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TIGHTNESS OF THE FLANGE CONNECTION OF AN ALL-COMPOSITE FIBER FUEL TANK

The article is devoted to the issue of ensuring the tightness of the flange connection of an all-composite carbon fiber fuel tank. Based on the presented studies, the feasibility of individual structural and technological solutions of flange joints has been established. The conclusions on the work and evaluation of the results are presented. [dx.doi.org/10.29010/89.4]

Keywords: fuel tank; carbon fiber; flange joint; tightness.

In the modern world, composites have confidently taken their place in all industries. The maximum value of the specific strength of carbon plastics increasingly raises the question of their use in such a complex node of the launch vehicle (LV) as fuel tanks. Understanding that fuel tanks occupy a significant part of the dry weight of the rocket is a matter of critical importance when it comes to reducing the weight of the upper stages of the launch vehicle, as well as the entire light class launch vehicle, where it is technologically possible to implement effective composite structures. To reduce costs and research time, it is advisable to apply them in stages, confirming or discarding certain structural and technological solutions (STS). The strength and tightness of the power shell of the fuel tanks is investigated and made of a material of sufficient thickness. And the tightness of the flange connection, as well as the tightness of the flange housing in the area of contact with the power shell and in the field of built-in fasteners are poorly understood. The design problem is especially difficult when predicting the interaction of all structural elements under conditions

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of cryogenic temperatures and requires many additional studies.

Ensuring the operability of the structure under conditions of cryogenic temperatures imposes a number of fundamental limitations. This preservation of strength and ensuring a sufficient level of stiffness of the material when exposed to cryogenic temperatures.

flange, its sealing and the need to work at cryogenic temperatures. Due to the limited information on the design of the flange and the flange joint made of CFRP, an experimental design adapted to another seal was prepared for testing (Fig. 1).

The results showed a leak in the flange connection and, as a result, the inoperability of the adopted struc-

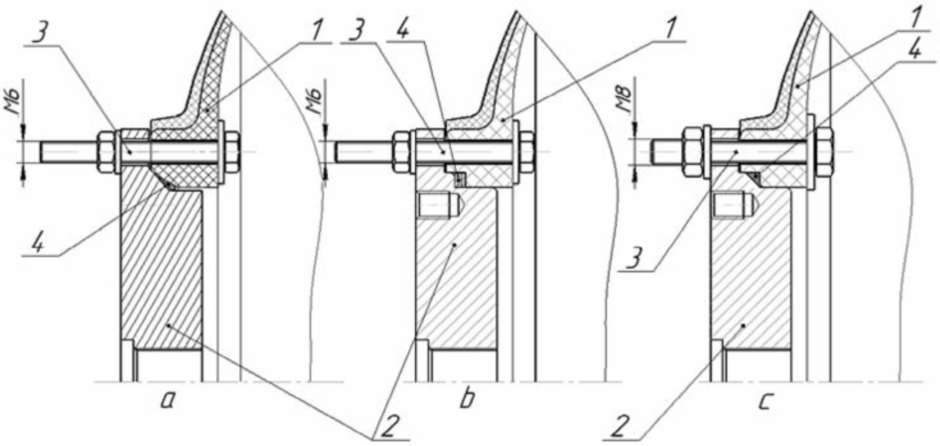

Fig. 1. The design of the flange joint during the preparation and testing of the experimental design for:
a — water pressure, *b* — gaseous nitrogen, *c* — liquid nitrogen.
1 — Pole flange; *2* — cover; *3* — fasteners; *4* — sealing element

tural solutions and seals. The limited sealing surface, as well as the low and weakening torque of the fasteners did not allow ensuring the quality of the connection. Also to the possible places of leaks can also be attributed to the adhesive joint fasteners. Since viewing this area is difficult, this is just an assumption. Since only the flange connection was problematic, and the whole structure was the object of testing, it was decided to change it as part of the structure. The increase in the bearing capacity of the fasteners and the moment of their tightening made it possible to ensure the tightness of the connection at operating pressure and to carry out leak tests with excess pressure of water and liquid nitrogen (Fig. 2).

A large difference in the linear thermal expansion coefficients of the contacting structural elements significantly affects the tightness of the fuel tanks. This makes it impossible to use composites with metal. Metals are used only as fasteners.

The aim of this work was to study a number of structural forms of the flange connection of the fuel tank and the use of composite materials designed to work at cryogenic temperatures.

For research, materials resistant to kerosene and cryogenic temperatures were selected. Preliminary tests were carried out on unidirectional samples. Based on the test results, materials were selected for the manufacture of the fuel tank design. For the power sheath, it is carbon fiber based on high strength fiber. For composite flange and covers, this is a carbon fiber-reinforced plastic (CFRP) based on a simple weave fabric.

Based on the results obtained, it was found that both materials are highly resistant to thermal deformation along the reinforcement and low in the direction perpendicular to the reinforcement [1]. Taking into account the operating conditions of the fuel tank and its design, the implementation of its basic elements from carbon fiber will allow full use of the capabilities of plastics reinforced with carbon fiber.

Given the design features and operating conditions of the fuel tank, an experimental design with a composite flange has been developed taking into account existing developments in the design of individual elements. Particular attention was paid to the composite

The problem was solved using a structurally similar assembly, made in full size with partial use of the existing technological mandrel. Not only has the sealing principle changed, but also the structural and technological design of fasteners [2]. High safety factor, tightening torques and surface resistance of carbon fiber and structural damage were taken into account. The main criterion for evaluating the provision of effective compaction was the study of tightness at excess air pressure before and after the process of thermal cycling in liquid nitrogen.

Assessment of the bearing capacity of the fasteners, as well as an assessment of the nature of the damage, was carried out on a sample flange of a similar design with one built-in metal element.

As a result of tests of a structurally similar specimen of a flange with one integrated metal element, the

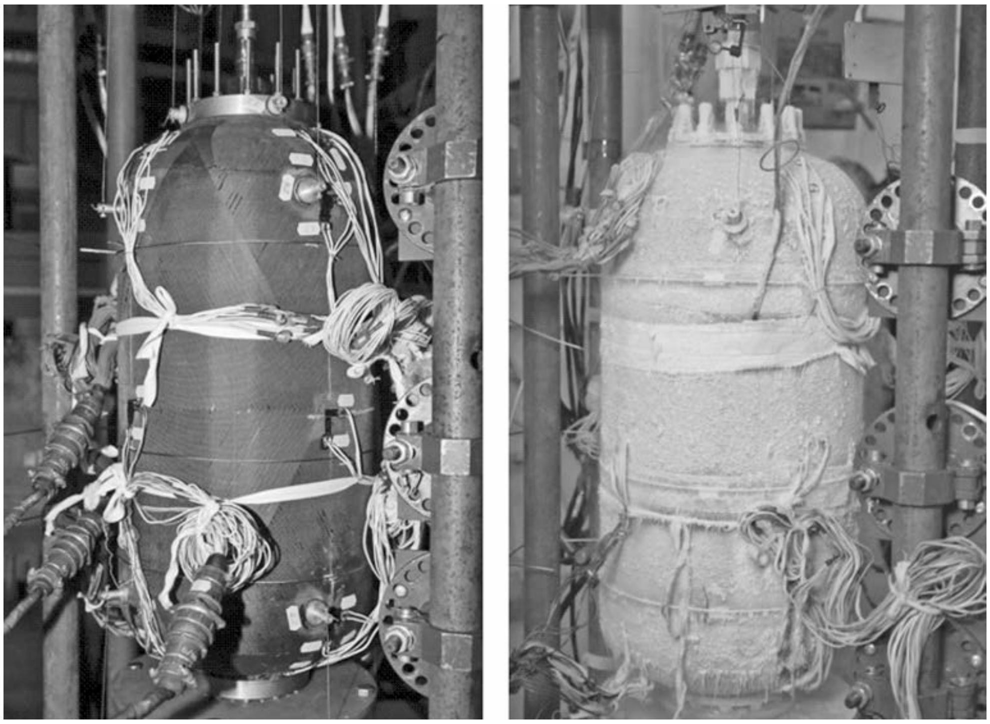

Fig. 2. Experienced fuel tank design for water/liquid nitrogen overpressure tests

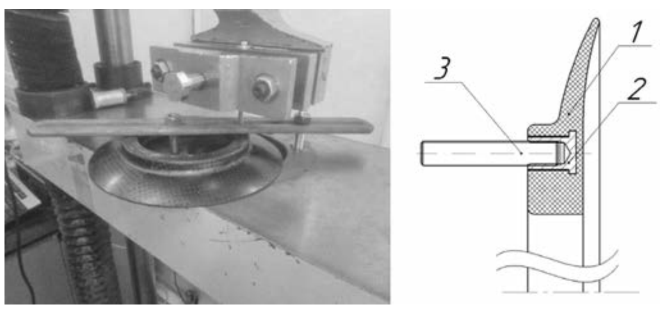

Fig. 3. The process of determining the bearing capacity of an individual metal embedded element and its design.
1 — flange body; *2* — fastener sleeve; *3* — threaded fasteners

pulling force of the studs from the housing of the integrated metal sleeve is determined. The destruction occurred by crushing the threads of the fasteners. There were no permanent deformations or visible damage on the surface of the composite flange. The axial fracture force was 9830 Newton (Fig. 3).

The next stage of research was the manufacture of a structurally similar unit, repeating the basic elements of the flange connection of the fuel tank. Structurally, the assembly precisely repeats its performance in the fuel tank, except for the presence of a preformed front wall, which is part of the flange and closes the sealing circuit (Fig. 4).

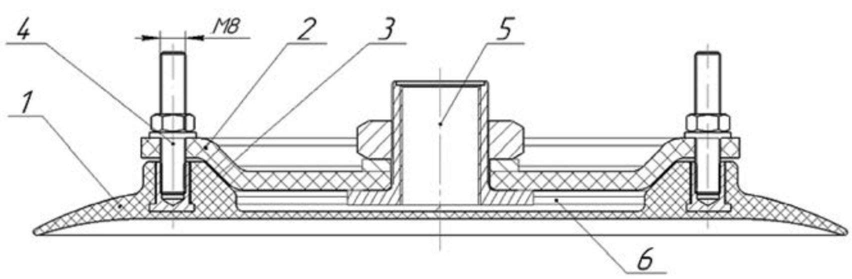

Fig. 4. Assembly design for model testing.
1 — CFRP flange; *2* — CFRP cover; *3* — sealing element; *4* — metal fasteners; *5* — pressure connection; *6* — sealing circuit

The conducted leak tests consisted of preparing and assembling the assembly, conducting its thermal cycling using liquid nitrogen (t = minus 196°C) and checking the tightness at an air pressure of 0.81 MPa with a holding time of 15 minutes (Fig. 6). The results of a set of tests for flange connections for leaks, including in the framework of the experimental design, are shown in table 1.

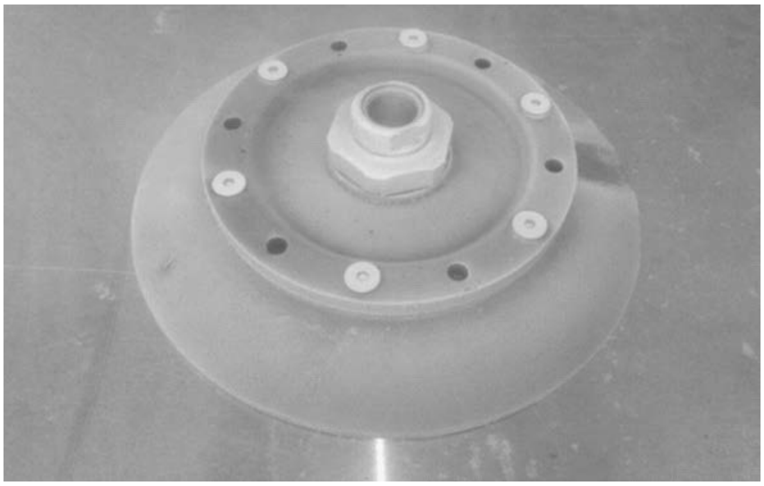

Fig. 6. Flange assembly after thermal cycling

The reduction in free volume, as well as testing of one unit, made it possible to carry out the necessary number of experimental designs safely and with minimal training costs. The test results are confirmed by the effectiveness and correctness of the developments of structural and technological solutions. The implemented design is easily scalable for any type and size of fuel tanks, and research and methodology will serve as the basis for further developments.

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Table 1

Flange joint test results

№	Test object	Test conditions	Result
1	Experienced design FT with CFRP flange version No. 1	Processing medium — air pressure 0.81 MPa, excerpt 15 minutes	Hermetic, no pressure drop.
2	Experienced design FT with CFRP flange version No. 2	Processing medium — water pressure 1.52 MPa	Leak at refueling pressure (0.2 MPa), extensive leaks at operating pressure.
3	Experienced design FT with CFRP flange version No. 3	Processing medium — water pressure 1.52 MPa, 3 cycles pressure / decline, excerpt 15 minutes	The upper flange is leaky at a pressure of more than 1.2 MPa, drop at maximum pressure 0.02 MPa/min. Pressure drop up to 1.24 MPa.
4	Experienced design FT with CFRP flange version No. 4 (in liquid nitrogen)	Processing medium — liquid nitrogen pressure 1.52 MPa, 10 filling / draining cycles, excerpt 15 minutes	The upper flange is leaky when being pressurized with nitrogen gas, after thermal cycling proceeds at a pressure of more than 0.85 MPa. Maximum pressure drop.
5	Experienced design FT with CFRP flange version No. 5 (destruction)	Processing medium — water pressure 1.52 MPa, 3 cycles pressure / decline, pressure destruction of 6.08 MPa.	Extensive leakage at operating pressure. Destruction of the power shell of the fuel tank.
6	Structurally similar flange joint assembly	Liquid nitrogen thermal cycling. Processing medium — air pressure 0.81 MPa, excerpt 15 minutes	Hermetic, no pressure drop.

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ГЕРМЕТИЧНОСТЬ ФЛАНЦЕВГО СТЫКА ЦЕЛЬНОКОМПОЗИНОГО ТОПЛИВНОГО БАКА

Статья посвящена вопросу обеспечения герметичности фланцевого стыка цельнокомпозитного топливного бака из углепластика. На основании представленных исследований установлена целесообразность отдельных конструктивно-технологических решений фланцевых стыков. Представлены выводы по работе и оценка полученных результатов. [dx.doi.org/10.29010/89.4]

Ключевые слова: *топливный бак; углепластик; фланцевый стык; герметичность.*

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