

## VAPOR-COMPRESSION-REFRIGERATOR ENABLED THERMAL MANAGEMENT OF HIGH PERFORMANCE COMPUTER

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### ABSTRACT

With rapid upgrade of high performance computer, heat release from chips is increasing at a tremendous rate. Particularly, the emergence of the technology by integrating multiple CPU into a computer closet makes it more serious for the thermal management. Traditional air cooling, even liquid cooling may not be able to fulfill this urgent need. Therefore, active refrigeration is becoming an important option to solve such bottleneck problem. As a mature refrigerating method with high cooling capacity, high efficiency and low cost, vapor compression refrigerator appears as an excellent candidate in the computer industry. However, at the present stage, a reliable and integrated equipment is still not available. Here to tackle the high flux heating issue, we propose a vapor compression system for simultaneously managing heat released from multiple computer chips. The system is quite flexible when connected with four-CPU-chip. Besides, it allows use a completely close computer closet, which will thus have unique merits such as dustproof, low noise and long life-span etc. To evaluate the cooling capacity of the present refrigeration system, several conceptual thermal management experiments on high performance computer was performed. It was shown that temperatures for the first three chips near the refrigerant inlet can be reduced to about 20°C from 80°C in a high thermal load 180W. This study demonstrates that introduction of the integrated vapor compression cooling system may change the structure and working manner of a computer. It is very possible to become a competitive thermal management option in future high performance personal computer.

**Key words:** high performance computer; vapor compression refrigeration; thermal management

### 1. INTRODUCTION

With increasing numbers of transistor per chip in a high performance computer, the chip power is increasing rather rapidly over the past 30 years. Particularly, introduction of multiple CPU into a computer closet further makes the situations more serious for the thermal management. Therefore heat removal keeps as a critical issue in insuring the safe operation of computers. For thermal engineers, the most urgent task is to find an efficient, reliable and low cost cooling method.

Traditionally, fans are often adopted to enable a forced-air convection cooling in computers, but its noise level is pretty high which often disturbs people's work. New solutions are turned to liquid cooling (Strassberg,1994), thermoelectric cooling (Disalvo,1999), heat pipes (Hosoda et al.,1999). There are generally two moving parts (impeller and fan) in a liquid cooling system. Solid-state thermoelectric devices have no moving parts, which is perhaps their most attractive virtues. Unfortunately, the relatively poor Coefficient of Performance (COP) limits them to low power applications. In addition, high power applications may require additional active cooling to remove heat from the hot side of the thermoelectric

International Congress of Refrigeration 2007, Beijing.

device. Heat pipe has an advantage of low thermal resistance and its performance is relatively insensitive to the pipe length. Consequently, it can be arranged in many shapes to accommodate different configurations requested by the computer closet. This technique has in fact been implemented in laptop computers. Whereas in the desktop server application, a flat type rectangular heat pipe is attached under the base of the heat sink to guarantee its temperature uniformity, which will reduce the spreading resistance in the heat sink base and therefore improve the heat sink performance. It should be noted that heat pipe itself could not provide active cooling.

As CPU heat dissipation rate keeps increasingly large and computer has shifted toward being compact, both these requests have limited the cooling efficiency in a highly confined space. The conventional methods have either reached their practical limit or are soon to become impractical for recently emerging electronic components. Therefore application of active cooling is considered as an alternative to these conventional methods for cooling future high power processors (Heydari, 2002; John, 2001).

Among various refrigeration systems including thermoelectric, vapor compression, Stirling, pulse tube, sorption and reverse Brayton cycle, the vapor compression has the highest COP (Phelan et al., 2001). However, up to now, vapor compression system has not been commercially available due to difficulties in miniaturizing the system.

Kryotech has made a relatively small vapor compression refrigerator, which can be incorporated to cool an AMD chip down to  $-40^{\circ}\text{C}$ . However, this system is much larger than the mesoscale and microscale requirement, and is made to be installed below the tower of a desktop computer. A particular challenge to miniaturize the vapor compression refrigerator is to make a small, yet efficient compressor. Research is underway to develop micro vapor compressors (Phelan, 2004). Unfortunately, up to now no system performance data are reported yet.

In this study, we proposed a vapor compression system for simultaneously managing heat released from quad CPU, a challenging issue for the current computer industry. Four cooling heads are connected in series, soft link is used between them and closet. Besides, application of this cooling system allows a sealed computer closet, which has unique virtues such as dustproof, low noise and long life-span. To demonstrate the feasibility of adopting the cooling system for the thermal management of a high performance computer, a series of conceptual experiments are conducted.

## **2. MATERIALS AND METHODS**

### **2.1. Hardware fabrication**

Four cooling heads used as evaporator and one heat exchanger used as condenser with a fan were bought from market. Compressor with input power of 70W was used, with a capillary as expansion element. Hydrostatic tests on each cooling head and four linked cooling heads have been performed to evaluate the leak and pressure capacity before filling the refrigerator. For this project, R12 was used to match with compressor model. Bellows connection is used between compressor and heat sink. Fig. 1 shows the prototype of the vapor compressor cooling system.

To test the performance of the cooling system, four heating sticks are inserted in the hollow cavity drilled in four aluminum cylinders whose diameter is 50mm and height is 20mm to simulate a practical four-CPU-chip.

### **2.2 Methods**

The investigated high performance computer has used four CPUs, so the refrigeration system should satisfy the space requirement. Four heat sinks were designed to connect in series to meet the need.

In addition, it is found that cooling heads and simulant chips have high temperature difference. Consequently, some measures are taken to improve the situation. Screws preload of back plates was adopted for balance. Conductive silicone grease was filled between the heater and the cold plate in order to minimize the thermal resistance in surface contact. Flat and smooth surfaces for the plates are generally required. Heat conducting plates made of copper are also introduced to balance temperature distribution. During the test, surface temperature of heat sinks may be cooled to below dew point, a close closet and some drier are needed to avoid condensation.

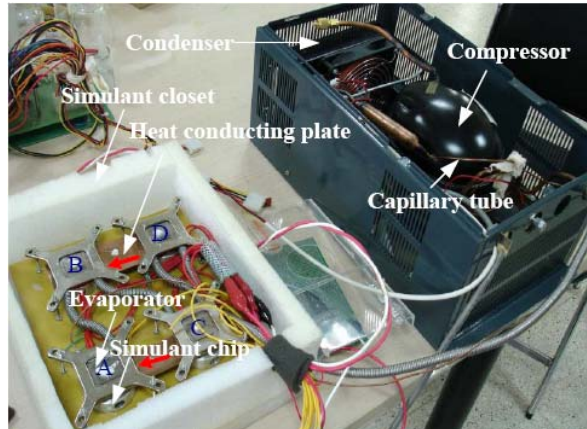


Figure.1 System schematic diagram

### 2.3 Measurement system

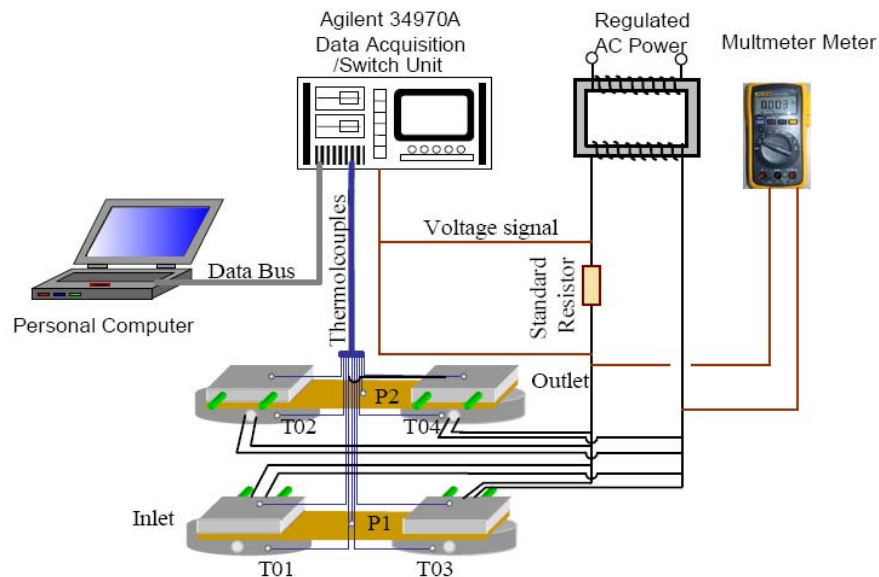


Figure.2 Schematic diagram of measurement on vapor compression cooling system

In this study, an apparatus and experimental procedure have been developed to facilitate a systematic study for thermal management of chip cooling. The schematic diagram of the apparatus is given in Fig. 2. The heating power is controlled by Regulated AC Power Supply, whose output voltage range is 0~250V. The thermocouples are calibrated in the ice water and an accuracy of  $\pm 0.1^{\circ}\text{C}$  is obtained. The transient temperature and voltage across the heater are measured using a 48 channels Agilent 34970A Data

Acquisition/Switch Unit connected with a computer. The acquisition software uses BenchLink Data Logger, which can immediately display, analyze and save the measured data.

Four thermocouples are placed on the surfaces of four evaporators. Another four thermocouples are mounted on the side face of the heaters to evaluate the cooling system performance. Each heater resistance was measured as  $500\ \Omega$ . The resistance of the total resistance was  $125\ \Omega$ .

### 3. RESULTS AND DISCUSSION

The performance of the vapor compression system, such as heating capacity, compressor input power and EER are measured in this study. The temperature of the heating heads, cooling heads and heat conducting plates are measured to test the influence of varying input heating power on the heaters and cooling system performance.

#### 3.1. Comparison of output simulant CPU temperature under different input power

To investigate cooling capacity of the system, the vapor compressor starts up after heaters have worked for 2 minutes. Generally speaking, the temperature of output evaporator is the highest due to superheat, so temperature of the fourth heater can be used as an index to check out the validity of the cooling system. In the present cooling system, heaters and cooling heads reach their heat equilibrium by conduction. Fig.3 shows the output heater temperature under input power of 120 W, 150 W and 180 W respectively. It can be divided into three phases from the curves. Phase I is for the heating and compressor startup stage, phase II is cooling state, phase III represents a steady state. In Phase I, temperature increases in the first two minutes due to heating. Later, although compressor has started up, it still cannot supply cold immediately. Consequently, heating capacity is larger than refrigeration capacity, temperature just keeps increasing. With the elevation of evaporation temperature, compression ratio reduces and volume efficiency increases, which results in an improvement of refrigeration capacity. Therefore, when refrigeration capacity overcomes the heating, temperature begins to fall in Phase II. As evaporator temperature reduces, refrigeration capacity becomes lessened. Finally, when refrigeration capacity equals to the heating, the heater temperature becomes in equilibrium. When input heat power is 150 W, there is a sudden reduction at the end of Phase II for refrigerant transformation from its superheat vapor phase to two-phase fluid. For input power of 120 W, 150 W and 180 W, the cooling system can lower the heater temperature from maximal  $100^{\circ}\text{C}$ ,  $80^{\circ}\text{C}$  and  $70^{\circ}\text{C}$  to  $70^{\circ}\text{C}$ ,  $30^{\circ}\text{C}$  and  $10^{\circ}\text{C}$  respectively, which proves the efficiency of the vapor compressor system.

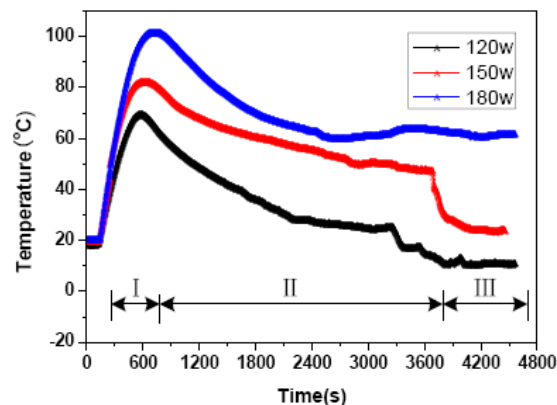


Figure 3. Output temperature of simulant CPU under different input power

### 3.2. Comparison of temperature of four simulat CPU at input power of 150W

If one requires CPU work at 40°C normally, the cooling system can support input power of 150 W well. In fact, computer and cooling system usually start up simultaneously, under this condition, the temperature responses of four heaters as input power of 150W are investigated. Experimental results presented in Fig. 4 indicate that the temperature increases gradually from inlet to outlet in unsteady phase and runs to convergence finally. Inlet heater comes to the steady state via a faster rate than that at the outlet. Temperature distributions for the first three heaters are similar to each other. It is found that the cooling degree for the four heaters is various, which would affect computer system operation. The connecting way of evaporators needs improvement in later study.

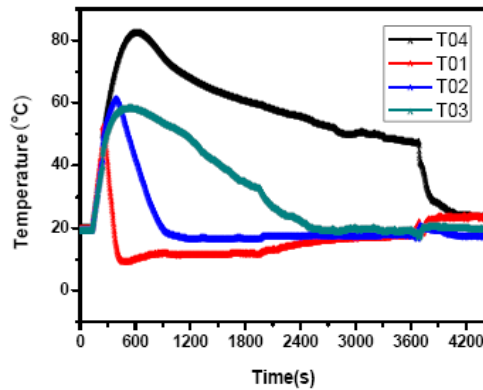


Figure 4. Temperature of quad stimulant CPU at input power of 150W

### 3.3. Amount of heat transfer through heat conducting plate

The temperature between each cooling heads is different in initial period. To balance the temperature distribution quickly, two heat conducting copper plates are adopted between heaters and evaporators to connect A and C as well as B and D (see Fig. 1). To evaluate function of heat conducting plates, heat conducted by copper plate  $Q_c$  is calculated by eq. (1). Direction of thermal conductivity is defined as red arrows in Fig. 1.

$$Q_c = A_c \frac{\lambda_c}{L} \Delta T \quad (1)$$

where,  $A_c=b \times \delta$  is the sectional area of the fin,  $b$  is the width of the copper plate,  $\delta$  is the thickness of the copper plate,  $\lambda_c$  is the thermal conductivity of the copper,  $L$  is length along conduction direction,  $\Delta T$  is the average temperature difference of the two connected heaters.

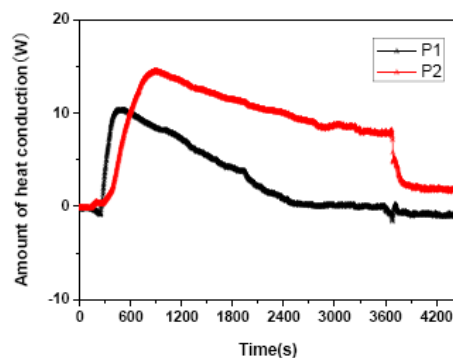


Figure 5. Amount of heat transfer through two heat conducting plate

Take input heating power of 150W as example, calculation results are depicted in Fig. 5. It is shown that copper plates have made contribution to heat balancing, especially at the beginning. Compared to copper plate 1 connected A and C, copper plate 2 with heat conduction of about 10W in start-up period plays a more important role in reducing temperature of outlet heater.

### 3.4. Energy efficiency ratio (EER) analysis

Energy efficiency ratio (EER) which is given in eq. (2) is an important index in evaluating vapor compressor system.

$$EER = \frac{Q_e}{W_{in}} \quad (2)$$

where,  $Q_e$  is refrigeration capacity,  $W_{in}$  is compressor input active power.  $Q_e$  is equal to input heating power of four heating resistor in parallel, which is calculated by measured voltage and current.  $W_{in}$  is gained from measured voltage and current of compressor. It is worth mentioning that phase of voltage and current of compressor is different, their phase variation is measured by oscilloscope. EER at different input heating power is depicted in Fig. 6. EER increases with input heat power in the test range.

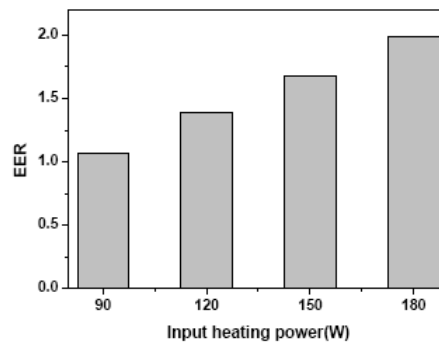


Figure 6. EER under different input power

## 4. CONCLUSIONS

A mesoscale-integrated refrigerator was fabricated to regulate heat release from four CPU chips in this study. A sealed closet is required to avoid hazardous condensation. The system successfully reduces the surface temperature of the heater to the normal working temperature. The cost of the effective system is equivalent to a domestic air conditioning, and can be cheaper if massively produced. At the present stage, noise of the fan used to cool condenser is still slightly larger than that of vapor compressor itself. The major refinement of vapor compression cooling is the size of vapor compressor. As launched study shows, the diameter of variable capacitance motor driven centrifugal compressor has reached 7.5cm (Agrawal et al., 2003) and size of micro vapor compression cooling has reached 120mm×3mm. These warrant future applications of incorporating the present system to thermally managing the computer closet, either in large or small scale.

### Acknowledgements

The valuable help from Prof. Ning-Hui Sun and Mr. Dong-Dong Wu from the Institute of Computing Technology, Chinese Academy of Sciences is greatly appreciated. This work is supported by the National Natural Science Foundation of China.

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