Newer approaches to the creation of the thermostable space platforms for the Earth remote sounding

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Abstract. A method for the integrated analysis and the determination of the composite construction parameters of a platform of the Earth remote sounding spacecraft, is proposed. The conditions of thermal load for a flight along a sun-synchronous orbit were analysed. The mathematical simulation of the operating conditions ensuring the effective operation of such satellites was performed. The method was tested with account of the input parameters of the «BelKA» satellite orbit. This method will be useful when selecting a working orbit for such satellites at the stage of technical proposals, since it includes determination of their orbital characteristics, as well as the heat flows onto the elements of their construction. The results of simulation of thermal regime of the composite structure options are presented.

Key words: the Earth remote sounding spacecrafts, sun-synchronous orbit, polymer composite materials, nonwoven material.

1. Introduction

For rocket and space equipment, three-layer structures with the covers made of a composite material (CM) and a honeycomb core are commonly used, which have increased bending stiffness with relatively low weight. Such constructions are often used for the Earth remote sensing (ERS) spacecraft (SC). The desired physicomechanical and thermophysical characteristics of the constructions can be achieved by combining the materials of the bearing courses and fillers. For the improvement of economic feasibility and reliability and for the reduction of three-layer constructions mass with strength and rigidity maintenance, the development of new types of covers and fillers, based on new materials, is required.

Applied to the SC platforms with stable dimensions, the important indicators are strength, aging and damping capacity. The CMs of high modulus carbon fibers meet these requirements. Along with the common CMs, the hybrid CMs of nonwovens are increasingly used. The nonwovens actually also belong to the composites, since they consist of two elements, one of which functions as a filler, the other - as a binder element [1]. Recently, new types of nonwovens have been created, the structure of which is similar to the honeycomb cores. However, in the literature there is no information on the characteristics of multi-layered panels in which nonwovens are used instead of the honeycomb core [2].

Creating of a ERS SC is a complex interdisciplinary problem. An integral part of their designing is the determination of the most effective orbit parameters from the point of view of information content, power supply and the duration of active spacecraft existence [3–6]. For the ERS SC with the platforms with stable dimensions and reflectors of space antennas [7–14], the development of simulation methods and construction optimization in view of the requirements of operation and technological limitations are essential.

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The purpose of this work is to improve the mass-dimensional characteristics of three-layer panels of the ERS SC platforms with the use of hybrid CMs of carbon fiber and organic nonwovens, as well as the reduction of the time spent on the designing in the framework of an integrated methodology for the ERS SC exploitation conditions..

2. The ERS SC dynamics simulation
A part of the design studies is the simulation of the orbital motion of a SCs, corresponding to their intended purpose. A set of requirements is imposed to the aims of ballistic design of the ERS SC: the Earth global view provision; the periodicity of the Earth selected areas review with a given frequency; SCs flight performing in a circular orbit, with constant height, as the SC equipment is usually adjusted to predetermined height before launching; the Earth’s territories survey on illuminated ascending or descending branches of the orbit; minimal changes in the conditions of the SC track illumination during the entire life of the SC; correction of the orbit height decreasing due to atmospheric deceleration.
As is known, due to the non-centrality of the Earth gravitational field, the orbital plane of the SC precesses noticeably around the earth's axis with a low speed of the orbit node displacement. This makes it possible to choose the height and inclination of the orbit, which ensures the equality of the precession velocity and the average angular velocity of the Earth’s annual motion around the Sun. Such orbits are called sun-synchronous orbits (SSO), or the Sun "tracking" ones, i.e. changing their position synchronously with the direction of the Sun-Earth. Since, unlike the diurnal, the annual motion of the Sun along the celestial sphere occurs from west to east, the SSO should also precess in this direction, therefore, the SSO inclination should exceed 90°. One of the important features of the SSO is the almost unchanged solar lapse of time of an SC passing over the same points of the route from turn to turn.
The main disturbing factor during the flight is the decelerating impact of the atmosphere, which reduces altitude and leads to a flight track shift of an SC. The correction maintains stability of the altitude profile, the properties of solar synchronicity and the characteristics of the tracks grid. The local time of the ascending node should be chosen so as to provide the required illumination conditions of the sub-satellite point for the surveys.
In this paper, we have constructed a mathematical model of the conditions for the operation of an ERS SC for the analysis of illumination and full coverage of the Earth’s surface by flight tracks. The paper takes into account the effect of the atmosphere onto the orbital motion and the corrections for maintainance of the altitude of the orbit. The methodology has been tested for an ERS SC, similar to «BelKA». [15].
With the help of mathematical models implemented as algorithms in the Matlab software package, the ERS SC working orbit parameters were determined: orbit height \( h = 514 \) km, orbit inclination \( i = 97,4^\circ \), local ascending node transit time \( m\Omega = 6 \) h. The orbit type is near-circular– (with eccentricity \( e = 0,00135 \), sun-synchronous, multiple (the multiplicity period is 14 days).

3. Simulation of the temperature field and the stress-strain state of the ERS SC platform.
The SC design is a complex procedure, the implementation of which is associated with the various physical processes. The ones of the most significant are heat exchange processes. They are determined by heating from the direct solar heat flow and the heat radiation flow from the Earth, and also by the onboard heat radiation.
In order to assess changes in the temperature field and its effect on the stress-strain state of the ERS SC platform, the special conditions were established that correspond to the motion in the orbit calculated above.
The study platform of an ERS SC had a box-like parallelepiped shape, the walls of which were three-layer panels formed by two carbon-fiber platings 2 mm thick and aluminum honeycomb core 12 mm thick. Simulation of the temperature state was carried out for a representative element of the construction with dimensions of 500x500x16 mm. Data on thermophysical characteristics necessary for simulation was borrowed from [16], and data on optical characteristics from [17]. The simulation was carried out
in the NX / Nastran software package. For all elements of the construction, the three-dimensional type of grid was set, with the element size of 10 mm.

The calculations were performed with a use of the "NX/Space Systems Thermal" module that implements the Monte Carlo method. For this method the orbit parameters, the SC orientation in space, the position of the Sun relative to the orbit during the simulation period, were set. The calculation was performed for one orbit pass of 45 s step. To study the impact of the redistribution of radiation from the elements of the construction, the object of modeling Radiation was used: setting of the radiant heat exchange between the model surfaces, as well as the influence of the surrounding space. Initial dynamic data of the SC was set in the object of modeling "Orbital heating". It helped to determine the conditions of thermal load, caused by the heat radiation flows of the Sun and the Earth. The simulation showed that temperature varies from minus 70° to plus 50° during the year (Fig. 1).

![Fig 1. Temperature field on the cover surface](image)

Operating stress in the longitudinal and transverse directions of a three-layer panel under extension/compression and bending ranges from minus 70 to plus 80 MPa. The displacements in the cover of a three-layer panel range within 0.1 mm in the longitudinal, and within 0.001 mm in the transverse direction (Fig. 2).
4. Experimental study of SC samples

Different types of reinforcing fillers are used in the three-layer constructions: metal, paper honeycombs, honeycombs from CM. The ways to perfection of such constructions are unlimited. Promising ones are the new types of fillers in the form of hybrid CM based on nonwovens.

In this work, the characteristics of the hybrid CMs with basis of polyester nonwovens with an ordered honeycomb structure were studied. Between themselves, the cells are separated by the channels that contain microspheres (Fig. 3).
Glass fiber of the brand “Ortex 560” and epoxy binder based on resin “ED-20” were used as the fibrous filler, as a hardener - isomethyltetrahydrophthalic anhydride and as an active solvent - diethylene glycol of the brand “DEG-1”. The mechanical characteristics of the materials used are given in Table 1.

| № | Material                  | Characteristics                      |
|---|--------------------------|--------------------------------------|
| 1 | Polyester nonwoven       | Specific weight, g/m²: 130            |
|   |                          | Strength, MPa at:                    |
|   |                          | - bending: 16;                        |
|   |                          | - compression: 4.                     |
|   |                          | Flexural modulus, MPa: 1000           |
| 2 | Fiberglass cloth         | Linear density (tex):                |
|   |                          | - basis: 1200;                       |
|   |                          | - weft: 1200.                        |
|   |                          | Breaking load, N                     |
|   |                          | - basis …: 6500;                     |
|   |                          | - weft: 5700.                        |
| 3 | Epoxy binder             | Strength, MPa at:                    |
|   |                          | - extension: 82                      |
|   |                          | - bending: 105                       |
|   |                          | Glass transition temperature, °C:    |
|   |                          |                                       |

Three types of samples were prepared and studied: without nonwoven, and with one and two layers of nonwoven material. Sample #1 was made of six layers of fiberglass, #2 - of seven layers (three layers...
of fiberglass + one nonwoven layer + three layers of fiberglass), and #3 - of eight layers (two layers of fiberglass + one nonwoven layer + two layers of fiberglass + 1 layer of nonwoven fabric + two layers of fiberglass). For all samples and all layers, the angle of calculation was 0°.

The mechanical characteristics of the produced CMs were studied with a use of a Netzsch 242E Artemis dynamo-mechanical analyzer (Table 2).

| Test temperature, °C | Sample № 1 | Sample № 2 | Sample № 3 |
|----------------------|-------------|-------------|-------------|
| 30                   | 11024       | 10664       | 13305       |
| 50                   | 9060        | 10575       | 13286       |
| 100                  | 1439        | 10183       | 12745       |
| 150                  | 1292        | 8367        | 9285        |
| 200                  | 1396        | 4867        | 4551        |

Analysis of the results showed that modulus of elasticity of a CM, consisting of two layers of nonwoven (sample #3) increases by almost 25% at a temperature of 30°C compared with the sample consisting of one layer of nonwoven (sample #2). Samples #2 and #3, compared with the original sample of fiberglass (sample #1) have at an average 3 times greater values of modulus of elasticity at temperatures up to 200°C [2]. Modulus of elasticity of a CM, containing a non-woven material, compared with the same but without it, starts to increase at a temperature of 50°C and further, as the temperature increases, these differences increase. Thus, the use of non-woven material in the structure of a CM allows to increase the values of modulus of elasticity.

5. Conclusion
A system of mathematical models was proposed. It was implemented as algorithms in the MatLab software package. The parameters of the working orbit of an ERS SC, similar to the BelKA SC meeting the requirements for the ERS SC orbits, were estimated.

With the help of numerical simulation, it was shown that the operating stresses in the longitudinal and transverse directions of a three-layer platform panel of an ERS SC flying through a solar-synchronous orbit, at extension/compression and bending, range from -70 to +80 MPa, which corresponds to the limit of allowable values of strength limit for carbon fiber. However, the main stress is taken by the cover, the material and structure of which were studied in this work. Displacements in the cover of a three-layer panel are expected to be within 0.1 mm in the longitudinal direction, and within 0.001 mm in the transverse direction.

The developed methodological techniques can be useful at the stage of technical proposals for the materials selection for the ERS SC constructions with stable form and dimensions.

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