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Development of a propulsion system for a maneuvering module of a low-orbit nanosatellite

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Abstract

Nanosatellites (NS) are one of the fastest growing branches of spacecraft technologies. One of the attractive areas of application for such spacecraft is real-time low-orbit remote sensing of the Earth. This paper aims to develop a concept of a propulsion system (PS) and a maneuvering module (MM) for a CubeSat3U format low-orbit nanosatellite (NS), that would enable such spacecraft to maintain the required orbit altitude for a few weeks or months depending on insertion parameters. Requirements for the maneuvering module are stated. Helium, nitrogen and liquefied propane are considered as propellants. Modeling showed that helium provides the greatest specific impulse, but its density is too low to store a sufficient quantity. Under specified conditions, nitrogen may be able to provide required characteristics of the maneuvering module; specific impulse can be nearly doubled by heating the propellant to 700 °C with electric heaters.

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Keywords: nanosatellite; low orbit; maneuvering module; thruster; propellant; electric heating

1. Introduction

Today development of nano-class research and educational spacecraft is a common practice for leading airspace universities. A nanosatellite is usually defined as a satellite weighing from 1 to 10 kg, and developed primarily for purposes of research and education. With non-hermetic design and commercial components, creation of this class of satellite requires only a relatively small expense of time and finances.

Analysis of space launches for the last few years shows that the number of nanosatellite launches has been growing exponentially, with most of these being commercial and university spacecraft and satellite constellations. Projects under development include NS constellations for observation over other spacecraft, remote sensing of the Earth, communication and retranslation, monitoring of geophysical fields, and other missions that require precise station keeping and ability to maneuver for successful experimenting or otherwise achieving the mission goal.

The importance of development of a PS-equipped maneuvering module is further supported by some specifics of NS insertion. In most cases these spacecraft are inserted as way cargo, so the initial insertion orbits are determined by the requirements of the main payload, and do not always coincide with the desirable orbit for the nanosatellite.

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On the other hand, the NS should not turn into space debris after the end of their active life (normally no more than 1 or 2 years). For this reason nanosatellites ought to be inserted to low orbits, where they can be naturally de-orbited by air drag. All these factors make it desirable for the nanosatellites to be equipped with maneuvering modules that will enable their station-keeping across their one-two year operational life.

Development of MM for NS will improve their autonomy and extend their application range, which in turn will decrease the costs of many space exploration missions.

The goal of this paper is to develop a concept for a propulsion system for a maneuvering module of a low orbit aerodynamically stabilized CubeSat3U-class nanosatellite.

2. Selection of design scheme for a maneuvering module propulsion system

The design scheme for a maneuvering module for a low altitude aerodynamically stabilized CubeSat3U nanosatellite faces the following constraints: the thruster must be environmentally safe, accident-proof during testing and exploitation, and provide delta-velocity budget no smaller than 20 m/s, which is enough to keep required altitude or position in formation flying for up to half a year.

In view of these constraints, the most attractive design scheme for a maneuvering module will be a cold-gas thruster. The basic scheme of this propulsion system is represented in Fig. 1.

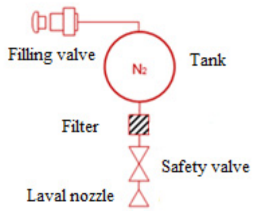

Fig. 1. Cold-gas thruster

The most important characteristic of the thruster is specific impulse of thrust, which characterizes exhaust velocity at nozzle exit w_e, m/s.

From the ideal gas law and the balance of energy in gas flow one can determine the exhaust velocity at de Lavale nozzle exit:

$$w_e = \sqrt{\frac{TR}{M} \cdot \frac{2k}{k-1} \cdot \left[1 - \left(\frac{p_e}{p}\right)^{(k-1)/k}\right]} \quad (1)$$

where w_e is the exhaust velocity at nozzle exit, m/s; T is absolute temperature of the gas at entry to the thruster; R= 8314,5 is the universal gas constant (J/kilomole/K); M is the molar mass of the gas (kg/kilomole); $k = c_p/c_v$ is adiabatic exponent; c_p is specific heat capacity at constant pressure, J/(kilomole K); c_v is specific heat capacity at constant volume, J/(kilomole K); p_e is absolute pressure of the gas at nozzle exit, Pa; p is absolute pressure of the gas at nozzle entry, Pa.

With p_e=0 it is possible to determine the theoretical maximum of exhaust velocity of the gas in vacuum, determined by the inner energy of the gas:

$$w_{max} = \sqrt{\frac{TR}{M} \cdot \frac{2k}{k-1}} \quad (2)$$

The biggest disadvantage of cold-gas thrusters is low specific impulse of thrust. This can be improved to some extent by heating the gas with electric heaters before it enters de Lavale nozzle (see Fig. 2).