THE INFLUENCE OF GRAVITY TO REMOVE WASTE HEAT OF POWER ELECTRONIC COMPONENTS USING LHP

MARTIN SMITKA, PATRIK NEMEC, ZUZANA KOLKOVÁ, MILAN MALCHO

Faculty of Mechanical Engineering, University of Žilina, Slovakia
  e-mail: martin.smitka@fstroj.uniza.sk

Given the rapid progress in the electronics industry, the thermal management of electronics components becomes an important and serious issue. Natural and forced cooling for heat sink are often deficient. One possibility of heat dissipation for high heat flux is using loop heat pipe. The loop heat pipe (LHP) is a two-phase device with extremely high effective thermal conductivity that utilizes the thermodynamic pressure difference to circulate fluid. It was invented in Russia in the early 1980's. This work deals with the design of LHP for cooling of Insulated gate bipolar transistor and impact of tilt angle of LHP on temperature of transistor. The maximum temperature of transistor is 100°C. LHP is made of copper pipe. Working fluid is distilled water.
Key words: loop heat pipe, cooling, electronic component, tilt angle.

Utjecaj gravitacije na uklanjanje otpadnih toplina elektroničkih komponenti korištenjem LHP-a. Obzirom na brzi napredak u elektroničkoj industriji, toplinsko upravljanje elektroničkih komponenti postaje važan i ozbiljan problem. Prirodno i prinudno hlađenje rashladnih tijela je često manjkavo. Jedna od mogućnosti postizanja visokog toplinskog toka u procesu hlađenja je korištenje toplinske cijevi u obliku petlje. Toplinska cijev u obliku petlje (LHP) je dvofazni uređaj s iznimno visoko učinkovitom toplinskom provodljivosti koji koristi termodinamičku tlačnu razliku za cirkuliranje fluida. LHP je izumljen u Rusiji u ranim 1980-im. Ovaj rad se bavi dizajnom LHP-a za hlađenje bipolarnog tranzistora s izoliranom upravljačkom elektrodom i utjecaju nagnutosti od LHP-a na temperaturi od tranzistora. Maksimalna temperatura tranzistora je 100°C. LHP je izrađen od bakrene cijevi. Radna tekućina je destilirana voda.
Ključne riječi: toplinska cijev u obliku petlje, hlađenje, elektronička komponenta, kut nagiba.

INTRODUCTION

A two-phase capillary pump loop, as Loop Heat Pipe (LHP), is an efficient heat transfer system based on the liquid-vapor phase change phenomena. It was developed in 1972 by Gerashimov and Maydanik of the Ural Polytechnic Institute. A loop heat pipe consists of an evaporator, a condenser, a compensation chamber, and liquid and vapor line for transport working fluid (Fig. 1). Only the evaporator and part of the compensation chamber contain wicks. The other components could be madeof smooth tubing. Like a conventional heat pipe, a two phase capillary loop uses capillary action to circulate the working fluid in a sealed enclosure and, in the process, to transfer waste heat from one location (heat source) to another (heat sink). LHP contains no mechanical moving part to wear out or require electrical power to operate. [1]
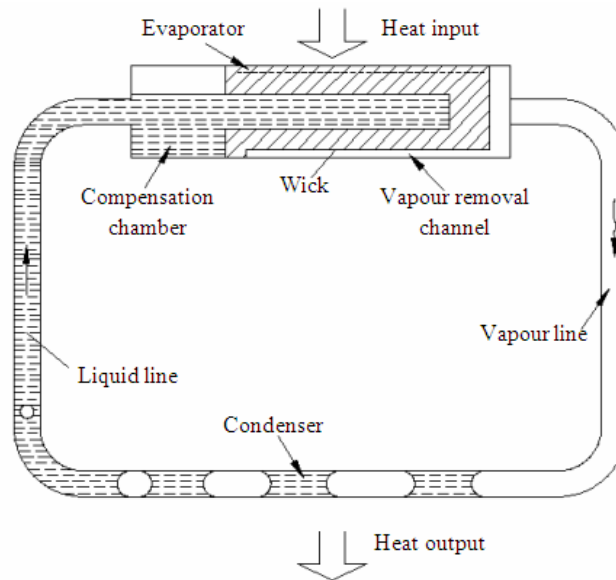
Figure 1. Schematic diagram of LHP[1]
Slika 1. Shematski dijagram LHP-a [1]

OPERATION PRINCIPLE OF LHP

A major part of heat input Q_{input} is used for the liquid vaporization on the outer surface of the primary wick (Q_V). The vapor generated in the evaporator is transferred along the vapor line to the heat exchanger where heat is transmitted to the ambient and turns back to liquid phase. The rest of the heat input, Qcc (called "heat leak") is conducted across the wick and tends to increase the compensation chamber temperature. [2] The amount of heat leak is proportional to the saturation temperature difference between the evaporator and the compensation chamber ΔTw. This tempera-ture difference (ΔTw) is a direct result of the pressure difference across the wick, induced by the vapor, condenser and liquid line pressure drops. The coupling between the pressure drop and the temperature drop across the evaporator wick is responsible for many of the peculiar behaviors found in LHP operation. Thus:

$$\underline{\quad\quad} \quad\quad \underline{\quad\quad}$$

where   is the mass flow rate,   is heat of vaporization,   is the thermal conductance between   the   evaporator   and   the compensation chamber,   and   is the temperature of evaporator and compensation chamber. [3]

At a specific heat input, an increase in the compensation chamber temperature tends to reduce the two-phase flow length in the condenser. A subcooled liquid flow region will appear before the condenser outlet. Then, the liquid subcooling will compensate a part of the heat leak in the compensation chamber:

where   is the liquid specific heat and   is the liquid temperature at the compensation

chamber inlet. At this state, the condenser is divided into three regions: the superheated vapour flow, the two-phase flow and the subcooled liquid flow. The LHP reaches a steady-state operation as the heat leak is totally compensated by the liquid subcooling. The LHP will adjust the saturation temperature until the energy balances for all the loop elements are satisfied. The feedback adjustment of the loop temperature is called "LHP auto-regulation". [3]

DESIGN OF LHP

Table 1. Main design parameters of the LHP
Tablica 1. Osnovni parametri dizajna LHP-a

LHP evaporator				
Total length (mm)	130		Length (mm)	140
Active length (mm)	86		**Charge mass**	
Outer/inner diameter (mm)	28/26		Distilled water	60%
Material	copper		**Vapor line**	
Saddle			Length (mm)	370
Size (length/high/wide)	118/89/40		Outer/inner diameter (mm)	6/4
Material	alumina		**Liquid line**	
Wick			Length (mm)	370
Sintered copper powder				
Number of vapor grooves	6		Outer/inner diameter (mm)	6/4
Porosity (%)	51		**Condenser**	
Outer/inner diameter (mm)	26/10		Length (mm)	300
Compensation chamber			Outer/inner diameter (mm)	10/8
Outer/inner diameter (mm)	35/33			

All tests were performed in the same LHP system. Tab.1gives the main design parameters of the LHP. The LHP position was changed from the vertical position (90°) to the horizontal position (0°) during the measurement. The LHP evaporator was built with copper with alumina saddle, and the wick structure was made from copper powder. Main design parameters of LHP are in table 1. As a working fluid was used distilled water and amount of the working fluid was 60% of the total volume of the LHP.All tests were performed under the near ambient environment, and the condenser sink temperature was controlled to 20 ± 2 °C by a water cooler (thermostat). The evaporator was heated by the IGBT (insulated gate bipolar transistor) electronic component, which was connected to DC power supply. The maximum allowed temperature of the IGBT is 100°C. The temperature of the IGBT and the LHP was measured with thermocouple. The thermo-couple measurements were recorded and transferred to the computer through logger. Schematic diagram of measuring device and location of 7 T-type thermocouples (deviation of ±0.2 °C) is given in figure 2 and figure 5.
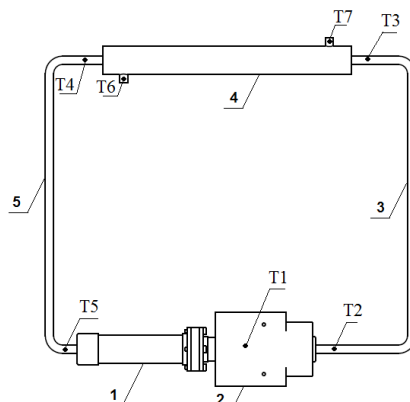
Figure 2. Scheme of LHP and the distribution of thermocouples: 1 compensation chamber, 2 alumina block, 3 vapor line, 4 condenser, 5 liquid line, T1-T7 thermocouples
Slika 2. Shema LHP i distribucija termoparova: 1. kompenzacijska komora, 2 blok aluminijevog oksida, 3 linija pare, 4 kondenzator, 5 linija tekućine, T1-T7 termoparovi
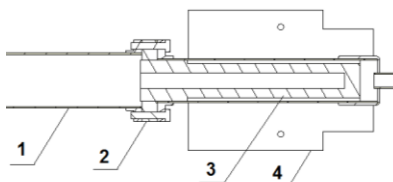

Figure 3. Section of evaporator: 1 compensation chamber, 2 rubber seal, 3 wick, 4 alumina block
Slika 3. Dio za isparavanje: 1. kompenzacijska komora, 2 gumene brtve, 3 fitilj, 4 blok aluminijevog oksida
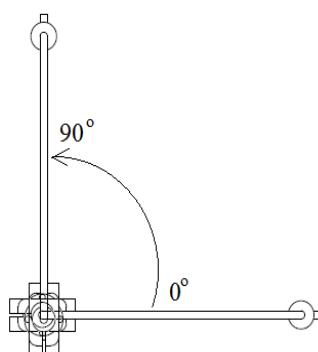
Figure 4. Tilt angle of the LHP
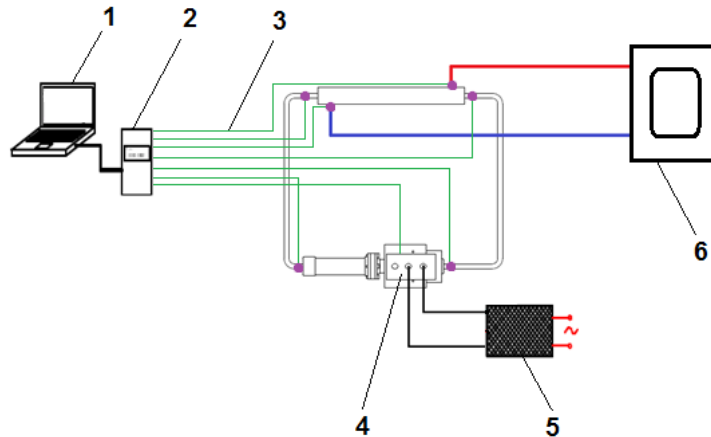**Slika 4.** Kut nagiba kod LHP-a

Figure 5. Schematic diagram of measuring device: 1-PC, 2- logger, 3-thermocouples, 4- IGBT, 5- power supply voltage and current, 6- thermostat
Slika 5. Shematski dijagram uređaja za mjerenje: 1-PC, 2- bilježenje, 3-termoparovi, 4- IGBT, 5- napajanje napona i struje, 6- termostat
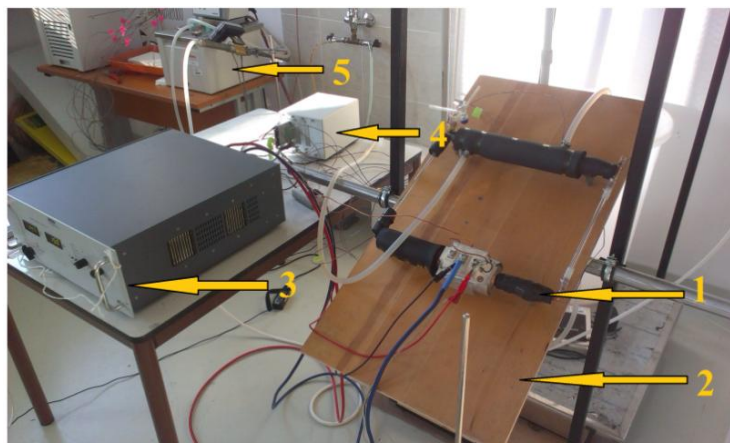

Figure 6. Measuring device: 1- LHP, 2- swivel plate, 3- power supply, 4- logger, 5- thermostat
Slika 6. Mjerni uređaj: 1- LHP, 2- zakretna ploča, 3- napajanje, 4- zapisivanje, 5- termostat

RESULTS AND DISCUSSION

The IGBT was connected to the DC power of source (Delta power Supply SM120-50). The maximum allowed temperature of the IGBT is 100°C. The IGBT was fixed on the aluminum saddle and it was cooled with the LHP. When the IGBT wasn't cooled its temperature exceed 100°C under load 50W. Therefore, it is necessary to cool the IGBT.

The first measurement was carried out in a vertical position (90°). The IGBT was gradually loaded by DC in the range from 100W to 300W. In figure 7 can be observed the temperature of the IGBT and the temperature of working fluid when electrical load was increased from 100W to 300 W. In figure 8 is shown that the temperature of IGBT didn't exceed 50°C when electrical load was 150W.
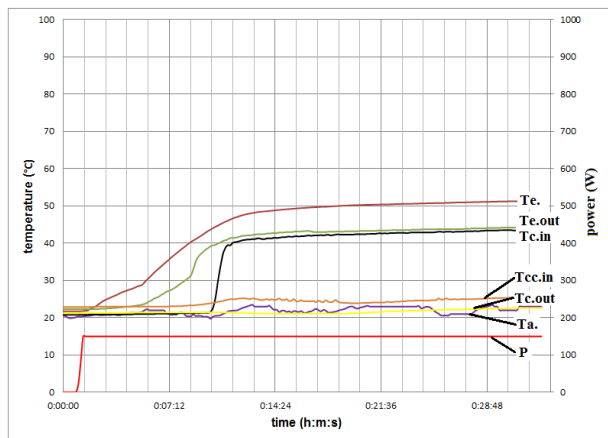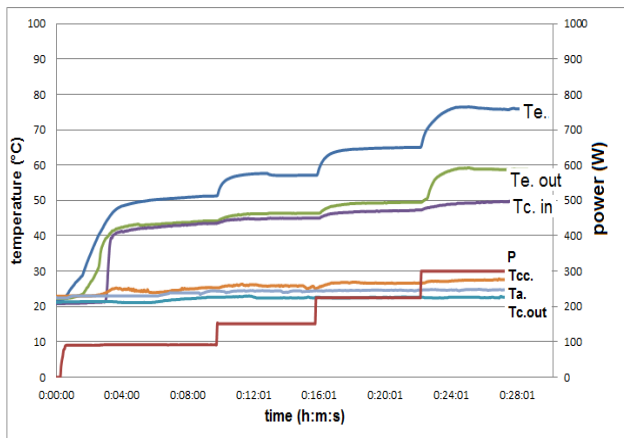
Figures 7 & 8. The temperature of the IGBT (Te.) and the working fluid in the vertical position (90°). The temperature of working fluid: Te.out- evaporator out, Tc.in- condenser in, Tc.out- condenser out, Tcc- compensation chamber, Ta- ambient

Slike 7 & 8. Temperatura IGBTa (Te.) i radni fluid u vertikalnoj pozociji (90°). Te.out je temperature radnog fluida, koji izlazi iz isparivača (T2). Tc.in je temperature radnog fluida, koja odlazi u kondenzator (T3). Tc.out je temperature radnog fluida, koji izlazi iz kondenzatora (T4). Tcc je temperatura radnog fluida, koji ide u kompenzacijsku komoru (T5). Ta je temperatura okoline. P je električna snaga IGBT-a
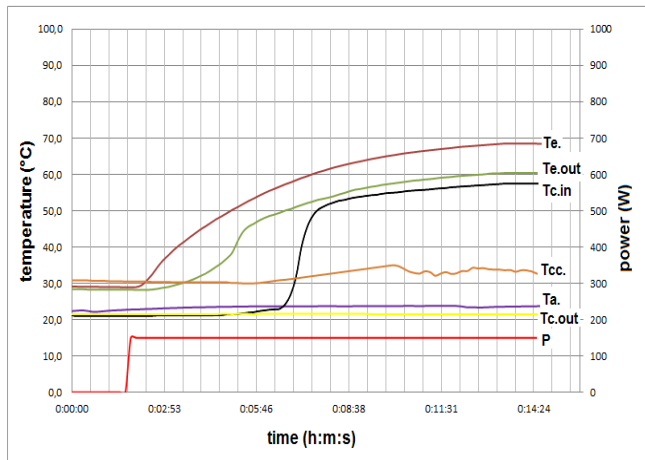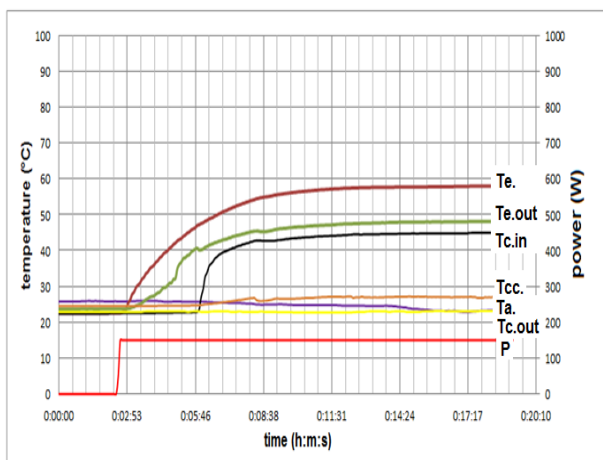
Figures 9 & 10. The temperature of the IGBT (Te.) and the working fluid at tilt angle of the LHP 45° and in the horizontal position (0°). The Electrical load was 150W

Slike 9 & 10. Temperatura IGBT-a (Te.) i radni fluid pod kutom nagiba od LHP-a 45° i radna tekućina u horizontalnom položaju (0 °). Električna snaga je 150W

The second measurement was carried out at 45° position of the LHP. Electrical load was 150W. In figure 9 can be observed the temperature of the IGBT and the working fluid of the LHP. There is shown that the temperature of the IGBT didn't exceed 60°C.

The third measurement was carried out in a horizontal position (0°). The electrical load was same as in the first and the second case 150W. In figure 10 can be observed that the temperature of the IGBT didn't exceed 70 °C.

CONCLUSION

The aim of this experiment was to design the LHP and determine the influence of gravity to remove waste heat from the IGBT. In figure 7 it can be seen that the IGBT doesn't exceed 80°C even electrical load was 300W. It demonstrates good cooling effect of the LHP and its possible to use in electronic cooling. In figure 8-10 it can be seen how gravity influence to remove waste heat from the IGBT. In figure 10 it can be seen LHP was able to work in the horizontal position. The best position to remove waste heat from the IGBT using the LHP is the vertical position. Change position from vertical to horizontal temperature of IGBT increases and performance of the LHP decreases.

The application of the LHP for cooling power electronic, especially electronic semiconductor devices, offers better cooling performance and improved cooling in area of higher power dissipation of about 200 W.

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