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ANALYSIS AND DESIGN OF CAPILLARY PUMPS FOR APPLICATIONS IN ELECTRONIC COMPONENTS COOLING SYSTEMS

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A prototype cooling system with a CPL device has been developed to study its capabilities and control methods. An important part of the project is the system of pump control. The cooling system actively reacts to changes of the power dissipated in the element.

The system has been experimentally investigated. The analysis of the capillary pump activity and the cooling system with a pump has offered the opportunity to create a theoretical model of the CPL. The model including all the loop elements and the essential physical processes has been designed. Static and dynamic states have been simulated using the model proposed. By comparing the experimental results and simulations for various states, the capillary pump and its model can be analyzed.

1. INTRODUCTION

In the project, the Capillary Pumped Loop (CPL) has been anticipated as an element taking the heat away from power components [1], [2]. The capillary pump is a device capable of transporting huge amounts of thermal energy for long distances. The long distance between the heat source and the external cooling environment solves the problems present in the standard cooling systems.

Capillary cooling systems are placed between the electronic component which generates heat and a heat sink (radiator, cooler, etc.). In the part of the system being in contact with the component in which a significant amount of heat is dissipated, the fluid evaporates. The heat is transported with the vapour towards the cooler, where it is dissipated and the vapour is condensed. The circulation is provided by the capillary pressure produced in the porous material. It should be noted that, for the cooling of electronic devices, systems with various media are used, e.g. with water, ammonia, freon, acetone or methanol. Higher latent heat of evaporation leads to better cooling efficiency.

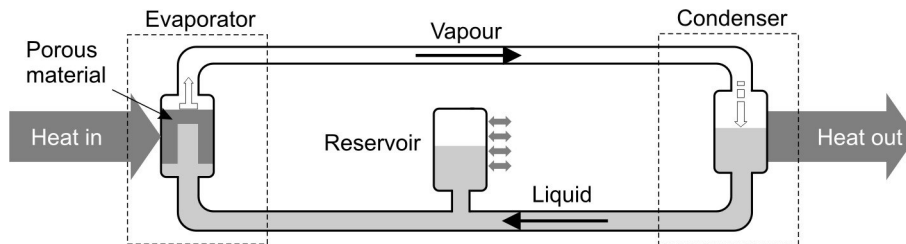


Fig. 1. Capillary Pumped Loop

The Capillary Pumped Loop (CPL) consists of an evaporator, condenser and two-phase reservoir. These CPL components are interconnected by transport lines (vapour and liquid lines) as illustrated in Figure 1. The evaporator is an element taking the heat directly from the cooling system. Inside, there is a porous material which plays a key role in the pump operation. Capillary forces present in the porous material cause the underpressure which sucks in the fluid delivered through the inlet. The heat from the heat source is applied to the porous material surface through the evaporator wall and vaporizes the working fluid in the pump. The vapour is carried away from the surface of the porous material through special grooves to the output. Then, it is transported through the vapour line to the condenser where heat is removed and vapour returns to liquid state. The liquid flows along the liquid line back to the evaporator. The two-phase reservoir is connected to the liquid line, and regulates CPL working condition.

2. COOLING SYSTEM

Figure 2 shows a prototype of a cylindrical CPL built in the Institute of Electronics at the Technical University of Lodz. The CPL evaporator base is made of copper. There is a porous material inside. The porous material was machined from a sintered glass block with vapour-grooves cut into the outer

diameter. The evaporator is closed by a silicone screw plug. The CPL condenser section is a finned tube with forced air convection cooling. A brass reservoir is used to regulate a liquid level within the loop. The reservoir controls the operating pressure of the system through the saturation temperature which is regulated by means of Peltier modules. The liquid and vapour lines are made of polyethylene, and have a 4mm diameter. Deionized water was chosen as the working fluid.

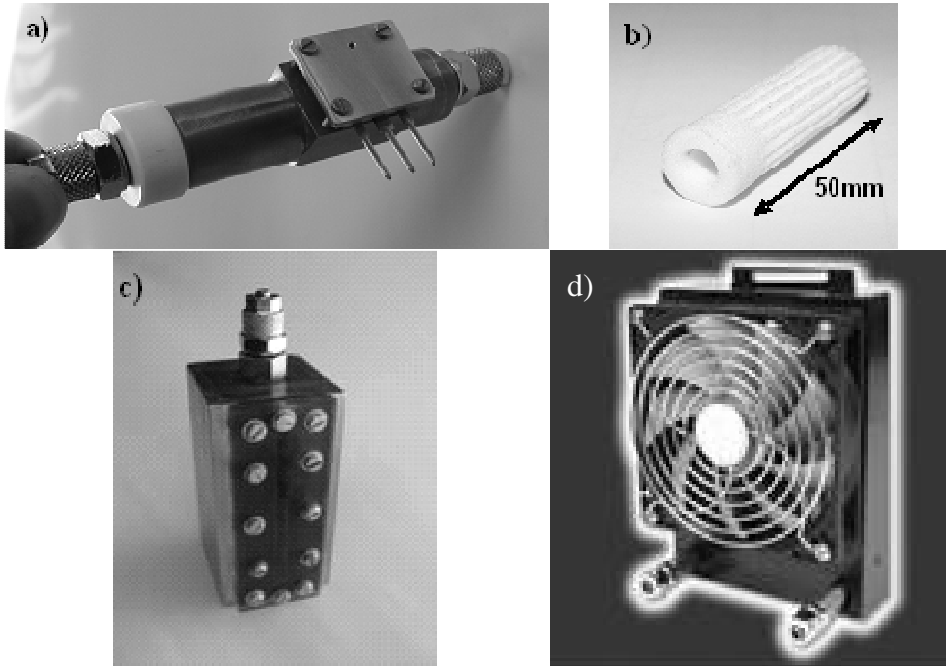


Fig. 2. Elements of the Capillary Pumped Loop prototype:
a) evaporator, b) porous material, c) reservoir, d) condenser

For the present investigation, the experimental setup includes:

- capillary pump with IGBT transistor,
- data acquisition card,
- computer with LabView environment;
- sensors: thermocouples, pressure and current sensors;
- Peltier modules with a controller.

The LabView program is used to control the CPL with the aid of an implemented algorithm. All the parameters measured are displayed on the computer in real time and recorded every second to a file. An IGBT (*Insulated Gate Bipolar Transistor*) working as a current source is used as a heater. It is attached to the evaporator to supply the required heat load. The maximum

power output is 210W (at 100°C case temperature). The current and voltage are measured by the DAQ (*Data Acquisition*) card. For protection reasons, a control system is used to cut off the heater power if the IGBT case temperature exceeds 100°C. The temperature at six CPL points (evaporator and condenser inlets and outlets; reservoir and ambient) is measured. All the K-type thermocouples are connected to the data acquisition system, where a program is used for monitoring the temperature. With the aid of a Motorola MPXA6115A sensor the reservoir pressure is also monitored.

The system control is realized by using Peltier modules to heat up or cool down the reservoir. It is the key for controlling the heat transfer rate of the pump. The regulation of the reservoir pressure causes a change in the circulating cooling medium amount. This method of the operating point control appears to be better than fluid temperature stabilization in the reservoir [3]. The CPL reservoir is also used for active control and pre-conditioning on start-up. During start-up time and changes of working conditions the pump is controlled through the reservoir pressure regulation.

3. MEASUREMENTS AND SIMULATIONS

After the system was built and initiated the measurements were performed. The power of the cooled IGBT was regulated in the range of 150-200W. The reservoir pressure was set at 350, 450, 550 and 650 hPa. In steady states the temperature of the cooled elements is the main parameter measured. In transient states a time constant of this temperature change also plays a significant role.

Theoretical investigations on the CPL system were developed simultaneously with the experimental research and were focused on the most important pump elements with a special emphasis on the evaporator. The model proposed bases on the model presented by Pouzet et al [3]. It describes pump operation both in steady and transient states but does not include the start and the stop of the system. According to the assumption, the theoretical model describes regular cooling medium flows with vapour lines filled only by vapour, liquid line and porous material filled only by liquid, and the case when the whole amount of vapour has liquefied in the condenser. The model was implemented to the Matlab and simulations of the system were performed.

The theoretical model results have revealed a good agreement with the measurements. In steady states the maximum difference between the temperature values predicted in the simulations and obtained in the experiments is smaller than 4.2 K. In transient states the element temperature variations predicted have the same characteristics as in the measured system. The temperature change rate is predicted with an error below 5.1%.

4. CONCLUSIONS

In the research:

1. A theoretical model of electronics cooling system with a CPL was built and verified. The model describes steady and transient states.
2. A cylindrical capillary pumped loop was developed.
3. A cooling system with a CPL was built and tested.

The proposed system with a CPL proved to be a good cooling method for electronic components, better than radiators generally used. In comparison with a radiator, the system's maximum power intake is twice as great.

By comparing the simulations and the experimental results it can be observed that the analytical description of steady and transient states is satisfactory.

The research shows that a capillary pumped loop is a promising thermal management device and can be used to take heat away from electronic components. However there are still some problems to solve, e.g. CPL start-up and control algorithms. Further research is assumed to investigate system optimization and to extend research on capillary pump start-up problems.

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ANALIZA I PROJEKTOWANIE POMP KAPILARNYCH DO ZASTOSOWAŃ W SYSTEMACH CHŁODZENIA UKŁADÓW ELEKTRONICZNYCH

Streszczenie

Badania przedstawione w tej pracy dotyczą systemów chłodzenia układów elektronicznych, wykorzystujących pompę kapilarną do odprowadzania ciepła z elementu chłodzonego. Pompy kapilarne charakteryzują się wysoką efektywnością chłodzenia i dzięki tej własności mogą być stosowane do chłodzenia elementów elektronicznych dużej mocy. Ze względu na możliwość odprowadzania ciepła z chłodzonego elementu na znaczne odległości, mogą być stosowane przy chłodzeniu elementów o mocno ograniczonych możliwościach odprowadzania ciepła w pobliżu danego elementu.

W ramach badań przedstawiony został projekt systemu chłodzenia elementów elektronicznych wykorzystującego prototypową cylindryczną pompę kapilarną. Równoległe do prac doświadczalnych, stworzony został model teoretyczny systemu chłodzenia z pompą kapilarną typu CPL. Zaproponowany model opisuje działanie pompy zarówno w stanach ustalonych, jak i przejściowych. Przeprowadzono symulacje działania pompy kapilarnej typu CPL w stanach ustalonych z wykorzystaniem opracowanego modelu teoretycznego, a następnie symulacje w stanach przejściowych. Z porównania wyników symulacji i pomiarów można stwierdzić, że stworzony model termiczny pompy kapilarnej typu CPL, do chłodzenia układów elektronicznych, poprawnie opisuje działanie pompy kapilarnej w stanach zarówno statycznych jak i dynamicznych.

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