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Operating temperature and distribution of a working fluid in LHP

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Abstract

One of the main factors that influence the operating temperature of a loop heat pipe (LHP) is the distribution of a working fluid in the device. The paper presents the classification of LHP operating modes on the basis of the criterion of presence or absence of the working-fluid vapor phase in the compensation chamber (CC). It gives a description of method of calculating the LHP operating temperature for every operating mode and shows the characteristic features, advantages and disadvantages of every mode.

Keywords: Loop heat pipe; Operating temperature; Operating mode; Temperature hysteresis

1. Introduction

The operation of many technical objects is accompanied by the heat emission Q^+, which disturbs the thermal regime of their operation. This heat is harmful and should be removed. The conditions for heat removal are significantly complicated when the object to be cooled and the heat sink are situated at a considerable distance from each other. To ensure an efficient thermal link between them, it is necessary to use an auxiliary element with a high thermal conductivity. A loop heat pipe [1] may be used as such an element. Presented in Fig. 1 is the scheme of one possible version of LHP. The device contains an evaporator and a condenser connected by smooth-walled pipelines for separate motion of vapor and liquid, which have a relatively small diameter. The evaporator is equipped with a special wick and joined to a compensation chamber, which serves to receive the working fluid displaced from the vapor line and the condenser during the start-up and from the condenser in the process of operation of the device.

By its functional definition the LHP is a heat-transfer device operating on a closed evaporation-condensation cycle with the use of capillary forces for pumping a working fluid. Owing to this the device contains no mechanically mobile parts and consumes no additional energy. The heat transfer in the LHP is realized with the use of latent heat of vaporization, which ensures a relatively small mass flow rate of a working fluid inside the device and an intense heat exchange in the evaporation and the condensation zone. A special system of vapor-removal channels in the evaporation zone, intended for an organized vapor removal, makes the process of evaporation at the surface of a fine-pored capillary structure as efficient as possible.

Loop heat pipes have a high heat-transfer capacity $Q_{\text{load}} \cdot L_{\text{LHP}}$ and at the same time a low thermal resistance R_{LHP} [2], which is determined in the following way:

$$R_{\text{LHP}} = \frac{T_{\text{ev}} - T_{\text{cond\_ext}}}{Q_{\text{load}}}, \tag{1}$$

where T_{ev} is the temperature at the external heat-receiving surface of the evaporator, $T_{\text{cond\_ext}}$ is the temperature at the external heat-losing surface of the condenser, Q_{load} is the heat load transferred by an LHP, L_{LHP} is the effective length of heat transfer.

Fig. 2 shows the scheme of a system of thermoregulation for a heat-generating object organized on the basis of an LHP. The length L_{LHP} corresponds to the distance between

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Nomenclature

G	working-fluid mass flow rate, kg s^{-1}
L	length, m
P	pressure, Pa
Q	heat load, W
Q_{ch}	heat load at which the LHP operating modes change, W
R	thermal resistance, K W^{-1}
T	temperature, K
V	volume, m^3

Greek symbols

α	heat-transfer coefficient, W m^{-2} K^{-1}
d	diameter, m
φ	slope, deg (°)
k	heat of vaporization, J kg^{-1}
g	free fall acceleration, m s^{-2}
μ	dynamic viscosity, Pa s
P	density, kg m^{-3}

Subscripts and superscripts

cond	condenser
cc	compensation chamber
ev	evaporator
ext	external
int	internal
l	liquid
ll	liquid line
sink	heat sink or heat receiver
source	heat source
v	vapor
vc	vapor removal channel
vl	vapor line

the object to be cooled and the heat receiver. The temperature of the object being cooled T_{source} exceeds the temperature of the heat receiver T_{sink} by a certain value $\Delta T_{\Sigma} = T_{source} - T_{sink}$, which according to the diagram of distribution of temperatures in such a system (see Fig. 2) is determined by the contribution of three components:

$$\Delta T_{\Sigma} = \Delta T_{source} + \Delta T_{LHP} + \Delta T_{sink}, \tag{2}$$

viz. the temperature drops in the heat-supply zone $\Delta T_{source} = T_{source} - T_{ev}$ and in the zone of heat rejection $\Delta T_{sink} = T_{cond\_ext} - T_{sink}$, and also the temperature drop ΔT_{LHP}, which is caused by the LHP thermal conductance:

$$\Delta T_{LHP} = T_{ev} - T_{cond\_ext}. \tag{3}$$

In this case, according to the data from Ref. [3], less than 50% of the total temperature difference ΔT_{Σ} falls to the share of ΔT_{LHP}. Therefore for increasing the efficiency of heat transfer in the thermal regulation system under consideration it is necessary to pay attention to each of the three components of the total temperature drop ΔT_{Σ}.

The temperature jump ΔT_{source} in the heat-supply zone is caused by the nonideal character of the thermal contact between the LHP evaporator and the object being cooled. The quality of the thermal contact joint between them depends on the means of joining used in a concrete thermoregulation system. If the thermal resistance of the contact zone is equal to R_{cont}, and the heat-release capacity of the object being cooled is equal to Q^+, one can write:

$$T_{source} - T_{ev} = Q^+ \cdot R_{cont}. \tag{4}$$

As for the temperature drop in the zone of heat-load rejection ΔT_{sink} (see Fig. 2), the relationship between the temperature at the external heat-losing surface of the condenser T_{cond_ext} and the temperature of the heat receiver ΔT_{sink} may be expressed by the following relation:

$$T_{cond\_ext} - T_{sink} = \frac{Q^-}{\alpha_{cond\_ext} \cdot S_{cond\_ext}}, \tag{5}$$

where S_{cond_ext} is the external heat-losing surface of the condenser, α_{cond_ext} is the coefficient of heat exchange at the external heat-losing surface of the condenser, Q^- is thermal capacity rejected. In most technical problems the heat receiver has a sufficiently high heat capacity, which is why with time its temperature remains unchanged

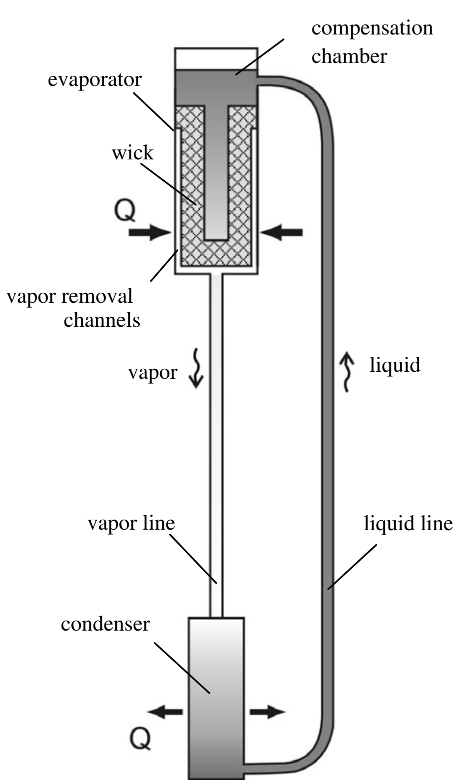

Fig. 1. Scheme of a loop heat pipe.