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Experimental research of a thermoelectric cooling system integrated with gravity assistant heat pipe for cooling electronic devices

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Abstract

As the computer systems process data more rapidly, large amounts of heat are generated in very small areas. Thermal management of the central processing unit has become crucial to avoid malfunction and failure of critical hardware. A thermoelectric cooling (TEC) system is proposed to remove the heat that is generated by electronic device in this paper. To improve the performance of this system, a gravity assistant heat pipe (GAHP) is attached on the hot side of the thermoelectric cooling module, serving as a heat sink. A mathematical model of heat transfer, based on the energy conservation, is established for the integrated system. A prototype is designed, built and tested in a climatic chamber under various conditions, comparing with a TEC system with air cooling heat sink. It is found that the cooling capacity is improved by approximately 73.54% and the electricity consumption was reduced by 42.20% to produce the same amount of cold energy.

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Keywords: Thermoelectric cooling (TEC); Gravity assistant heat pipe (GAHP); Cooling capacity; Energy consumption

1. Introduction

The server computers work continuously and provide services to many clients simultaneously, which results in greater heat production and high temperature that must be managed in order to avoid malfunction and failure of critical hardware [1]. In various applications, however, the traditional passive cooling systems, including air cooling, water cooling, liquid cooling and so on, are reaching the limits in terms of cooling capacity for high power electronic devices [2]. Under this condition, thermoelectric cooling (TEC) system, known as an active cooling method, is considered to be one of the alternative

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technologies with light and compact size, quiet and vibration-free operation, free from long-term maintenance, and operation with DC voltage [3].

It is important that the hot side of the thermoelectric module be cooled to prevent damage to the hardware and itself [4]. For this reason, the thermoelectric module must be combined with a cooler such as heat sink or water cooling to dissipate the heat of the hot side for effective operation. To improve the energy conversion efficiency of TEC system, kinds of methods were proposed to enhance the heat dissipation of the heat side[5]. Liu et al. [6] presented a thermoelectric mini cooler coupling with a micro thermosiphon cooling system for cooling CPU. A looped heat pipe heat exchanger was attached to the hot side of the thermoelectric cooler as a heat sink. It was found that the thermoelectric operating voltage of 12V could achieve the lowest thermal source surface temperature, maximum cooling capacity and higher COP. Tan and Zhao [7] utilized phase change material (PCM) as a heat sink to reduce hot side temperature of thermoelectric modules during daytime cooling period for space cooling purpose. The average system cooling COP was increased by 56% because of the PCM integration. Wang et al. [8] used a heat sink and a fan to enhance the heat dissipation of the hot side and maintain the temperature of optical chips of the laser. The results showed that the performance of TEC was improved by increasing the heat sink's size and fan's flow rate [9].

Among all the proposed techniques, TEC system integrated with heat pipe is more attractive because of the great amount of phase change heat transfer (condensation and evaporation). This paper proposed a thermoelectric cooling system integrated with a gravity assistant heat pipe for cooling electronic devices. A gravity assistant heat pipe (GAHP) is attached on the hot side of the thermoelectric cooling module, serving as a heat sink. A mathematical model of heat transfer, based on the energy conservation, is established for this integrated system. A full-scale prototype is designed, built and tested in a climatic chamber under various conditions, comparing with a TEC system with air cooling heat sink to illustrate the performance of this proposed new TEC system. The cooling capacity was used to evaluate the viability of the proposed system.

2. Description of the proposed thermoelectric cooling system integrated with heat pipe

The thermoelectric cooling (TEC) system integrated with gravity assistant heat pipe (GAHP) was designed and developed for cooling the electronic devices. Heat pipe, which can transport amount of heat with small temperature differences within short time because of the phase change heat transfer inside the pipes or tubes, is introduced to enhance the heat dissipation of the hot side of thermoelectric module, as shown in Fig. 1. To improve the heat absorption, a heat sink was installed on the cold side of thermoelectric module. The GAHP with a flat and smooth evaporation surface to reduce the contact thermal resistance, was attached on the hot side of thermoelectric module. An axial fan was installed above the heat sink on the cold side of thermoelectric module to cool down the temperature of electronic devices and on the condensation zone of the GAHP to blow the heated air into the surrounding ambient, respectively. When DC current was applied to the thermoelectric cooling system, the Peltier cells absorbed heat from the heat source and dissipated heat to the hot side of thermoelectric module. The heat was then passed through the evaporate zone of the gravity assistant heat pipe to further transport heat to the condensation zone, which could result in two-stage heat transfer process.

The cooling capacity of thermoelectric module was

$$Q_c = \alpha I T_c - \frac{1}{2} I^2 R - k\Delta T \tag{1}$$

where T_c was the cold side temperature, ^oC; T_h was the hot side temperature, ^oC; ΔT was the temperature difference between cold and hot sides, ^oC; I was the input current, A; R was the electric resistance of