ISSN: 0975-766X
CODEN: IJPTFI
Available Online through **Research Article**
www.ijptonline.com

THERMAL CONTROL SYSTEM OF THE ROBOT OF ANTHROPOMORPHOUS TYPE FOR WORK IN SPACE NEAR ISS AND ON THE MOON SURFACE

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Received on 25-10-2016 *Accepted on 02-11-2016*

Abstract:

This article describes operating conditions of a robot of anthropomorphous type (RAT) in the outerspace on a low Earth orbit, where the environment lacks convective component of the heat exchange. Thermal control process of emissivity and absorptanceof the surrounding environment is shown. Direct and reflected solar radiation in-orbit thermal loads are examined. The general concept of thermal design of RAT and its thermal control system are described. Details of the thermal control tests of the RAT are given; results of preliminary thermal calculations are discussed.

Keywords: Robot of anthropomorphous type, radiant and conductive heat exchange, conductive thermal communication, radiation slope, emissivity, solar absorptance, sunlight simulator, external heat flux (EHF), contact thermal resistance, multilayer insulation (MLI),thermal blanket, heaters, thermal sensors, thermal vacuum chamber, nitric screens, diagrams of distribution of temperatures.

Introduction

Usage of robots for handling operations on space objects will allow expanding the number of operations and range of use of these objects [1]. For these purposes systems called the robot of anthropomorphous type (RAT) are developed and made: RAT manipulative system, system of management of RAT and thermal control system of RAT [2, 3]. Currently requirements to constructive and technical characteristics of thermal control system of RAT, the functional scheme of control system of RAT, requirements to constructive and technical characteristics of the RAT manipulating system are developed; calculations of the thermal modes in different conditions of its functioning in the outside space are carried out, the program and technique of thermal vacuum tests are developed.

Results of the developed design documentation, the RAT manipulating system provides the attitude, orientation and the positioning of the grapple in service zone matching the one a human.The sizes of manipulating system at the maximum number of links make no more than 350 x 610 x 1170 mm.It meetsthe following requirements:

- Number of degrees of freedom on each manipulator without degrees of mobility of grapples - not less than 6;
- Speed of the power units - to 30 grad. / with;
- Payload capacity - not less than 5 kg;
- Positioning accuracy of the operating part of the manipulator - not less than 10 mm.

The control system of RAT provides management of the RAT manipulating system. As the operating range of movements of the operator in the vertical plane sector 140 ˚, in horizontal - 120 ˚ is accepted; the maximum radius of zone of service makes 690 mm.

Control system of RAT consists of:

- The device for registration of control signals - the device of the copying type (DCT) with the encoder fixing turning angles in each kinematic couple (for registration of movements of the hand it is necessary to use the accelerometer and gyroscope for receiving three turning angles of the wrist);
- The device to transform the managing signals - the personal computer of the operator to which DCT is connected;
- The device to form and deliver the managing signals - consisting of the motherboard, power unitsof the motors and other necessary devices;
- System of video registration of the working area of the robot;
- Graphical user interface of the working area of the robot;
- System to transfer the information from RAT to the operator (and other way around).

To provide the thermal operation mode during the work of the RAT in the conditions of the outside space its thermal control system (TCS) is created. It bases on thermal emissions of engines of the manipulator, additional heaters, thermal sensors, radiation surfaces with preset values of emissivityand solar absorptance. Part of the surface of the RAT is covered with multilayer insulation (MLI) or thermal blanket. The programs of thermal vacuum tests are developed.

Next sections consider the development of the thermal control system.

Boundary Thermal Conditions for a Robot Working In Outer Space.

The major factor determining RAT design temperatures is theemissivity and the absorptance of surrounding space [4].

When there are no internal thermal emissions from RAT, within several hours from initial temperature of +20^{o}C(so-called "reference conditions") it will come near to 4^{o}K (residual temperature of the relic radiation). Expected autonomy of the robot does not provide its thermal communication with the satellite and receiving heat fluxes from it. Therefore, the heat emission in surrounding space and maintenance of the temperatures, admissible for RAT, can be provided only due to heat emission the internal construction and concealment ofthe RAT in MLI.

Carrying out calculations and tests of the design in the mode“Surfusion, Storage” the 1st limit worst option is imitated: the robot is in the environment with temperature T= 4˚K andabsorptance degree ε=1in all directions. External heat fluxes of RAT, heat emission caused by operation by the engines the RAT are absent.RAT is covered by a thermal blanketwith 20 layers with effective thermal resistance of 20 K/W*m^2 (MLI-2V-20). The RAT body has significant area and will demand heatersof considerable power to maintain in the comfortable range of temperatures without MLI. The body covered with MLI according to preliminary estimates will demand heaters with power no more than 15 W. The manipulator is not going to be covered withMLI because ofthe high thermal emissions in its design during the work and its small sizes.

Let's consider the 2nd limit worst option: “Overheat, Work mode”. The robot is in the outside space around ISS or on the Moon surface (in both cases - around Earth orbit); it is in the way of a direct solar radiation with the density of about 1400 W/m^2. Certain additional contribution (up to 30% in case of the ISS) is given by the albedo and the planetary radiation. It is necessary to consideraging and degradation of the properties of the outer coating of the RAT, increased with time of its solar absorptance. It brings to an increase in temperature equilibrium of the surface lit by the Sun and as a result a temperature rise of internal components.

Also it is necessary to consider elements of surroundings: they can hide up to half of the surrounding cold space area and to considerably reduce heatlosses. Operation of the RAT on the surface of the Moon where the maximum temperature can reach +120 ˚C will be the most adverse from this point of view.

At the same time internal thermal emissions in engines can reach tens of watts that for space operation are big numbers. Tentative estimations show that the described factors of the “Overheat, Work” mode establish values of the temperatures on the RAT exceeding admissible values 80 ˚C. It will demand installations of additional radiation surfaces on manipulator (which will increase heat radiation in the “Surfusion, Storage” mode), or pauses in the operation of the manipulator.

So, when carrying out calculations and planning tests in the “Overheat, Work” mode the 2-d limit worst option is imitated: the design of RAT has the minimum cumulative value of angles of radiation (the minimum so-called radiation bond) with the outside space, the maximum As of outer surfaces, corresponding to the value of the end of the term of active existence (TAE). At the same time the albedo and planetary radiation have the maximum value. Also the operation of the manipulator with the maximum power consumption and the maximum heat emission in engines is imitated.

Long-term experience of working in the space industry shows that even at production of the same space products, the results of calculations which are based on thermal models with known characteristics can differ by tens of degrees from real data from experiment.

It is caused, firstly, by a big uncertainty in determination of values of thermal conductivity of configuration items in the vacuum. The second factor is the dispersion of emissivityε and absorptanceof As of surfaces. The third factor is an uncertainty of coefficient of thermal resistance of MLI at a small standard sizes (as for this RAT) and large number of excesses and insertions. Therefore at this stage priority is to carry out thermal vacuum tests.According to results the models will be adjusted further.

Preparation for the thermal Vacuum Tests of TCS of Rat

Currently a model of the RAT representing fragment of the body of the robot to which the manipulator fastens is produced. The manipulator is assembledfrom standard engine blocks. The model of the engine and the designed elements provide the characteristics declared above in introduction. The RAT body is covered by the MLIto prevent excess thermal losses and lowering up to the temperatures to critical. Elements of the manipulator keep working capacity at temperature not below - 40 ˚C.

At the moment it is planned to investigate the opportunity to provide minimum temperatures of these critical elements in the “Surfusion, Storage” mode without the use of MLI. Necessary thermal emissions are going to be received, giving certain low values of electric power on the electric motor of each joint in its waiting mode. Film heaters of special space production will be the second heat source. During the forthcoming tests it is going to be determined the electric powers of the first and second sources by each joint of the manipulator of the robot, necessary to maintain the above-stated minimum temperatures. Also it is going to be found what are the temperatures of the manipulator will be during the mechanical operationsand the conditions of the maximum in-orbit thermal loads. For this purpose configuration items according to Figure 1, are equipped with research thermal sensors (T1 … T11) andheaters (H1 … H7).

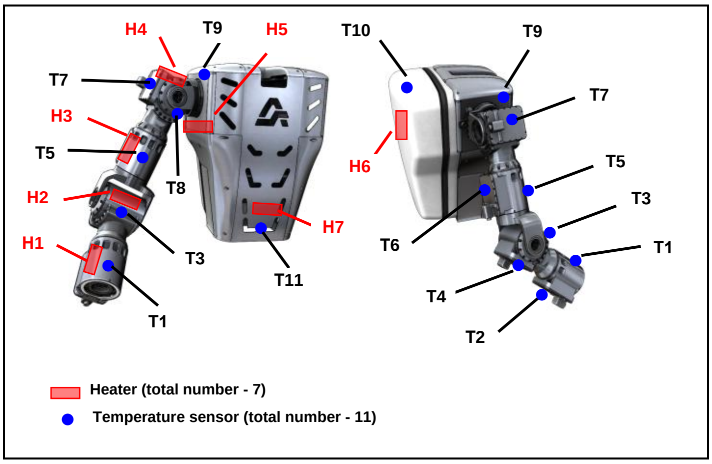

Figure 1 – Position of temperature sensors and heaters on the RAT.

Thermal vacuum tests are carried out in the thermal vacuum chamber (TVC). Used elements:

- System of vacuum pumping;
- Cryogenic of TVC;
- Simulators of heat fluxes (SHF);
- System of measurement of temperature parameters;
- Control system of wattage of SHF and the heating elements.

The TVC bench provides the following external conditions for the object of tests:

- Chamber pressure - no more 1×10^{-4}mmHg;
- Temperature of internal cryogenic screens of the camera - minus (170±10) °C;
- Emissivity of the cryogenic screens of the chamber - not less than 0.9 at 20 °C;
- Solar absorptance chamber screens - not less than 0.9;
- Measurement error of power consumptions of electric heaters of the TCS no more than ±2%;
- Measurement error of power consumptions of the SHF panels no more than ±5%;

The modes of thetests are given in Table 1.

Table 1.

Test mode	Task solved	Characteristicconditions
Mode 1 «Surfusion 1»	Obtaining values of temperature at imitation of minimum levels of external thermal loads and the first power level of TCS heaters of the model (30 W). The manipulatorof theresearch object	Pressure in a chamber no more 1×10- 4mmHg. Temperature of cryogenic screens - minus (170±10) °C. Temperature of a basic support - minus 20 °C.

Test mode	Task solved	Characteristicconditions
	(RO)is in a state of "rest".	The external thermal stream is absent. Mode duration - before achievement of a steady thermal state (<1 °C/h). Approximateduration - 6 h.
Mode 2 «Surfusion 2»	Obtaining values of temperature at imitation of minimum levels of external thermal loads and the second power level of TCS heaters of the model (20 W). The manipulator of RO is in the state of "rest".	Conditions carried out in mode 1
Mode 3 «Surfusion 3»	Obtaining values of temperature at imitation of minimum levels of external thermal load and the third power level of TCS heaters of the model (10 W). The manipulator of RO is in the state of "rest".	Conditions carried out in mode 1
Mode 4 «Overheat 4»	Obtaining values of temperature at imitation of maximum levels of external thermal load. The manipulator of RO is in the state of "rest".	Pressure in a chamber no more 1×10- 4 mmHg. Temperature of cryogenic screens - minus (170±10) °C. Temperature of a basic support is -50 °C. Mode duration - before achievement of a steady thermal state (<1 °C/h)
Mode 5 «Overheat 5»	Obtaining values of temperature at imitation of maximum levels of external thermal loads. The manipulator of ROmaking standard movements in the mode 1 (internal thermal loads).	Conditions carried outin mode 4. Way of control of the manipulator of RO - in automatic (or manual) mode using instrumentations and automatic equipment of RO (in operating mode 1)
Mode 6 «Overheat 6»	Obtaining values of temperature at imitation of maximum levels of external thermal loads. Manipulator ofRO producing standard movements in the mode 2 (internal thermal loads).	Conditions carrying out in mode 4 Method of control of the manipulator of RO - in automatic (or manual) mode using instrumentations and automatic equipment of RO(an operating mode 2)
Mode 7 «Overheat 7»	Obtaining values of temperature at imitation of maximum levels of external thermal loads. Manipulator of RO	Pressure in a chamber no more 1×10- 4 mmHg. Temperature of cryogenic screens - (21±5) °C (a condition of screens after anheating).

Test mode	Task solved	Characteristicconditions
	producing standard movements in the mode 1 (internal thermal loads).	Temperature of the basic support - 50 °C. Method of control of the manipulator - in automatic (or manual) mode using instrumentations and automatic equipment of RO (an operating mode 1)

Results of Predesigns

Results of predesigns of thermal mathematical model of the developed universal "joint" of the anthropomorphous robot are given below.

In software suite Solid Woks the 3D model of a joint was constructed and simplified for further thermal calculations.

In figure 2 the joint geometry is presented (section).

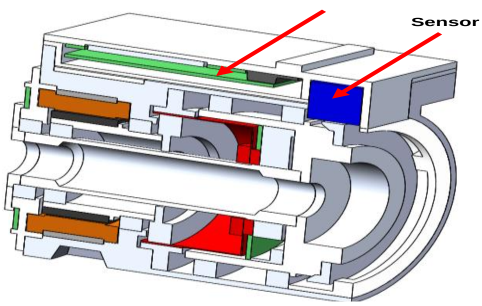

Figure-2 – Cross-section of a joint of the RAT.

Calculations for the following boundary conditions were made:

Imitations of work in a vacuum chamber (T_{env} = 20 °C). Diagram of temperatures are presented in Figure 3.

Solar radiation is taken corresponding to Earth orbit ($_{Qs}$ = 1422 W/m2).

The solar flux is directed perpendicular to a cover closing the element with chips and sensor. Diagrams of temperatures are presented in Figure 4.

Imitation of work in space without sunlight($_{Qs}$ = 0 W/m2).

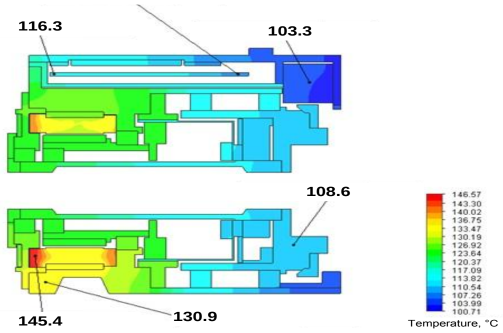

Figure 3 – Imitation of work in vacuum chamber ($T_{env.}$ = 20 °C)

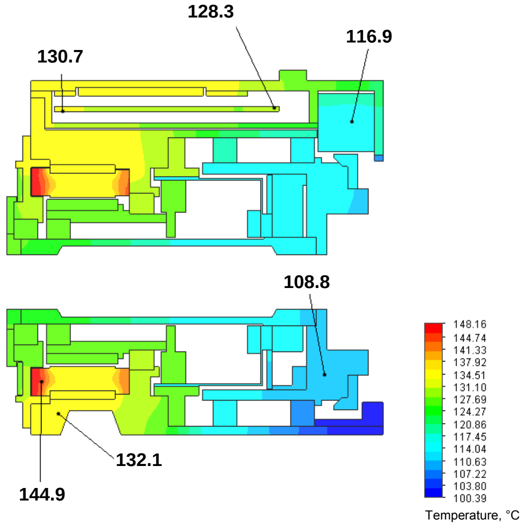

Figure 4 – Imitation of work in space taking into account solar radiation ($T_{env.}$ = -269°C, Q_s = 1422 W/m^2)

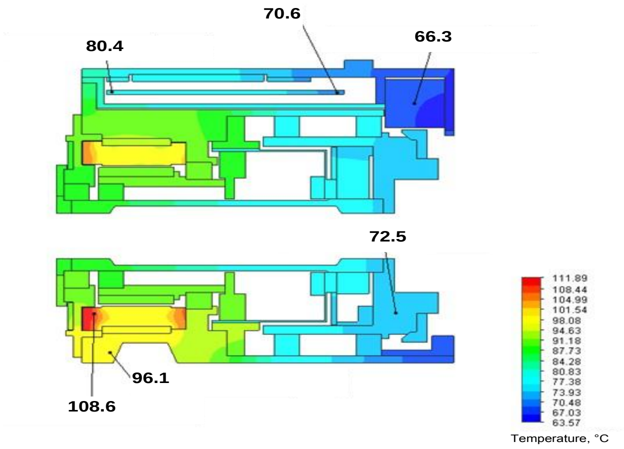

Figure 5 – Imitation of work in space without solar radiation ($T_{env.}$ = -269 °C, Q_s = 0 W/m^2).

Thermal emission power during the operation of the engine with the maximum load in all three cases was accepted equal to 24W and was put in the lower part motor windings. This place was the hottest in all three calculations and temperature results were +145.4 °C, +144.9 °C and +108.6 °C respectively. Calculation with imitation of work in a vacuum chamber with ambient temperature (Figure 3) is necessary for modeling a situation when the part of space around the robot are the elements of surrounding structure and for imitation of a part of external thermal radiation which are inconvenient for imitating "the artificial Sun" or infrared heaters simulators.

It is visible that in all three situations of temperature of elements of a joint almost everywhere exceed temperature + 80 °C and reach in the most heat-stressed mode (Figure 4) +144. 9 °C on windings, from +128 to 130 °C on an electronic chip board and + 117 °C on the sensor.

Due to the obvious overheating non-stationary thermal calculations which results are presented on figures 6 and 7 were made. Dependency of the temperature from time of the most heat-stressed node (winding)is shown.

It can be seen that when given the maximum power of 24 W, within 300 seconds (5 minutes) temperature of the winding increased from 22 … 25 °C to 38 … 42 °C. After switching off of the engine in 400 seconds it almost came back to reference values. It means that if during tests the designs overheatis confirmed similar to the calculated and it will not be possible to overcome structurally, then selection of the acceptable cyclogram of work is possible.

Conclusion

The general description of the RAT for work in an outer space is provided.

The review of the boundary thermal modes which can arise at the operation of RAT is made.

Information on carrying out thermal vacuum tests of such RAT is provided.

Results of preliminary thermal calculations are presented.

The possibility of operation of such RAT in various modes in an outer space is shown.

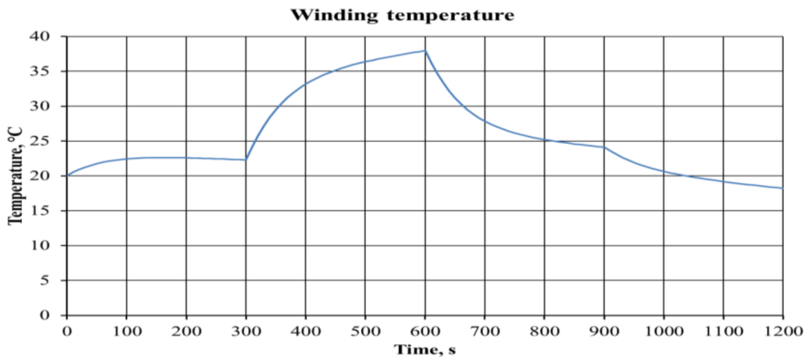

Figure 6 – Imitation of the work in space with no solar radiation

($T_{env.}$= -269 °C, Q_s = 0 W/m^2). Dynamiccalculationbyacyclogram: 4,8W – 300s, 24 W – 300 s, 4,8 W – 300 s, 0 W – 300 s, initial temperature of the joint 20 °C

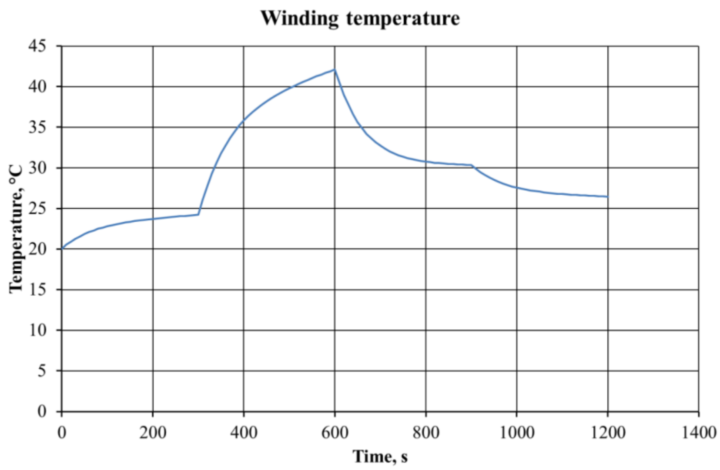

Figure 7 – Imitation of work in vacuum chamber ($T_{env.}$= 20 °C). Dynamic calculation by a cyclogram: 4,8 W – 300 s, 24 W – 300 s, 4,8 W – 300 s, 0 W – 300 s, , initial temperature of the joint 20 °C.

ACKNOLEGMENTS

The work was supported by Ministry of Education and Science of the Russian Federation under the agreement No. 14.578.21.0141 (unique project identification number RFMEFI57815X0141).

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