, orbit-correction maneuvers must be executed once per 88-day Mercury year to keep the periapsis altitude under the nominal altitude (McAdams 2006). In fact, for orbits with high eccentricity, spacecraft may finally collide with Mercury at periapsis.

After the averaging method was developed by Kozai, people achieved a better understanding in long-term characters of perturbed orbits. The analysis of perturbation has