Testing of spaceboard solid sate cryogenic accumulator for IR coolsystem equipment

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Abstract: The experimental results of a cold accumulator with the actuating fluids propane, nitrogen are reported in this paper.

Keywords: solid state cryogenic accumulator, phase transition, melting and solidification processes, cooling system resource.

1. INTRODUCTION

Aerospace purpose onboard cooling systems significantly differ in their resource, reliability, time of operation. Thus when the latest developments of throttle systems (for example, with pre-cooled actuating fluid [1]) have twice as increased time of operation, then having expendable actuating fluid, they are not suitable for space systems. Space cooling systems (for example, based on a gas cryogenic refrigerator (GCR)) despite their long life when operating in the shooting mode also require certain restrictions regarding vibration and conditions of heat transportation from a cooled object to the GCR. In connection with this fact use of a cold accumulator as part of the cooling system is perspective

A cryogenic accumulator (CA) is designed for cryostatting of lines with sensitive elements of an infrared radiation photodetector and other elements of the construction at a temperature level corresponding to the temperature of phase transition.

In a cryogenic container that uses fusion heat, phase transition [2] takes place almost without an increase in the specific volume of the actuating fluid, which allows multiple application of the container in case of cyclic freezing-thawing using a gas cryogenic machine. Use of the cryogenic accumulator with a photodetector allows to avoid unwanted system vibrations which usually accompany the operation of a gas cryogenic refrigerator (GCR) and lead to degradation of performance of photodetectors.

A disadvantage of cryogenic accumulator operating at liquid-gas transition is temperature non-uniformity of a cold-conductor during cryostatting due to an increase of pressure in the cylinder and a rise of boiling temperature accordingly [3].

The aim of this work is to study a cryogenic accumulator at liquid-solid body transition in order to determine the criteria for more rational use of the resource of a gas cryogenic machine, as well as to solve the problems of cryostatting temperatures range extension.

2. EXPERIMENTAL INVESTIGATION OF CRYOGENIC ACCUMULATOR

2.1 CRYOCONTAINER EXPERIMENTAL SETUP

To obtain objective parameters of the cryogenic accumulator its experimental sample was made and tested using nitrogen and propane. A design-layout scheme of the test sample is shown in Figure 1.

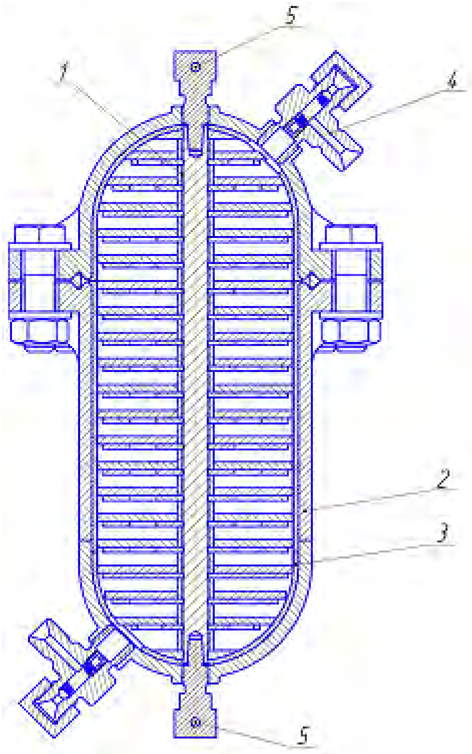


Figure 1 – Design-layout scheme of the cryogenic accumulator experimental sample

1 – cold conductor; 2 – pressure vessel; 3 - copper inner casing; 4 - charger; 5 - temperature sensors, sensors of connections to GCR cold conductors and thermal load sensors locations.

Basic technical specifications of the accumulator:

– actuating fluid - propane;

– filled actuating fluid weight (0,2 ± 0,01) kg;

– operating temperature of the test sample (phase transition temperature of the actuating fluid; "liquid phase - solid phase") in case of nitrogen filling - 63.2 K, in case of propane filling - 85.2 K;

– unconfined space of the inner cavity - 0.0005 m3;

– gas pressure inside the accumulator at T = 313 K in case of nitrogen filling is 42.2 MPa; in case of propane filling is 1.2 MPa.

The cryogenic accumulator is placed into a cooled housing (Figure 2) with a coolant temperature of the GCR fist stage, which allows to reduce the radiation flux to the accumulator. With the same purpose the experimental setup elements (cooled screen, cold conductors, "thermal" switch, etc.) are protected with screen vacuum insulation. To control the parameters and to carry out further analysis of the processes pressure and temperature sensors were installed (on the GCR, the cryogenic accumulator and on the cooled screen).

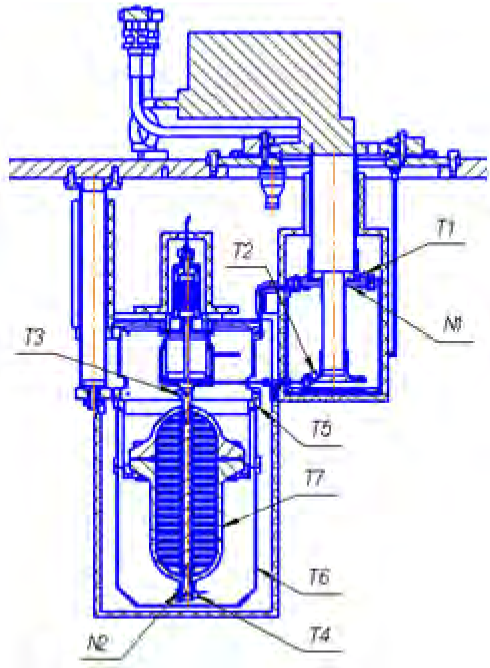


Figure 2 – Layout of the cryogenic accumulator in the container, temperature sensors and heaters location.

A heater installation (N2) on the cryogenic accumulator is provided to control the process of cryostatting during solid propane melting. Heaters, installed on coolers of the I and II stages of GCM are used to determine cryogenic machine cold-performance.

2.2 INVESTIGATION ASPECTS DESCRIPTION

Investigation targets

The following objectives were set during the tests of the experimental cryogenic accumulator:

- argumentation of the possibility of cryogenic accumulator operation on solid propane with a temperature level of 85.2 K for cryostatting of lens hood of infrared radiation band photodetector;

- assessment of the possibility of use of capillary action for liquid propane supply to the area of heat inflows to cold conductor of the cryogenic accumulator in order to ensure a stable temperature level;

- study of the process of cooling, solidification, and melting of the actuating fluid.

Investigation objectives

The current tasks of the experiment were:

- optimization of constructive solutions for the cryogenic accumulator (accumulator leakage test after improvement of cold conductor nodes of inlet into the casing),

- optimization of the technology of cryogenic accumulator filling ,

- determination of load characteristics of the cryogenic accumulator, required temperature driving forces of gas cryogenic machine stages (temperature driving forces required for processes of solidification and melting of the actuating fluid within a reasonable time intervals)

- estimation of efficiency of the thermal blanket, thermal bridges of the cryogenic accumulator suspension for implementation of the planned thermodynamic processes in the system.

During the tests of the cryogenic accumulator assembly three cycles of propane crystallization and melting were carried out.

Investigation results

The test results of the cryogenic accumulator are given for the cryogenic accumulator operating on solid propane.

The analysis of temperature and pressure growth in a container at a total heat gain of 0.25 W was conducted according to the following formula:

$$\Delta P = \frac{q \cdot r \cdot d\tau}{M \cdot Cs \cdot T(\upsilon'' - \upsilon')}$$

where q - heat leakage power, W; r - heat of vaporization, J/kg; M - mass of the component, kg; υ"- vapor phase specific volume, m3/kg; υ'- liquid phase specific volume m3/kg; Cs – liquid phase heat capacity at saturation line; ΔP - pressure rise in volume, Pa; dτ - process duration, sec.

The correlation for ΔP is obtained from the Clausius-Clapeyron formula for the phase equilibrium curve.

To maintain the boiling temperature within the ranges of 77 .. 82 K the pressure in the cryogenic accumulator should not rise above 1.6 105.. 2.0 105 Pa, which can be realized when the process lasts for 3.5 .. 5 hours depending on the level of heat leakage.

The system can be reset (77 K and 0.097 MPa) at a power of GCR N = 1 W during 2.5 – 3 hours depending on the level of heat leakage.

Calculation data of a temperature regime of the cryogenic accumulator during thermal conditioning of plates of the IR photodetector using a phase transition in nitrogen are shown in Figure 3.

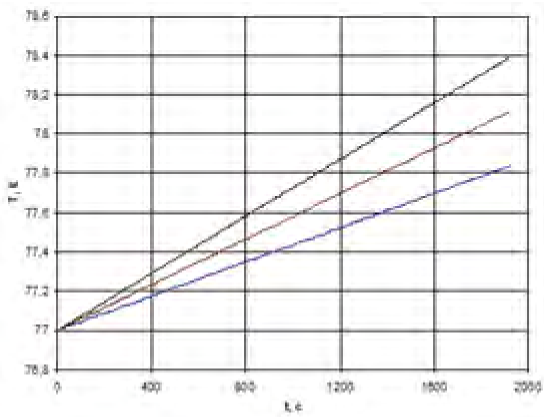


Figure 3 – Temperature change of the cold conductor of an accumulator operating on liquid nitrogen by time for different thermal loads.

Figures 4 and 5 show a temperature curve for a system with an accumulator operating on solid propane. Cycle time tc of a combined system is equal to:

$$t_c = t_a + t_{ac} = \frac{1}{n} \cdot t_{ol} \cdot \lambda + t_{ca}$$

where ta - time of accumulation of cold, produced by GCM during actuating fluid freezing; tac - time of object cryostatting using the accumulator during actuating fluid melting; tol – GCM operational life; n - number of cryostatting cycles; λ≤1 – multiplier that takes into an account operational life reduction in case of multiple switching of the cryogenic generator (GCM).

Minimum required cooling performance of GCM is determined by:

$$N = N_0 + \frac{M \cdot r}{t_a}$$

where N0 - heat load on the accumulator during cryostatting (external parasitic heat leakages); M - weight of the actuating fluid; r - heat of fusion; ta – time of system preparation for cryostatting.

A graphical representation of the temperature on the experimental setup of elements in a cryogenic accumulator operating on propane is provided in Figures 4 and 5.

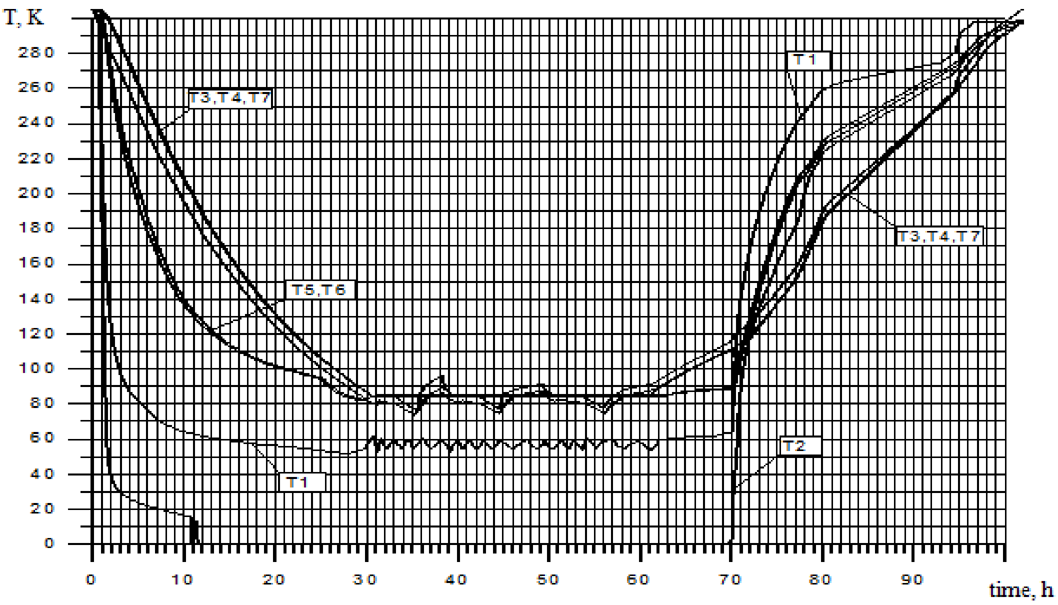


Figure 4 - Temperature curve during the testing process (propane)

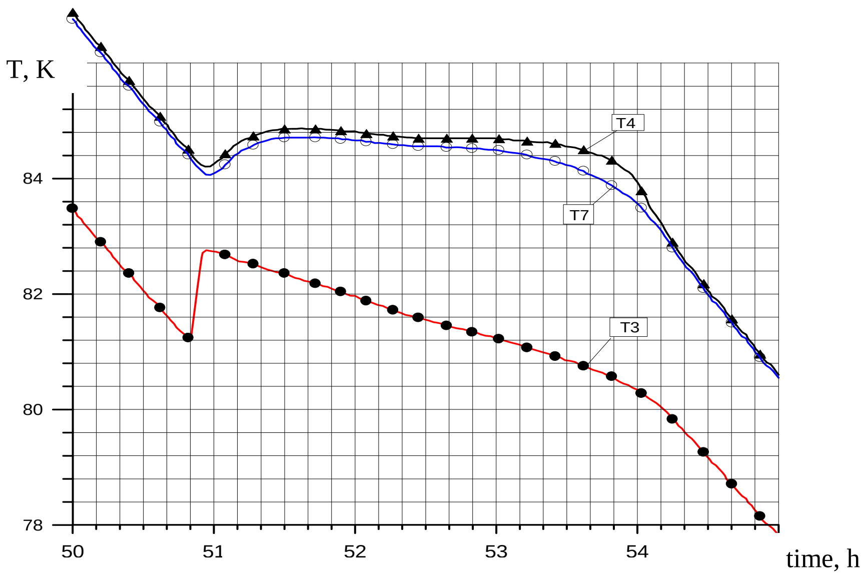
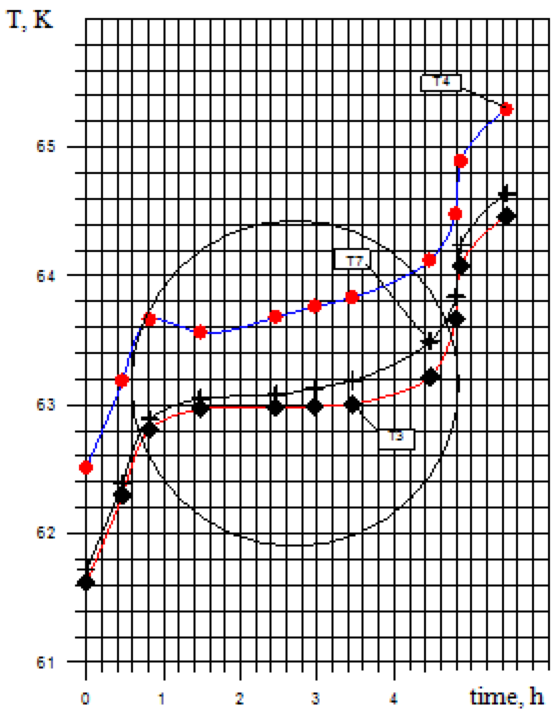


Figure 5 – Temperature change during propane crystallization (third stage)



Nitrogen melting temperature T=63.2 K

Figure 6 – Change of the system temperature at the segment of actuating fluid (nitrogen) melting.
T3- cold conductor temperature, T4- casing bottom temperature, T7- casing wall temperature.

A temperature curve for the cold conductor when testing the accumulator operating on nitrogen is shown in Figure 6. The experiment confirms high stability of cryostatting temperature in the process of solid-liquid phase transition.

In the process of cryostatting the gas cryogenic machine is switched off and thermal coupling with the cryogenic accumulator should be interrupted (by "thermal" switches or electromagnetic interruption from the control system).

Analysis of chilldown and solidification process

Chilldown time of the system operating on propane to a temperature of ~ 85K was about 30 hours in the experiment (Figure 5). A high gradient of pressure decrease in the accumulator holds for ~ 10 hours, hereinafter up to the start of solidification the speed of pressure reduction was low.

The nature of solidification process is shown in Figure 5. The process of propane solidification starts at a temperature slightly below 85 K, and lasts for ~ 2.6 hours (sensors T4 and T7), while the temperature at the cold conductor T3 is (1 .. 1.5) K lower than the temperature of solidification (maintenance of the temperature head by Gifford – McMahon’s machine takes place).

Analysis of the process of propane melting

Three sections of propane melting implemented during the tests are shown in Figure 5. All the sections are characterized by 3 .. 3,5 K higher temperature in the heater T4 zone.

Readings of the sensor T3 on the cold conductor monitor the temperature of propane melting in practice, readings of the sensor on the accumulator casing T7 are 0,5..2 K higher than the melting point.

The duration of the melting process (cryostatting) is about 2.5 hours (except for the first "stage", where the melting process duration is ~ 1.2 hours due to the high power thermal flux (~ 4 W) supplied by the heater N2).

Evaluation of the heat leakage to the accumulator made according to the heat of melting is 1.77 W

Since the melting process involves heat absorption both from propane, and from the accumulator design, the actual heat leakage to the actuating fluid will exceed this value.

3. CONCLUSIONS

1. The test results showed high efficiency of propane as the actuating fluid for cryostatting elements of IR photodetectors at a temperature level of ~ 85.2 K.

2. The high level of melting heat (~ 80 kJ/kg) allows to increase the time of cryostatting significantly using a small amount of an actuating fluid (0.2 kg of propane allow to carry out the cryostatting process for about 2.6 hours at a heat load of ~ 2 W). Propane mass M = 0.5 kg allows to conduct cryostatting of an object with a load of 0.46 W for 24 hours, the time of system setting up is ~8hours at a power of GCM of ~ 1.85 W.

3. To extend the range of cryostatting temperatures it is advisable to use hydrocarbon mixtures as an actuating fluid when designing cryogenic accumulators for cooling systems.

4. A system with a cryogenic accumulator operating on solid propane, all other conditions being equal, allows to significantly increase the total time of cryostatting and to make the operational life of the cooling system equal to 32000 hours at the gas cryogenic machine operational life equal to ~ 10,000 hours, while ensuring high temperature stability.

CONFLICT OF INTEREST

The author confirms that this article content has no conflict of interest.

ACKNOWLEDGEMENTS

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