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Chinese Astronomy and Astrophysics 41 (2017) 92–108

CHINESE ASTRONOMY AND ASTROPHYSICS

Orbit Control of Fly-around Satellite with Highly Eccentric Orbit Using Solar Radiation Pressure[†] [⋆]

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Abstract The method of controlling highly eccentric accompanying flight orbit using the solar wing is proposed in this paper. The formation is maintained by controlling the orbit of the accompanying satellite (follower). The accompanying satellite rotates around its inertial principal axis with a constant angular velocity. The control on the accompanying satellite is divided into the in-plane control and out-of-plane control. The in-plane control is superior to the out-of-plane control. The out-of-plane control force is applied when the in-plane error is eliminated or the in-plane control force can not be supplied due to some geometrical factors. By the sliding mode control method, the magnitude and direction of the control force required by the in-plane orbit control are calculated. Then accordingly, the expression of the solar wing orientation with respect to the satellite body in the control process is derived, so that by adjusting the orientation of the solar wing, the required control force can be obtained. Finally, the verification on this method is performed by numerical simulations, including the orbit adjustment, error elimination, and the orbit maintenance. It is shown that this method can keep the error less than 5 m, and it is feasible for the space formation flight.

Key words space vehicles—celestial mechanics—methods: numerical

[†] Supported by Natural Science Foundation (11125315, 11173056)

Received 2015–04–02; revised version 2015–05–26

[⋆] A translation of *Acta Astron. Sin.* Vol. 57, No. 1, pp. 52–65, 2016

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doi:10.1016/j.chinastron.2017.01.008

1. INTRODUCTION

The design, control and application of the accompanying flight orbit are one of the most popular research fields in space science. Great achievements have been made after 20 years' development in this field. By the cooperation between the primary satellite and its accompanying satellite (the follower), or the cooperations among a group of satellites in formation, space satellites can accomplish many complicated space missions. Compared with the traditional single large satellite, the satellites in formation have the virtues such as the low cost, high replaceability, high flexibility, wide applicability, and therefore a broad market in practical applications. Generally, the accompanying flight orbit is not stable under the influences of various perturbations, so the geometrical relationship between the primary satellite and the accompanying satellite needs to be maintained by constant orbit adjustment, which consumes a lot of space-borne fuel. Consequently, to reduce the fuel consumption in the control process has become a key problem in the study of accompanying flight orbits.

There are two ways to reduce the fuel consumption. The first is to carefully design the initial orbit so that the disturbing effect on the accompanying flight orbit from the already-known perturbations (mainly the Earth's non-spherical J_2 perturbation and others with certain secular effects) can be reduced to the minimum level, and consequently both the necessary number and force of controls can be substantially reduced. The second way is to optimize the control strategy so as to increase the fuel efficiency. Many system control methods, such as the linear system control method, LQR control method, and the nonlinear control method Sliding Mode Control (SMC), have been applied to the control of accompanying flight orbit[1−3]. By adjusting the control scheme, the fuel can be saved to a certain extent. As the control force is generally provided by chemical fuel, the consumption of onboard fuel is unavoidable. The proposed application of solar radiation pressure as a control force can save fuel greatly.

The altitude of the satellite on a highly eccentric orbit varies very much from the perigee to the apogee, so that the satellite may experience a variety of different space environments, including the low, medium and high orbits in one cycle. Therefore, the satellite with a large orbital eccentricity has many advantages in space exploration, communication and navigation. For a primary satellite on a highly eccentric orbit, the accompanying flight orbit can also be designed. For example, the formation satellite Cluster II has been successfully launched, and it consists of four satellites to form a tetrahedral structure. Around the perigee, it can measure the Earth's gravity field, while around the apogee it can make the solar wind and space weather observations[4].

The concept of using a small thrust to control the orbit has been proposed and studied by many researchers[5−8]. To equip the satellite with the solar wing and atmospheric friction sailboard, and to use the tiny force of the solar radiation pressure and atmospheric friction for the orbit control can also be regarded as the application of small thrust for the orbit control. Through the appropriate adjustment of the orientation of the solar wing, the damage