Optimisation of the temperature control system of a geodetic space complex satellite

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Abstract. A frequency generator is used to measure the signal delay between two surveying space objects. Thermostatting allows an increased level of stability. The temperature control system is the main thermal mode support system onboard. The mathematical model of this system is considered in this article. The analysis of factors influencing on Earth Satellite Vehicle is carried out. The variant of protection against kinetic influences is offered.

1 Introduction

A global space-based geodetic network is currently being developed to support the Earth-wide coordinate system, geodetic support GLONASS, and orbital spacecraft missions [1].

Applications of Earth Satellite Vehicles (ESV) for coordinate-metric problems is based on their ability to be visible from large areas of our planet's surface. This makes it possible to extend the visibility range of terrestrial objects to the size of the satellite's line of sight, and thus create conditions for measuring the relative position of objects with unknown coordinates [2-5]. Determining relative motion parameters for ESV and ground objects is based, among other things, on measuring the transit time of an electromagnetic pulse between them. To measure the signal time delay between two objects, an electromagnetic pulse is generated at one object and sent towards the other, where it is received by a receiving device. Using a Coordinated Universal Time system (UTC), the time the signal is sent and received is recorded. The time difference makes it possible to determine the distance between objects. In this measurement scheme, UTC should be installed at both sites. Cooling and UTC thermostatting elements. The heat generated is generated by the equipment that is in operation inside the compartments.

The internal heat is generated by operating equipment inside the ESV compartments. The level of heat flux varies over time. Temperature deviations from the specified ranges can lead to failure of the respective instruments. Thus, the measuring system cannot function without a strictly defined temperature regime, which is ensured by an on-board thermostatting system ().

The heat transfer dynamics of the heat transfer process usually not only makes it possible to ensure the thermal ESV with high precision but can also ultimately lead to lower manufacturing costs TSS.

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Selecting the simplest parameters TSS is carried out at the initial design stage. In this case, it is acceptable to perform a simulation of the functioning of the system based on ordinary differential equations. Let us consider the construction of a mathematical model TSS based on the node method. Breaking it down TSS for \( n \) isothermal knots. In the general case the thermal interaction of the nodes with each other and the surrounding space can be represented as a system of ordinary differential equations:

\[
\frac{dT_i}{dt} = \sum_{i \neq j} k_{ij} (T_j - T_i) + \sum_{i \neq j} m_{ij} (T_j^h - T_i^h) + I_i^q (t);
\]

where \( T_i \) - average node temperature; \( k_{ij} \) - coefficients determining the convective heat transfer; \( m_{ij} \) - coefficients determining the radiant heat transfer between nodes; \( c_i \) - effective heat capacities of the units; \( I_i^q \) - external and internal heat load on the units.

The system of equation (1), supplemented by the coupling conditions, the governing equations and the initial conditions at time \( \tau_0 \), fully characterises the extended state vector of the system at the time interval in question \([\tau_0, \tau_1]\).

The flow rates in all circuits, the pipe diameters of a given length and the design parameters of the heat exchangers unambiguously determine the thermal state of the system of a given structure. They are the main parameters to be optimised, and their combination makes up the vector \( U = (U_1, U_2, \ldots, U_r) R^r \), which is the control vector. And \( c_i = c_i(U) \); \( k_{ij} = k_{ij}(U) \); \( m_{ij} = m_{ij}(U) \).

The system of equations (1) will be written as:

\[
\frac{dT}{dt} = f(T(t), U, \tau).
\]

Restrictions on system state variables and control variables:

\[
h_i(T, \tau) \leq 0, \ i = 1, \ldots, p;
\]

\[
g_j(U, \tau) \leq 0, \ j = 1, \ldots, s; \ \tau_0 \leq \tau \leq \tau_1,
\]

where \( p \) - number of temperature limits; \( s \) - the number of constraints on the independent design parameters.

The reduced mass of the system is determined by the functional dependence on the independent variables

\[
M = M(U).
\]

The constraints on the control variables of the form (4) can be time dependent. If we consider the optimisation of the highest value of the reduced mass TSS over the time interval in question, then the value of the target function (5) is independent of time. This can be achieved by introducing appropriate logical links at the programming level.

The modelling option considered is applicable for convective TSS and subsystems with changes in the aggregate state of the refrigerant. As an example, dynamic optimisation of the convective TSS, a diagram of which is shown in figure 1. The symbols here are: RHE – radiant heat exchanger; LLHE – liquid/liquid heat exchanger; GLHE – gas/liquid heat exchanger; \( Q_e \) – external heat flux; \( Q_i \) – internal heat flow; \( W \) – water equivalent. This TSS was split into 33 nodes, which ensured sufficient modelling accuracy. The flow rates and pipe diameters in the two fluid circuits and the radiation surface areas of the radiation heat exchangers were chosen as independent control variables.
Using the created methodology, the selection of design parameters for the constructed discrete TSS taking into account restrictions on design and mode parameters. Analysis of the obtained results showed that reduction of the reduced mass is achieved mainly by reducing the radiating surface area of the radiator heat exchanger, which allows reducing the number of radiator panels (taking into account the heat capacity of the radiator and the cooled equipment).

Figure 2 shows the steady-state periodic operation graphs for comparison TSS with parameters selected as a result of static optimization (lines 1,2,3), and system operation graphs with parameters obtained as a result of dynamic optimization (4,5,6). Lines 1,2,3 - refrigerant temperature at the inlet and outlet of the radiation heat exchanger, at the outlet of the gas-liquid heat exchanger, respectively. Lines 4,5,6 - temperature at similar points for TSS with the parameters selected as a result of dynamic optimisation. It can be seen from the figure that TSS, optimum for unsteady operation, operates at a higher temperature level without exceeding the permissible range. Selection of design parameters TSS, carried out in a real non-stationary operating mode, allows the dynamic nature of the heat exchange processes to be taken into account, improves the mass and energy characteristics of the system and therefore allows the parameters to be chosen more reasonably TSS.
In 2022, several accidents involving damage to the spacecraft hull were reported (SC) kinetic impact elements. Figure 3 shows the result of a breach of the aggregate compartment force structure with the destruction of the temperature control system pipework. In a real accident situation, several destructive factors are to be expected, e.g., impact ESV a meteor shower, a fragment of the old SC or other kinetic element [6,8-10].

The analysis has made it possible to bring together the non-regulated influences on ESV and possible consequences (outcomes) [7,9-11].

Let us present a particular indicator of the survivability of a satellite in orbit PL as the product of the probability of no unacceptable damage from flow defeaters $P_0^n$ and the likelihood of the absence of the same damage from single projectiles $P_0^f$.

Probability of penetration $n$ of particles of a flux of projectile masses $m_i (i = 1,2,3..., n)$ can be determined according to the formula

$$P_n = \frac{(nNF')^n}{n!} \exp\left[-NnF'\tau\right], \quad (6)$$

where $N_n$ – The average flow of a munition capable of causing unacceptable damage to a vulnerable surface ESV; $F'$ – exposed surface area; $\tau$ – the exposure time of the flux of lethal elements. Then

$$P_0^n = \exp\left[-N_nF'\tau\right]. \quad (7)$$

**Fig. 2.** Functional calculation results TSS.
Fig. 3. Effect of the kinetic striker.

The expression (6) shows that improving the survivability of a satellite in orbit can be achieved by reducing the exposed surface area. One option for achieving this is the use of a shield. In some cases, the installation of stationary shields may be undesirable. A shield with retractable elements should then be used [7,15-17]. The structure is already deployed after the ESV into orbit when all the necessary elements (antennas, solar panels, etc.) will be in the deployed state.

Installing a shield deteriorates the mass-dimensional characteristics ESV, However, this will prevent possible destructive effects on the site.

References

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