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Desktop PC CPU Cooling System Design and Analysis

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ABSTRACT: Desktop PC CPUs have been significantly required to be the necessity of thermal management while they have satisfied the extensive data and graphic processing requirements. So the cooling systems assembled with heat pipes embedded in a metal cooling plate, and fins are widely used in the desktop PC markets. Due to a number of demands such as the confined space of desktop PCs, higher heat density of CPUs, and acoustic noise, however, there is the main drive to improve continuously cooling systems. This paper presents the flow and thermal behavior of the cooling system by using the computational fluid dynamics(CFD) code.

Key words: CPU Cooling Solution, Desktop PC, and CFD

Nomenclature

A	: area (m^2)
Q	: heat rate (W)
R	: thermal resistance (℃ / W)
T_{cpu}	: junction temperature (℃)
T_{base}	: base plate temperature (℃)
T_{air}	: ambient temperature (℃)
P	: pressure (Pa)
u	: velocity (m/s)
ρ	: densisty, (kg/m^3)
σ_{ij}	: stress tensor
t	: time (s)
g_i	: gravity (m/s^2)
β	: coefficient of volume expansion (1/℃)
α_t	: diffusion coefficient (m^2/s)
k	: turbulent energy (m^2/s^2)
ϵ	: turbulent dissipation rate (m^2/s^3)

1. Introduction

Desktop PCs incorporated with the high performance CPU have became faster and greater functionality. However, the heat dissipation of CPUs has kept increasing significantly in the meantime but the size of die on the CPU was reduce or remained the same size. Then the normal operating temperature of silicon chips such as the CPU and etc. is required to be below 70℃. Bar-Cohen et al. pointed out that the reliability of the chips decreases by 10% for increasing every 2℃ above normal operating temperature. Thus, it is necessary to rapidly remove heat generated by the CPUs for normal operation. [1][2][3]

Typically, heat sinks fabricated of copper or aluminum, assembled with heat pipes, and small fan are used to induce forced convection in order to cool down heat generated by CPUs. However, increasing the surface area of heat sinks results in increase of the cost, and is not

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simultaneously discrepant from tiny trends of desktop PCs. Boosting the small fan speed also results in noise, vibration and more power consumptions.

So the cooling system design concentrates the fan solution and heat sink solution to be optimized under the limitation of overall volume, weight and acoustic level. This study has the objective of presenting both design and analysis of the cooling system to meet the cooling demands as thermal target specification against CPU recently released.

The paper describes the flow and thermal behavior of the cooling system by using the CFD code.

2. Modeling for design and analysis

A commercial CFD code SC-Tetra Ver.7.0 (Software Cradle Co., Ltd.) was used in this study, and an upwind difference scheme, SMPLEC were used to calculate the convection terms, the pressure-correction, respectively. As shown in Figure 1, the cooling system was designed with the length of 61.35 mm, the width of 108 mm, and the height of 132.5 mm. Compared with the existing models, this model is significantly smaller and used just two heat pipes to satisfy the demand for the confined space of desktop PCs. The heat generated by the CPU is transferred from the bottom of a base plate fabricated of copper to 2 ea of heat pipes embedded in the base plate, and then the heat pipes remove heat from 125 ea of copper fins to the surrounding by using forced convection through a fan of diameter 110mm. The boundary condition of this system were designed to be the fan velocity of 288 rad/s, the ambient temperature of 30℃, and the heat source of 130W. One end of both heat pipes inserted into the base plate as the evaporation section and another end embedded with fins as the condensation section. The working fluid of heat pipes evaporates when heating, and then condense through heat dissipation. It assumed the thermal conductivity of the heat pipes is $40,000\ W/m \cdot K$ .The number of meshes is about 60,000,000, and thermal contact resistance between heat pipes and the base plate and thermal contact resistance between heat pipes and fins are ignored.

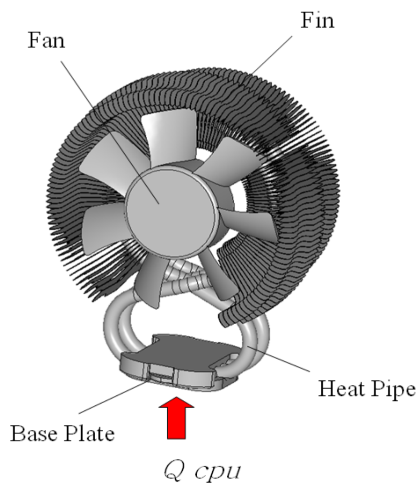


Fig1. Cooling equipment for a desktop PC CPU

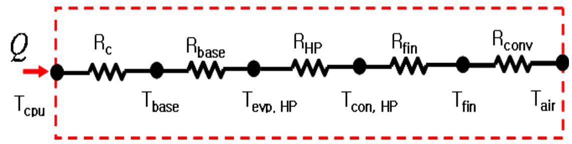


Fig2. Thermal path and thermal resistance

3. Theoretical background

2.1. Thermal resistance analysis

As shown in the Fig.2, the thermal path and the thermal resistance can be expressed for the cooling system. The rate of heat transfer Q from the heat source generated by the CPU to the temperature difference($T_{cpu} - T_{air}$) between the ambient temperature(T_{air}) and the CPU temperature can be expressed.

$$Q = \frac{T_{cpu} - T_{air}}{\sum R_{total}} \quad (1)$$

$$\sum R_{total} = R_c + R_{base} + R_{HP} + R_{fin} + R_{conv} \quad (2)$$

where ΣR_{total} denotes the total thermal resistance of the system, R_c is the thermal contact resistance(℃/W) between the heat source(T_{cpu}) and the base plate(T_{base}), R_{base} is the thermal resistance between the base plate and the evaporator section of the heat pipe ($T_{evp,HP}$). R_{HP} is the thermal resistance between the evaporator section of the heat pipe($T_{evp,HP}$) and the condenser section of the heat pipe($T_{con,HP}$), R_{fin} is the thermal resistance between the condenser section of the heat pipe and fins(T_{fin}), R_{conv} is the thermal resistance for convection(℃/W) between the condenser section of the heat pipe and the ambient temperature(T_{air}).

2.2. Governing equations

The governing equations consist of continuity equation (3), momentum equation (4), energy equation (5), and dissipation rate equation (5, 6 and 7).

$$\frac{\partial(\rho u_i)}{\partial x_i} = 0 \, (i = 1,2,3) \quad (3)$$

$$\frac{\partial(u_i u_j)}{\partial x_j} = -\frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_j}\left(\mu \frac{\partial u_i}{\partial x_j} - \overline{\rho u_i' u_j'}\right) + \rho g_i \quad (4)$$

where $\overline{\rho u_i' u_j'} = -\mu_t \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) + \frac{2}{3}\rho k \delta_{ij}$

$$\frac{\partial(\rho u_j T)}{\partial x_i} = \frac{\partial}{\partial x_j}\left(\Gamma \frac{\partial T}{\partial x_i} - \overline{\rho u_i' t}\right) \quad (5\text{-}1)$$

$$\frac{\partial}{\partial x_i}\left(k_s \frac{\partial T}{\partial x_i}\right) + \dot{q} = 0 \quad (5\text{-}2)$$

$$\frac{\partial(\rho u_j k)}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\frac{\mu_t}{\sigma_k}\frac{\partial k}{\partial x_i}\right) + G_s + G_t - \rho\epsilon \quad (6)$$

$$\frac{\partial(\rho u_j \epsilon)}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\frac{\mu_t}{\sigma_\epsilon}\frac{\partial \epsilon}{\partial x_i}\right) + C_1 \frac{\epsilon}{k}(G_s + G_t)(1 + C_3 R_f) - C_2 \rho \frac{\epsilon^2}{k} \quad (7)$$

So the standard turbulence k-ε model was used for the equations as mentioned above.[4][5][6]

5. Results and discussion

The velocity distribution of the cooling system is shown in Fig.4 at the steady state. The flow velocity was getting spreaded out diagonally. The temperature distribution of the system is shown in Fig.5. It showed that temperature was higher at the below part of the fins embedded with the heat pipe. At the upper part of the fins, temperature was lower because of the air flow. The total thermal resistance is about 0.169℃/W and the temperature at below of the base plate is about 52℃. And then it is expected that the CPU temperature would be within at least 54℃ if the thermal contact resistance is taken into consideration. So it seems to need a good thermal grease and constant pressure in an actual test.

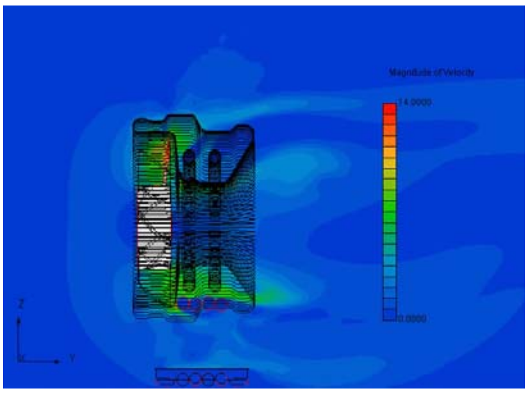
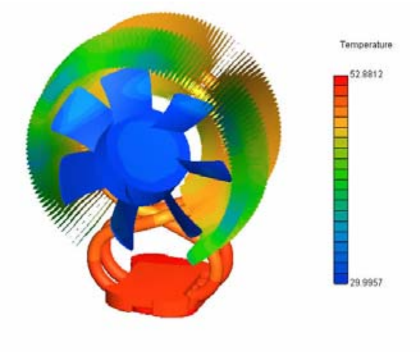
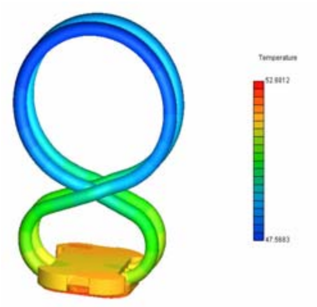


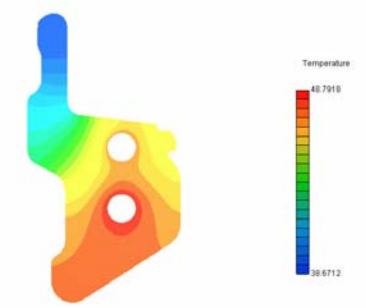
Fig4. Flow distribution at 293 rad/s of the fan



(a) Cooling system



(b) Heat pipes with a base plate



(c) fin

Fig5. Temperature distribution

6. Conclusion

Compared with the existing models, this model is significantly smaller and used just two heat pipes to satisfy the demand for the confined space of desktop PCs. In order to design it optimally, the cooling system for desktop PC CPUs, which was assembly of the smaller copper fins and only two heat pipes was analyzed by using CFD code at 130W of heat source. As results, the total thermal resistance is about $0.169℃/W$ and the temperature at below of the base plate is about 52℃ despite the worst condition. Thus, the analyzed model is in good agreement with the required demands of the desktop PC market

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