The Combined Power Generation in Pre-Start Thermostating Systems

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Abstract*: Modern requirements to the operational parameters of pre-start thermostating systems require a new approach to their creation or upgrading. Therefore, there is a need to consider the possibilities of using the combined power generation in pre-start thermostating systems. Launch vehicles include the equipment that requires certain temperature conditions for operation, which modifies its characteristics and disrupts normal functioning. The temperature also determines the characteristics of onboard power supplies, the reliability of the engine units and pre-start thermostating systems. For the normal functioning of pre-start thermostating systems, it is necessary to supply various combinations of power for the spacecraft. The recent open access publications were considered, including the combined types of power generation in pre-start thermostating systems. The thermostating systems of spacecrafts should have several sources of power, i.e. the combined power generation in pre-start thermostating systems has not been considered yet. The examination of the possibilities of using the combined power generation in pre-start thermostating systems. The thermostatic systems for performing the functions of pre-start thermostating systems are to have several sources of energy that will increase the reliability of their operation. Energy can also be supplied from an external source, which is essential for pre-start thermostating systems, especially in launch units. The possibilities of using the combined power generation in pre-start thermostating systems are considered, providing the reliability increase of their functioning. The application of mechanical, thermal, electrochemical and solar power plants, as well as the use of nuclear isotope and reactor power plants is suggested.

***Index Terms*: Pre-start thermostating systems, combined power generation, spacecraft, power plants.**

I. INTRODUCTION

Currently, the sharp competition of space goods and services on the global market urges its participants to provide their potentials in the shortest possible time, on the highest grade and at low prices without reducing the target efficiency of the space systems [1], [2]. The main obstacle during the market promotion is the high cost and duration time of the spacecraft (SC) creation, the launching devices, the pre-start thermostating systems, as well as the high cost of launches and a long time of their preparation. One of the options for making the launches cheaper, according to domestic and foreign experts, is a dramatic reduction in the mass of the SC.

For the space industry of Ukraine, it is important to ensure the competitiveness of launch vehicles (LVs) using carrier rockets (CRs) in the space services market. The experience of commercial use of CRs [3], [4] has shown that in connection with the requirement to create more comfortable conditions for modern SC there appeared tasks for upgrading and modernization of the staffed thermostating systems.

The ever-increasing use of CRs within the framework of commercial projects, their modernization in terms of expanding the SC compartment size, the creation of new CRs, substantiate the relevance of the new approach to the problems of modernization and development of pre-start thermostating systems.

A. Formulation of the Research Problem

Launch vehicles include the equipment that requires certain temperature conditions for operation, the change of which decreases its characteristics and disrupts its normal functioning. The temperature also determines the characteristics of the onboard power supplies, the reliability of the engine units, the propulsion of solid-fuel accelerators in the launch vehicles, of the engines of the emergency rescue system for SC and pre-start thermostating systems.

B. The aim of the research

For the normal functioning of pre-start thermostating systems, it is necessary to develop methods of supply a SC with various combined power plants types.

II. ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

Thermostatting of the fuel components provides the specified temperatures of the oxidant and the fuel component entering the engine, and the required density, as well as the thermostating of the cryogenic components, with the reduction of their losses due to evaporation. Thermostatting of the SC is designed to maintain the required air temperature in the compartments with the equipment, structural elements and separate units and devices (appliances, the serviced power sources, tanks, etc.), as well as to provide the life support of the astronauts during the prep aration for the start-up [3], [5].

The optimal temperature range depends on the design of the CR and the systems of the SC, on the type of the equipment installed, the fuel, the components used, the design execution of the engines with solid fuel, etc. Normally, for CR compartments and engines, the optimal range is from +5 to + 25°C, and for solid fuel CR and emergency propulsion engines of the spacecraft – from 0 to + 40°C or a positive temperature range without limiting the upper limit. For some CRs, the temperature range is not limited, and such launch vehicles can be prepared and launched without the use of any special thermostating devices at any ambient temperature [2], [6], [7].

For land-based SCs, the temperature range from +15 to +25°C is considered to be optimal, although some deviations from these values are possible. Thus, the air temperature in the working areas on a spacecraft or a space station is permissible from +10 to + 30°C. The temperature of 0 to + 15°C is considered to be the prevailing temperature for the food containers on a spaceship (spacecraft or station). The permissible temperature range of the SC after filling its fuel tank at the space station is limited significantly [4], [8].

Thermostating problems include both the heat supply to the elements of launch vehicles, and their removal. Heat is typically supplied when the launch vehicle is outside of the facility at low ambient temperatures (during transportation, in the starting position, etc.) and is distanced away from the starting complex; during the transportation of the launch vehicle ("the upper module") within the space center and in the launch system. In the pre-start system, as a rule, an excessive amount of fuel is removed from the internal volume of the spacecraft during electrical tests, as well as from the compartments where people are situated and operate. During transportation and in the start position the upper module is protected from high ambient air and solar radiation temperatures [5], [9], [10].

Thermal environment of the SC is sometimes supported by the joint work of the ground thermostating devices with an onboard thermal regulation system. As a rule, the onboard thermal regulation system of a spacecraft consists of two hydraulic circuits – the cooling one and the heating one. The excessive heat is removed from the inner space of the SC by the cooling circuit, which by means of an intermediate liquid-liquid thermostating heat-exchanger is connected to the external circuit – a system for maintaining the thermal conditions [3], [9], [11].

In the hydraulic circuit of the inner circuit, is maintained the temperature required for the work of the SC assemblies, which execute the heat removal from the compartments. The temperature in the circuit is regulated either by the change in temperature, or by the amount of the cooled heat-transfer fluid in the outer circuit, or by regulating the elements in the circuit itself. The heating circuit is also connected to the external circuit by way of using an intermediate liquid-liquid thermostating heat-exchanging unit; in this case, the heated heat-exchanger is fed into the outer circuit [2], [4], [12].

Air systems are also used to thermostate the systems of the launch vehicle to maintain the thermal conditions that provide and feed the heat-enchanger.

Proceeding from the analysis of the design features of the thermostating systems of the SC [4], [6], [7], [13], the new requirements to the characteristics of the system should be formulated. Previously, the requirements for thermostating systems were determined by the technical conditions for the parameters of the thermostatic air – the limits of change in temperature and humidity, the air volume flow, the excess pressure in the compartment of the spacecraft in the mode of the ground thermostating unit and at the moment of discharging the main shroud [2]-[7], [13]. The new up-to-date requirements for the thermostating systems consist in the additional valuation of its characteristics, such as:

- the level of average heat transfer coefficients when the cooling system is cooled by a general thermostating system;
- the level of average velocities of the thermostating air near the SC surface;
- the clean space of the SC compartment on the level of international standards;
- the level of average of heat transfer coefficients and air velocity for local cooling devices of heat-stressed SC units.

The additional requirements to the thermostating system can be met by the following design improvements of the existing thermostating systems [4], [6]-[8], [11], [13]:

- installation of additional intake elbows, which will increase the multiplicity of air exchange in the compartment of the spacecraft, if necessary;
- installation of water meters on the outgoing hatches of the thermostating system and membrane filters on the partitions between the compartment of the spacecraft and the device compartment (DC);
- installation of autonomous devices for local cooling of heat-stressed SC units;
- installation of lattices, perforated screens, panels, which provide a more consistent SC ventilation.

An important prerequisite for the CR launch is to provide temperature-humidity mode in its compartments during pre-start preparation before launching.

The current requirements to the thermostating system work parameters demand a new approach to its creation or modernization. First of all, it must be taken into account that the RC payload compartment, the SC compartment, should allow it to accommodate different SC types. At the same time, the change in payload can be ensured with minimal advancements of the SC compartment, including thermostating systems. Thus, it is necessary to create a thermostating system of a universal type, which allows to reconfigure the payload compartment in order to meet the comfort conditions, taking into account the SC diversity.

The optimal principle of design and construction of the thermostating system is a modular one, which consists in creating a unified system from individual modules. It simplifies the overall installation of various system options and makes setting and operation easy. Each thermostating system module should be a unified interchangeable unit that performs an independent function at different options for the thermostating system configuration.

Thermostating systems can be divided into the following modules:

- modules for air distribution (gas lines, collectors, pipelines);
- modules for side cooling of SC (perforated screens, nozzle blocks, shielded plates);
- modules of the frontal cooling of SC (sprayer screens, nozzles, reflecting devices);
- modules for local cooling of the units (nozzle blocks);
- generating modules.

All the modules must have

the unified docking units with quick couplings.

The basic design elements (inlet and outlet ports, perforated screens, output devices, etc.) for a given type of RC remain unchanged when using different SC. Additional variable elements (sprayer elbows, nozzle devices, guiding screens, etc.) take into account the specifics of the particular SCs.

The development of the modular structure of the thermostating system optimum mass must be performed taking into account the condition of its one-time use. This will allow the use of lightweight non-metallic materials, plastics for the construction of variable structural elements of the thermostating system. The average coefficients of convective heat transfer of the surface of the SC can also be enhanced by increasing the uniformity of the SC design, the level of flow turbulence, increasing its speed. For the compartments of the SC, the multiplicity of air exchange with thermostat with medium degree of filling the compartment volume of varies from 35 to 140. One of the main conditions for the modernization of available thermostating systems is to ensure the combined power generation.

The analysis of the constructive and functional characteristics of the existing systems of the RC thermostating shows that these systems do not fully guarantee the maintenance of the safety and efficiency of modern SCs, requiring enhanced cleanliness of the compartment space, lower level of thermal and aerodynamic loads on the SC. Therefore, the development of new thermostating systems and the modernization of the existing ones must be carried out at a qualitatively new technical level with the use of universal modular systems providing the combined power generation.

The modular principle of the thermostating system design consists in the creation of a system of separate modules, each of which is a unified interchangeable unit performing an independent function under different versions of the thermostating system design. This essentially simplifies the overall adjustment of system options and facilitates the setting up and operation of the compartment for various types of modern SCs and ensures the combined generation of energy in pre-start thermostating systems.

A. Identification of the Uninvestigated Aspects of the Problem

Thermostatic SC systems should have several sources of energy while the combined generation of energy in the pre-start thermostating systems has not been considered previously.

B. Setting the Objective

The purpose of the paper is development of complex methodology of the combined power generation systems for pre-start thermostating systems application.

III. Proposed Methodology

As it was shown above development of the efficient pre-start thermostating system is quite complex task which should include analysis of the up-to-date requirements list and considering of the modular design (figure 1).

Further analysis should include components of the system modules and requirements sets. Key components are generating modules which have to be used to power system modules and taken in account at analysis of the pre-start SC thermostating system requirements. Components of the main system characteristics could be also classified as general thermostating system parameters and local cooling devices which will be specified by the different requirements to the power system modules (figure 2).

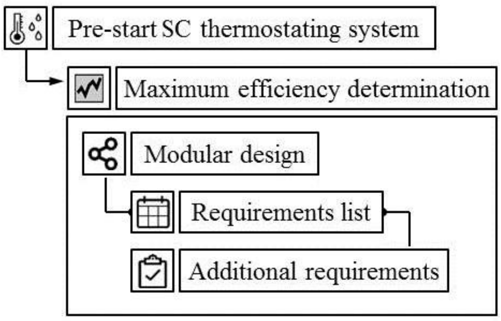

Figure 1 Basic diagram of pre-start SC thermostating system development

Thermostatic systems for performing the functions of pre-start thermostating systems should have several sources of energy that will increase the reliability of their operation.

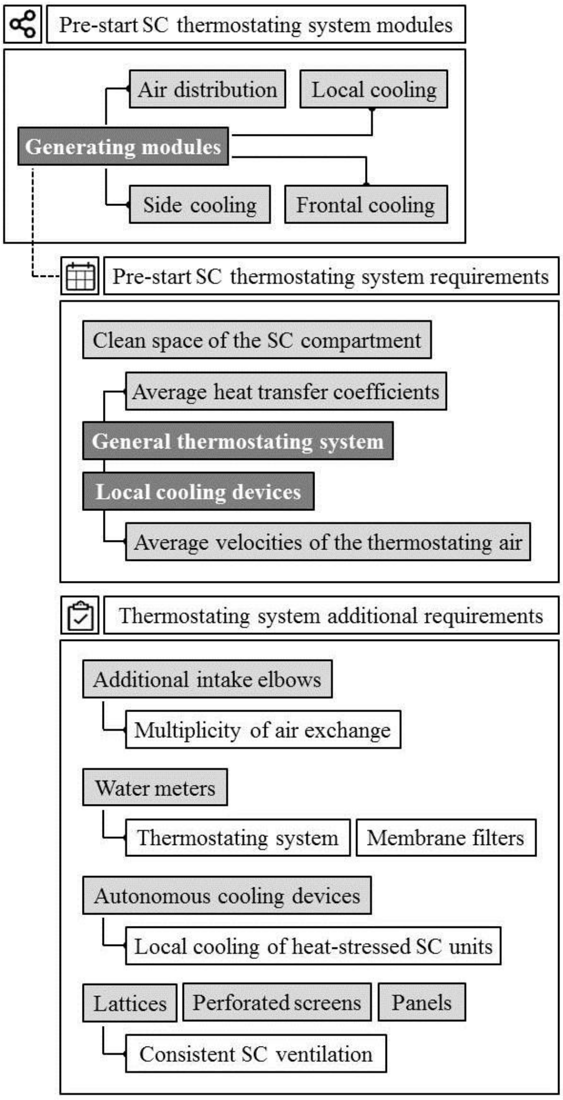

Figure 2 Advanced diagram of pre-start SC thermostating system development

Energy can also be supplied from an external source, which is essential for pre-start thermostating systems, especially in launch complexes. The entire variety of power plants can be classified according to the types of energy sources that provide power generation for the power supply of various systems, including those that can be used in the SC thermostating systems.

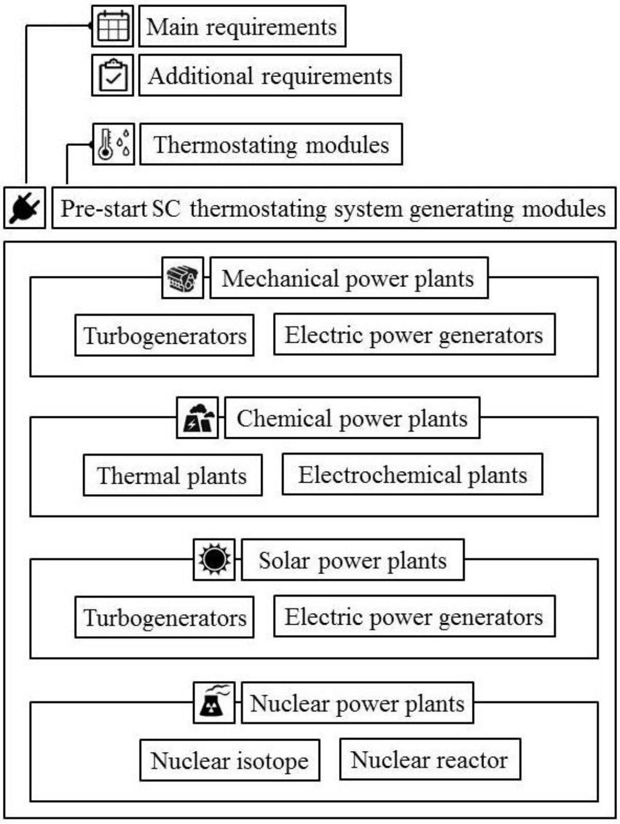

Figure 3 Diagram of pre-start SC thermostating system power plants application

We propose classify pre-start SC thermostating system power plants as follows:

- mechanical power plants that can be used to generate energy from a mechanical one. Such power plants are executed in the form of open cycle turbogenerators, which are rotated by compressed gas in high pressure cylinders, or electric power generators with a reaction wheel on gas-dynamic or electromagnetic bearings having a reserve of kinetic energy;
- chemical power plants that can be used to generate energy from chemical energy stocks which is produced by the interaction of two chemical components – the fuel and the oxidizer (for example, kerosene and oxygen, hydrogen and oxygen, etc.). Chemical power plants are divided into thermal and electrochemical. In such thermal power plants, the chemical energy of the fuel and the oxidant is obtained as the heat of combustion, which then must first be converted into mechanical energy using an open cycle turbogenerator, or an internal combustion engine with an electromechanical generator, or a magnet-hydrodynamic generator of open cycle with subsequent transformation into the electric energy. In electrochemical power plants takes place a direct transformation of the chemical energy of fuel and oxidant into electric on the basis of electrochemical reactions. Battery packs and electrochemical generators based on fuel cells can be electrochemical sources of the current.
- solar power plants that can be used to generate energy using solar fluxes of light. These power plants are

divided into the thermal and photoelectrical ones. In such a thermal power plant, the concentration of radial solar energy takes place with the help of mirror-concentrators, in the focus of which is the heat-receiving device, where the transition to thermal energy occurs. Next, the transformation of thermal energy into electricity takes place; the dynamic or static converters are used. The dynamic converters include gas turbine or steam turbine closed-loop converters, the Sterling engine with an electromechanical generator; to static converters – thermionic and thermoelectric converters, where thermal energy is directly converted into an electric without a mechanical phase. In the solar photoelectric power supply plant, solar energy is directly converted into the electrical energy, with the use of photoelectrical converters incorporated into the solar cells;

- nuclear isotope power plants that can be used to generate the thermal energy from radioactive decay of isotopes. The conversion of the thermal energy to electric energy occurs on the basis of dynamic or static converters. The linking of static thermoelectric or thermionic converter units occurs around isotopic thermal sources that are radioisotope generators;

- nuclear reactor power plants that can be used to generate electrical energy from the thermal energy generated during the course of chain nuclear reactions. The transformation of thermal energy into electrical energy is carried out using static, dynamic or magnet-hydrodynamic converters of a closed circuit.

It was shown at the Figure 3 that pre-start SC thermostating system power plants' choice depends on the system module which has to be powered and full set of the module's requirements.

One of the opportunities for Ukraine to strengthen its position in the rapidly growing high-tech space services market is the development and use of space nuclear power, including in pre-start thermostating systems.

IV. RESULT ANALYSIS

The conducted analysis of the design and functional characteristics of the existing SC thermostating systems showed that the development of the new thermostating systems and the upgrading of the existing ones should be performed on a qualitatively new technical level using universal modular systems with the provision of combined power generation.

Performed investigation has shown relations between components of the system modules and requirements sets which allowed developing the methodology of the combined power generation systems for pre-start thermostating systems application.

V. CONCLUSIONS

The modular principle of the thermostating systems design consists in the creation of a separate modules system, each of which is a unified interchangeable unit, performing an independent function under different versions of the thermostating systems linking. This greatly simplifies the overall installation of system options and facilitates the setting up and operation of the compartment for various types of modern SCs, ensuring the combined generation of energy in pre-start thermostatic systems.

Thermostatic SC systems must have several sources of energy. Therefore, the possibilities of using the combined power generation in pre-start thermostating systems are considered in the paper, which will ensure the reliability of their operation. That said, it is possible to differentiate the use of combined power generation in pre-start thermostating systems using mechanical, thermal, electrochemical, and solar power plants, as well as to note the promising use of nuclear isotope and reactor power plants

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