МОДЕЛЮВАННЯ ТА ОПТИМІЗАЦІЯ В ТЕХНОЛОГІЇ КОНСТРУКЦІЙНИХ МАТЕРІАЛІВ

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MODELING OF MANDREL FOR CREATION OF THIN-WALLED LINERLESS FUEL TANKS OF ROCKET CARRIERS FROM COMPOSITE MATERIALS

The object of research is a mandrel for the manufacture of thin-walled fuel tanks from carbon fiber by automated winding / stacking. The methodologies of substantiation of necessary conditions of maintenance of manufacturability of the considered designs from composite materials on calculation of requirements and constructive realizations of technological mandrel are considered in the work.
Keywords*: Fuel tank; carbon fiber; mandrel; manufacturing technology.*

Об'єктом дослідження є оправка для виготовлення тонкостінних паливних баків із вуглепластика методом автоматизованої намотки/викладки. В роботі розглянуті методології обґрунтування необхідних умов забезпечення технологічності розглянутих конструкцій із композиційних матеріалів із розрахунку вимог і конструктивних реалізацій технологічної оправки.
Ключові слова*: Паливний бак; вуглепластик; оправка; технологія виготовлення.*

Problem's Formulation

Increased requirements are imposed on structures and materials in rocket and space technology in terms of not only strength, reliability, but also the accuracy of the mutual arrangement of individual assembly units and parts in them.

Up to 90 % of the launch mass of rockets in their traditional configuration is the mass of the fuel. Accordingly, a significant part of the mass of the structure are fuel tanks, pipes and sealed cylinders.

One of the most important factors determining mass perfection is the creation of fundamentally new technologies for manufacturing structural elements that can significantly reduce the mass of the launch vehicle.

Analysis of recent research and publications

The minimum mass of fuel tanks, main pipelines and pressurized cylinders is achieved when using materials with the maximum specific strength (the ratio of the ultimate strength of the material to its density. The most promising and modern material is carbon fiber reinforced plastic. They are used to make not only separate power structures, but also entire compartments of launch vehicles, including fuel ones. Such designs are subject to increased requirements for geometric parameters.

Formulation of the study purpose

Of particular interest are the designs of fuel tanks, including large and long ones. Their creation requires the use of axisymmetric mandrels with a high degree of rigidity, onto which they are wound with the subsequent possibility of their removal from the cavity of the reservoir [1]. Composite structures such as composite fuel tanks use long, large axisymmetric mandrels with high rigidity. A load-bearing shell is wound on them, followed by polymerization of the material. After that, it is required to remove the fragments of the mandrel from the cavity of the tank. Depending on the location and design of the fuel tanks, its geometry can be complicated by the presence of frames or by the geometry of the bottoms or flanges. Since additional equipment is located in the tank cavity, it becomes necessary to provide access for service [2]. This requires making one or both pole holes in the size of Ø460 mm, and ensuring the connection with the cover with a split joint. For light launch vehicles, the cylindrical section of the hull is up to 1400 mm.

Presenting main material

In the work of research on the creation of high-precision thin-walled linerless shells of the fuel tank body. At the same time, we considered the structural layout diagram shown in Fig. 1.

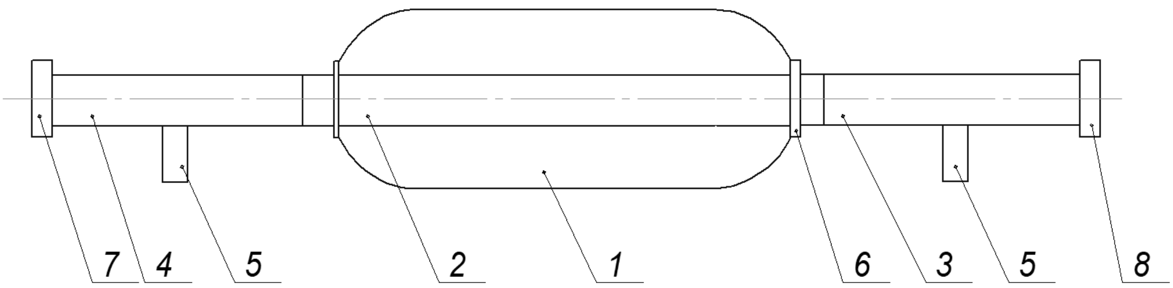


Fig. 1. Mandrel design: 1 — Mandrel surface; 2 — mandrel shaft; 3 — support trunnion; 4 — drive trunnion; 5 — support (machine steady rest); 6 — flange holder; 7 — drive cam; 8 — support cam

The surface of the mandrel includes many sections, which, after polymerization of the shell, are removed through the pole hole 2. The support trunnion 3 and the drive trunnion 4 ensure the position of the mandrel in the working area of the machine, resting on the supports 5. In the end parts of the trunnions, they are fixed in the cams 7 and 8. The given block diagram is identical for all-metal, sand-polymer and light frame mandrels. In the conducted research, we considered sand-polymer mandrels with full filling of its cavity, collapsible with aluminum-prefabricated cards, as well as collapsible metal mandrels with one-piece milled elements. Additionally, a variant of the design of a collapsible frame mandrel with cards made of structural fiberglass is considered.

To determine the initial imperfections of the geometric shape of the composite fuel tank, the deformations of the mandrel were determined, the design diagram and the deflection diagram of which are shown in Fig. 2.

They are associated with the deformation of the mandrel, namely, the misalignment of the flanges, the flatness of the joints and the value of the deflection of the cylindrical part.

When calculating it, we used three options for the design of the mandrel (Fig. 3). In the first, a sand-polymer mandrel with full filling of the mandrel cavity is considered. In the second, a collapsible mandrel with aluminum-prefabricated cards is considered. In the third, metal with solid-milled cards.

When calculating all options for the mandrel, a number of assumptions were made. Since in collapsible metal mandrels the cards that are located around the shaft are not connected to each other and are fixed only on the base shaft, their rigidity can be neglected. The same as the rigidity of the sand-polymer filling or the frame with the cards made of structural fiberglass. The base shaft for all types of mandrels is of the same design.

In this work, the determination of the geometric parameters of the mandrel was solved as the inverse problem of determining the weight and volumetric density for each type of mandrel. It was found that when using a polymeric mandrel and collapsible metal mandrels, the required stiffness value is not provided, according to the criterion of the shaft deflection, which should be no more than 0.16 mm.

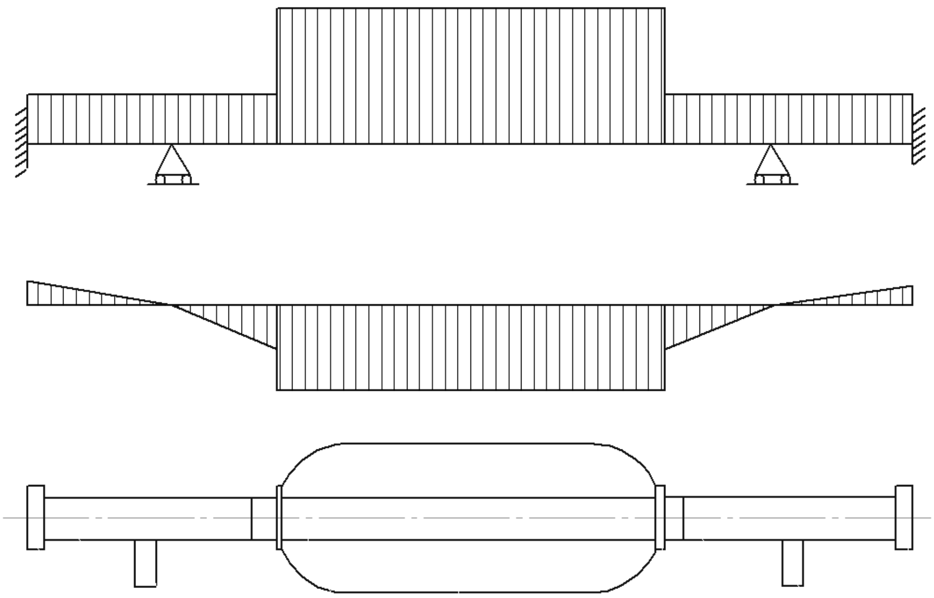
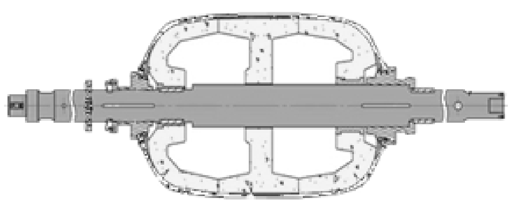
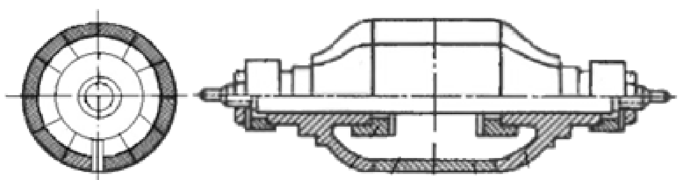


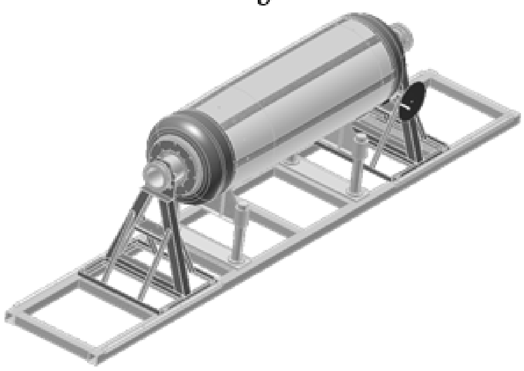
Fig. 2. Design scheme of mandrel and deflection diagram



a



b



c

Fig. 3. Design options for mandrels: a — sand-polymer equipment; b — collapsible steel equipment; c — collapsible aluminum equipment

As a result of the calculation, it was found that for the accepted geometric parameters of the tanks, the use of sand-polymer mandrels, as well as metal collapsible ones, does not allow providing the required value of the accuracy of the relative position of the two flange planes. It is worth noting that the washing out of the sand-polymer mixture from the cavity of a thin-walled fuel tank is accompanied by significant heating by steam, as well as the risk of collapse of large fragments, which can lead to damage and leakage of the structure. Also, performing manipulations when turning over or installing a fuel tank in devices for extracting the shaft or flushing, when the weight of the entire filling will be concentrated on the bottom or flange of one of the sides, leads to local loads, the value of which can exceed the critical ones. The same risks exist when removing the metal card segments.

For the considered structures and the hollow cross-section of the shaft, obtained from standardized rolled products with an outer diameter D = 300мм, axial moment of inertia J_x and the moment of resistance in bending W_x determined:

$$J_x = J_y = \frac{\pi(D^4 - d^4)}{64}, \quad (1)$$

$$W_x = W_y = \frac{2J_x}{D}. \quad (2)$$

The following notations are used in the equations: d — maximum size of the inner cavity of the equipment.

Having worked out several possible options and design implementations (Fig. 4, Tabl. 1), it was determined that when choosing a mandrel for the manufacture of all-composite fuel tanks the main criteria are:

$$\theta_A = \theta_B = \frac{ql^3}{24EJ_x}, \quad (3)$$

$$f = \frac{q\,(2lx^3 - x^4 - l^3x)}{24EJ_x},\ f_{max} = \frac{4ql^4}{384EJ_x}. \quad (4)$$

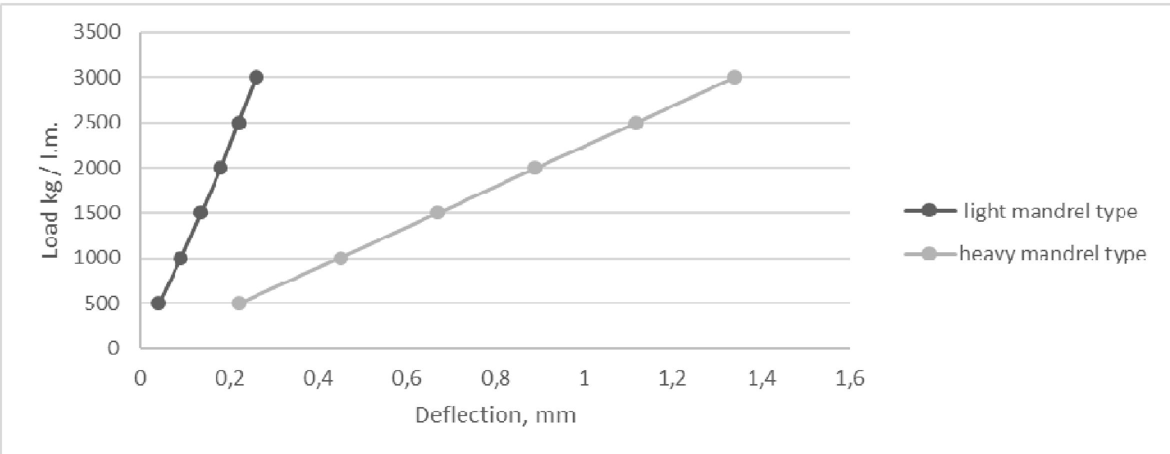


Fig. 4. Graph of fallowness of the deflection to the shaft from the installation

Table 1. Physical characteristics of mandrels of different types

Mandrel type	Mandrel weight, kg	Bulk density, kg / m3	Deflection, mm
Sand-polymer	4200	800	0,14
Collapsible steel	5400	1200	0,171
Dismountable with prefabricated aluminum cards	5550	1800	0,172
Dismountable frame with structural fiberglass cards	1280	-	0,05

The following notations are used in the equations: E — modulus of elasticity of the first kind of shaft material, EJ_x = const; θ_A — angle of rotation of the shaft on the supports; f_{max} — deflection of the shaft and structure of the card segment; l — the distance between the support dunes of the machine, when modeling the accepted standard design for all mandrels, is 4000mm.

Based on the results of the calculations, as well as the described design features of the sand-polymer and collapsible metal mandrels, it can be assumed that for the creation of large-sized thin-walled fuel tanks it is preferable to use mandrels, the segments of which are made of composite materials. Elements of a collapsible frame mandrel, the elements of which are made of composite materials, have not only less weight, but also less have close coefficients of linear thermal expansion, which allows it to jointly deform and minimize thermal shrinkage [3].

Conclusions

The process of substantiating the necessary conditions for ensuring the manufacturability of the considered structures made of composite materials is presented, using the example of different types of mandrels for large-sized thin-walled fuel tanks, using the theory of elasticity, considering practical examples of considering structural elements of different types of mandrels. A rational way of creating new complex elements of rocket and space technology, such as thin-walled laneless fuel tanks made of composite materials, has been determined with substantiation of the requirements for manufacturability and efficiency of using the applied technological equipment.

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МОДЕЛЮВАННЯ ОПРАВКИ ДЛЯ СТВОРЕННЯ ТОНКОСТІННИХ БЕЗЛЕЙНЕРНИХ ПАЛИВНИХ БАКІВ РАКЕТ-НОСІЇВ ІЗ КОМПОЗИЦІЙНИХ МАТЕРІАЛІВ

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Реферат

Стаття присвячена процесу моделювання конструктивних схем оправок для виготовлення тонкостінних оболонок з композиційних матеріалів. При розробці деталей з композитів проектування конструкції, створення матеріалу і технологія його виготовлення є невід’ємною частиною одна одного. Враховуючи цю особливість композитів, вибір технології виготовлення та технологічної підготовки є одним із найважливіших аспектів, що визначають облік усієї конструкції.

На початкових етапах проектування розглядається питання обґрунтованого вибору технологічного обладнання для виготовлення конструкцій із композиційних матеріалів, у тому числі паливні баки. Сучасним напрямом розвитку цього напрямку є моделювання розрахункових схем за допомогою програмних засобів. Їх використання дозволяє не тільки спростити розумін-

ня процесу створення деталей з композитів, а й при високій автоматизації обробляти велику кількість конструктивно-технологічних реалізацій обладнання та конструктивних компонування.

Крім того, моделювання дозволяє попередньо оцінити можливі недосконалості деталей, визначені технологічними обмеженнями. Це дозволяє ефективно розробляти обладнання та технологію виготовлення на етапі проектування з урахуванням технологічних і конструктивних особливостей. Розглянуто процес наукового обґрунтування вибору та реалізації різних варіантів конструкції оправок. Велику увагу приділяли розгляду конкретних реалізацій та використанню різноманітних структурних схем обладнання. Визначено раціональний шлях створення нових складних елементів ракетно-космічної техніки, таких як тонкостінні безлейнерні паливні баки із композиційних матеріалів з урахуванням вимог по технологічності і ефективності використання технологічного оснащення що застосовується. Представлено оцінку отриманих результатів та висновки про проведену роботу.

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