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Research Paper

Development and tests of a loop heat pipe with several separate heat sources

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HIGHLIGHTS

- A loop heat pipe with several separate heat sources of different capacity was tested.
- Main and additional sources were cooled by an evaporator and heat exchangers on pipelines.
- The cooling capacity of the liquid heat exchanger is higher than of the vapor heat exchanger.
- Thermal action on the liquid line has a great effect on the overall temperature level.

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Cooling system
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ABSTRACT

The paper presents the results of development and experimental investigations of ammonia loop heat pipe (LHP) intended for a simultaneous cooling of several heat sources dissipating a variable capacity. The LHP was equipped with two heat exchangers located on the liquid line and one heat exchanger on the vapor line, which were in thermal contact with some additional heat sources. The LHP evaporator was in thermal contact with the main, the most powerful heat source. It has been shown that at a nominal heat load of 120 W on the main heat source the total heat load on the additional heat sources located on the liquid line may reach 34 W. The maximum heat load on an additional heat source located on the vapor line, in the same conditions, was 9 W. It has also been shown that a thermal action on the liquid line has a considerable effect on the temperature of the main heat source, whereas a thermal action on the vapor line does not influence it.

1. Introduction

The main design features of loop heat pipes (LHPs) that differentiate them from other types of heat pipes are the local siting of the capillary structure (CS) and the separation of vapor and liquid flows between the evaporator and the condenser along separate pipelines (Fig. 1). Another essential feature of an LHP is the presence of a special vessel communicated with the inner absorbing side of the CS, which has been named a compensation chamber (CC). The main function of a CC consists in accumulating the liquid displaced from the vapor line and condenser during the LHP operation. The liquid circulation in the device proceeds on an evaporation-condensation cycle and is ensured by the capillary forces of the CS and also the pressure drop between its evaporating and absorbing surfaces caused by the action of an external heat load applied to the evaporator. Such a design ensures the LHP high heat-transfer capacity at different orientations in the gravity field and zero-gravity, and also the possibility of any configuring and creation of various ramified schemes [1].

Initially, LHPs were developed for space technology, where they have been successfully employed in systems of thermal regulation [2,3]. The development of LHP ramified schemes is connected with the necessity of cooling several heat sources and using heat sinks separated in space. The results of a number of investigations [4–6] have proved the serviceability of such schemes, in which at least two evaporators and two condensers are connected in parallel. It has been shown that the heat loads of the evaporators may be different, and in the case of zero load on one of them the last one may play role of a condenser. The conditions of cooling of the condensers may also be different, which is quite useful when they are located on spacecraft with a variable illumination of the sides. At the same time, such peculiarities of the LHP operation as the availability of a minimum start-up load and the possibility of appearance of pulsation operating modes at low heat loads [7] increase the probability of an unstable operation of a ramified scheme. For the reliability of the start-up it is proposed to use such active elements as thermoelectric modules [8,9] or additional heaters [10], which help to realize control over the operating temperature and create conditions for a favorable liquid distribution before the start-up. In this case, however, the properties of passivity and self-regulation of

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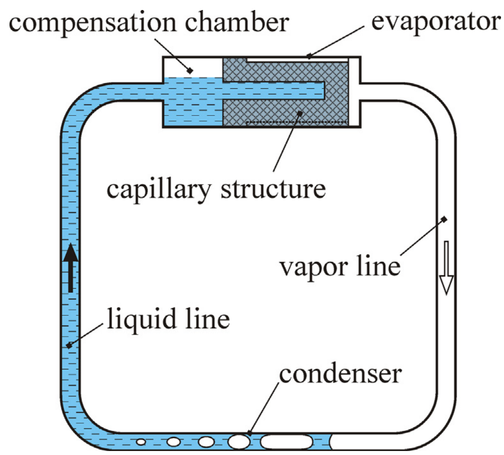

Fig. 1. LHP schematic diagram.

the device are lost. Another drawback of multi-evaporator systems is connected with the limitation on the number of evaporators owing to the proportional increase in the volume of their CCs and, as a result, the degree of filling with a working fluid for a successful start-up. In the opinion of the author of Ref. [11], realization of a scheme with more than three evaporators is quite problematic, with the exception of cases where the evaporators have the same or similar heat loads, or are combined by a common heat-conducting plate.

Also known is a series-parallel LHP scheme with multiple evaporators and condensers [12]. It has, at the minimum, two evaporators and two condensers connected and alternating with one another. In this case the CCs of the evaporators communicate with one another through a common chamber. However, no data confirming the serviceability of such a scheme have been presented. It can only be noted that the system is rather complex, which makes it difficult to locate it in the block of electronics it is intended for.

A new concept of an LHP, intended for cooling multiple heat sources and called a "Multi-Stages" LHP, was suggested in 2011 [13]. In this concept it is proposed to use one capillary evaporator and several condensers, among which additional heat exchangers are located. The capillary evaporator creates a flow of a working fluid in the loop under the action of a heat load from the main source. After the evaporator, this flow is partially or totally condensed in the first condenser and enters an additional heat exchanger, where partial or total evaporation takes place under the action of a heat load from an additional source. Before entering the evaporator, the flow passes through the final condenser so that there will be liquid at the evaporator inlet. The intermediate vaporization-condensation cycle may be carried out several times until the pressure drop exceeds the CS maximum capillary pressure. The results of experimental investigations of models with one and three additional sources have shown the reliable operation of the "Multi-Stages" LHP [14]. In this case the heat load of the additional sources reached 70% of the heat load of the main source. Likewise, no problems were observed as regards the start-up and variations in temperature at a low heat load of the additional sources. A new architecture of a "Multi-Stages" LHP with three auxiliary smooth-pipes heat exchangers added between the two condensers was also tested [15]. It has been shown that the total power of the auxiliary heat exchangers can be equal to the power of the main evaporator if the vapor is completely condensed on the first condenser. At the same time, in most tests the stable operation of the LHP was maintained if 80% of the heat load of the main evaporator was supplied to the auxiliary heat exchangers. All these properties make the concept suggested quite promising, in particular, for cooling electronics with a great number of elements of different capacity. Among the drawbacks one can mention a great number of pipelines and condensers, which are difficult to locate at a close-packed arrangement of electronic components.

In all the solutions mentioned above, in one way or another, use is made of the LHP capacity for the automatic control (thermostabilization) of its operating mode based on the automatic liquid redistribution between the CC of the evaporator and the condenser. The same property makes it possible to realize active control of an LHP by means of a thermal action on the CC [16]. In this case it is impotent that the CC heating in certain limits does not lead to the deterioration of serviceability, which means that the liquid line may also be heated, for instance, by additional sources without the use additional condensers. Besides, there are no fundamental limitations for heat removal by a vapor flow moving in the vapor line.

The aim of the present work was to investigate the possibilities of cooling several sources with the help of single LHP containing one evaporator and one condenser, with additional sources being cooled by heat exchangers located on the vapor and liquid lines [17]. The present design is more simple and compact and may prove to be preferable for some problems of thermal management.

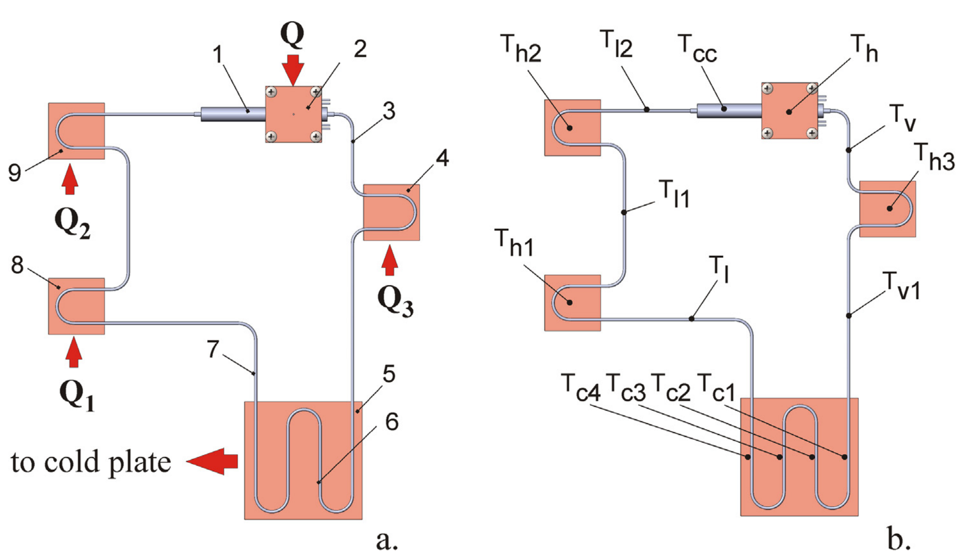

Fig. 2. LHP scheme (a) and location of thermocouples (b): 1 – evaporator; 2 – heater block; 3 – vapor line; 4 – vapor heat exchanger; 5 – condenser plate; 6 – condenser; 7 – liquid line; 8, 9 – liquid heat exchangers.