Investigating the temperature field of large elastic elements of a small spacecraft for the Earth remote sensing to assess the effect of a temperature shock on its rotational motion

A. Sedelnikov
Institute of Aviation and Rocket and Space Technology
Samara National Research University
Samara, Russia
axe_backdraft@inbox.ru

D. Orlov
Institute of Aviation and Rocket and Space Technology
Samara National Research University
Samara, Russia
grand_99v@mail.ru

A. Nikolaeva
Institute of Aviation and Rocket and Space Technology
Samara National Research University
Samara, Russia
ezhevichka333@gmail.com

E. Khnyryova
Institute of Aviation and Rocket and Space Technology
Samara National Research University
Samara, Russia
khnyryova@gmail.com

V. Serdakova
Institute of Aviation and Rocket and Space Technology
Samara National Research University
Samara, Russia
valeriay.121@yandex.ru

***Abstract*—The paper considers the effect of the temperature shock of small spacecraft large elastic elements during its immersion in the Earth's shadow. The one-dimensional problem of thermal conductivity is solved. The results of numerical simulation are presented. The results of the work can be used to solve the problem of ensuring the required orientation of the Earth remote sensing spacecraft, as well as transporting space debris to burial orbits.**

***Keywords*— temperature shock, rotational motion, small spacecraft, large elastic elements.**

I. INTRODUCTION

For high-quality performance of the Earth remote sensing tasks, it is necessary to ensure the target orientation of the spacecraft [1, 2]. At the same time, significant restrictions are imposed on the rotational motion parameters values of the Earth remote sensing spacecraft [3, 4].

Similar tasks of stabilizing the angular position of one spacecraft relative to another arise when transporting space debris to burial orbits. At significant speeds of relative rotation of the tug and space debris, the connection between them may be disrupted and further transportation will be impossible.

Studies show that the temperature shock affects the rotational motion of a small spacecraft, at least from the point of view of the requirements for micro-accelerations during the implementation of gravity-sensitive processes on board. It is possible that such an influence is also significant when solving remote sensing tasks, as well as space debris transportation. This work is devoted exactly to such studies.

II. PROBLEM STATEMENT

Let us consider the case of a small spacecraft immersing into the Earth's shadow. At the same time, we assume that the initial temperature field is uneven only along the thickness of the plate (Fig. 1).

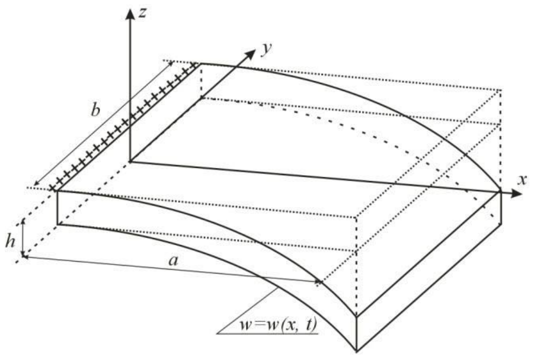

Fig. 1. The elastic element scheme

The lateral surface is considered too small, which makes it possible to neglect the heat exchange through it. It is assumed that for the entire time of heat exchange, the temperature of the elastic element points is a function of only one spatial coordinate and time. These simplifying assumptions make it possible to pose an initial boundary value problem with boundary conditions of the third kind:

$$\begin{cases} \dfrac{\partial T}{\partial t} = a^2 \dfrac{\partial^2 T}{\partial z^2},\ 0 \le z \le h,\ t > 0; \\ T(z,\ 0) = f(z),\ 0 \le z \le h,\ t = 0; \\ \lambda \dfrac{\partial T}{\partial z} = -\varepsilon\sigma\left(T^4 - T_c^4\right),\ z = 0,\ z = h,\ t > 0. \end{cases} \tag{1}$$

where a is the coefficient of temperature conductivity; ε is the degree of blackness of the elastic element material; σ is the Stefan-Boltzmann constant; λ is the coefficient of thermal conductivity; T_c is the ambient temperature; h is the thickness of the elastic element; $f(z)$ is some predetermined initial temperature distribution at the end of the solar section of the small spacecraft orbit.

We will get rid of the dimension of the problem with the following scale coefficients:

$$\begin{cases} T = T_0 T'; \\ z = hz'; \\ t = t_0 t'. \end{cases} \tag{2}$$

ωηερε $T_0 = \max\limits_{0 \le z \le h} f(z)$; $t_0 = \dfrac{h^2}{a^2}$.

Taking into account (2), the initial boundary value problem (1) will take the form:

$$\begin{cases} \dfrac{\partial T'}{\partial t'} = \dfrac{\partial^2 T'}{(\partial z')^2},\ 0 \le z' \le 1,\ t' > 0; \\ T'(z',\ 0) = f'(z'),\ 0 \le z' \le 1,\ t' = 0; \\ \dfrac{\partial T'}{\partial z'} = -\alpha'\left(T'^4 - T_c'^4\right),\ z' = 0,\ z' = 1,\ t' > 0. \end{cases} \tag{3}$$

where $\alpha' = \dfrac{\varepsilon \sigma h}{\lambda} T_0^3$; $f'(z') = \dfrac{f(z)}{T_0}$.

Thus, a dimensionless third initial boundary value problem is posed, which will be solved numerically in the following part of the paper.

III. NUMERICAL MODELING

The small spacecraft for the Earth remote sensing «Aist-2D» was selected for numerical simulation. This spacecraft have two elastic elements in the structural layout scheme.

Fig. 2 shows the dynamics of the temperature field obtained using the ANSYS package. It is the same for both small spacecraft, since all the conditions of the initial boundary value problem (3) for these spacecraft are the same.

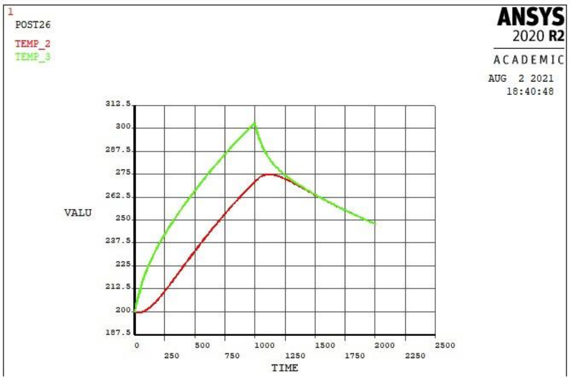

Fig. 2. Dynamics of the temperature field of the elastic element upper and lower layers (abscissa scale - t, ms; ordinate scale - T, K): 0...1000 ms - heating (solar area of the orbit); 1000...2000 ms - cooling (shadow area)

During the temperature shock, disturbing factors arise due to the influence of dynamic deformations of elastic elements. The rotational motion of the small spacecraft will be affected by the transverse inertia force and the moment from the inertia forces, which will be transmitted to the body of the small spacecraft through the elastic element attachment unit.

With the absolute symmetry of the spacecraft, temperature deformations of large elastic elements will not affect the rotational motion of a spacecraft having two symmetrically arranged large elastic elements (Fig. 1). However, in practice, the center of mass of the spacecraft is mostly often shifted relative to the geometric center. Therefore, the temperature deformations of large elastic elements do not completely compensate each other. Therefore, the maximum angular acceleration caused by the temperature shock will have the form:

$$\dot{\omega}_{\max} = \frac{2m\xi}{aI_y} \int_0^a w(x,\ t)\,dx \tag{4}$$

where m is the mass of the elastic element; a is the length of the elastic element; ξ is the displacement of the center of mass of the small spacecraft relative to its geometric center; w(x, t) is the function of the elastic element deflections during its temperature deformations (Fig. 1); I_y is the axial moment of inertia of the small spacecraft.

For a spacecraft with a single elastic element, this effect is significantly higher. In this case, the maximum angular acceleration can be estimated as follows:

$$\dot{\omega}_{\max} = \frac{m}{aI_y} \int_0^a w(x,\ t)(x+s)\,dx \tag{5}$$

where s is the distance along the longitudinal axis of the elastic element from its attachment point to the center of mass of the small spacecraft.

The obtained estimations (4) and (5) of angular acceleration are somewhat overestimated. They correspond to the case of a flat shape of an elastic element at the time of the temperature shock onset. It is shown that in the presence of an initial deflection of an elastic element, for example, due to its own oscillations, the effect of the temperature shock will be somewhat lower.

Thus, the results obtained allow us to assess the significance of the temperature shock impact on the effective performance of the Earth remote sensing tasks and space debris transportation.

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