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System of Maintaining the Thermal Regime of a Space Radio Telescope

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Abstract—We present the results of developing a system of thermal regime maintenance for the onboard complex of scientific instruments of the space radio telescope installed on the *Spektr-R* spacecraft. The structure of the system of thermal regime maintenance is presented that includes a set of autonomous systems of constructive elements of the radio telescope. Basic schemes and composition of aggregates are presented, and main principles of operation of the autonomous systems supporting the thermal regime of the radio telescope are considered.

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INTRODUCTION

The onboard set of instrumentation of the space radio telescope (SRT) of the *Spektr-R* spacecraft is presented in [1, 2]. For all components of the onboard complex of SRT instruments the requirements to temperature conditions of their functioning as parts of the *Spektr-R* spacecraft are specified. The temperature requirements are determined by working temperature ranges of instrumentation units, as well as by requirements to geometrical stability of the SRT construction. The specified temperature conditions of exploitation are ensured by the system of thermal regime maintenance (STRM) of the SRT, which includes the autonomous STRM of each component of the onboard instrumentation complex.

SUPPORT SYSTEM FOR THERMAL REGIME OF CONTAINER WITH SCIENTIFIC INSTRUMENTS

The STRM of the container with scientific instruments (CSI) provides for maintaining the following temperature conditions of functioning for the units of scientific instruments mounted in a hermetic container: the temperature of gas at its entrance to instruments should range from 5–35°C. The scheme of SRT STRM and composition of STRM aggregates are presented in Fig. 1.

Container with scientific instruments (2) is installed in the cavity of passage framework (3) joining SRT spacer (4) with the spacecraft base unit. The required temperature regime of the units of scientific instruments mounted in the sealed container is sup-

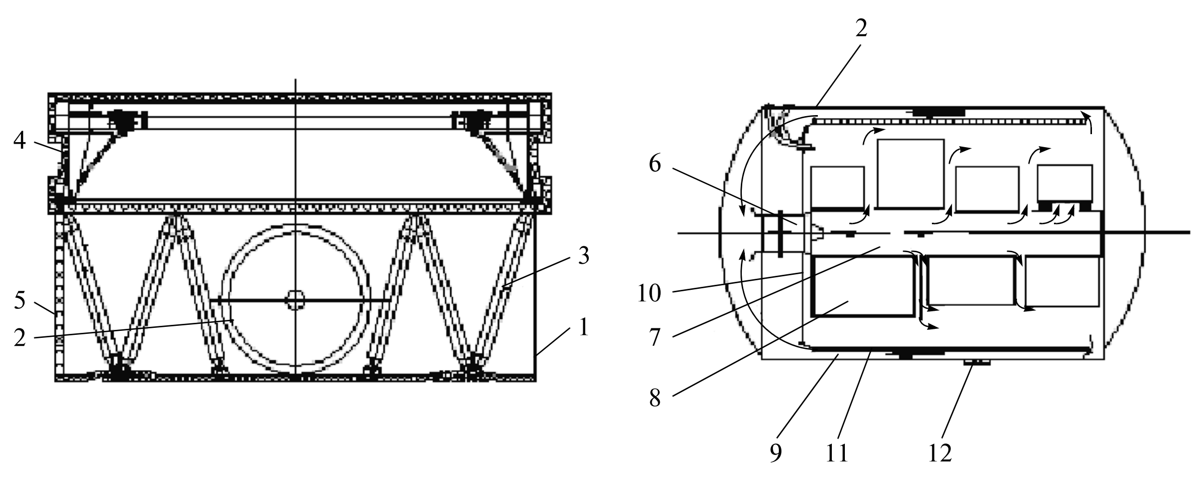

Fig. 1.

ported by a gas-circulation system of thermal regulation located inside the container and by means keeping normalized heat exchange of the CSI surface with ambient space (heat-regulating screen (1) and thermal insulation (5)). The gas pressure in the container with scientific instruments is 157 kPa, the volumetric capacity of the fan is no lower than 0.016 m^3/s, and the fan head is no less than 29 Pa. Gas circulation in the container proceeds like this. From fan (6) gas comes into instruments frame cavity (7). Passing through distributing holes in the frame, gas blows off blocks of scientific instruments (8) installed on the instrumental frame. After blowing off the blocks of scientific instruments gas enters eight gas guides (9) located inside on the container body. From gas guides, gas enters the common intake zone of fans, which represent a part of the CSI cavity separated from the general cavity by diaphragm (10) and located in the zone of the container base. Then, gas again comes to the fan and is directed to the instrument frame. In order to compensate for the deficit of heat (when instruments are out of operation), the electric heater (11) is installed on the gas guides. The electric heater consists of 16 sections mounted in pairs on each gas guide. Control thermal sensors (12) are installed on the gas guide to control operation of the electric heater. When the temperature of the SCI surface in the zone where control thermal sensors are installed falls down below +12°C, all sections of the electric heater are switched on and, when the SCI surface temperature in this zone is higher than +20°C, all sections of the electric heater are switched off. The heat released by block of scientific instruments is exported by the convective heat exchange to SCI surface; then, by way of radiation heat transfer, it is emitted from the body to surrounding space. The SCI outer surface has no thermal insulation and is covered by enamel paint with a high degree of blackness. In order to ensure normalized heat exchange of the SCI external surface with an ambient medium, a cylindrical heat-regulating screen is installed outside the passage frame. It is partially covered by screen-vacuum thermal insulation.

SUPPORT SYSTEM FOR THERMAL REGIME OF FOCAL CONTAINER

The system of thermal regime support for the focal container (FC) was designed to keep temperature conditions of functioning of FC instrumental units in the range of gas temperatures at the entrance to scientific instruments block from +5 up to 35°C. The scheme of STRM of FC and composition of the FC STRM devices are presented in Fig. 2.

The focal container is a part of the focal module. Gas parameters in the focal container are similar to those in the scientific container. Gas circulation in the focal container proceeds in the following way. Gas comes from fan (2) to the focal container cavity and blows off blocks (4) of scientific instruments installed

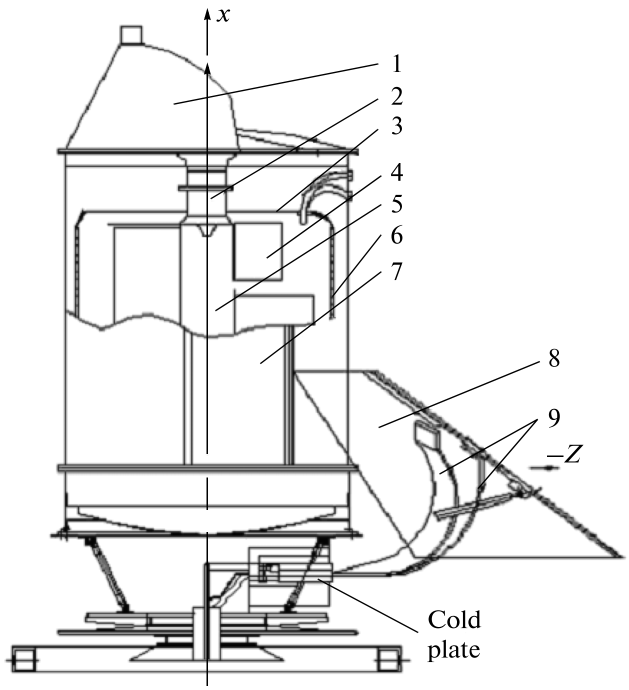

Fig. 2.

on instrument frame (3). After blowing off the blocks of scientific instruments the gas enters two gas guides (5) located on the body of focal container inside it. From gas guides gas enters a mixer installed on the focal container cup, and it comes again to the fan. The heat released by blocks of scientific instruments is exported by convective heat exchange to FC body; then, by way of radiation heat transfer, it is emitted by the body to ambient space. To ensure normalized heat exchange of the focal container body with environment the focal container external surface is used, on which there is no thermal insulation. Radiation surfaces (7) represent a part of the cylindrical surface of the focal container body and the surface of the focal container cup. The radiation surface was covered by enamel paint with a high degree of blackness. For a guarantee of preventing direct solar radiation from hitting the FC radiation surface at standard orientation of *Spektr-R* object in its working orbit, there is a special protective screen (1) on the focal container body. In order to compensate for the heat deficit, when the focal container is exploited as a part of *Spektr-R*, three-section electric heater (6) is installed on the surface of gas guides. The operation control of the gas heater is realized by control thermal sensors. When temperature in the zone where the control thermal sensors are installed falls below +10°C all sections of the electric heater are switched on, while at a temperature in this zone higher than +25°C, all sections of the electric heater are switched off. The external surface of the focal container is covered (excluding the radiation surface) by screen-vacuum thermal insulation.

SYSTEM OF SUPPORTING THERMAL REGIME OF COLD PLATE

The cold plate (CP) with instrumentation installed on it (low-noise amplifiers, LNA) and block of antenna exciters (BAE) is mounted at the SRT focal node point. The STRM of the CP is designed to keep the required thermal regime of mounting sites for LNA and BAE: temperature for LNA mounting sites should be kept in the interval from −123 to −183°C, while for antenna exciters the interval is from −73 to −143°C.

The general appearance of CP STRM construction within the focal module is shown in Fig. 2. The CP STRM includes the following basic components and elements: radiator (8), heat conductors (9), and screen-vacuum thermal insulation. The radiator of the CP STRM is placed of the shadow side of the focal container and consists of three flat trapezoidal sections combined with each other in a single unit. The radiator is arranged on the FC in such a manner that its working surface should avoid being exposed to emission of SRT reflector and relatively warm segments of the FC surface. The radiator back surface is covered by screen-vacuum thermal isolation. To ensure the necessary strength of the construction upon its injection using a carrier launcher the radiator is rigidly fixed to the FC, i.e., in the middle of the upper part a supporting arm is used together with a spherical hinge, while in middle parts of the lateral trapezoidal sections, there four sticks. After the injection segment the rigid ties between the radiator and FC are uncoupled. For this purpose there are hinges on the stick ends at places of their junction with the container. On the other sides, the sticks have calking elements with pyrocartridges. After release using springs, the sticks are lowered down (in the direction of the *X* axis) and are fixed by arresters. In order to limit conductive heat flows to the radiator, the heat resistance of the upper element of fastening the CP STRM radiator to the container (spherical hinge with a cantilever) is normalized and, in the construction, there are inserts made of materials with low heat conductivity. This scheme of fastening the radiator allows one to reduce the stress produced by the CP STRM construction on the focal unit, which is necessary in order to diminish thermal deformations and to ensure stable position of receiving devices of BAE at the geometrical focus of the SRT reflector. The coating of the working surface of the radiator has a high degree of blackness and small coefficient of solar light absorption. Material of the radiator and heat conductors is an aluminum alloy with high heat conductivity at low temperatures. Cases of LNA have coatings with a small degree of blackness. Constructions of heat conductors and of the cold plate with LNA installed on it are concealed by screen-vacuum thermal insulation.

SYSTEM OF SUPPORTING THERMAL REGIME OF PLATFORM WITH RADIO-TRANSMITTING EQUIPMENT

The system of supporting thermal regime of the platform with radio-transmitting equipment (RTE) is designed to keep the temperature of a matching site of the monoblock of radio transmitting device in the range of temperatures of 0–40°C. The RTE platform is manufactured in the form of a channel bar whose lateral faces are thermally stabilized bases (TSB). Blocks of two sets of radio-transmitting equipment, STRM electric heaters, and control thermal sensors are installed on the inner surfaces of the RTE. When exploiting the instrumentation, only one set of equipment is in operation, and the second one is kept under standby conditions. The RTE platform is manufactured from an aluminum alloy with high heat conductivity.

The external surface of each RTE is a radiation surface. In the process of exploitation the radiation surfaces are subject to action of direct solar radiation; therefore, they are covered by a coating with a high degree of blackness and small coefficient of absorption of solar radiation. A three-section electric heater is installed on the inner surface of each RTE. If the RTE temperature at the place where control thermal sensors are installed is lower than +5°C, all sections of electric heaters are switched on; at RTE temperature at control thermal sensors place that exceed +7°C, all sections of electric heaters are switched off. The outer surface of the RTE platform (excluding radiation surfaces) is concealed by screen-vacuum thermal insulation.

SYSTEM OF SUPPORTING THERMAL REGIME OF PLATFORM WITH INSTRUMENTS OF PHASE SYNCHRONIZATION

The system of support of thermal regime of the platform with instruments of phase synchronization (IPS) is designed to keep the temperature of matching sites for phase-synchronization instruments in the range of 0–40°C. The IPS platform construction includes a frame with a plate fixed on it. Instruments of phase synchronization are mounted on this plate manufactured from an aluminum alloy. The plate is fastened to the frame by a heat-conducting paste. The phase synchronization instruments are placed on the plate surface from the side of a pencil-beam antenna. On the opposite side of the IPS platform facing the ambient space, some elements of the wave-guide transmission line of the antenna-feeder system (AFS) are located with two-section electric heater and a group of control thermal sensors.

The IPS platform surface that faces the side of the open space and is free of elements of the wave-guide transmission line of the AFS, is a radiation surface covered by a coating with a high degree of blackness and a small coefficient of solar-radiation absorption. In order to compensate for a negative thermal balance, a two-section electric heater is installed on the IPS platform surface. The electric heater is switched on and off in accordance with readings of the group of control thermal sensors. If the IPS platform temperature where control thermal sensors are installed is lower than +10°C, the electric heater is switched on and, if the temperature of the IPS platform where the control thermal sensors are placed exceeds +25°C, the electric heaters are switched off. The outer surface of the IPS platform (including the platform surface with elements of the wave guide transmission line and instruments of phase synchronization and excluding radiation surfaces) is concealed by a screen-vacuum thermal insulation.

SYSTEM SUPPORTING THERMAL REGIME OF SRT REFLECTOR AND SPACER

The system of supporting thermal regime of the SRT reflector is designed to keep the temperature of a frame tube of the SRT reflector petal in the range of −50 to +50°C and the temperature of the petal blanket surface in the range of −160 to +90°C.

The parabolic SRT reflector consists of 27 petals that open up in space. They are installed on 27 supporting arms of the SRT spacer together with constructing elements of the mechanism of deployment of reflector petals. Each petal of the SRT reflector consists of a structural tube of the petal frame, petal blanket, and bearing supports fastening the blanket to the structural tube. The petal blanket is made as a three-layer construction including carbon-filled plastic jackets and aluminum honeycombs, the structural tube consists of three sections of carbon-filled plastic tubes.

In order to compensate heat drains, eleven electric heaters are installed on the structural tube of each petal. The electric heaters installed on 27 petals are divided in nine groups, each of which includes electric heaters mounted on three adjacent petals. The state of each of nine groups of electric heaters is only controlled in the mode of time regulation, and no provisions are made for the mode of temperature regulation. During the standard operation of the SRT after the deployment of the reflector, the duty cycle of the operation of the electric heaters of the STRM reflector is equal to 0.78; in this case, seven groups of electric heaters are energized simultaneously. In order to reduce uncontrollable heat exchange with the ambient medium, the petals of the reflector on its outer side are concealed by screen-vacuum thermal insulation.

The RTSM of the SRT spacer is designed to keep temperature of the SRT spacer in the range from +5 to +35°C with a temperature drop on its height of no more than two degrees. The SRT spacer is a cylindrical construction including an upper bulkhead, cylindrical shell, and lower bulkhead. The lower bulkhead of the spacer is fastened to the frame of the instrumental module. In the zone of the upper bulkhead of the SRT spacer, the SRT central mirror is installed and the frames on which the focal module construction is mounted are also fixed to it.

Two semi-ring thermal tubes are installed on each bulkhead (upper and lower). In order to compensate for the heat deficit in the course of exploitation of the SRT spacer, one electric heater is installed on it in the middle of each thermal tube. Control thermal sensors are installed on the bulkhead surfaces in order to control the operation of electric heaters. At a bulkhead temperature in the zone where the control thermal sensors are installed that falls below +19°C, the corresponding electric heater is switched on and, when the bulkhead temperature in this zone exceeds +21°C, the corresponding electric heater is switched off. The external surface of the SRT spacer is concealed by screen-vacuum thermal insulation.

SYSTEM SUPPORTING THERMAL REGIME OF ONBOARD HYDROGEN FREQUENCY STANDARD

The SRT onboard hydrogen frequency standard (OHFS) is an instrument two sets of which are installed on the SRT spacer. The OHFS RTSM is designed to keep the temperature in the zone of matching sites of bases of OHFS cases within the limits +30 ± 5°C and support the temperature with an accuracy of ±1°C during the entire time of carrying out the experiment with the SRT onboard *Spektr-R*. The rate of variation in the temperature of OHFS case base in the matching site zone should not exceed 0.3°C per hour over time intervals that are important for scientific experiments. These time intervals are 1000 s and 13 h; one measurement of the average temperature is performed for 1000 s and 13 h (maximum) and separate two adjacent measurements between which temperature should not change by more than a specified value.

The OHFS RTSM includes the following basic components: radiator, matching bases of OHFS, heat-conducting path of OHFS bases, collector, and the heat conductor of the radiator. Axial heat pipes form heat-conducting paths for the OHFS bases. The heat-conducting path for the radiator is based on a contour heat pipe which consists of evaporator, compensation cavity, pressure regulator, transport channels, and condenser (the latter is located in the zone of passage of the contour heat pipe through the radiator). The radiator of OHFS RTSM is placed in the hole of central mirror of the SRT reflector. In order to reduce radiation heat exchange with environment the cases of OHFS instruments, heat-conducting paths, collector, and the back surface of the radiator are concealed by screen-vacuum thermal insulation.

In order to prevent the heat-carrying agent (ammonia) from freezing up in the heat-conducting path of the radiator, an electric heater is installed on the heat conductor. The operation of this heater is controlled using data of the control thermal sensors installed on the radiator. The electric heater is switched at a temperature of the radiator in the zone of installation of control thermal sensors below −50°C and, when the radiator temperature in the zone of installation of control thermal sensors is higher than −30°C, the electric heater is switched off.

The system functions in the following way. Heat flux from an operating instrument comes to OHFS matching base through a junction (conductive coupling) between the instrument and matching base. A heat-conducting path that represents a heat pipe in the form of a ring is embedded into the matching base. The heat flow is extracted to the collector along the heat pipe. From there, it goes to the evaporator of the heat-conducting path of the radiator (contour heat pipe), through which it is transferred to the radiator. The heat flux having reached the radiator is emitted into open space.

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