Design of the solar panel frame of the spacecraft by 3D printing with composite materials

M A Mirzaev¹, I G Smirnov², A I Dyshekov³, V E Slavkina¹, M A Shereuzhev⁴ and S A Aliev⁵

¹Laboratory of innovative structural polymer, composite and biocomposite parts of agricultural machinery, Federal Scientific Agroengineering Center VIM, Moscow, 109428, Russia
²Department of intellectualization, automatization and robotic of rural production, Federal Scientific Agroengineering Center VIM, Moscow, 109428, Russia
³Laboratory of intelligent digital systems of monitoring, diagnostics and process control in agricultural production, Federal Scientific Agroengineering Center VIM, Moscow, 109428, Russia
⁴Special mechanical engineering, Bauman Moscow State Technical University, Moscow, 105005, Russia
⁵Department of road transport, Dzhambulatov Dagestan State Agrarian University, Moscow, 367032, Russia

mirza.pochta@gmail.com

Abstract. The optimal design of the skeleton panel of the solar panels of the spacecraft was designed taking into account the increased physical and mechanical characteristics through the use of composite materials and the method of topological shape optimization.

1. Introduction
The technology of 3D printing is actively used in the aerospace industry to produce prototypes, parts and equipment. Its use makes it possible to reduce the cost of producing single- or small-scale products, improve their operational characteristics and significantly reduce the manufacturing time of individual products. This production method also allows using composite materials [1;2]. The key criteria which should be prioritized in the production of solar batteries (SB) panel frame are weight, structural rigidity, natural frequencies, shear strength, tensile strength, compression and thermal conditions [3,4]. The weight limit is of particular importance in launching of a spacecraft (SC) into orbit. This is due not only to the additional increase in fuel mass, but also to the requirements for the opening of solar panels.

2. Experimental details
The properties of the material used in the calculations play an important role in obtaining the maximum characteristics of the SB panel frame. It is also important to take into account the
production technology of the frame. The paper [5] investigates the additive technology with the use of continuous carbon fiber impregnated with heat-curing binder.

3. Experimental results

Materials with increased mechanical characteristics are used for rocket and space technology products, so the basis of this calculation was a high-module fiber M46j 6k, whose properties are compared with the previous calculation of T300 fiber [6]. Composite materials (CM) on the basis of this fiber do not have sufficient experimental data on the values of physical and mechanical characteristics, in particular for 3D printing. In this connection, the properties of this composite material will be calculated in the future. As a matrix polyesterimide (PEI) Ultem 1010 will be used because this material has increased thermal resistance, tensile strength and high Young's modulus. Calculation was made in two stages. In the first stage, the properties of the fiber impregnated with epoxy resin were calculated, and in the second stage, on the basis of the obtained properties of the fiber, the analysis of the final characteristics of the resulting material was carried out. While determining the properties of impregnated fiber, the mass fraction of the reinforcing element based on experimental data from literature sources is approximately 60%.

The following output data was obtained in the course of the analysis: Young's modulus along the fibre is equal to 2.579E+11 Pa; Poisson's coefficient is 0.318; Shear module is 8.882E+9 Pa (Figure 1).

When determining the properties of a composite, the mass fraction of the fiber is set at 30%. Calculation output data: Young's modulus along the fiber is 8.865E+10 Pa; Poisson's coefficient is 0.32; Shear modulus is 2.216E+9 Pa; density is 1.450 g/cm3 (Figure 2).

On the basis of the calculated material, a geometric model was created taking into account the topological optimization of the form.
Figure 3. Generative analysis results used in the design of the geometric model (a); preliminary geometry of the SB panel frame created in the Femap with NX Nastran environment (b)

The geometry is based on a design of longitudinal and transverse stiffening ribs to ensure the fastening of SB panels. In addition to it, stiffening ribs designed on the basis of generative analysis will be added (Figure 3). For static analysis it is necessary to specify the load. For models under design, this is an all-body acceleration of 5 g in different directions (OX, OY, OZ). For the model, the value of the distributed non-constructional mass is also selected in such a way that the total mass of all the elements is equal to 8 kg with an error of no more than 0.1 kg. In the course of the calculation for the definition of the non-constructional mass, the value of the first natural frequency, equal to $v_1 = 20.12$ Hz, was obtained, which meets the requirements of the specification. The mass of the resulting model is $m = 3.98$ kg.

Table 1. Results of frequency calculation

| Number of natural frequency calculation | Structural weight, kg | Cross section, mm×mm | First proper frequency, Hz. |
|----------------------------------------|-----------------------|-----------------------|-----------------------------|
| 1                                      | 5.66                  | 4.5×0.15              | 30.58                       |
| 2                                      | 5.03                  | 4.0×0.15              | 26.83                       |
| 3                                      | 3.98                  | 3.17×0.15             | 20.12                       |

Axis loads are taken into account in the analysis of stress-strain state and stability reserve. Voltages at acceleration of 5g along the OX axis are shown in Figure 4. The OX-axis stability margin is 9.17.

Figure 4. Voltages under OX-axis load (a); Form of stability loss (b)

Voltages at acceleration of 5g along the OY axis are shown in Figure 5 (a). The stability margin is equal to OY 12.8 (Fig. 5).
Voltages at acceleration of 5g along the OZ axis are shown in Fig. 6 (a). The stability margin is equal to OZ 2.0 (Figure 5).

**4. Discussions**

To evaluate the result the data of the framework panels SB will be given: the first, designed taking into account the generative analysis and the second, designed on the basis of optimized analysis of various design solutions. The calculation conditions are identical - both models are calculated in the same software, with the same loads and the same type of finite elements. Table 2 shows the main characteristics of the models taking into account the application of generative analysis.

| Model parameters                          | Initial Model | Developed model |
|-------------------------------------------|---------------|-----------------|
| Structural weight, kg                    | 5.90          | 3.98            |
| Non-constructional weight, kg             | 7.98          | 7.99            |
| Stability margin for OX-axis loads        | 11.3          | 9.2             |
| Stability margin for OY-axis loads        | 2.2           | 12.8            |
| Stability margin for OZ-axis loads        | 1.0           | 2.0             |
| Profile, mm*mm                            | 1.6*45        | 1.5*317         |
| First frequency, Hz                       | 21.73         | 20.12           |
5. Conclusions
The design of the SB panel frame with the use of topological optimization methods and carbon fiber material M46j 6k has resulted in a significant improvement in the characteristics of the frame:

- 33% weight reduction;
- 2-fold increase in the OZ-axis stability margin;
- increase in the stability margin by 6 times in the OY-axis;
Other parameters remained at the same level.

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