DEPLOYABLE RADIATOR QUALIFICATION

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Abstract

In 2004–2006 developed the Engineering model of Deployable Radiator based on Loop Heat Pipe. It was designed for qualification tests.

Ammonia application as LHP working fluid is stipulated by its high thermal physical properties. However Ammonia freezing temperature is of 77 °C. Such fact impedes Ammonia application when operation temperatures of LHP Radiator are lower this value. Application of other working fluids with lower freezing temperatures (propylene for example) leads to rather essential decreasing transferred heat power or increasing LHP dimensions and mass that is not acceptable in many cases.

An important task that shall be solved during Ammonia LHP application is recovery of LHP operation ability after working fluid freezing in radiator-condenser. To recover working fluid circulation in LHP it is necessary to defreeze the whole LHP. During multiple freezing/melting cycles of LHP working fluid LHP depressurization may occur. This paper is dedicated to solving aspects of Radiator operation ability recovery after its freezing.

Aspects of passive temperature control of LHP evaporator using pressure regulator and aspects of LHP active temperature control using heaters and Peltier elements mounted to compensation chamber are also considered in this paper.

Development of new key components made it possible to design Deployable Radiator with specific mass of less than 10 kg/kW. The Deployable Radiator parameters are described in the paper.

1. INTRODUCTION

Since the spacecrafts require more power the area of radiator needs to be increased to ensure heat sink. The spacecraft surface may be insufficient to locate the radiators. Application of the deployable radiators (DR) based on loop heat pipes (LHP) after 1997 when they obtained the public recognition became the commonly used and classic solution of the task. First the DR for space platform was designed with TAIS participation in the Eauropean project Atleed in Bradford Engeneering [1]. The DR based on LHPs found their first real application in spacecrafts in the USA. Designed by Hughes, Dynatherm Company and supported by TAIS the DR have been successfully used in powerful telecommunicational platforms for 10 years [2]. The DR based on LHPs have higher mass-power characteristics in comparison with the radiators on base of traditional heat pipes or liquid loops. The possibility of using the small diameter tubes, different control systems of evaporator temperature makes the DR based on LHPs quite valuable for the designers of thermal control systems used in spacecrafts. The DR that we designed by the request of Alenia company shows its evident superiority [3].

In the radiators mentioned above ammonia is used as the working fluid. Ammonia is used in LHP due to its high thermo-physical properties but the freezing temperature of ammonia is minus 78 °C and this makes the ammonia using difficult when the radiator operation temperatures are below minus 78 °C. Relatively high freezing temperature of ammonia imposes significant limitations on the thermal-control system of spacecraft.

Use of lower-temperature working fluids (propylene with freezing temperature minus 189 °C) partially solves this problem. We have used propylene in a whole series of the spacecrafts to avoid working fluid freezing [4–6]. Propylene was also successfully used in the spacecraft Glass [7]. However, thermo-physical properties of propylene like the thermo-physical properties of the other low-temperature working fluids are considerably worse [8]. Application of these working fluids makes mass and overall dimensions characteristics of the radiators significantly worse. Diameters of the transport lines, condensers are increased abruptly. Increase of LHP internal volumes leads to increase of the dimensions and mass of the compensation chamber.

Therefore, the important engineering task is to recover LHP operation ability after the working fluid freezing in condenser. The possibility of multiple freezing-melting cycle of the working fluid in the condenser is the most critical point in LHP operation for its reliability. As a result of changing of the phase change working fluid density at there is a probability of the loop leakage. In this paper the authors are trying to find solutions of the temperature control problems and how to recover the LHP operation after the working fluid freezing.

2. DEPLOYABLE RADIATOR DESIGN AND ITS CHARACTERISTICS

DR is a heat transfer device based on LHP with a condenser as a part of radiation heat exchanger that deploys after the spacecraft orbiting.

Designed by the request of CAST the DR must have high mass-power characteristics:

The specifications requirements of the DR were defined taking into account the typical needs of scientific and telecommunications satellites and maximum possibility of up-to-date two-phase technology. The driving parameters are the following. Heat transfer and rejection capability from 10 to 600 W.

The evaporator temperature at min and max heat load is not allowed to exceed the range from minus 10 up to 50 °C. The thermal resistance of the LHP at maximum heat power are 0.015 K/W on orbit and 0.018 K/W on ground in vertical position (evaporator above the condenser).

The Deployable Radiator assembly is able to withstand typical natural and induced environments during integration, ground testing and launch phases.

The deployment mechanism provides the necessary torque at the mobile panel interface and with a latch engaged when in fully deployed position. Manual resetting for on-ground tests is foreseen.

To fulfil the above challenging requirements a wide range of technical alternatives were object of trade-off to obtain the appropriate design. Most of the DR key components have been improved from previous projects [9, 10].

DR consists of two honeycomb panels attached to each other with the deployable and locking mechanisms (Fig. 1).

DR parts:

- Deployable panel with LHP.
- Internal panel.
- Deployable mechanism.
- Locking mechanism.
- Service frame for tests and transportation.

The deployable part of the DR assembly consists of a honeycomb panel (14 mm thick) with embedded LHP condenser. The LHP condenser sections are formed by an array of embedded aluminium profile with internal diameter 3 mm. The condenser profiles were developed to combine thermal performances (the heat is rejected from both sides of radiator) and mechanical characteristics in order to withstand the freezing of the working fluid.

The LHP condenser consists of 3 parallel sections connected through capillary isolators.

The recovery from freezing is obtained by dedicated heaters allowing an initial thawing in one section; progressively the entire panel returns to operational conditions.On the internal panel there is an LHP evaporator connected to the condenser through the transport lines (vapor line and condenser line) which have flexible sections that allow the external deployable panel to open. The transport lines are made up of thin-walled tubes with outer diameter 3 and 4 mm. The fixed part of the DR assembly (corresponding to a traditional spacecraft wall) consists of a honeycomb panel (18 mm thick).

The heat load is applied by heated plates mounted with the bolts on the LHP evaporator. To minimize the thermal resistance at the interface between heater and LHP evaporator the latter is mounted on a "window" of the panel. A thermal filler (graphite foil has been used) is located between the LHP evaporator and heated plates.

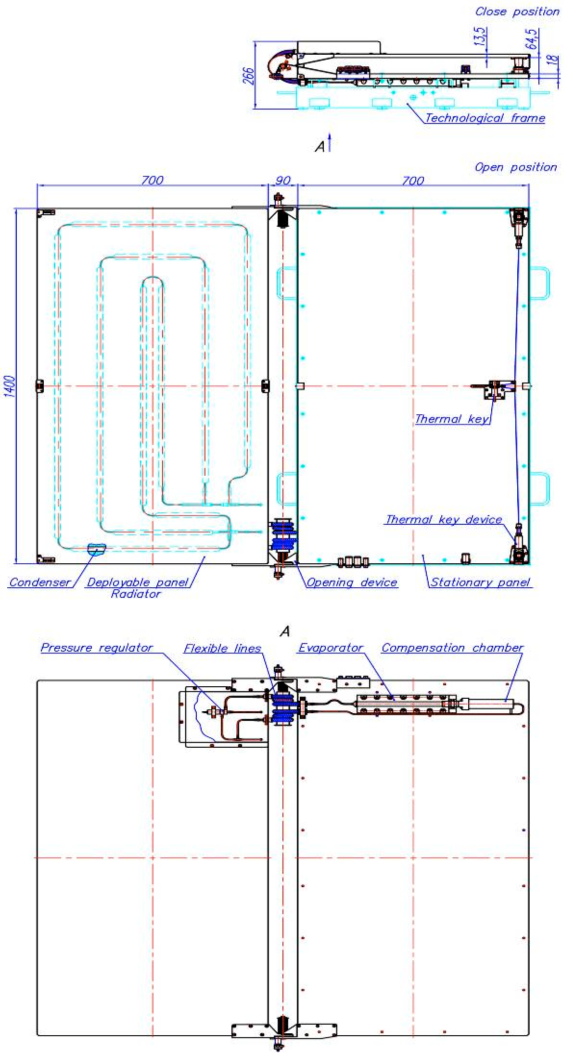

Fig. 1. DR overall drawing

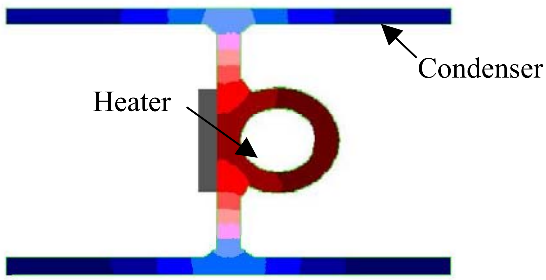

Fig. 2. Condenser profile

Thermal-hydraulic connection between locking and deployment LHP elements is provided by stainless steel flex hoses, to allow the 180 ° rotation of the hinge during the deployment.

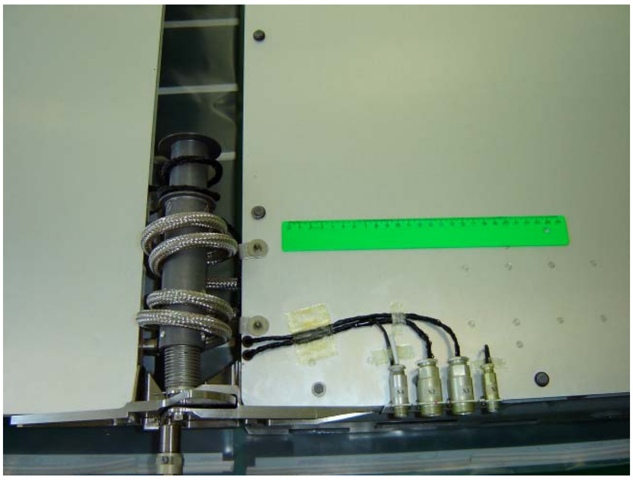

Fig. 3. Flexible sections.

The deployment actuator (spring loaded) is able to perform its function also on ground, with the DR in vertical position, without the help of anti-gravity compensation mechanisms.

With the DR in stowed configuration it is prevented from deployment by a blocking device electrically operated. It consists of a “Thermal Key” (Fig. 4) which is filled with a special fluid with high ratio of temperature volume expansion. The “Thermal Key” has been designed specially for the Deployable Radiator and provides significant advantages compared with alternative systems (pyro devices, fusible elements etc.).

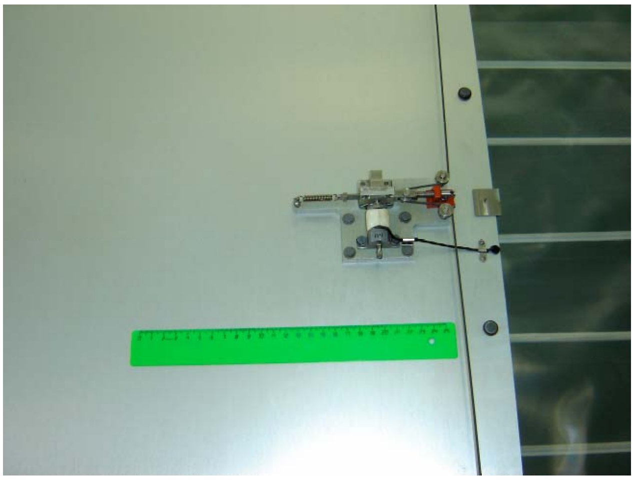

Fig. 4. Thermal key

It has small dimensions, low weigh, no safety hazards, can be operated with low power (few watts), allow multiple activations on ground and is self- redundant in the DR installation: in case the Thermal Key electrical heating is not available (preventing the deployment) the heat load on the fixed panel is not rejected efficiently and the temperature of the panel increases until the Thermal Key (mounted on it) is heated by thermal conductivity up to its activation temperature. At that point the deployment takes place and the nominal conditions are recovered. The activation temperature can be changed in the design phase by chosen PCM materials.

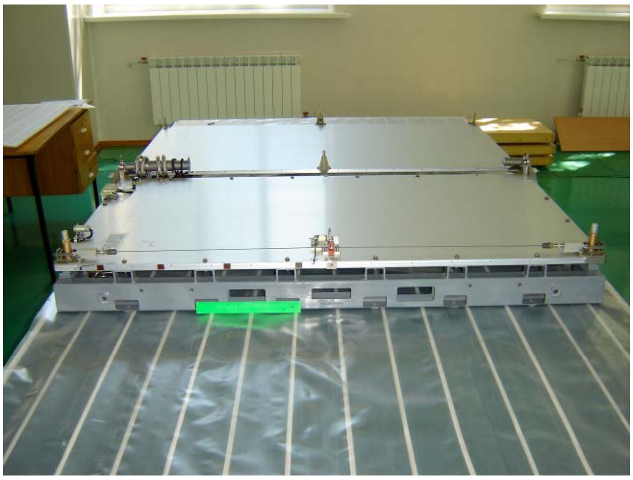

Fig. 5. Deployable radiator

The passive temperature control is achieved with great efficiency by combined use of a pressure regulator with by-pass line. The reserve mean of temperature control is a heater on the LHP compensation chamber. The latter task can also be accomplished by using Peltier elements connected to the evaporator body and to the compensation chamber as alternative to the heater.

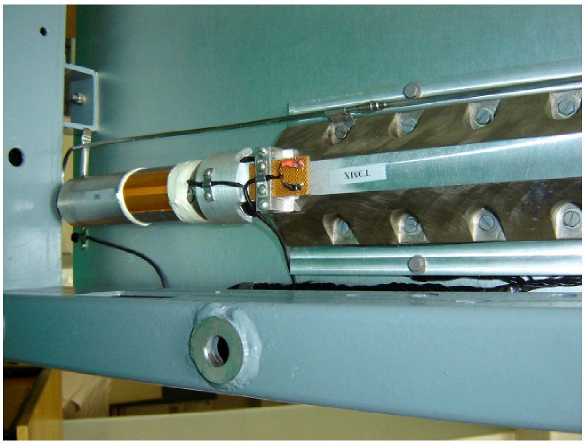

Fig. 6. LHP evaporator.

3. LHP CONDENSER LINE

One of the main task of activities was to research the process of the working fluid freezing/unfreezing in the condenser lines. The LHP condenser was made up of aluminum alloy 6063. The cross-section of the condenser profile was chosen due to the hypothesis about the working fluid compressing while the material of the condenser may be left in the zone of elastic deformation i.e. the pressure of the melting working fluid does not exceed ultimate strength of the condenser material. Preliminary strength analysis had been made and afterwards the experiment was carried out.

A piece of the condenser aluminum profile 880 mm long was selected as an object for the tests. The compensation chamber was welded to the one end of the profile. Simulator of the LHP condenser was charged with ammonia. The LHP condenser sample was connected to the aluminum sheet of 800*300 mm and 1 mm thick simulating the radiator.

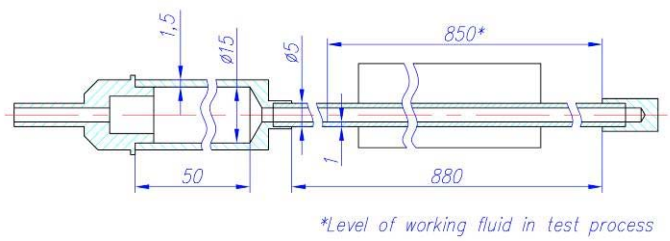

Fig. 7. LHP condenser model

The tests of the LHP condenser model were carried out in the vacuum chamber. The procedure of the tests was as follows.

The LHP condenser model was cooled down using nitrogen screen by 10–20 ºC lower than the temperature of ammonia freezing with afterwards heating by means of the simulator of the solar radiation. Heat flux power during heating was 1500 W/m^2. The sample was placed in the chamber inclined with regard to the vertical position by 20 degrees and with compensation chamber above. This position ensured complete filling of the profile with liquid phase of the working fluid while freezing. Cooling and heating of the LHP condenser model was arranged in such a way that the freezing and melting of ammonia started from the low blind edge. After completion of the freezing cycle under these conditions the ammonia solid phase filled the condenser profile uniformly. During ammonia melting the top part of the profile contained an ice blockage and the melting ammonia was not able to come out to the compensation chamber until the complete melting. The ammonia liquid phase was blocked in the low part of the profile that created the most critical situation for the LHP condenser model. Testing layout is presented in Fig. 8.

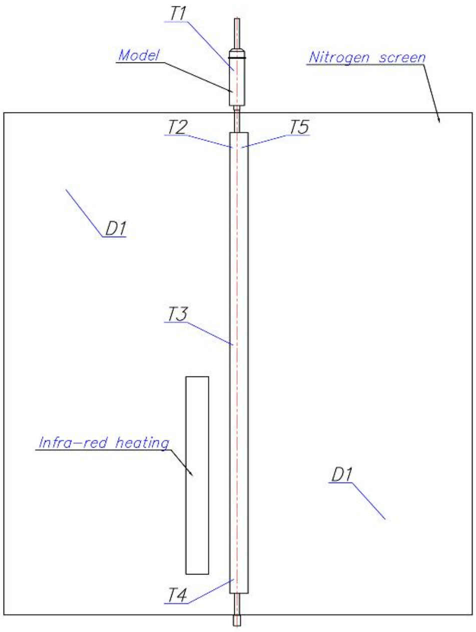

Fig. 8. LHP condenser model testing layout

Ten freezing/unfreezing cycles have been performed for the sample within the temperature range from minus 85 to 0°C. Environment was at most approximated to the real space conditions. The sample had sustained the tests without changing its dimensions and was not broken down. Test results are presented in Fig. 9.

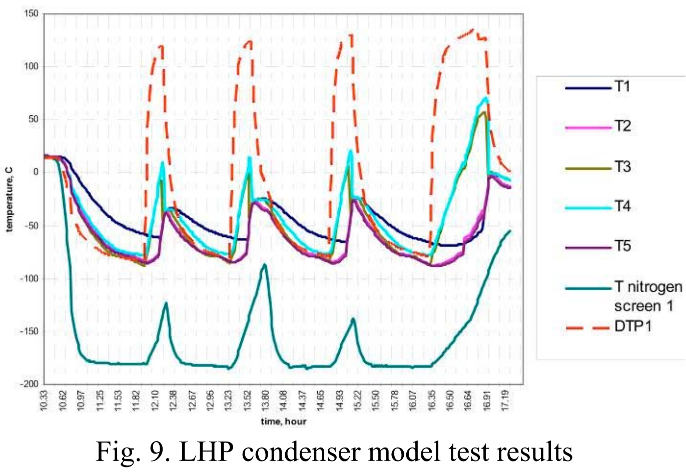

Fig. 9. LHP condenser model test results

These test results as well as the previous experience on DR designing for Alenia company have been taken into consideration while developing this DR [3]. The parameters of the presented DR are not worse than parameters of the modern DRs designed in Europe and in the USA [11, 12].

4. LHP CONDENSER DEFROSTING SYSTEM

Let us assume that we have managed to design the condenser profile that can sustain multiple cycles of freezing and melting. But it does not yet solve the problem of developing the real condenser of LHP that would make it possible to recover the radiator operation ability after the working fluid freezing. There are two more problems to be solved when developing the real radiator:

In the joints of the condenser profile and LHP liquid and vapor lines the welding joints that are not withstand the pressure of the melting ammonia have been usually used. Their strength is far lower than the strength of the main profile. We intended to avoid the working fluid freezing in the transport lines, flexible sections, bypass line and pressure regulator. With this purpose the part of the deployable radiator with the pressure regulator, bypass line and the working fluid inlet/outlet from the panel was covered with a special shell and three film heaters were glued to the panel surface. These heaters switched on when the temperature of either transport lines or valve-regulator approximated to minus 70 °C. So the working fluid circulation was maintained in the bypass line and the LHP flexible sections were prevented from freezing. After the working fluid freezing in all parallel sections of the condenser the working fluid circulation in them is stopped.

Fig. 10. Flexible lines and special shell

If the heat power applied to the LHP evaporator increases the working fluid in the radiator cannot be melted as there is no circulation in it. The evaporator heating without heat sink will be continued up to the moment of its destruction. In this situation it is necessary to heat at least one section of the condenser from the external heat sources to start the working fluid circulation in the condenser.

This heating can be done through electrical heaters located on the radiator panel. This is the simplest method. While designing the DR the heaters were glued inside the radiator panel on the profile of the “small” section of the condenser (Fig. 11).

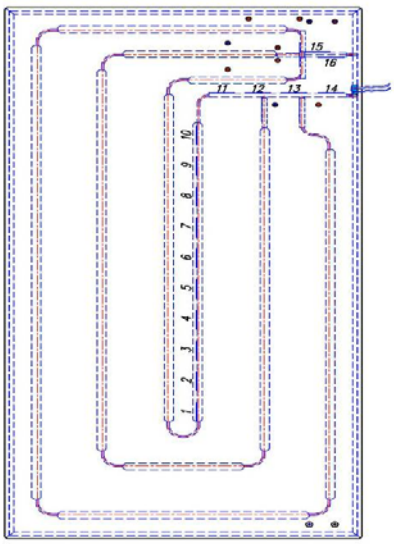

Fig. 11. Defrosting heaters layout

At switching on the heaters the “small” section of the condenser starts heating and the working fluid in it starts melting. After renewing the circulation in the “small” section of the condenser the temperature of part of Radiator increases and working fluid in other Radiator sections is being defrosted by thermal conductivity through Radiator skins. This design provides gradual switching on of all sections of the condenser when increasing power applied to LHP evaporator. The selected layout of the heaters location allows reducing electric power and time required for the radiator unfreezing.

To minimize hazard of the loop leakage it is necessary to create directed front of the working fluid melting inside the condenser profile so that the closed volumes of the working fluid liquid phase during melting would not be created. This requirement was taken into consideration when selecting the layout of the heaters location and their operating modes. Step and unit capacity of the separate film heaters were chosen to provide the initial melting of the working fluid in the zones of the condenser sections and liquid/vapor lines joining. Close to the joints heaters spacing was minimal and the unit power was maximum. As moving far away from the joints the specific heat generation of the heaters decreased in accordance with the linear law.

5. DR TEST RESULTS

Tests of the DR in atmospheric conditions were carried out horizontal and vertical positions. Startup power was 10 W, maximum transferred heat power was 600 W. The tests verified the possibility of the LHP active control by means of the compensation chamber heater and thermal electrical micro-cooler (TEMC). LHP thermal resistance at the power 600 W in horizontal position was 0,0187 K/W, in vertical position – 0,0195 K/W.

During thermal vacuum tests the following modes have been carried out:

Permanent heat transfer (includes determination of the LHP thermal resistance at maximum heat power, capacity of valve-regulator, compensation chamber heater and TEMC for temperature control of the LHP evaporator and operation of the DR when simulating the external heat flux).

Freezing/unfreezing of the LHP condenser.

The results of thermal-vacuum tests:

Heat power transferred by the LHP was within 30–550W.

Maximum thermal resistance of the DR at maximum heat power Q_{max} = 550W and maximum temperature of evaporator without temperature control was 0,025 K/W.

Valve-regulator provides temperature of evaporator $T_{evap} > 5$ ºC.

Compensation chamber heater and TEMC provide active control of the LHP operation.

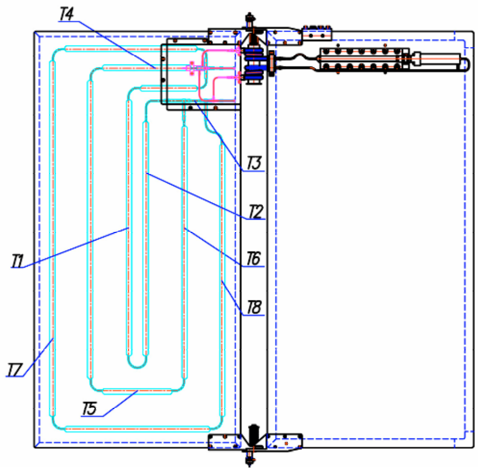

Fig. 12. Layout of thermo-couples location

Two freezing/unfreezing cycles of the deployable panel (LHP condenser) have been carried out. One cycle of the complete freezing (all three lines of the condenser were frozen).

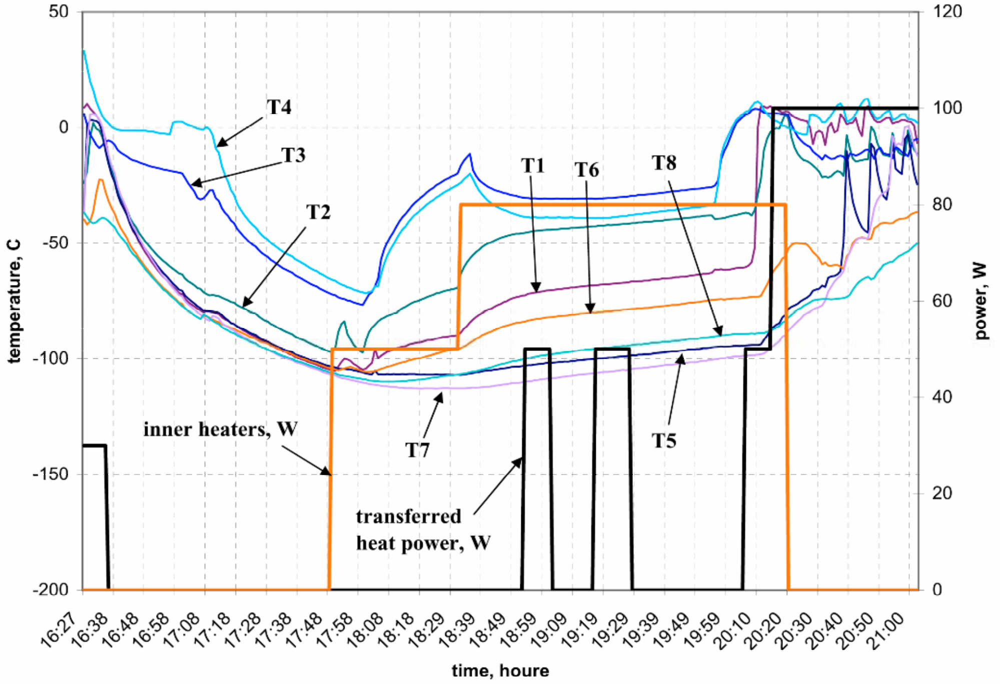

Fig. 13. The radiator complete freezing

After heating up to operation temperature, LHP functioned properly. Leakage of working fluid and any changes of LHP dimensions and mass were not detected. When Radiator freezing, Evaporator temperature remained above 0 °C. The experiment was repeated for three times.

Experiments with partial freezing of working fluid in Condenser were carried out also. The two lines of Condenser were frozen during these cycles. When Radiator freezing, evaporator temperature remained above 0^{o}C.

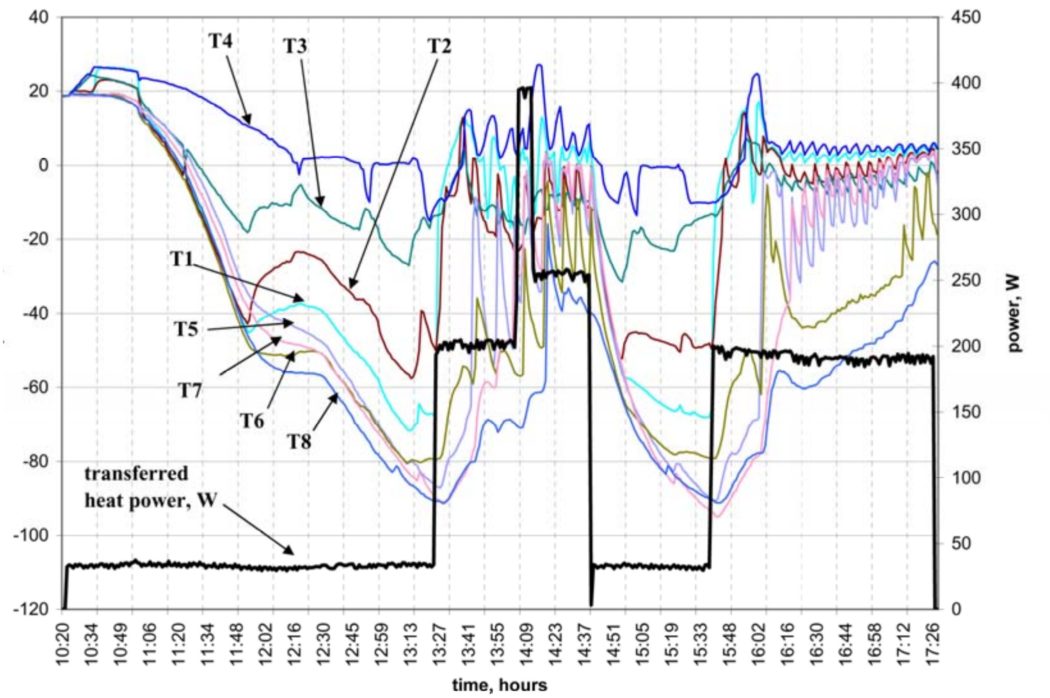

Fig. 13. The radiator freezing without "small" line

In the third line ("small") circulation of the working fluid was maintained. The temperature of the "small" line was maintained higher than the freezing temperature of the working fluid using the heaters embedded inside the panel. During the freezing mode the temperature of the panel was minus

112 °C. The temperature of the pressure-regulator, transport lines, bypass line and flexible sections of the DR was not lower than minus 63 °C due to using of the heaters glued onto the panel.

CONCLUSIONS

1. The concept of Deployable Radiator on basis of LHP was developed. All DR components were designed, built and successfully passed qualification tests.
2. The task of development of DR condenser that withstands multiple (complete or partial) freezing of working fluid was solved.
3. System of forced condenser defreezing that provides reliable recovery of working fluid circulation in LHP was developed.

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