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Electric propulsion plasma plume interaction with "Phobos-Soil" spacecraft structural components

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Abstract

Assessment was made by calculations for the possible consequences of the effect of plasma plume injected by the solar electric propulsion system (SEPS) on the structural components of "Phobos-Soil" spacecraft (SC). Propulsion system comprises three SPT-140 thrusters, two of which should secure the required total thrust impulse during 8000 hours of operation approximately. Variation of the solar panel (SP) properties as a result of their surface contamination with the products of erosion of thruster and SC structural components is the primary negative consequence of plasma plume effect on the SC. Calculation study for the processes of erosion, particle flow distribution, and contaminating coating formation on the SP surface was made for different SEPS arrangements. It is shown that power reduction for the landing module SP sections, which are subjected to the contaminating coating deposition to the most extent, will not exceed 5% of the nominal level.
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1. Introduction

Possibility to use solar electric propulsion system (SEPS) based on three thrusters of SPT-140 type, developed by "Fakel" Experimental Design Bureau, at the heliocentric trajectory leg is considered at the current stage of the project aimed at the delivery of Phobos soil samples to the Earth ("Phobos-Soil" project) [1]. SEPS use for this project allows to secure independence of SC mass delivered to the Mars observation orbit on the date of mission start. Minimum gain in mass efficiency as a result of SEPS use will be in 2009. For this start epoch the SEPS use may not be foreseen within the SC arrangement concept. A SC arrangement option with the SEPS use is studied for increasing reliability of project realization in the case of possible start slippage to a later period. The SC and SEPS designs, ballistic parameters of the mission and problems of SEPS application for a long-term interplanetary mission were discussed in [2]. Actuality for the consideration of problem of plasma plume interaction with the structural components of the "Phobos-Soil" spacecraft (SC) is substantiated by the fact that duration of consecutive operation of two SPT-140 thrusters should be *over* 8000 hours, during which SPT plume can interact with the SC structural components. In general case, such interaction may cause the following effects:

(1) The influence of high-energy xenon ions on the solar panel (SP) protective glasses may cause their erosion, that in its turn may lead to their transparency worsening and SP power reduction.

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(2) The influence of high-energy ions on other SC surfaces may cause their erosion; at that, erosion products may deposit on the SP surfaces causing reduction in their transparency also.
(3) Erosion of the discharge chamber internal surfaces takes place during the SPT operation and erosion products may deposit on the SP surfaces also.
(4) Charge–exchange ions appear at the interaction of high-energy ions with the neutral atoms of the non-ionized propellant (xenon) or SC self-environment components. These ions are "pushed out" of the plume by its own electric field and may reach SC surfaces. Depending on their energy, such particles may cause both SP surface erosion and decontamination. At that synergetic effects are not excluded, which lead to the formation of micro-relief on the SP protective coatings that can change optical properties of the surface substantially.

Information on the SPT plume influence upon the SP characteristics is currently rather limited. In particular, this is associated with the fact that total duration of SPT operation on board SCs is still relatively short and it seems practically impossible to distinguish SP power losses from the losses being a result of its natural aging. However, for example, it was revealed in 1978 during the SPT test on board the Russian SC of "*Meteor-Priroda*" type [3] that when the ion flow with density of 0.25 A/m^2 and energy of about 100 eV influenced SP, the electric power of exposed SP part reduced by 35% after 300 hours. It was revealed as a result of laboratory simulation [4,5] that this effect was associated with the formation of micro-relief with characteristic size of non-uniformities of 0.5–1 μm on the glass surface. At that, strong decay of luminous flux reaching photovoltaic converter took place.

Thus, at the long-term operation the SPT plume may cause considerable negative effect on the SC SP. The well-developed methods of mathematical modeling allow to assess consequences for the SPT plume interaction with SC at the design stage for optimizing SEPS integration on board SC from the view point of minimization of harmful effects of such interaction. Results of such mathematical modeling as applied to "Phobos-Soil" SC are presented herein after.

2. SC design model and plasma plume model

2.1. SC and SEPS arrangement

SEPS arrangement on board SC at the stage of heliocentric flight from the Earth orbit to the orbit of Mars is clear from the design model presented in Fig. 1. Three SPT-140 thrusters (1, 2, 3) are surrounded by a cylinder skirt (4), intercepting peripheral flows of poorly focused high-energy ions. The square area of two SPs (5, 6) is about 60 m^2. The SC structural components, which are exposed to the influence of different plasma plume particles, include supports (7, 8, 9) of the landing module and the skirt (4).

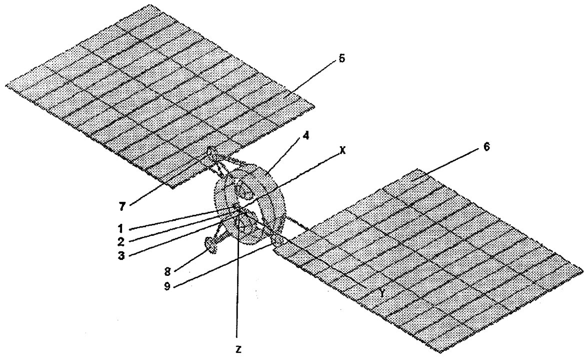

Fig. 1. Model of SC components used for the calculation of plume effect.

Computational study for the interaction processes was aimed at the optimization of arrangement and configuration of supports and skirt length. It is obvious that SP sections adjacent to the SC body are the most vulnerable. These sections are the parts of the landing module and will continue their operation after SEPS separates from SC at the Mars approach trajectory. It is important to assess potential in-flight worsening of characteristics for these sections exactly.

2.2. SPT-140 plume parameters

Plume model is based on the test data for the distribution of ion current density in angle ϑ and energy ε_i. SEPS power varies more than 2.5 times during flight, so the plume model should be valid within the following range of SPT-140 parameters: discharge voltage $U_d = 350$ V, discharge current $I_d = 6$–15 A, power $N = 2.5$–5.25 kW.

Current density as a function of angle ϑ between the selected direction and thruster axis has the following form:

$$j_i(\vartheta) = \frac{j_0}{r^2} e^{-b\vartheta} \quad \text{where } \vartheta \text{ is in degrees.} \tag{1}$$

This formula is characterized by sufficient accuracy at $\vartheta \geqslant 10°$. Coefficients j_0 and b for different power levels and distance $r = 1$ m are presented in Table 1.

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