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Experimental measurement, calculation and thermal visualization condenser temperature of cooling device with a heat pipe technology

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Abstract. This work deal with evaluation of condenser temperature by experimental measurement, calculation and thermal visualization of cooling device working with a heat pipe technology. The referred device in the article is cooling device capable transfer high heat fluxes from electric elements to the surrounding. One from many things influenced the heat flux amount transferred from electronic elements through the cooling device to the surrounding is condenser construction, its capacity and option of heat removal. The work contain description, working principle and construction of cooling device. Experimental part describe the measuring method and mathematical calculation to condenser temperature evaluation of cooling device depending on the loaded heat of electronic components in range from 250 to 750 W. The mathematical calculation is based on physical phenomena of boiling, condensation and natural convection heat transfer. The results of experimental measurement and mathematical calculation are verified by thermal imagining of device condenser by IR camera.

1 Introduction

The cooling device with heat pipe technology may be visualised as a long hollow pipe, bent and the ends joined to form a continuous loop, filled with working fluid and orientated in a vertical plane. If the one side of the loop is heated and the other side cooled, the average density of the fluid in the heated side is less than in the cooled side. An essentially hydrostatic pressure difference, as a result of the thermally induced temperature gradient between the hot and the cold sides, rives the fluid flows around the loop. The ‘buoyancy’ force, as it is often termed, driving the fluid is in turn counteracted by an opposing frictional force that tends to retard the flow [1]. Cooling device can transfer heat from the interior of a microelectronic system to a central location where space limitations are less stringent. The advantages that a cooling device with heat pipe technology enjoys over a conventional refrigeration system include: (1) absence of moving parts leading to a more reliable system operation, (2) increased choices for selecting a working fluid compatible with microelectronics chips since it does not have to go through a refrigeration cycle, (3) reducing the decomposition rate of the working fluid as the higher temperatures at the compressor discharge in a vapour compression refrigeration system are not encountered, (4) clean operation as no oil is circulated through the system. In comparison to pool boiling systems employing vapour space condensation, a heat pipe technology offers more flexibility in terms of providing a centralized condenser with different feed lines to individual evaporator stations. Further, with the addition of a liquid circulating pump in a cooling device, higher heat transfer coefficients associated with flow boiling systems could be realized [2].

2 Cooling device construction

The main parts of cooling device are:

- evaporator,
- condenser,
- pipeline,
- filling and closing valve,
- working fluid

The model of cooling device is shown on Fig. 1.The evaporator enables on the base of a phase change (boiling) of the working fluid an intensive heat removal from its surface. It has to be constructed so that it will prevent the leakage of the working fluid, maintain pressure differences in all the walls and enable heat transfer from the electronic component into the working fluid as well as a suitable distribution of liquid and vapour phases of the working fluid. When choosing the material suitable for the construction of evaporator, it is necessary to pay attention to its thermokinetic characteristics. To provide a minimal temperature drop between a heat source and evaporator, the evaporator material must feature high thermal conductivity. To prevent escape of vapour, it should not be porous. The material should have high strength but, at the same time, it should be easily machineable and compatible with the working fluid [3]. The evaporator body is a plate with

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dimensions 116 x 206 x 30 mm. To provide the working fluid circulation there are two 12 mm openings drilled horizontally on the plate and connected with twenty one 6 mm vertical connecting channels. They provide the transport of heated fluid vapour from the bottom to the top section of the evaporator. On the outer contact surface of the evaporator and electronic component there are three grooves with a mounted temperature sensor.

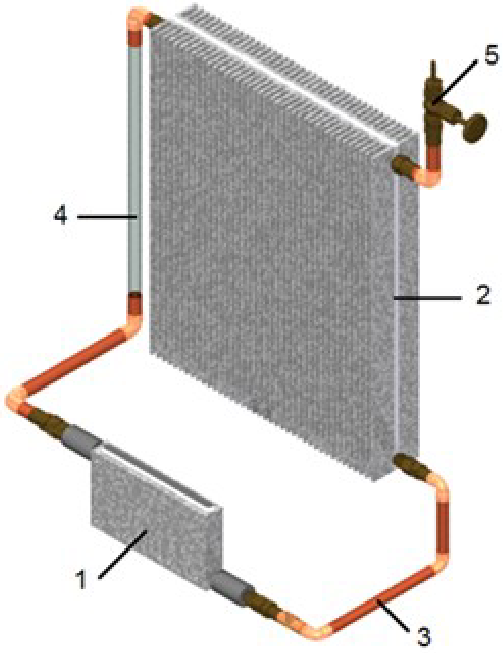

Fig. 1. Model of loop thermosiphon 1 – evaporator, 2 – condenser, 3 – vapour pipeline, 4 – liquid pipeline, 5 – filing and closing valve.

The condenser is proposed so that it was possible removed heat in to the surrounding by natural convection. It is created from two alumina fin coolers with dimensions 400 x 480 mm and fin height 45 mm. The each cooler has on the back side along the length ninety 7.5 mm deep and wide vertical grooves, and on the top and bottom two 10 mm deep and wide horizontal grooves. The cooler are soldered together on the back side and through the grooves can the working fluid flow down to the evaporator. This robust condenser construction allow remove high heat fluxes loaded to the evaporator [4].

The vapour pipeline and liquid pipeline connect evaporator with condenser and are transportation parts through the working fluid circulate in closed loop. The pipelines are made from copper material, due to its good installation properties and compatibility with almost all mediums used in heat pipe [5].

The working fluid in cooling device is Fluorinert FC 72, due to its compatibility with most metals, low boiling temperature (56 °C) and solidification (-90 °C) and, first of all, due to its excellent dielectric characteristics [6].

3 Mathematic calculation

The condenser temperature calculation is based on heat transfer calculation of the film condensation and laminar flow down condensate on the condenser wall and heat transfer by conduction to the condenser fin and heat transfer at free convection.

Assumption of the mathematical calculation condenser temperature is:

- Film condensation and vapour friction neglecting,
- substance properties of the condensate are not influenced by temperature,
- vapour density is lower than condensate density ($\rho_p << \rho_c$)

Basic of the mathematical calculation are heat transfer equations and criterial equations. The condensate flow down character is define by Reynolds criterion.

$$Re = \omega_c \, \delta_c / \upsilon_l \qquad (1)$$

Where $\omega_c = (g/\upsilon_l)\,(\delta_c^2/3)$ is condensate flow down velocity of film condensation, $\delta_c = (m_c \upsilon_l 3/g \rho_l c_c n_k)^{1/3}$ is condensate film width, c_c is channel circumference, n_k is number of channels and m_c is heat flux defined by $m_c = Q/l_v$.

Conductive heat transfer through the condensate film at the laminar flow down is define by Fourier equation

$$q_c = (\lambda_l/\delta_c)(t_v - t_{w1}) \qquad (2)$$

Where q_c is je heat flux density on condenser inner surface given by $q_c = Q/A_{c1}$, t_v is condensing vapour temperature equal boiling temperature and t_{w1} is condenser inner surface temperature.

Condensation heat flux is given by Newton equation

$$Q_c = \alpha_c(t_v - t_{w1})A_{c1} \qquad (3)$$

Where A_{c1} is condenser inner area, α_c is condensation heat transfer coefficient.

Condensation heat transfer coefficient is defined by Nusselt criterions.

$$Nu = 1.14(GaPr_cKu)^{1/4}\text{, where } Re_{crit} < 400 \qquad (4)$$

$$Nu = H_c\alpha_c/\lambda_l \qquad (5)$$

Where $Ga = gH_c^3/\upsilon_l^2$ is Galileo criterion, $Pr_c = \upsilon_l/\alpha_l$ is Prandtl criterion, $Ku = l_v/c_p(t_v - t_{w1})$ is Kutaladze criterion.

It can be expressed by relation.

$$\alpha_c = 1.14(\lambda_l^3\rho_l g l_v/H_c(t_v - t_{w1})\nu_l)^{1/4} \qquad (6)$$

Where H_c is characteristic parameter in direction of condensate flow.

Heat transfer at a free convection express Newton formula.

$$Q_{fc} = \alpha_{fc}\,(t_{w2} - t_s)A_{c2} \qquad (7)$$

Where Q_{fc} is heat flux at free convection, A_{c2} is condenser outer area, t_{w2} is condenser outer surface temperature, t_s is surrounding temperature, α_{fc} is a heat transfer at free convection.

Condenser outer surface temperature t_{w2} is determined by Fourier formula.

$$t_{w2} = t_{w1} - (\lambda_c/\delta_{wc})q_c \qquad (8)$$

Where δ_{wc} is condenser wall thickness.

Heat transfer coefficient at free convection is defined by Nusselt criterions.

$$Nu_{fc} = 0.55(Gr_{fc}Pr)^{1/4}(Pr/Pr_{fc})^{1/4} \quad \text{at } Gr_{fc}Pr < 10^9 \qquad (9)$$

$$Nu_{fc} = H_{wc}\alpha_{fc}/\lambda_t \qquad (10)$$

Where $Gr_{fc} = \gamma\theta Ga$ is Grashoff criterion, $Pr_{fc} = \nu_t/\alpha_t$ is Prandtl criterion at free convection, $Ga = gH_{wc}^3/\nu_t^2$ is Galileo criterion, H_{wc} is condenser wall high at direction of acceleration due to gravity, θ is temperature difference of wall surface and surrounding, γ thermal volume expansion [7, 8].

4 Experiment

Fig. 2 show scheme to measure cooling efficiency of cooling device. Measurement consist from heat load of evaporator part and temperature detection on the evaporator and condenser part. On the evaporator part of the cooling device are fixed electric components connected to the DC power supply source and load heat flux to cooling device. Between surface of electronic element and evaporator surface are inserted three thermocouples (on the left side, on the right side and in the centre) to scanning electronic component temperature because the highest admissible temperature on the contact surface is 100 °C. The temperature of the condenser is measured by two pair's temperature sensors. One thermocouple pairs is placed in the centre of condenser and second thermocouple pairs is placed on the top of condenser. On the condenser is connected pressure sensor to measure pressure in cooling device. All sensors are connected on the measuring unit where measured parameters convert and transmit signal to the PC. The measurement of the cooling efficiency of the cooling device starts at the input electric power 250 W and continuously increased by step of 100 W till the 750 W. Value 750 W was limited by the maximal electric power capacity of the DC power supply source. The measurement take place in the laboratory conditions at surrounding temperature around 25 °C [9].

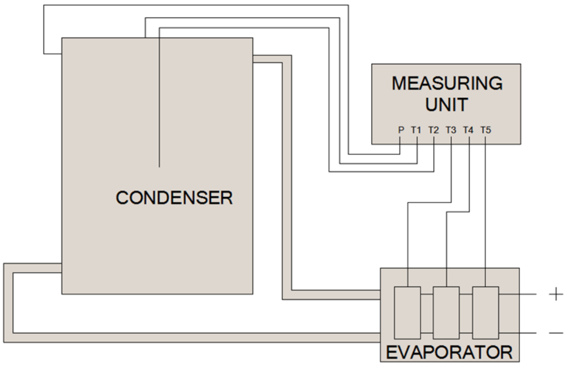

Fig. 2. Measuring scheme of loop thermosiphon cooling efficiency.

During the cooling efficiency of the cooling device measurement was the condenser of the cooling device scanned by IR camera to monitoring condenser wall temperature. Goal of the temperature monitoring is comparison measured temperature values and if the temperature distribution in the condenser is uniform or if there are some places with higher and lower temperature. To results guarantee scanned temperatures by IR camera was condenser painting by black colour with emissivity value 0.96 [10, 11].

5 Results

In the figure 3 is shown measured and calculated condenser temperature of cooling device depending on heat load. In the figure is seen that the calculated and measured results are very similar. This mean that the formulas chosen for condenser temperature calculation in this case was correct and can be applied in other similar cases of heat transfer calculations.

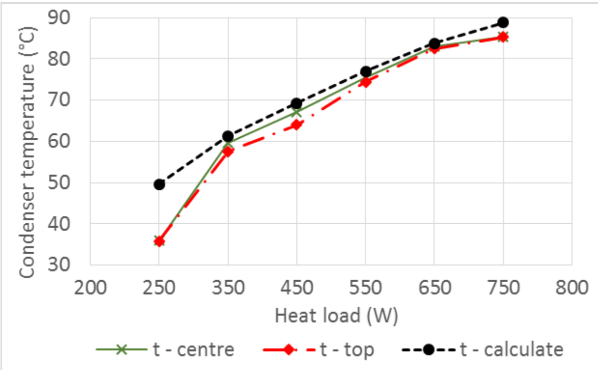

Fig. 3. Measured and calculated condenser temperature of cooling device depending on heat load

In the figure 4 and 5 are shown results of condenser temperature scanned by IR camera. The image in the figure 4 was made at heat load 500 W and image in the figure 5 was made at 750 W. In the figure 4 is seen non-uniform temperature distribution in the condenser, there are place on the right side with much more high temperature than in the centre or left side condenser. In the figure 5 is seen more uniform temperature distribution in the condenser. This result confirm measured and calculated results and is seen that the condenser of the cooling device is able remove much more heat flux to the surrounding.

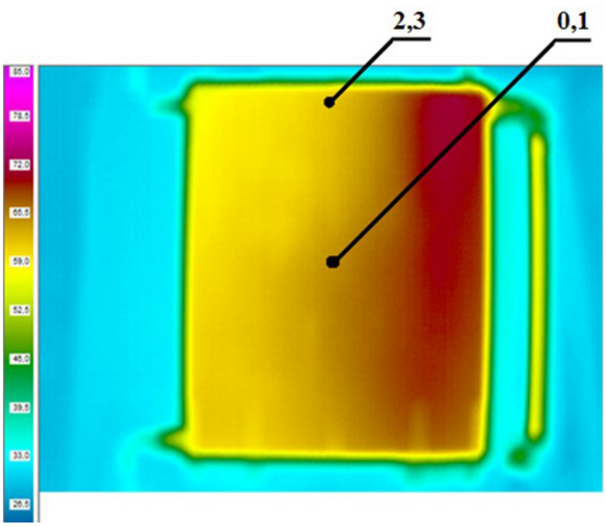

Fig. 4. Condenser surface temperature scanned by IR camera at cooling device heat load 500 W (0,1 – area thermocouples location, 2,3 – area thermocouples location).

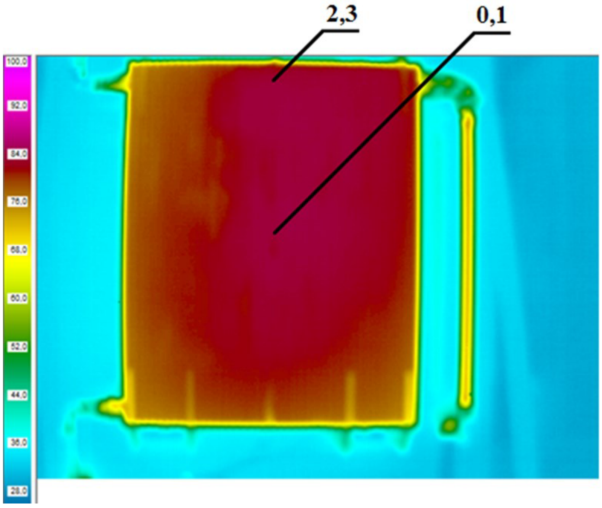

Fig. 5. Condenser surface temperature scanned by IR camera at cooling device heat load 750 W (0,1 – area thermocouples location, 2,3 – area thermocouples location).

6 Conclusion

Experiment was aim at evaluation of condenser temperature by experimental measurement, calculation and thermal visualization of cooling device working with a heat pipe technology. Heat flux transferred by cooling device to the surrounding is limiting with construction condenser. This was observed at the thermal images. Thermal visualization of cooling device condenser show that the condenser construction is capable transfer high heat fluxes around 750 W from electric elements to the surrounding and much more. Conclusion of results comparison obtained by calculation and measurement is that in the calculation were chosen correct formulas and they can be applied in other similar cases of heat transfer calculations.

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