UDC 629.78

Siberian Journal of Science and Technology. 2017, Vol. 18, No. 4, P. 858–867

DEPLOYMENT CONCEPT MECHANICAL SYSTEM OF A RADAR ANTENNA FOR SPACE PURPOSES

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One of the basic requirements to deployable mechanical systems is observance of requirements on execution of the first eigenfrequency of structure. In case of transformed structure like solar array, when the structure consists of any panels series connected with joints, this requirement is supplied with high rigidity of a structure. At low rigidity (lower then require) inevitably engenders unnecessary effects on orientation and stabilization system of spacecraft on orbit.

Other major aspect of designing of space engineering is decrease in final weight of a product. The most typical line of designing of various systems of space vehicles is compromise search between decrease in weight of a product, and, as consequence, decrease rigidity and strength properties of a structure.

In the article the proposed option of a design of a deployable mechanical system. The basic load-bearing element is set of laminate composite panels, connected with joints. The main feature is additional elements (pipe or plate) combined with basic panels. The form of a sectional structure is equilateral triangle. Selection of the given type of a structure is proved by two kinds of analyses: the kinematic analysis of a deployment from a shipping rule in working, and the modal analysis for reliability acknowledgement on first eigenfrequency. The parametric analysis of geometry of a design is carried out, optimum versions are shown.

For deeper optimization of design parameters it is necessary to carry out the following engineering analyses which have been not presented within the limits of the given article: the analysis of reliability of a deployment of mechanical devices; the structural analysis; the analysis of temperature deformations and so forth.

The given design can be applied as the power basis to solar array, antennas, and cluster orbital systems.

Keywords: modal analysis, kinematical analysis, mechanical system.

Сибирский журнал науки и технологий. 2017. Т. 18, № 4. С. 858–867

РАЗРАБОТКА КОНЦЕПЦИИ РАСКРЫТИЯ МЕХАНИЧЕСКОЙ СИСТЕМЫ РАДАРНОЙ АНТЕННЫ КОСМИЧЕСКОГО НАЗНАЧЕНИЯ

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Одним из основных требований к крупногабаритным раскрываемым конструкциям является соблюдение требований по обеспечению первой частоты собственных колебаний конструкции. В случае трансформируемых конструкций типа солнечных батарей или радарных антенн, когда конструкция представляет собой несколько последовательно соединенных шарнирными узлами панелей, это требование обеспечивается высокой жесткостью конструкции. При низкой первой собственной частоте колебаний (ниже требуемой) возникают нежелательные эффекты в работе системы ориентации и стабилизации космического аппарата на орбите.

Другим важнейшим аспектом проектирования космической техники является снижение конечной массы изделия. Наиболее характерной чертой проектирования различных систем космических аппаратов является поиск компромисса между снижением массы изделия и, как следствие, снижением жесткостных и прочностных характеристик конструкции.

Предложен вариант конструкции трансформируемого механического устройства. Основным элементом данной конструкции является набор трехслойных композиционных панелей, соединенных шарнирами. Ключевой особенностью являются введенные дополнительные элементы (трубы или пластины), которые в сочетании с несущими панелями в рабочем положении образуют в сечении конструкции равносторонний треугольник. Выбор данного типа конструкции обоснован двумя видами анализов: кинематическим анализом раскрытия из транспортировочного положения в рабочее положение и модальным анализом для подтверждения требования по первой собственной частоте колебаний в рабочем положении. Проведен параметрический анализ геометрии конструкции, показаны оптимальные варианты. По результатам анализов были выбраны такие проектные характеристики конструкции, которые удовлетворяют всем критериям проведенных анализов.

Для более глубокой оптимизации проектных параметров необходимо провести следующие инженерные анализы, не представленные в рамках данной статьи: анализ надёжности раскрытия механических устройств; механический анализ; анализ температурных деформаций и пр.

Данная конструкция может быть применена в качестве силовой основы для фотопреобразователей солнечных батарей, антенных решеток радарных антенн, зеркал кластерных орбитальных систем. Возможно развертывание солнечного паруса большой площади с использованием данной схемы раскрытия конструкции.

Ключевые слова: модальный анализ, кинематический анализ, механическое устройство.

Introduction. One of the basic requirements to a large deployable mechanical system is compliance with the requirements for the first eigenfrequency of structure. In the case of transformed solar batteries or radar antennas, where the design is a series of consecutively connected panels, this requirement is ensured by a high stiffness of the structure. With a low first eingenfrequency (below required), undesirable effects occur in the orbit orientation and stabilization system of a spacecraft [1; 2].

Another critical aspect of space technology design is the reduction of final weight of the product. The most typical feature of various spacecraft systems design is the search for a compromise between the reduction of product weight and, as a result, the reduction of rigidity and strength characteristics of the structure [3].

Description of the structure. The object of the study is the construction of a mechanical space-based system. Fig. 1 shows the system in the start configuration. Fig. 2 shows a piece of the system in the deployment configuration position. The overall size of the system under which the structure is designed is presented in fig. 3.

The design concept is based on the use of honeycomb sandwich panel set [4], connected by hinges. A key feature is the use of additional elements – thin plates (thickness up to 0.1 mm) or tubes [5; 6]. The option of shared use of both types of elements is also considered. Additional elements are pinned to sandwich panels in such a way as to form the equilateral triangle in the section in the deployment configuration (fig. 4).

Description of deployment logic. Only one deployment scheme has been proposed under this article. This example shows how to address the challenges of dynamics and kinematics.

In hinges, connecting neigbouring panels, there are torsion springs that create the torque. Also in hinges there are the delay nodes that do not allow the hinges to deploy until the hinges of the previous panel deploys by 175°. Side features also deploy using delay nodes. The sidebar opens when the main panel on which it is placed comes into deployed configuration. The stages of deployment are shown in fig. 5. Start configuration complies with fig. 5, *a*. Under torsion springs, the panel set begins to rotate around the axis shown in fig. 5, *b*, all the panels of the package are retained by the delay nodes. After the set has been positioned according to fig. 5, *c*, the root hinge is fixed, the delay node of the second panel opens, and the set begins to rotate around the hinge of the second panel. After passing the deployment angle of 95 degrees, the sidebar delay node is opened, according to fig. 5, *d*. The sidebar deployed by 60° is fixed in the deployed configuration on the spacecraft. When the set arrives at the position shown in fig. 5, *e*, the sidebar delay nodes and the next hinge are deployed, and the set repeats the deployment steps. Whereas each subsequent sidebar is fixed with the previous side panel on arriving at deployed configuration. Fig. 6 shows a set of eight deployed panels.

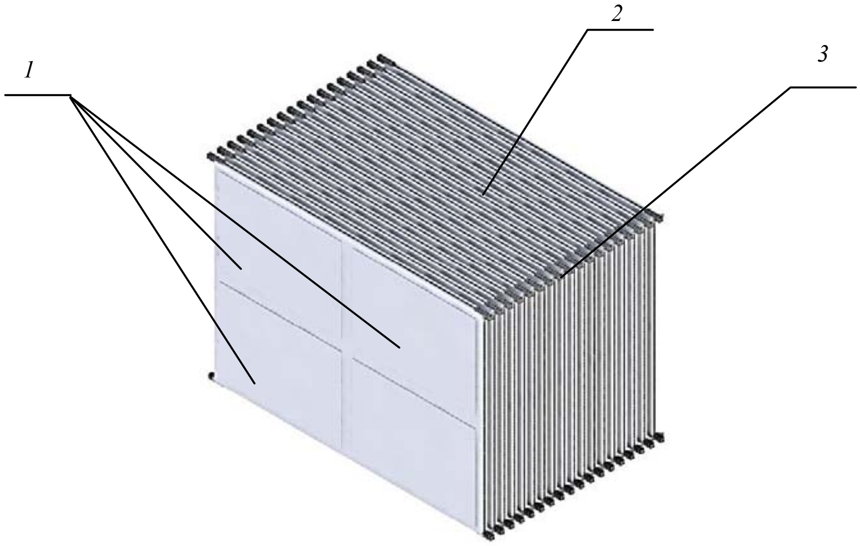


Fig. 1. Object of research – mechanical system in start configuration:
1 – payload on sandwich panel; *2* – honeycomb sandwich panel set; *3* – hinges

Рис. 1. Объект исследования – механическое устройство в транспортировочном положении:
1 – полезная нагрузка, расположенная на сотовой панели; *2* – набор трехслойных сотовых панелей; *3* – шарнирные узлы

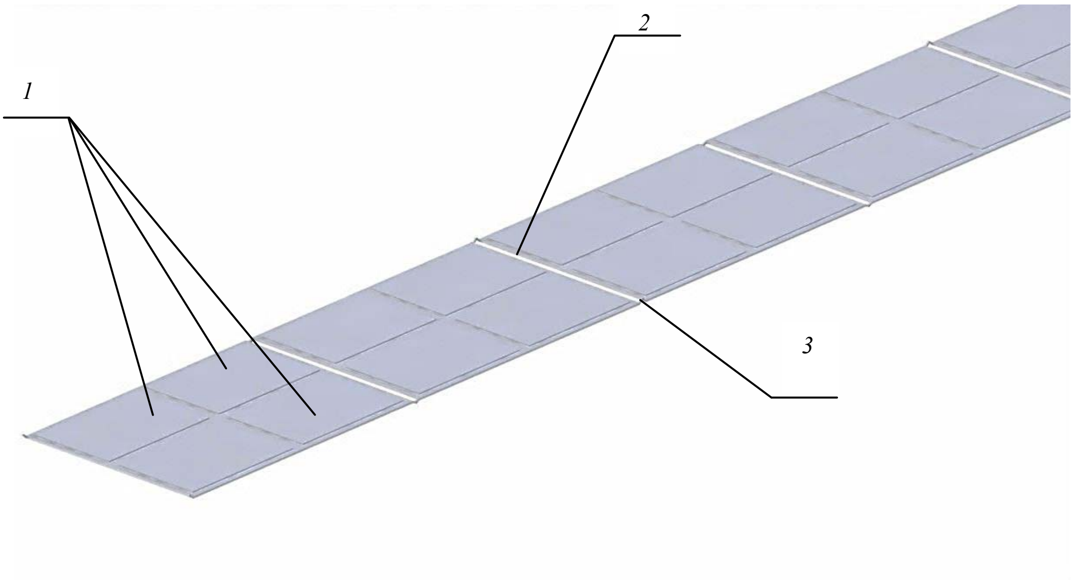


Fig. 2. Object of research – mechanical system in deployed configuration (fragment):
1 – payload on sandwich panel; *2* – honeycomb sandwich panel set; *3* – hinges

Рис. 2. Объект исследования – механическое устройство в рабочем положении (фрагмент):
1 – полезная нагрузка, расположенная на сотовой панели; *2* – набор трехслойных сотовых панелей; *3* – шарнирные узлы

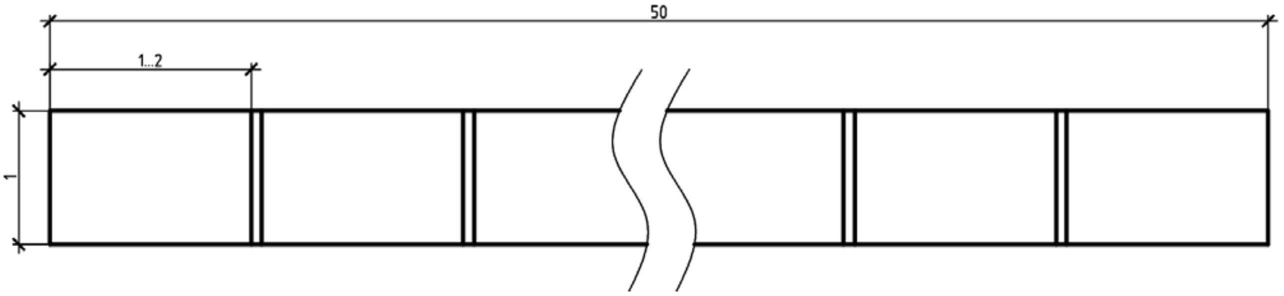


Fig. 3. Geometric dimensions of the structure, m

Рис. 3. Геометрические размеры конструкции, м

In order to reduce the number of mechanisms in the system, it is suggested that the fixation of adjacent side panels should be repositioned by locating neodymium magnets in the fields of fixation.

This type of magnet obtains magnetic energy from 200 to 420 kj/m^3. This means that the axial force that must be exerted to break the two chained magnetic cubes with the face of 10mm varies in the range of 38–60 N. Magnetic locks of small linear dimensions may thus hold the side panels with tightening force of several, up to a few dozen kilograms of power.

The factors of outer space do not affect the characteristics of neodymium magnets, and the loss of magnetic properties equals 1–2 per cent in 10 years.

For the design of a magnetic lock based on neodymium magnets, the data obtained from the calculation of the system's deployment performance must be used.

Deployment performance analysis. The calculation of deployment performance is done to determine the loads that are active in the structure elements during the deployment process. Based on the calculation model of the mechanical design system, it is necessary to identify the characteristic patterns of the movement of deploying elements with the simulation of active forces, hinges, and other elements of the kinematic scheme [7; 8].

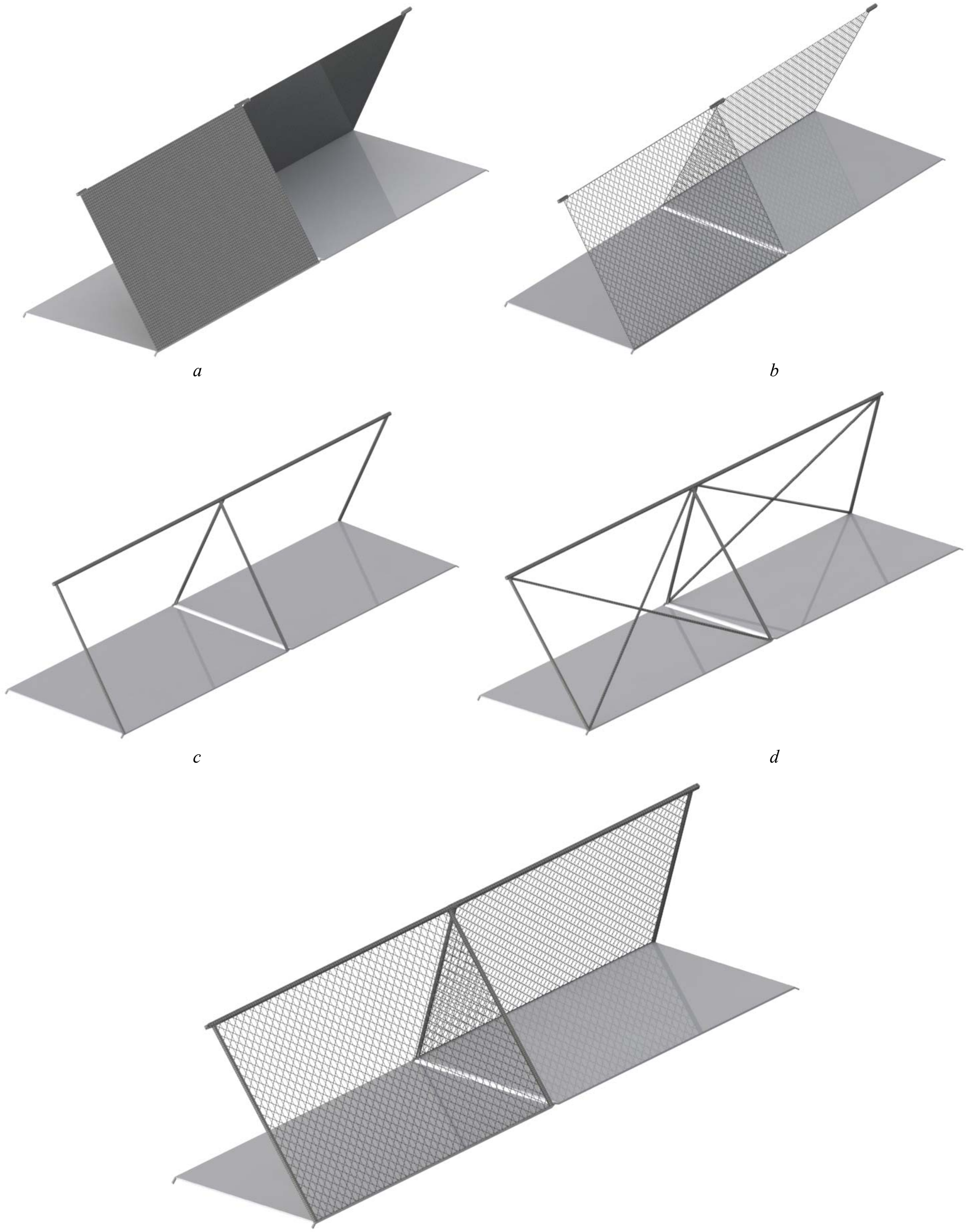
The source data for calculations of the structure panels deployment is the mass characteristics of its elements, as well as information on the characteristics of active forces in the hinge model [9].

Since the moment of inertia of the revolving set decreases during the deployment process, it is useful to use less energy-related springs in each further hinge [10]. Springs' driving moment diagram in the first and last hinge are presented in fig. 7.

Fig. 8 shows dynamic model of panel constructions in fold position, using all necessary geometrical, kinematical and force objects.

Panel width equals one meter, length – 1.5 m. Set of 34 panels gives the total of ~50 m.

Model summary is given in tab. 1. Fig. 9 shows the force on the interface between the first additional panel and KA. Since the maximum bending moment appears in the first hinge under the system deployment, the system also gains the maximum force.



a *b*

c *d*

e

Fig. 4. Design variants of additional elements:
a – using membranes; *b* – using lattice membranes;
c, *d* – using tubes; *e* – combined version

Рис. 4. Варианты исполнения дополнительных элементов:
а – с использованием тонкостенных пластин; *б* – с использованием сетчатых тонкостенных пластин; *в*, *г* – с использованием труб; *д* – комбинированное исполнение

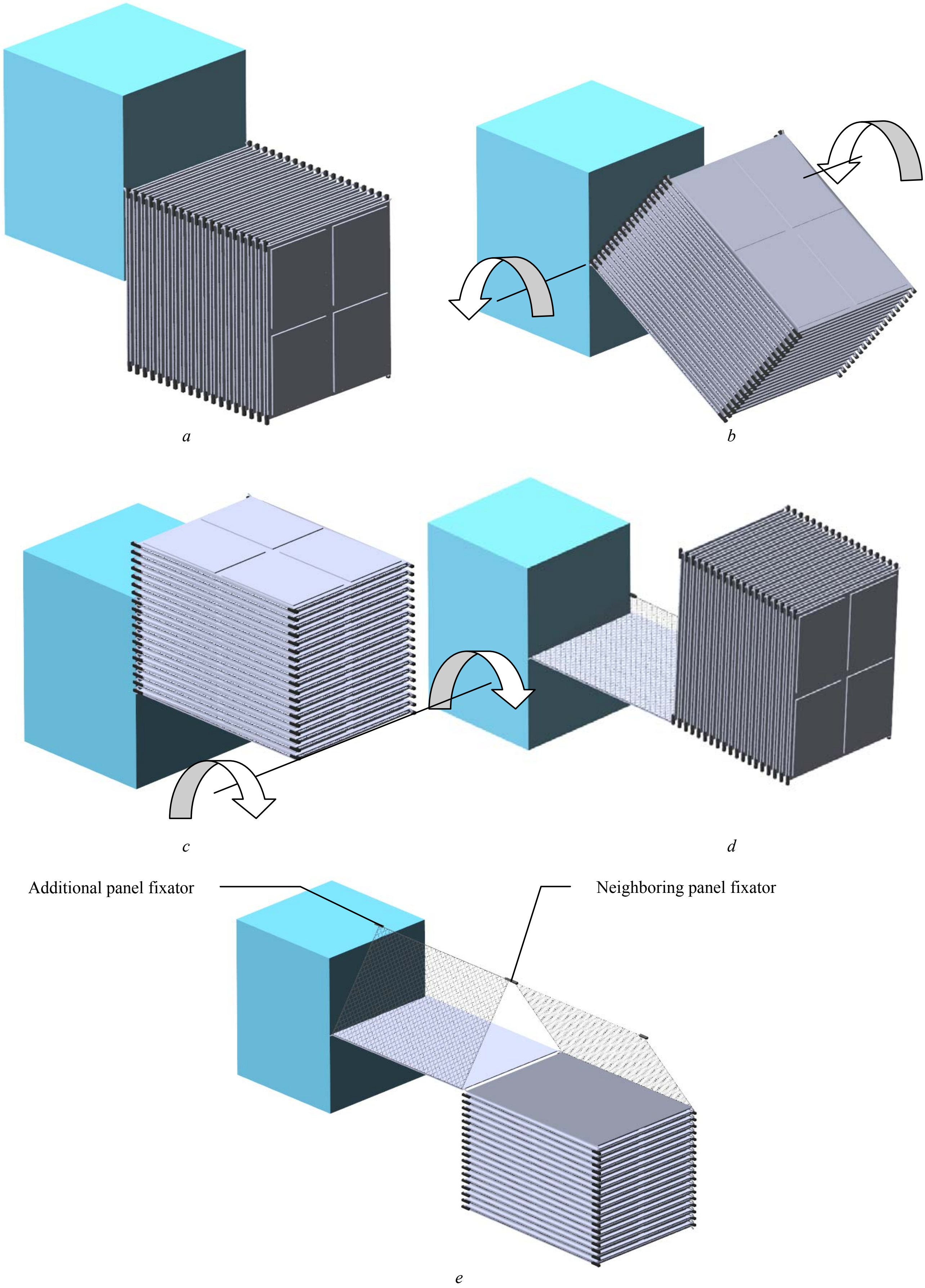


Fig. 5. Deployment stages

Рис. 5. Этапы раскрытия конструкции

In order to ensure a tightening force of 300 N, the linear dimensions of the neodymium magnet should be as follows: width a = 30 mm, height b = 30 mm, length l = 10 mm. The weight of one magnet with the above dimensions will be 65 grams.

By applying the fast Fourier transform (FFT) to this graph, we receive maximum perturbation frequency [11]. The graph of the function obtained through the Fourier filter is presented in fig. 10.

The graph shows that the most perturbations in the system occur at the frequency of 0.125 Hz, which corresponds to the first frequency of the structure vibration.

Modal analysis. A modal analysis is performed to confirm the requirement for the structure's first eigenfrequency vibrations [12]. The lower bound of the first eigenfrequency in 0.1 Hz is set as the criterion. Fig. 11 shows the finite element model (FEM) of the system in different configurations. Honeycomb panels are simulated using LAMINATE elements, additional plates by PLATE elements, pipes by BEAM elements (Circularbar). Honeycomb panels consist of two carboned patches with a thickness of 0.00035 m and an aluminum honeycomb filler of 0.0193 m. Panel total thickness is 2 cm. The upper tube has a diameter of 0.05 m and a wall thickness of 0.0012 m. The tubes connecting the honeycomb panel and the upper tube have a diameter of 0.03 m. The solver uses the NASTRAN calculation set [13–15].

Tab. 2 gives the summary of the modal analysis results.

Conclusion. This article provides a design option for a mechanical system to host a payload. Approaches to solving various design tasks are shown. Based on the calculation of deployment performance, the materials and configuration of hinges elements are selected. Modal analysis has shown that the design satisfies the requirement for the first eigenfrequency of vibrations.

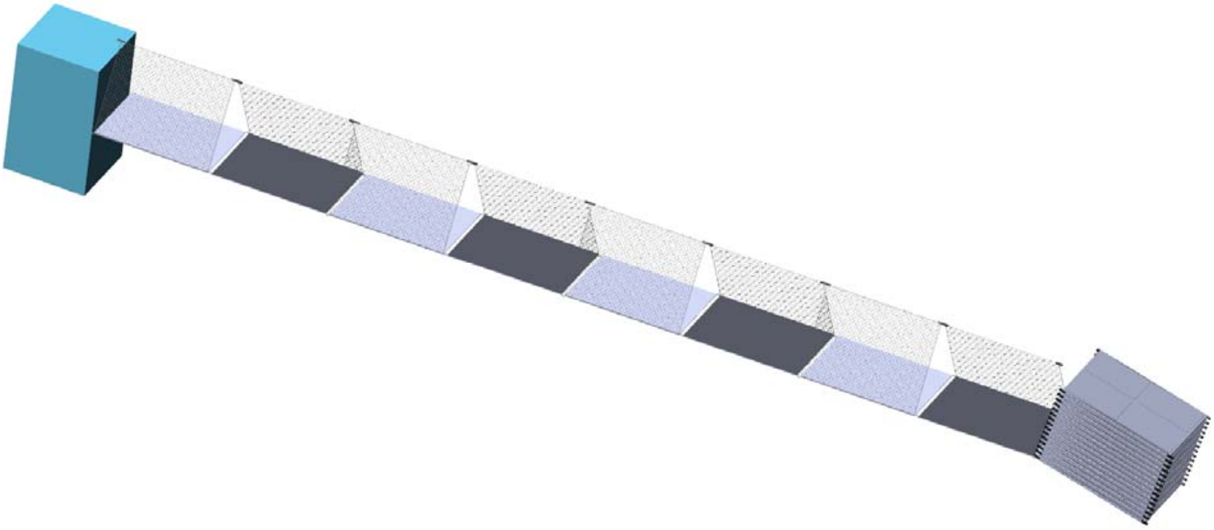
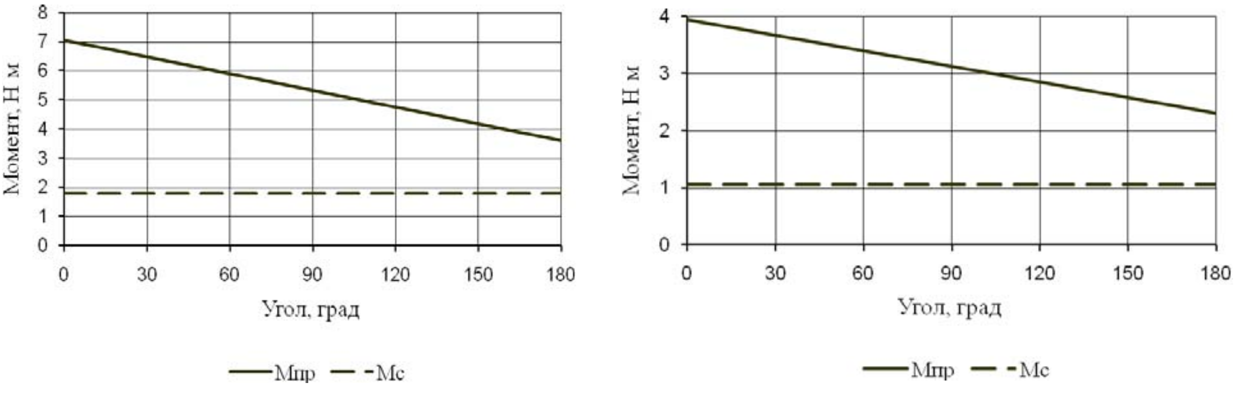


Fig. 6. Partially deployed construction

Рис. 6. Частично раскрытая конструкция



a *b*

Fig. 7. Driving moment diagram of different hinges: *a* – driving moment in first hinge;
b – driving moment in last hinge, driving moment in additional panel hinge

Рис. 7. Диаграмма действия пружины в различных ШУ: *а* – момент в ШУ первой панели;
б – момент в ШУ последней панели, момент в ШУ боковых панелей

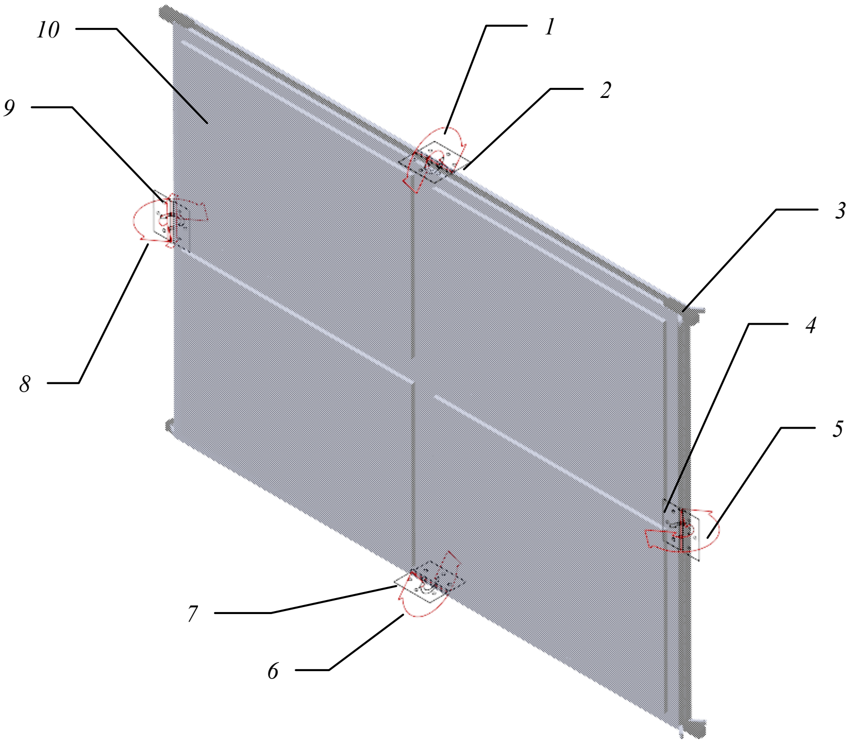


Fig. 8. Dynamic analysis model: *1* – driving moment and delay mechanism in second additional panel hinge; *2* – revolute joint in second additional panel hinge; *3* – neighbor additional panel fixator; *4* – revolute joint in first panel hinge; *5* – driving moment and delay mechanism in first panel hinge; *6* – driving moment and delay mechanism in first additional panel hinge; *7* – revolute joint in first additional panel hinge; *8* – driving moment and delay mechanism in second panel hinge; *9* – revolute joint in second panel hinge; *10* – first panel

Рис. 8. Динамическая модель двух панелей: *1* – активные силы, моделирующие движущий момент и узел задержки в ШУ второй боковой панели; *2* – вращательный шарнир второй боковой панели; *3* – элемент, моделирующий зачековку смежных боковых панелей; *4* – вращательный шарнир в ШУ первой панели; *5* – активные силы, моделирующие движущий момент и узел задержки в ШУ первой панели; *6* – активные силы, моделирующие движущий момент и узел задержки в ШУ первой боковой панели; *7* – вращательный шарнир первой боковой панели; *8* – активные силы, моделирующие движущий момент и узел задержки в ШУ второй панели; *9* – вращательный шарнир в ШУ второй панели; *10* – первая панель

Table 1

Deployment performance model's units

Unit title	Number
Parts	76
Revolute Joint	76
Fixed Joint	37
Single Component Force	114

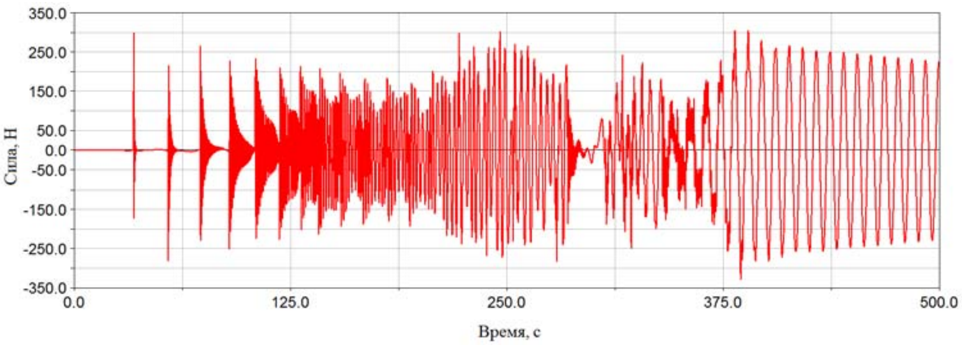


Fig. 9. Neighbor panel fixator maximum force diagram

Рис. 9. Максимальная сила, действующая в узле зачековки боковых панелей

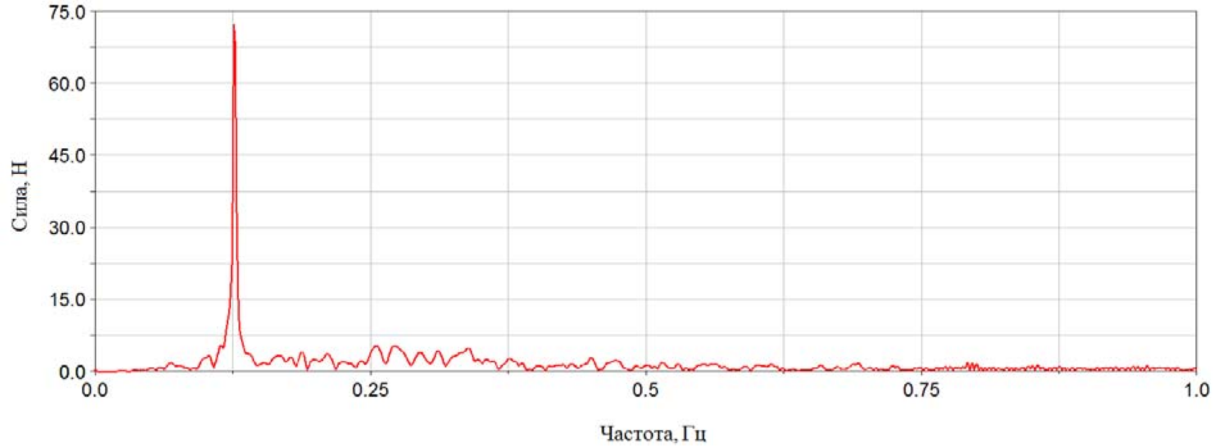
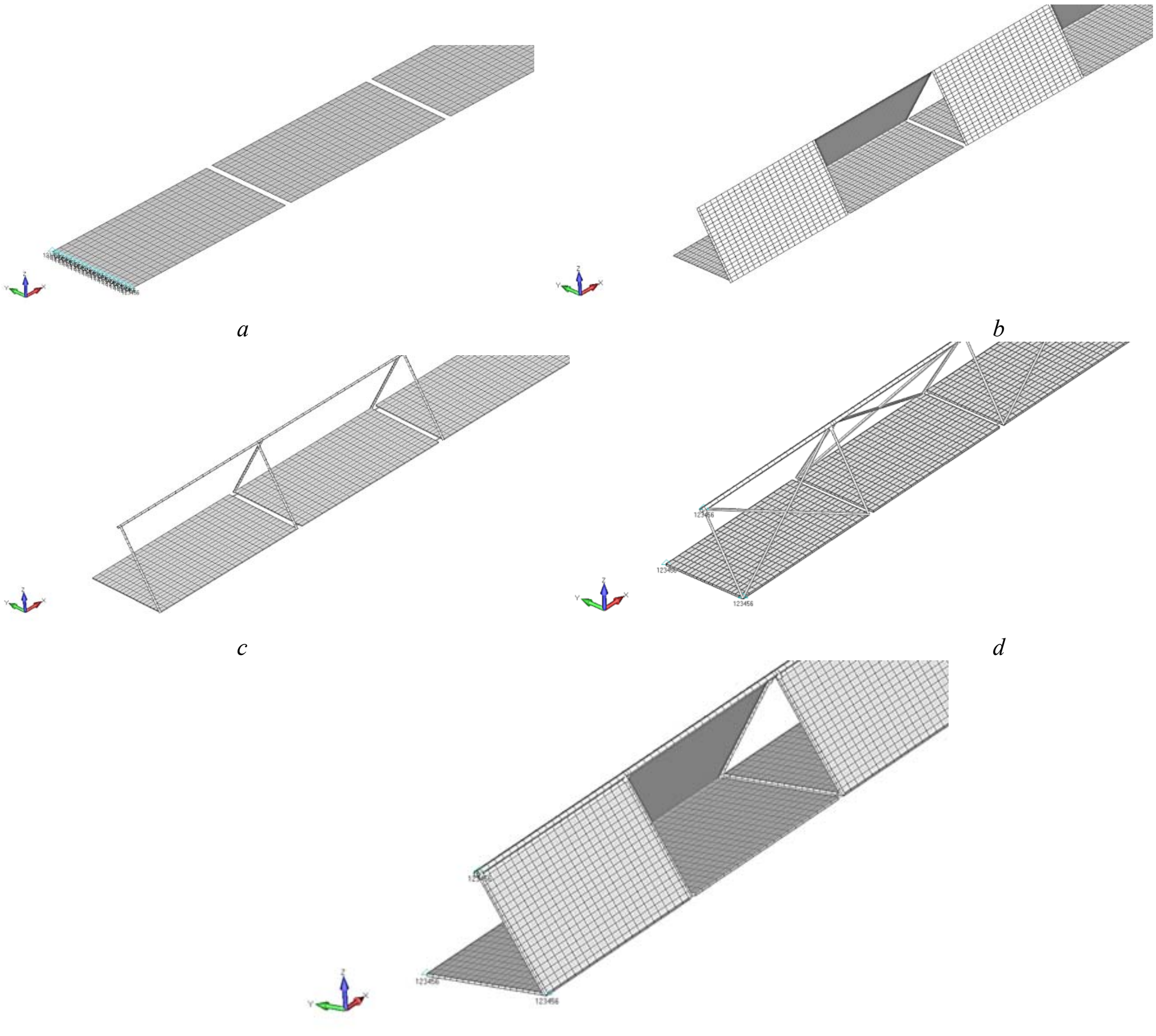


Fig. 10. Maximum perturbation frequency

Рис. 10. Частота наибольших возмущений



a *b*

c *d*

e

Fig. 11. FEM of construction. Design variants:
a – without additional elements; *b* – using membranes;
c, *d* – using tubes; *e* – combined version

Рис. 11. КЭМ конструкции. Варианты исполнения:
а – без дополнительных элементов; *б* – с использованием тонкостенных пластин; *в*, *г* – с использованием труб;
д – комбинированное исполнение

Table 2

Values for the first eigenfrequency vibrations for different constructions

Section size, m	Sections number	First eigenfrequency Hz				
		fig. 11, *a*	fig. 11, *b*	fig. 11, *c*	fig. 11, *d*	fig. 11, *e*
1	47	0.007	0.1	0.13	0.17	0.178
1.2	40	0.007	0.1	0.128	0.18	0.184
1.6	30	0.008	0.12	0.11	0.2	0.2
2	24	0.006	0.2	0.19	0.25	0.28

Further research, such as an analysis of the deployment reliability required to predict the probability of a product's fail-free operation, a mechanical analysis that shows the strength properties of the structure, the buckling calculation that determines conditions for preserving the structure form and other types of calculations will make clear conclusions about the correctness of the design decisions.

Achnowledgements. The work was supported by the Ministry of Education and Science of the Russian Federation, the unique identifier of the project – RFMEFI57517X0144.

Благодарности. Работа выполнена при поддержке Министерства образования и науки Российской Федерации, уникальный идентификатор проекта RFMEFI57517X0144.

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