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DESIGN OF THE THERMOMECHANICAL CLAMP JOINT OF MATERIALS WITH SHAPE MEMORY EFFECT FOR UNMANNED AERIAL VEHICLE

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Currently, materials with shape memory effect (SME) are widely utilized in the field of joining thin-walled shells. The application of SME materials in the joining of unmanned aerial vehicle (UAV) compartments makes it possible to increase the accuracy, high assembly manufacturability to perform multiple joint assembly-disassembly work and ensures the forces transfer from UAV different surfaces in compliance with the specified strength conditions. The paper considers a design technique for a detachable clamp (tape) joint, made up of SME material, of UAV small-diameter compartments. The clamp is an open shell made up of SME material. Before installation, the clamp is cooled, and the required shape is given to it. When heated, its diameter reduces to the specified to ensure tightness and absence of clearances in the design. The critical parameters were specified. They are required to solve the problem of parametric optimization of the clamp joint, whereby the joint will meet the strength requirements and have the minimum mass. Based on the calculation of a clamped joint, the calculation algorithm, that allows the calculation of tape connections for various diameters UAV compartments, was obtained. A computer model of joining in CAD Solid Works with the parameters that comply with the structural strength requirements was created. Based on geometry of the model and the properties of the stated materials, the calculation of structural mass under various values of the inclination angle of the clamp surface was carried out. The method of designing a clamp joint, made up of titanium nickel, is represented. The dependences of compartments joints strength on the clamp parameters and a set of parameters, allowing us to design the working structure of the clamp joint with the lowest mass, are found.

Key words: unmanned aerial vehicle, clamp joint, shape memory effect.

INTRODUCTION

When designing small-sized unmanned aerial vehicles (UAVs) with a mid-ship diameter less than 800 mm, in addition to the classic tasks of reducing weight and increasing the strength of the design, problems of ensuring the article high technological effectiveness arise.

Currently, the two types of joints: point and contour, are primarily used in UAV designs for connecting compartments to each other. The use of point (flange) joints leads to the necessity of making numerous threaded holes and flanges, which increases the structural mass [1]. Therefore, the contour joint is prevalent for connecting small diameter UAV compartments. These joints are comprised of telescopic and clamp (tape) connections. A telescopic one has a number of drawbacks – big length, the requirement of high accuracy for frames surfaces, the complex structural assembly [2]. As a result, it is more efficient to use clamp (tape) joints to connect UAV compartments of small diameter. The disadvantages of this joint involve available tightening bolts that are necessary to ensure the sufficient tension of the clamp, which affects the UAV performance. A possible solution to this problem may be

SME materials utilization in the construction. The effect of shape memory is the property of the extensive class of materials, which possess the reversibility of inelastic deformation [3–11]. SME alloys have been widely utilized in aerospace engineering, which is represented in works [12–15], e.g. as special couplings that provide the required tension. The use of SME detachable clamps for missile bodies will not only allow us to ensure all the forces transfer from one part of the UAV to another in conformity with the conditions of strength and rigidity, but also to fulfill the key technological requirements i.e., to automate a process of assembly, improve its accuracy, create the possibility of high-quality compartments joining without special tools and cooperative processing of compartments mating surfaces.

This article solves the designing problem of a clamp joint for small-diameter UAV compartments using SME materials, which have high manufacturability and meet the strength conditions.

SOLUTION ALGORITHM

The design of the studied clamp (tape) demountable joint is shown in Figure 1. A clamp tape is an open envelope made up of SME material. When heated, its diameter decreases to the specified to provide tightness and absence of clearances in the structure. The application of SME clamp ensures absence of after-assembly residual stress and makes it possible to fulfill a hidden threaded coupling that is flush with the article caliber, which has a positive effect on the UAV performance. Compartments are connected by means of a projection on one of the frames [16] in order to limit radial displacements. Thus, the clamp is utilized to prevent axial movements and shells turnover along the axis of rotation.

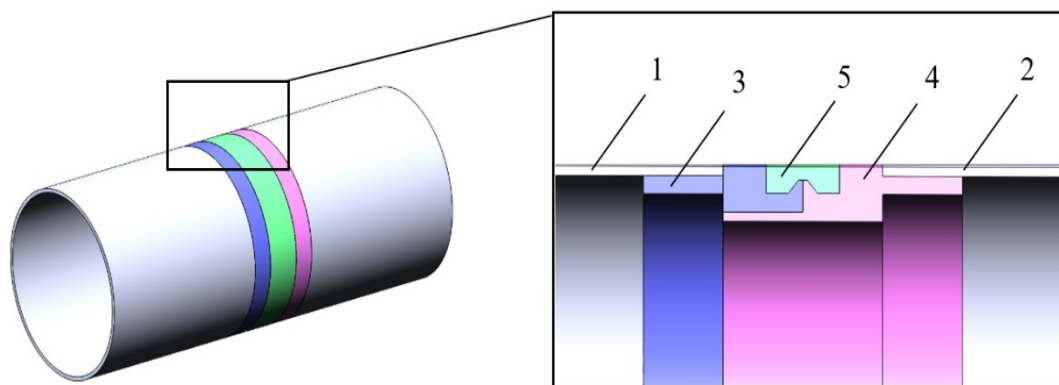


Fig. 1. The clamp (tape) demountable joint of the UAV compartments:
1, 2 – UAV compartments body; 3, 4 – joint frames; 5 – the clamp

AMg6 aluminum (which has breaking strength $\sigma_b = 300$ MPa) and titanium nickel TN-1 ($\sigma_b = 800$ MPa) were selected as the model materials for the UAV body and clamp, respectively.

At the first stage of designing, it is necessary to establish an initial set of clamp geometric parameters stemming from the limitations imposed on the UAV body (fig. 2). After identifying the parameters for the purpose of reducing the joint unit mass and increasing its strength performance, it is essential to accomplish a task of parametric structure optimization [17]. At the same time, establishing the optimal parameters for the clamp joint, under which the joint will satisfy the strength, resistance to aerodynamic heating requirements and have the minimal mass, is required.

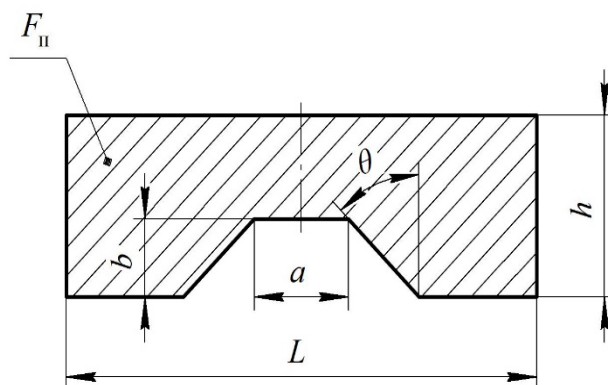


Fig. 2. Geometric parameters of the clamp cross-section

The major parameters for this problem solution are as follows:

- the average radius of clamp R ;
- the angle of clamp surface inclination θ ;
- the area of clamp cross-section $F_{II} = hL - ab - b^2 \tan \theta$ (fig. 2);
- the area of joint section $F = 2\pi \bar{R} \delta$.

While contour connecting, loading from one UAV compartment to another is imposed along the entire perimeter, which makes the skin operate in full (fig. 3).

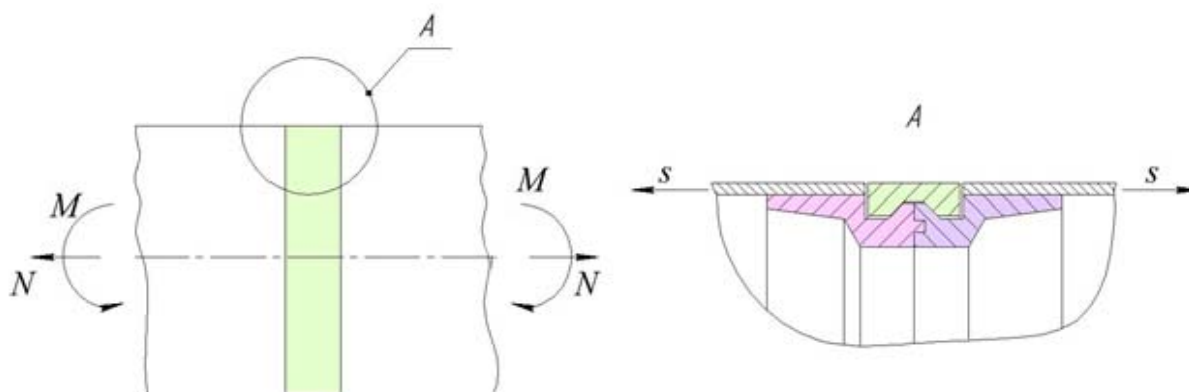


Fig. 3. Loading scheme of the clamp joint

Linear load on the joint is calculated on the basis of the plane sections hypothesis:

$$s = \left(\frac{M}{J} R \cos \varphi + \frac{N}{F} \right) \delta = \frac{M}{\pi \bar{R}^2} \cos \varphi + \frac{N}{2\pi \bar{R}}, \quad (1)$$

where M is the bending moment; N is the longitudinal force; J is the inertia moment; φ is the circumferential coordinate; δ is the wall thickness; $\bar{R}$ is the average radius.

In the loading case, the clamp is the element responding merely to tensile loads. Load s exerts pressure q from the frame side on the contact surface with the clamp and friction forces μq within the contact plane (fig. 4, δ).

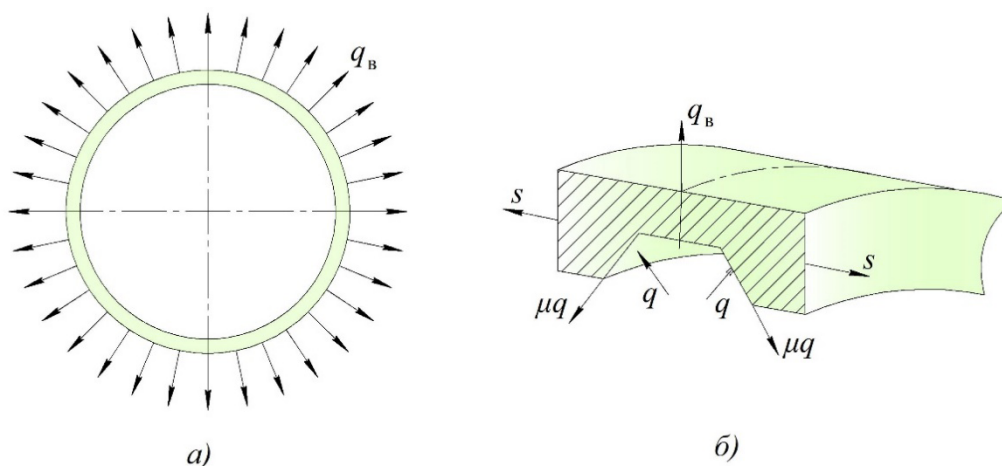


Fig. 4. Loading scheme of the clamp

The projection of these forces on the horizontal line should be equal to s :

$$q \cos \theta + \mu q \sin \theta = s \quad (2)$$

From which

$$q = \frac{s}{\cos \theta + \mu \sin \theta} \quad (3)$$

If the value of q is known, you can find the resulting vertical component q_B

$$q_B = 2q(\sin \theta - \mu \cos \theta) \quad (4)$$

Since the friction coefficient depends on many factors and can be very small, it can be accepted as $\mu = 0$, and the load can be determined by the following formulas:

$$q = \frac{s}{\cos \theta}, \quad q_B = 2s \operatorname{tg} \theta \quad (5)$$

Distributed forces q_B (fig. 4, a), acting around the clamp circumference, cause the clamp elongation. The value of the tensile forces N_φ can be found on the basis of the equilibrium condition, mentally cutting the clamp by a horizontal diametrical section (fig. 5). The acting force on the clamp element will be equal to $q_B R d\varphi$, where $d\varphi$ is the central angle corresponding to the element.

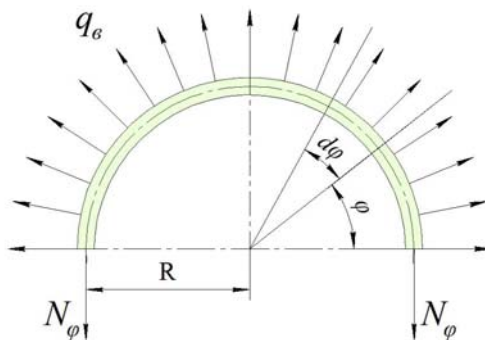


Fig. 5. Tensile forces in the clamp section

Having taken the sum of the forces vertical components acting on half a clamp, we obtain the following equilibrium equation:

$$2N_{\varphi} = 2 \int_0^{\pi/2} q_B R \sin \varphi d\varphi \quad (6)$$

From which

$$N_{\varphi} = q_B R \quad (7)$$

Tensile stress in the clamp, which determines the condition of strength, can be obtained by means of dividing the force of N_{φ} by the cross-sectional area of the clamp F_{Π} :

$$\sigma_{max} = \frac{N_{\varphi}}{F_{\Pi}} \leq [\sigma] \quad (8)$$

Further, a stress analysis is executed. The factor of safety: $n = \sigma_B / \sigma$ is equal to 1.5.

If the condition (8) is not met, the checking calculation is repeated under a new set of parameters.

Figure 6 shows the algorithm of designing computation for the clamp demountable joint, which can be utilized to compute joints of UAV compartments with different diameters.

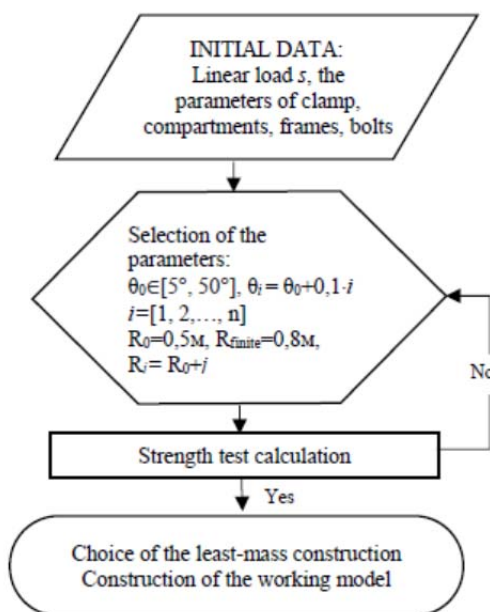


Fig. 6. The algorithm for computation of the clamp detachable joint parameters

CALCULATION RESULTS

On the basis of the developed algorithm, some calculations were carried out, the results of which are graphically displayed in Figures 7–10. The calculation was conducted for the following parameter values: $L = 50$ mm, $a = 20$ mm, $b = 13$ mm selected from the condition of the highest manufacturability.

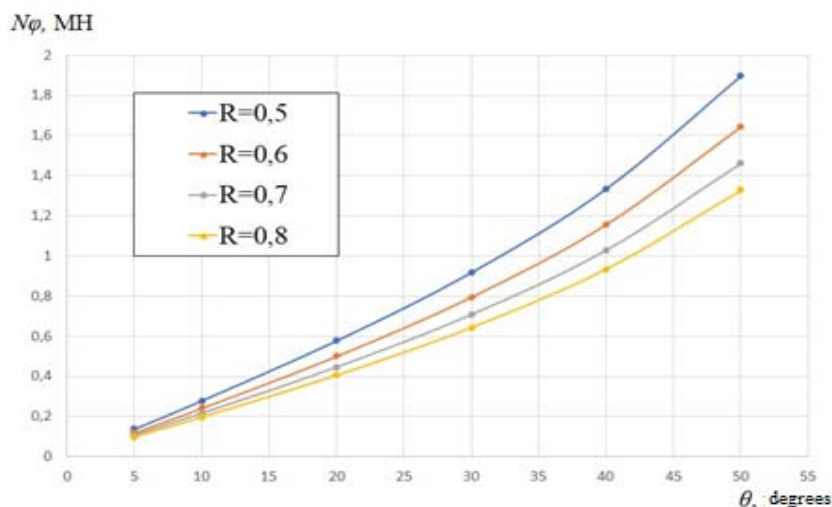


Fig. 7. Dependence of the tensile force on the surface inclination angle θ

Figure 7 illustrates that the tensile force increases steadily as the inclination angle of surface θ does. Herewith, the radius of the clamp connection R influences its increase: the greater the value of R , the lower the value of N_φ .

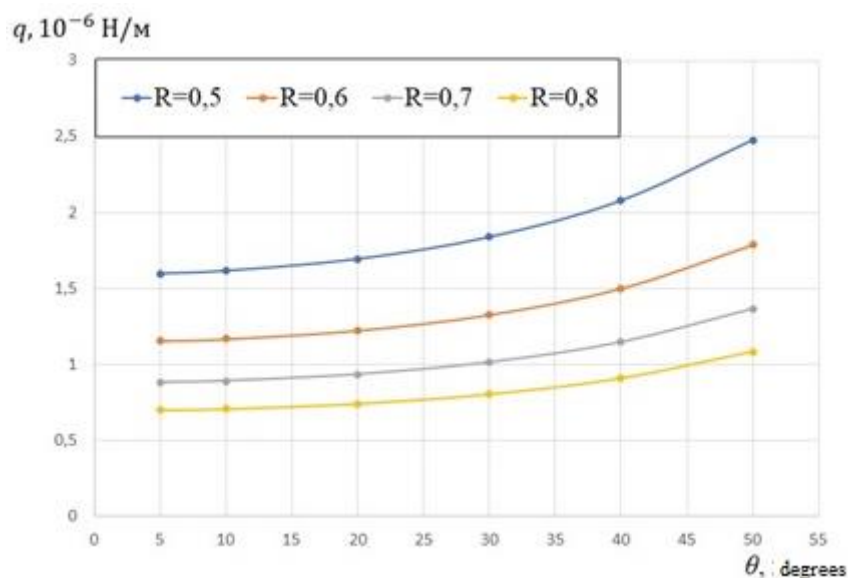


Fig. 8. Dependence of the frame pressure on the clamp on the inclination angle of the clamp surface θ

Figure 8 gives that the pressure from the frame side on a clamp increases steadily along with the angle increase θ . Likewise, in Figure 9, a dependence of the value q_θ on the value of R is noticeable: the greater the value of R , the lower the value of q_θ , which indicates that when choosing an optimal diameter of a clamp connection from a variety of options, from the point of view of strength, a clamp joint with the maximum value of R is preferable.

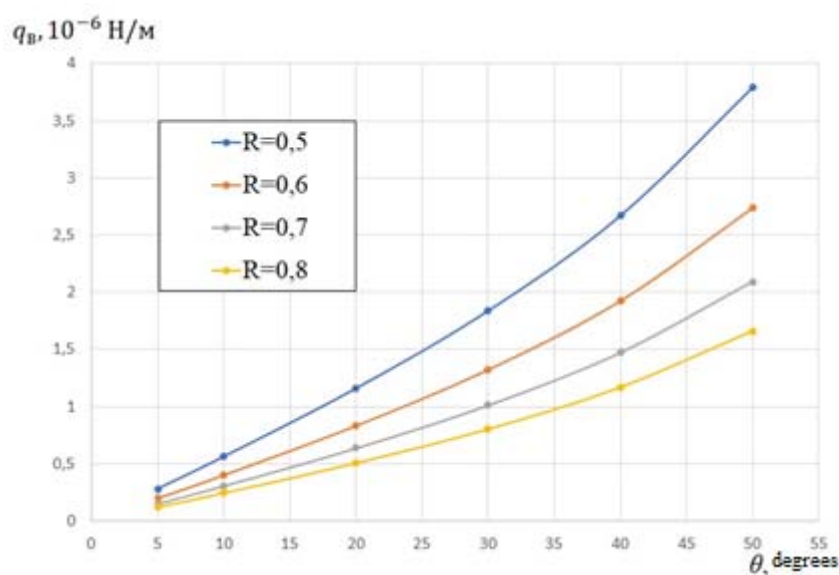


Fig. 9. Dependence of the resulting vertical component on the angle of inclination of the clamp surface

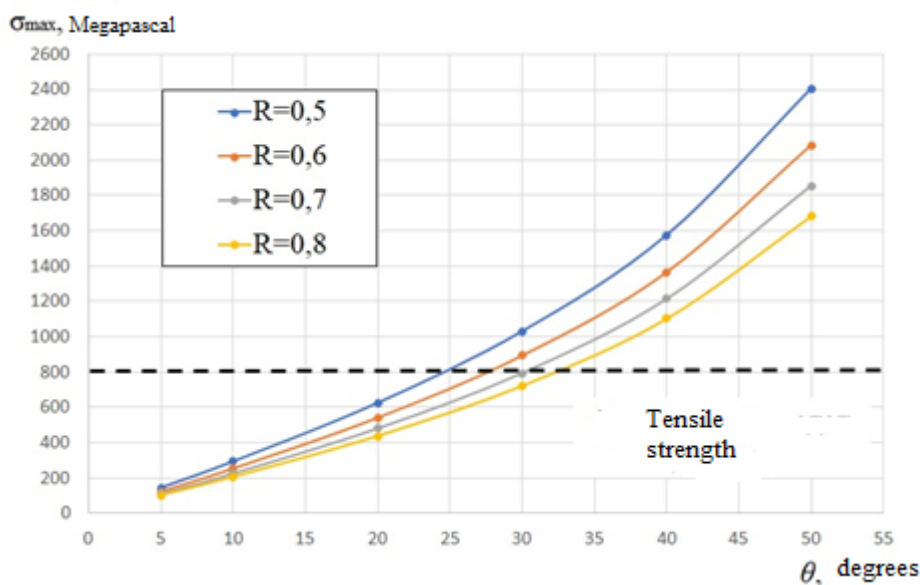


Fig. 10. Dependence of the joint strength on the angle of inclination of the clamp surface

Figure 10 illustrates the area within which the strength condition for TN-1type material with SME (this area is below the tolerance limit) is met. In accordance with Figure 10, one can find the maximum allowable values of clamp surface inclination angles for different radii of clamp fitting under which the strength condition for the nitinol clamp is fulfilled:

- $\theta \leq 24^\circ$ for $R = 0.5$ m;
- $\theta \leq 27^\circ$ for $R = 0.6$ m;
- $\theta \leq 30^\circ$ for $R = 0.7$ m;
- $\theta \leq 32^\circ$ for $R = 0.8$ m.

At the angles of θ , exceeding the specified values, the tensile force and the pressure, acting on a clamp from the side of frame, fall outside the allowable maximum load, as it is depicted in Figure 10.

Based on the computation results of the ANSYS software solutions, a parametric finite element clamp model was designed. Using the "Response Surface Optimization" module, the analysis of the model with the parameters of the clamp geometry, physical and mechanical characteristics of the material and the maximum values of stresses and deflection under limitations was carried out:

$$\sigma_{\max} \leq \sigma_{\text{доп}}$$

$$w_{\max} \leq w_{\text{доп}}$$

where $\sigma_{\text{доп}}$ and $w_{\text{доп}}$ are the tolerance values of stresses and deflection,

$w_{\max}$ is the maximal deflection value.

Multi-purpose search was adopted as an optimization algorithm. As a result of optimization, the region of compromise solutions, which visualization is represented in Figure 11, was obtained. The criterion of minimum mass was selected as the major optimization one. According to this criterion, the optimal design and engineering solution of the clamp construction was selected from a variety of the obtained compromises. The value of the optimal parameters of a clamp joint is given in Table 1.

The resulting set of parameters allows you to design the working structure of a clamp joint with the lowest mass.

Table 1

Parameter	Value
θ , degrees	32
R , meters	0.8
h , m	0.025

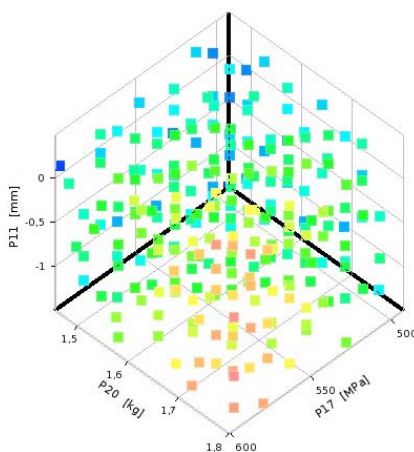


Fig. 11. Region of compromise between the equivalent values of stresses, deflections and clamp mass

CONCLUSION

The design problem of a clamp joint of small diameter, using SME materials, was set and solved.

The computations with the use of the ANSYS and SolidWorks software solutions enabled us to design the optimal clamp joint construction that meets the conditions of strength and minimum mass.

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ПРОЕКТИРОВАНИЕ ТЕРМОМЕХАНИЧЕСКОГО ХОМУТОВОГО СТЫКА ИЗ МАТЕРИАЛОВ С ЭФФЕКТОМ ПАМЯТИ ФОРМЫ ДЛЯ БЕСПИЛОТНЫХ ЛЕТАТЕЛЬНЫХ АППАРАТОВ

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В настоящее время материалы с эффектом памяти формы (ЭПФ) нашли широкое применение в области соединения тонкостенных оболочек. Использование материалов с ЭПФ в соединении отсеков беспилотного летательного аппарата (БПЛА) позволяет повысить точность и технологичность сборки, выполнять многократную сборку-разборку стыка и обеспечивает передачу усилий с разных поверхностей БПЛА с соблюдением заданных условий прочности. Рассмотрена методика проектирования разъемного хомутового (ленточного) стыка, выполненного из материала с эффектом памяти формы ЭПФ, отсеков БПЛА малого диаметра. Хомут представляет собой незамкнутую оболочку, выполненную из материала с ЭПФ. Перед установкой хомут охлаждается, и ему задают необходимую форму. При нагреве его диаметр уменьшается до заданного для обеспечения герметичности и отсутствия зазоров в конструкции. Были определены основные параметры, необходимые для решения задачи параметрической оптимизации хомутового стыка, при которых соединение будет отвечать требованиям прочности и иметь минимальную массу. На основе расчета хомутового стыка был получен алгоритм расчета, позволяющий проводить расчет ленточных соединений отсеков БПЛА различных диаметров. Была создана компьютерная модель соединения в САПР SolidWorks с параметрами, отвечающими требованиям прочности конструкции. На основе геометрии модели и свойств указанных материалов был проведен расчет массы конструкции при различных значениях угла наклона поверхности хомута. Приведена методика проектирования хомутового стыка, изготовленного из никелида титана. Найдены зависимости прочности соединения отсеков от параметров хомута и набор параметров, позволяющий спроектировать рабочую конструкцию хомутового соединения с наименьшей массой.

Ключевые слова: беспилотный летательный аппарат, хомутовый стык, эффект памяти формы.

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