UDC 531.13

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SINGLE THRUSTER CONTROL OF THE ION BEAM SHEPHERD SATELLITE TO MAINTAIN ITS RELATIVE POSITION

Abstract. The “ion beam shepherd” is a recently proposed concept for removing space debris in a contactless manner. A shepherd satellite must be controlled to move at a certain small distance in front of a space debris object during the de-orbiting phase. Because of the considerable duration of this phase, the propellant consumption is a key requirement for the control design. In this presentation, the in-plane relative position of the shepherd is maintained using a small thrust variation of the compensation thruster. To control the IBS relative motion in a direction perpendicular to the orbit plane, a small variation of the yaw angle is used. The estimations show that this control strategy is more efficient in terms of propellant consumption than the conventional approach with multiple chemical thrusters.

Key words: space debris removal, ion beam, electric thruster, relative dynamics, robust control

Despite the considerable efforts of the leading space agencies, the space debris (SD) problem is getting more acute every year. The recent modeling studies of the space debris population show that the situation for some near-earth orbits is already critical. In this regard, the space community is actively studying methods and developing technologies for the direct SD removal from near-Earth orbits.

To mitigate the SD problem, the "Ion Beam Shepherd" (IBS) concept was proposed [1] for contactless SD removal. The main idea of the IBS concept is to use the ion plume from an electric thruster (ET) for transmitting a de-orbiting momentum to a SD object.

To implement this concept, the IBS satellite has to be controlled in the de-orbiting phase to move at a certain small distance in front of the SD object. Due to the considerable duration of this phase, the propellant consumption is a key requirement for the controller design.

In this presentation, control of the relative motion in an orbit plane is implemented using a small thrust variation of the compensation thruster of the shepherd. The controller is designed and analyzed taking into account the impacts of the ion beam and a wide range of orbital disturbances, as well as inaccuracies in measuring the relative position and implementing the control impacts, limitations on the magnitude of the control output, time-varying and parametric uncertain plant.

The system robustness and specified requirements are confirmed both by formal criteria and by numerical simulations. The estimations show that this control requires significantly less propellant to maintain the relative position of the shepherd.

However, the control with only tangential thrust does not provide controllability of the formation in the direction perpendicular to the orbit plane. Because of that, an approach, based on variation of the IBS yaw angle in a small range, was proposed to control the IBS relative motion in a direction perpendicular to the orbit plane. The implementation of this approach is challenging due to the fact that a variation of the yaw angle leads not only to a change of the projections of the ET forces, but also to a change of the force transferred to the SD object by the ion beam [2].

Algorithms to control the IBS yaw angle have been designed, which maintain the required IBS relative position in the direction perpendicular to the orbit plane. An extended state observer [3] is used to estimate the perturbations and velocities. It is shown that the range of the variations of the yaw angles can be bounded in such a way to keep the SD removal rate acceptable.

The analysis shows that the IBS relative position can be controlled using only one compensation thruster. The control strategy proposed in this paper allows significantly reducing the propellant mass needed to fulfill a de-orbiting mission.

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement n°607457.

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