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Yu. A. Mitikov, PhD, I.D. Dubrovskiy, M. I. Vasin
(Oles Honchar Dnipro National University, Ukraine)

Pressurization systems using oxygen vapor for oxygen tank of oxidizer-rich staged combustion cycle

A new approach of pressurization system designing based on autonomous pressurization system using oxygen vapor for oxidizer tank is proposed. Methods of implementation of such systems are considered.

A key feature of the present time in rocket and space technique (RST) is that noncommercial organizations of the United States, China, India, New Zealand, and Japan came to the launch services market. Due to progress in electronics and energy for the last decade, there has been a significant miniaturization of satellites. The time of their active work is already approaching 15 years [1]. Medium-range launch vehicles (LV) are now able to simultaneously output such satellites to orbits in hundreds. In this regard, despite the steady growth in the requirements for space technology, the average number of launches of rockets by all countries in the world for the past ten years has been an average of 18 per year [2]. Not surprisingly, the famous company SpaceX has reduced the number of launches in 2019 by ~ 40% due to the "lack" of satellites. Naturally, the competition for providing start-up services in the world is constantly growing. And it will continue to grow.

It is on the economic effectiveness of the adopted technical solutions, the creation of fundamentally new models of RST primarily aimed at scientists and designers of Ukraine "State-wide target scientific and technical space program". It is not surprising that today the RST-workers intensively revises the approaches formed earlier, when the governments of a number of countries, in order to achieve political goals, sought to enter space at any cost.

At present, liquid oxygen (LOX) and hydrocarbon fuel of kerosene type (RP-1, T-1, T-6, further - RP-1) are most widely used for modern liquid-propellant rocket engines in the foreseeable future. These are the cheapest propellants (at the factory!) with high characteristics, produced in all technologically advanced countries regardless of the need for RKT.

The pressurization system is one of the most important subsystems of the LV, both from the economic and functional points of view. The pressurization systems are part of the pneumohydraulic fuel delivery system to the rocket engine and are one of the most difficult parts of the launch vehicle. Their significance is determined by the fact that its mass can reach 7% of the final mass of the stage and the fact that the this system largely forms the design of the propulsion system and the LV. Also, it determines the pre-launch preparation time, the structure of the starting position, the number of staff and the amount flight testing.

To pressurize the fuel tanks of modern rocket engines working on these components, helium was widely used as a working fluid for a number of reasons. Helium pressurization systems objectively have a number of advantages, due to which they have been successfully used for more than fifty years. They are sufficiently well studied, the technology of working with it is debugged at all stages of the work. Helium pressurization systems do not need a large amount of experimental testing, the high qualification of power system designers, which, perhaps, is the main argument of their popularity in the world. It is known that helium pressurization systems are the most expensive parts of LV after their liquid propellant rocket engine (LPRE) [3].

Due to the world's largest distribution of hot helium pressurization systems, there can be an impression of their increased reliability. However, it is not. Because of them, only in recent years there have been more accidents than because of much more complicated LPREs. So, the accident occurred on the LV Falcon-9 (three times), LV "Angara" [4].

History shows that earlier in the RST, the generator, steam and other autonomous pressurization systems were used as widely as possible without using additional resources from the start.

One of the main reasons, due to which today simple steam pressurization systems for oxygen tanks are not used, is the fear of condensation of a small amount of water vapor and carbon dioxide inside the tank. In modern LPREs with afterburning of oxidizing gas turbines of booster pumps operate on this gas, which is then discharged into the oxygen supply line. The amount of possible condensate is estimated in hundredths of a percent.

Let us consider possible ways of eliminating the condensation of water vapor inside the oxidizer tank [5]. As is known, condensation can be volumetric and superficial. For the occurrence of volumetric condensation of water vapor, it must be supersaturated. Therefore, in order to eliminate this condensation, it is necessary to raise the gas temperature in the free volume of the tank as quickly as possible and to ensure that the saturated vapor exceeds its partial pressure in the tank.

It should also be noted that the presence of impurities in the gas significantly inhibits the condensation of any constituent of the gas mixture in the volume under consideration. In the case we are considering, the impurities are not less than 95% (oxygen vapor). Also at the initial moment of the work of the pressurization system, the partial pressure of the water vapor in the tank is zero. This provides a short time without conditions for volumetric condensation.

The problem is proposed to be solved as follows. During the precharging stage, a working fluid with a temperature above the oxygen temperature is injected into the free volume of the tank. This method leads to an increase in the pressure of saturated water vapor at the mean mass temperature of the gas in the free volume of the tank. In other words, the potentially possible amount of water vapor increases with further boosting in the gas volume at the achieved temperature. At the stage of positive boosting with oxidizing generator gas after the turbine from the moment of starting the propulsion system, it is necessary to reduce the costs of water and carbon dioxide in the working medium of the pressurization, for example, using silicagel. At the same moment, the time for the reduction of water and carbon dioxide consumption in the working body of the pressurization should not be less than the time at which the mass-average temperature of the gas in the tank will ensure that the saturated vapor pressure of its partial pressure exceeds the pressure. Also, during this period of time, it is necessary to provide the speed and direction of the injection of the working body of the pressurization that its jet does not fall on the free surface of oxygen in the tank.

When used as a working fluid to pressurize liquid oxygen after the pump, it is proposed to reduce the water and carbon dioxide costs in the working pressurization in two stages, first - after the high-pressure pump to the heat exchanger inlet, mechanically filter the working heat, in the second stage, after the heat exchanger , purify oxygen vapors with silica gel.

To ensure rapid evaporation and heating of oxygen vapors, it is advisable to heat the heat exchanger and the pressurization path up to permissible temperatures before the launch of the launch vehicle. To achieve the maximum allowable temperature of oxygen vapors at the tank inlet, it makes sense to use a high-temperature solid fuel gas generator as the coolant. After the heat exchanger, the reducing gas generator is expediently used for pressurizing the fuel tank or driving the turbine of the booster pump along the fuel line.

The filtration time (the mass of captured water vapor) determines the size of the filter and the mass of silica gel.

The shorter the filtration time, the smaller the mass of the filter elements. To reduce filtration time (~ 25seconds), it is necessary to increase the temperature of oxygen vapors, for example, by increasing the temperature of the coolant. Such technical solutions are already known.

To exclude surface condensation, it is sufficient that the injected gas does not reach the free surface of liquid oxygen. This issue is technically solved by means of devices with a floating reflector or radial gas guides.

The transition from the helium supercharging system to the pressurization system of the main component, in addition to significantly simplifying the design of the launch vehicle and the rocket site, allows reducing the total mass of the pressurization system, taking into account the use of the volume of the oxidizer tank freed from the helium balloons. For example, for the tank of the first stage of the "Zenit" launch vehicle, this transition will increase the mass of the payload (the mass of the satellite) by not less than 80 kg.

The fuel tanks can also be pressurized with purified liquid oxygen with evaporation inside the tank [6]. All the necessary safety requirements can be guaranteed.

Therefore, the introduction of such a proposed method makes it possible to consider the question of the complete elimination of the cold helium system from the side of the carrier rocket. This will significantly simplify and reduce the cost of the propulsion system, LV and raise the efficiency of the entire Ukrainian missile system.

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