Part 2. Systems for providing of isothermal mounting faces for the devices installed

Sources:

- V. Baturkin at all. Component thermocontrol system on the basis of heat pipes for scientific device compartment of small space laboratory “REGATA”, Proceedings of 8 IHPC, Beigin, PRC, 1992, report E-1
- V. Baturkin at all. Heat pipe application for thermal stable bench arrangement in small satellite design, 30th ICES, Toulose, France, 2000, report 00ICES –114

ABSTRACT

Results of the examination of autonomous system supporting heat regime for the device compartment of small cosmic laboratory in the design "REGATA" are presented. Special system feature is the combination of flat device panels with heat pipes of constant conduction mounted in those and heat pipes of variable conduction for the temperature control on all stages of flight. The fundamental technical characteristics of the system are: the level of operating temperatures of a device compartment (283...303) K, the heat release of devices (0...240) W.

In the thermocontrol system the aluminium heat pipes with ammonium and the stainless steel gas-filled heat pipes of with ammonium and nitrogen as a non-condensable gas are used.

INTRODUCTION

For the investigation of Sun-planet connections, tasks of space astrogeometry, examination of plasma and so on it is offered as quite advisable to create spacecrafts of small dimensions and fabrication-cheap, deciding the problem of one (or two-three) experiment(s). One of such developments, executed by Institute of space research (RAS, Moscow) is a small space laboratory (SSL) for the realization of a design "REGATA" with helpful device loading more than 40% of its mass. The major distinctive characteristic of SSL is the passive uniaxial sun orientation system, using the pressure of Sun luminous flux on a stabibizator (sail). This device has provided during 50-60 hours of the SSL flight (injection time) the stabilization of a spacecraft spatial position and its keeping in operating conditions of durable time.

The feasible trajectory of SSL motion on stages of it injection and operating position, as well as an approximate laboratory arrangement are showed on Fig.1. Fundamental elements of SSL are the solar batteries 1, based on a principle of solar energy concentration, device compartment, formed by panels 2 with devices 3; elements provided the heat regime and emitting radiators 4 and 5, solar sail 6 with the mechanisms of it opening and control.

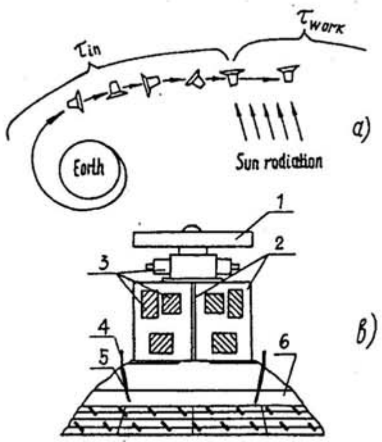


Fig. 1 Schemes of main stages of SSL operation (a) and its principal parts (b).

The preliminary computations of heat balance have illustrated, that in the time of injection on an orbit ($\tau < \tau_{in}$) the device compartment and devices have a tendency to cooling up to the level 210 K. This fact can produce negative consequences for device workability.

The technical demands, maked a claim to the thermocontrol system (TCS), are presented below:

- TCS should provide the temperature of mount places of devices on carrier panels within (298 ± 10) K in the operating regime of station and not go below (278...283) K on an initial trajectory section ($\tau < \tau_{in}$), duration of which can attain 60 days;

- maximal heat flow, released by devices in operating regime, equals 240 W however, in some standard conditions it can be decreased down to 0 W;
- TCS is a structural unit for the devices' mounting and should also provide the isothermality of mount places of devices not exceeding 5 K;
- TCS should possess by minimum lag and bulk; not exceeding 55 kg (together with device panels);
- the technical decision in a form of passive TCS without mechanical elements on the basis of radiative heat exchange, possessing by high reliability for 7 years old of the experiment and by absence or minimum value of the power consumption, has a priority.

CONCEPTUAL PRINCIPLES

Analysis of starting demands to TCS has concluded to following principles. TCS has following elements: four isotermal device panels, for the every panel the autonomous system of gas-filled heat pipes, for every panel the autonomous source of subsidiary heat energy.

The principal scheme of unit complete set is presented on Fig.2 (in the device compartment 4 complete sets at whole). Here and further will be discussed the unit complete set characteristics. The composition of the complete set: 1 - device panel; 2, 3, 4 - heat pipes, mounted in inside panels; 5 - devices; 6 - heat pipes of subsidiary VCHP radiator; 7 - subsidiary VCHP radiator; 8 - VCHP; 9 - main VCHP radiator ; 10 - VCHP reservoirs; 11 - source of subsidiary heat energy.

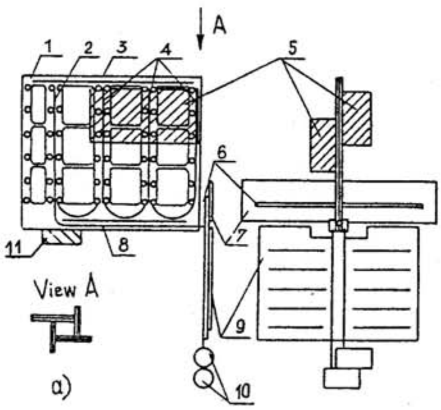


Fig. 2 Design of single set of thermo-control system and method of TCS's combination in device compartment (a).

TCS operates as follows. The heat flow from a source of the heat energy through the contact surface has been passing in zones of the positioning of HP 2, 4 and VCHP 8. By means of HPs the part of heat flow is spread, practically, on whole surface of device panel 1 and provided with maintaining of the panel temperature on a predescribed level and compensation of heat losses into environment. The another part of heat flow is supplied to VCHP 8, reached to radiators 7, 9 and removed in the outer space.

Parameters of all system and the VCHP construction are computed so, as the temperature of mount places of not operating devices was not below the lower limit of their permissible operating temperature.

When SSL has pass on the operating orbit and standard devices have begun functioning, it has been arisen the complementary sources of heat, summary heat load of which on the panel from devices has attain 60 W. The fundamental regulating function, in this case, accomplishes by VCHP 8 and it radiators 7, 9. By the computations it was instituted, that to the moment of approximation of the temperature of mount places to upper limit (maximum heat temperature to the panel) the radiator 9 of VCHP 8 has opened for the heat release onto (70...80) % of it surface.

CONSTRUCTIONS OF ELEMENTS OF THE TERMOCONTROL SYSTEM

1. Device panel

The device panel (Fig.2) is the double-layer flat construction 1 with dimensions 0.69 x 0.75 m making of aluminium alloy . Every layer has thickness 0.01 m and contains from inside the five semispherical flutes of 0.014 m in diameter beneath HP 2, 3, 4. The connection of those elements into panel is performed by means of screws.

The fixing of devices 5 is provided for by means of through openings with the certain step by horizontal and vertical. The connection of panels itself in the unit forms in plan the cross-like form (see Fig.2). Space, being formed by surfaces of neighboring panels, is the compartment, which is filled up by scientific devices and equipment, placed on surfaces of panels 1.

In isotermal panels it is used up three standard sizes HPs, made of aluminium casing, outer diameter 0.014 m with grooved capillary structure, filled by ammonium as a heat-carrier. One HP 3 has a recti-linear form (L = 0.63 m); the rest of the HPs (2, 4) have bending in one plane with different radiuses. Three of them (of type 4) have 0.82 m in length with the radius of bend R = 0.09 m, and HP 2 (L = 1.2 m) is made with the radius of bend R = 0.06 m.

By the application of such scheme it were decided the tasks of: assuring of an every HP independence; collecting of the heat from devices and it transferring to VCHP; heat input to devices from a panel, equalization of the panel surface temperature and provision of the heat connection between all heat pipes and also redundancy of heat transferring canals.

2. Variable conductance heat pipe

System for the heat control of panels is based on an application of gas -controlled heat pipes VCHP 8 in the amount 2 pieces on each panel. The VCHP casings are made of stainless steel with 0.012 m in diameter and combined capillary structure in the form of thread and gauzed arteria.

The pipes have the Γ-like form and are fixed by one beam (heating zone) by means of flanges onto lower part of the panel (see Fig.2), and another - on emitting radiator 9 . The total length VCHP was 0.96 m, lengths of heating zone 0.38 m, of transport zone - 0.12 m, of condensator 0.465m. VCHP has cold reservoir with metall-fiber wick. It was considered the variant of use of the compact reservoir temperature regulator too.

For an increase of the radiative release area, except main radiator 9 the complementary radiator 7 is used. The heat connection of radiator 7 with the condensation zone of VCHP is fulfilled by heat pipes 6. These HPs have 0.01 m in diameter and grooved structure.

Simplified heat scheme of the complete set "devices-panel-VCHP" is presented on Fig.3.

The panel has conditionally parted onto four subregions (heat transferring canals), corresponding to heat pipes 2, 4´, 4˝, 4´´´. The devices with a heat capacity C and heat release Q are connected through heat resistance R_{d-i} with proper heat pipes.Every canal is characterized by the temperature of vapor space Tv. Heat pipes have a contact with the heat pipe T_{v3} and with zone Tc. In this zone it is arranged the contact with a source of complementary heat energy (Cad, Qad) and two gas-filled heat pipes, characterized by vapor temperatures $T_{v(1)}$, $T_{v(2)}$. The abstraction of a heat energy is discharged into environment with varying temperature $T_o(\tau)$.

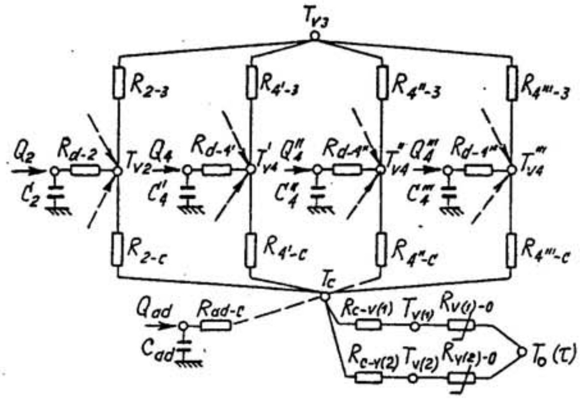


Fig. 3 Thermal scheme of TCS.

EXPERIMENTAL INVESTIGATION OF MOCK-UP OF THERMOCONTROL SYSTEM

Experimental examinations of heat characteristics of the system are provided for following stages:

- investigation of panel characteristics (examination of separate heat pipes before assembling, of panel characteristics in an assembly, qualified tests);
- examinations of VCHP (separately and in assembly);
- examination of the complete set "devices-panel-VCHP ";
- examination of a compartment mock-up from 4 complete sets.

1. Panels test results

Characteristics of aluminium heat pipes with diameter 0.014 m and grooved structure have following orders (at T_v = 293 K):

- maximum heat transfering ability near 100 (W m),
- heat transfer coefficient

in a heat supply zone 2000...3000 W/m^2K,
in a condensation zone 3000...5000 W/m^2K.

The heat pipes normally functioned at heat flow densities in a heat supply zone up to 2,5 10^4 W/m^2, temperature irregularity by perimeter did not exceed (0.5...1)K at flows up to (40...80)W and increased to (5...7)K at Q attains Qmax.

It was conducted examinations of the influence of heat supply irregularity at the panel surface on the isothermality. Four simulating heater were mounted on panels in a zone most removed from heat supply. Areas of heater contact with the plate are accordingly 84, 84, 107 and 53,5 sm^2 at heater lengths 21, 21, 28.6 and 28.6 sm. Non-isothermality of panels is rose at the heat-supply irregularity increase

(Fig.4). So, under conditions Q4´= Q4" = = 20 W, Q4´´´= Q2 = 10 W the temperature difference on panel attains 2,5 degrees, and in the case of the abruptive expressed irregularity of heat releases (Q4´= Q4" = 30 W; Q4´´´= Q2 = 0) - up to 5 degrees (see Fig.4).

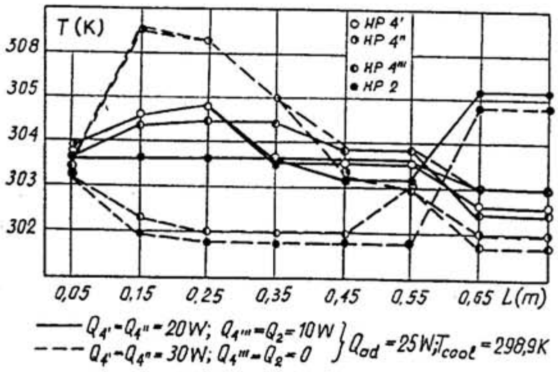


Fig.4 Results of testing of device panel at normal condition.

2. Results of VCHP tests

VCHPs primarily were investigated in normal conditions at the heat abstraction by convection and radiation. The supplied heat capacity was 5...120 W at horizontal and tilt (up to 0.01 m) position of the plane of pipes. The range of evaporator temperature adjustment began with 10 W, maximum heat transferring ability was not less 80 W, resistance "flange-vapour" was 0.08·K/W. Data obtained into normal conditions were recomputed for the prediction of characteristics in conditions of radiative heat release by means of analytical model VCHP. In the case, if predicted characteristics meet demanded ones, VCHP was studied in a vacuum chamber with the simulation of operational conditions. By analogy, it was explored the assembly of two VCHPs. Connection of heat pipes in parallel, main and subsidiary radiators construction had guaranteed the abstraction of a heat capacity not less 80 W by both one and two VCHPs, that would raise the reliability of a whole system.

3. Results of TCS investigations

The unit complete set "devices - panel-VCHP" was studied in a vacuum chamber in conditions, simulating different heat transferring mechanism. The complete set was mounted on lowconductive holders in vacuum chamber, the panel plane had been leveled. Devices, panel and non-emitting surfaces of radiators were installed by vacuum heat insulation. The external radiative fluxes were simulated by film heaters. In the course of the experiment it was simulated the flight stages after separation from carrier ($\tau < \tau_{in}$) and the operating regimes ($\tau > \tau_{in}$). Some typical results are presented on Fig.5. The part A corresponds to the time $\tau < \tau_{in}$, when devices and the system of power supply do not function, heat supply in the system Qad = 25 W is from the autonomous source of a heat flow. The average temperature of panel and devices has been stabilized at the level 278 K, temperatures of radiators and reservoirs of VCHP are near (160...180) K. Sections "B", "C" and "D" correspond to different conditions of heat loading on devices 45 W, 60 W, 0 W. The maximum average temperature of devices on section "C" does not exceed 303 K, that corresponds to requirements.

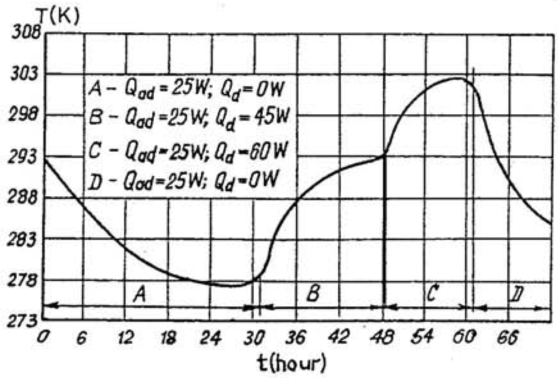
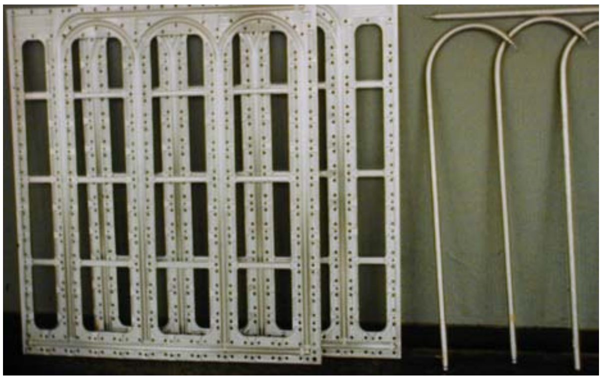


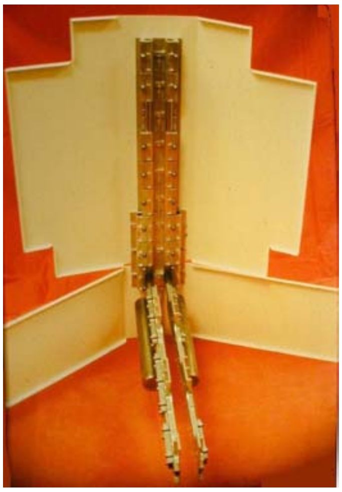
Fig. 5 Resalts of TCS´s examination in vacuum chamber.

CONCLUSION

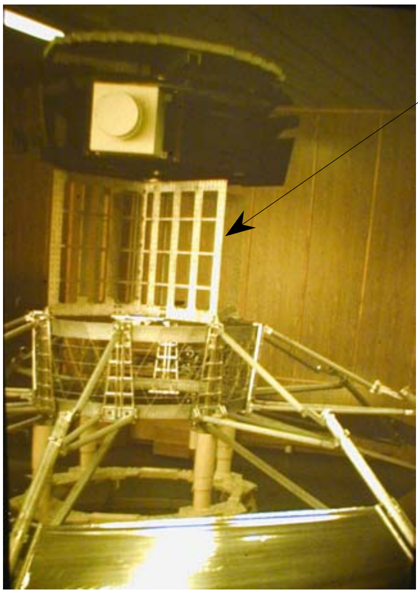
It was showed the construction principle of large-scaled isotermal device panels with handled temperature. Executive devices for the assuring of isothermality are heat pipes with constant heat resistance, ones for the adjustment of temperature - VCHPs. Every device panel has the helpful area equals to 1 m^2 and allows to mount in an arbitrary place up to 70 kg of device equipment with the heat capacity 0...60W at panel mass 9 kg. The use of complementary source of heat energy (mass 2,5 kg), as well as VCHP (mass 2,5 kg) does system enough independent from an operation of the space laboratory power supply system and external conditions. The achieved range of temperature adjustment is (278(283)...303) K at all disturbances simulating from minimum up to maximum values.Developed construction principle of TCS had used in the designs of series "REGATA".



Mounting panels and heat pipes before assembly



VCHP for passive thermal control



4 Mounting Panels with Heat Pipes embedded

Bus of Small laboratory “Regata” with thermostable mounting panels, scientific compartment (on top), fiberglass rods for solar sail

Part 2.1. Thermal stable structures with heat pipe usage

Terminology "Thermal stable structure" supposes the ability of structure to provide the required temperature regime and geometric positioning of object installed. For most payloads the second function is not critical and most of structural materials with different coefficient of thermal expansion (CTE) can be used for structure manufacture. Mainly for high precision optical devices above-mentioned requirements are realized by two technical solutions used in parallel (thermal control and mechanical design with implementation of low CTE materials). Nevertheless there are some examples where both designs are combined in one unit and heat pipe fulfill both structural and thermal functions.

In [1, 2] the principle of thermal stable 3-D girder is considered. Heat pipe ramified system is intended to re-distribute heat generated by devices and external fluxes coming from the Sun and the Earth and to carry the payload about 600 kg (figure 2).

Other sample of thermal stable structure is presented in [3, 4]. Here the inner shell of coaxial stainless steel heat pipe was used as mechanical support and simultaneously as isothermal coating for high precision gyroscope. Regulated temperature level and minimal temperature variations (along the length 0.3 m they do not exceed 0.3 K) give possibility to reduce temperature strain of inside located components even at inner power generation of 30 W.

So, in the certain conditions when the tasks of heat regulation are being solved together with geometrical stability of object the heat pipes can be useful means. Aspects of this technical problem is subject of separate analysis.

2.1.1. Heat pipe implementation in BIRD satellite design

The technical description of BIRD project (German Aerospace Center – DLR) and small satellite features are described in [5, 5]. The technical requirements to parallelism of optical axes of payload optical instruments

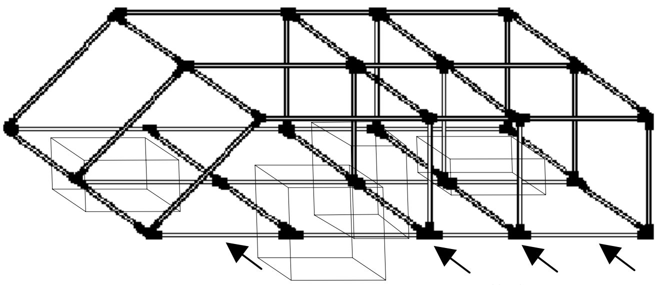


Figure 1. Scheme of isothermal part of 3 D girder design with overall dimensions 2965 x 1700 x 700 mm

The temperature uniformity of large size load-bearing girder reaches several degrees under one-sided radiation heating that allows to achieve the temperature strain on level 0.1 mm at basic length 3 m. All components of girder are made of aluminum alloy, capillary system – grooves-based, working liquid - ammonia.

(figure 4) and to geometric location of focal planes have initiated the selection of baseplate design as the assembly of two carbon fiber/ aramid honeycomb structures with embedded between them 3 mm layer of Carbon Fibre Carbon (CFC) - material with low coefficient of thermal expansion. This layer has high thermal conductivity (155

W/mK). It fulfills the functions of heat transfer line between payload devices and heat pipe flanges which are attached to opposite sides of payload platform. Further heat energy is transported by heat pipes to main radiator located in service segment area. Heat energy transfer can be realized in both directions that prevents overcooling of payload device in non-operating conditions. Large thermal mass of main radiator smoothes the variation of external heat fluxes (solar, Albedo Earth and IR Earth), including shadow phase.

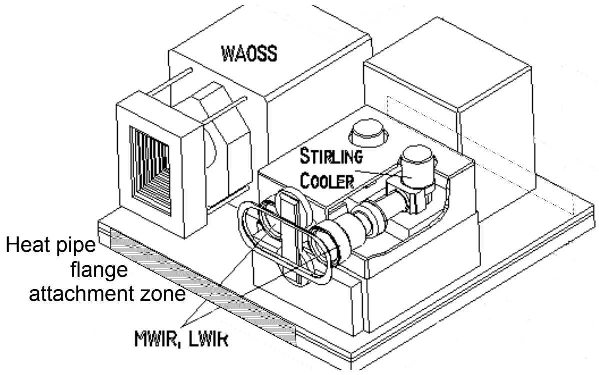


Figure 2. Payload optical instruments: WAOSS (Wide Angle Optoelectronic Stereo Scanner), MWIR (Medium Wave Infrared Sensor), LWIR (long wave Infrared Sensor) location on payload platform

Two symmetrically located heat pipes are applied. Operational temperature range is –20 ÷ + 50 ^{0}C with maximal heat flux transferred up to 50 W and temperature difference 5 K between flanges in heat input and output zones.

Reference to Addition 1

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