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Special refill spacecraft debris collector, equipped with electro rocket engine of low-thrust, design parameters optimization

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Abstract

The problem of near Earth space debris is studied in this article. A special spacecraft debris collector, equipped with electro rocket engine of low-thrust, for large space debris disposal is introduced. The mass model of spacecraft debris collector, one-off or reusable, is obtained. Ballistic scheme, spacecraft debris collector orbital transfer from parking orbit to space debris orbit, its disposal in Earth atmosphere and reusable spacecraft return to the parking orbit are studied. For the introduced criteria of transport transfer efficiency and assumption about consistency of acceleration from thrust, analytical relations for spacecraft design parameters calculation are obtained. The design parameters calculation results are shown in a generalized form.

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Keywords: space debris; special spacecraft debris collector; criteria function; characteristic velocity gains; design parameters; total resource

1. Introduction

Fragments of space debris (FSD) – are all man-made objects and their parts in space, which are uncontrollable, and cannot be used for any purposes, but pose a danger for active spacecraft.

FSD can be divided into categories. First, FSD of diameter less than 1 cm. Second, FSD with a diameter of 1 – 10 cm and, third, FSG diameter with a diameter greater than 10 cm. Many of this objects are observable and information about its orbit storage in catalogs. Orbits of FSD can be classified. First, low Earth orbits of 400 – 1000 km altitude. Second, FSD at geostationary orbit and, third, FSD at altitudes about 1000 – 5000 km [1].

Methods of space debris disposal can be divided to two categories: passive (preemptive) and active methods. Active methods propose special spacecraft (SDC), which transfer FSD to low disposal orbit (LDO), that perigee height is about 200 km, and from that FSD enter to Earth atmosphere. An especially important problem for SDC is disposal FSD near the International Space Station – the most expensive object in space.

The most dangerous is large FSD – uncontrolled spacecraft, booster stages and other. These objects cannot completely burn in atmosphere and, during landing, can damage Earth objects. Furthermore, point of landing forecast, for these objects, during its self-locking in Earth – poses a difficult technical problem. The FSD dissent and landing in predetermined area of Earth surface is an important and current problem, and SDC can solve this problem.

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SDC equipped with electro rocket engines (ERE) of low-thrust are justified [2] as they are characterized by high specific impulse and allow low mass spacecraft with long operational time to be created. ERE can be used as sustainer engines and also as engines in orientation and docking systems. Nowadays, there are two types of SDC. The first type are SDC of one time in use and and the second one is a reusable refill SDC.

The ballistic schemes of SDC operations are introduced next. SDC stay at a parking orbit with an altitude of 400 km. At the first stage, other services determine the FSD, that will dispose, and transfer data to SDC. The motion control system of SDC calculates the control program and SDC makes orbital transfer to the FSD, makes rendezvous transfer and fixed FSD on-board.

Next, if possible, the SDC moves to another FSD and fixes it it on-board. At the second stage, FSD makes orbital transfer to LDO and stays there, until sufficient conditions for FSD disposal to a predetermined area of Earth surface. Next, SDC makes disposal of FSD, it enters into the Earth's atmosphere and FSD burns in atmosphere or lands in predetermined area.

Reusable SDC, after unfixed FSD, at a third stage, moves to a parking orbit, refills as necessary, and is ready for the next operation. For reusable FSD, this cycle repeats.

Modern methods of spacecraft design assume iterations, during design and ballistic parameters optimization. In this article, we consider "zero" iteration, to determine area of design and ballistic parameters, based on simple mass models.

2. Mass model of one-time use SDC

Let us study mass model of a one-time use SDC:

$$M_0 = M_{\mathrm{E}} + M_{\mathrm{T}} + M_{\mathrm{C}}, \tag{1}$$

where M_0 – initial (start) SDC mass, M_{E} – SDC mass, determined by effective power of power plant, M_{T} – SDC mass, determined by active operational time (working fluid mass), M_{C} – fixed and constant mass of SDC (mass of constructions, navigation and control systems, FSD docking and fixed system and other constant masses).

Mass components M_{E} and M_{T} are written in the in the formula:

$$\begin{aligned} M_{\mathrm{E}} &= \gamma \cdot \frac{P \cdot C}{2}, \\ M_{\mathrm{T}} &= t \cdot \left(\frac{P}{C} + m_{\mathrm{C}} \right), \end{aligned} \tag{2}$$

where P – total sustainer engines thrust, C – exhaust velocity of ERE, t – total ERE operation time, m_{C} – working fluid flow rate (in one second) for SDC orientation supporting, γ – specific (dimension less) mass of power plant, taking into account mass of solar panel and its degradation with time.

The next assumptions are introduced :

1. ERE exhaust velocity C and thrust P stay constant during all SDC resource.
2. Acceleration from thrust, during every stage of SDC operation, is constant and calculated for average SDC mass.

Total operation duration is written in the next formula:

$$t = t_1 + t_2 = \frac{V_x^1}{w_1} + \frac{V_x^2}{w_2}, \tag{3}$$

where V_x^1 and V_x^2 – gains of characteristic velocity at first and second stage, w_1 and w_2 – average acceleration from thrust, which, in accordance with assumptions, are determined as: