Heat Transfer Enhancement by Heat Sink Fin Arrangement in Electronic Cooling

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Mohamed Elnaggar
Palestine Technical College

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Mohamed H.A. Elnaggar
Engineering Department
Palestine Technical College-Deir EL-Balah
Gaza Strip, Palestine
mohdhn@yahoo.com

***Abstract*—This paper presents an analytical investigation of the effect of fins number and fin thickness on the performance of heat sink. The results showed that both the increase in fins number and thickness leads to an increase in heat transfer rate, but the increase in fins numbers significantly has more effect on the heat transfer rate than the increase in fin thickness does. The increase in the thickness of fin results in an increase in the heat transfer rate, but more increase of the fin thickness results in a decrease in the distance between fins. The distance among fins must be maintain to allow the cooling fluid to reach all cooling fins and to allow good heat transfer from the heat source to the fins as well.**

Keywords—heat sink; electronic cooling; heat transfer; styling; fins arrangement.

I. INTRODUCTION

Development of information technology IT growing rapidly, as a result performance requirement for computers and other electronic devices becomes higher and higher, this means the core of computers or devices, central processing unit (CPU), must have a higher efficiency and can conduct operations faster. Consequently CPU generates more and more heat, and this trend will continue in the coming future. Thus one of the bottlenecks of IT's further development is cooling technique. Hence it's highly desirable to investigate the high-performance cooling devices.

The traditional method to dissipate heat from electronic components was forced convection using a fan with a heat sink directly [1]. In the past, the method used for solving the high heat capacity of electronic components has been to install a heat sink with a fan directly on the heat source, removing the heat through forced convection. Webb [2] pointed out that it is necessary to increase the fin surface and fan speed of the direct heat removal heat sink in order to solve the ever-increasing high heat flux generated by CPUs. The total thermal resistance is used to evaluate the thermal performance of a heat sink. Zhipeng and Mzychka [3] increased the heat dispersing surface area of the heat sink fins, reducing the total thermal resistance from 0.55 oC/W to 0.35 oC/W. Lin et al. [4] boosted the fan speed to obtain an optimum total thermal resistance value of 0.33 oC/W at a maximum speed of 4000rpm. However, increasing the surface area results in an increase in cost and boosting the fan speed results in noise, vibration and more power consumption, which increase the probability of failure to electronic components.

In modern electronic components, the processor's surface where most heat is generated is usually small, however, for better cooling, the heat must spread over a larger surface area [5].

The space available near the processor is limited. Hence, low power consumption is desired. The heat sink performance has become the focus of many studies. Heat sinks should be designed to have a large surface area since heat transfer takes place at the surface [6].

Additionally, the distance between the fins must be maintain to allow the cooling fluid to reach all cooling fins and to allow good heat transfer from the heat source to the fins as well.

Therefore, the current study investigates the effect of fins number and fin thickness on the performance of heat sink with embedded heat pipes to further enhance the heat transfer rate.

II. MATERIALS AND METHODS

A. *Prototype design*

The appearance of the new heat sink with embedded heat pipes is shown in Fig. 1, where the construction has multiple heat pipes, with four heat pipes each and increased surface area. The heat pipes use Fluid Mechanics to draw heat away from the copper base and move it to the fins. This is designed to handle the newer releases of CPU's more efficiently and effectively. The lower half is the copper base and the upper half is made from aluminum. These two halves sandwich four copper heat pipes, creating a total of eight heat pipe risers. These copper risers (four on each side) pass through 56 aluminum fins. On most heat sinks of this type, the fins create one large area of cooling, but the present design has two distinct towers are created, thus giving you 112 aluminum fins and more surface area for cooling. confirm that you have the correct template for your paper size. The exterior dimensions of this heat pipes–heat sink are 120x120x25 mm and the total surface area of the fins is around 0.3 m^2.

Fig. 1. *Heat sink with embedded heat pipes*

B. *Determine heat transfer coefficient*

The heat transfer coefficient required depend on the flow patterns involved, the characteristic velocity, V used in determining the Reynolds number. For the surface of plate fins, h_f is evaluated by using an expression for the Nusselt number for developing flow between isothermal parallel plates [7]:

$$Nu = 7.55 + \frac{0.024\chi^{-1.14}}{1+0.0358\chi^{-0.64}Pr^{0.17}} \quad (1)$$

Where $\chi = \frac{x}{D_c.Re.Pr}$ *and* $D_c = 2\Delta$ for parallel plate fins and h_f is obtained from equation (2)

$$Nu = \frac{h_f D_c}{K_{air}} \quad (2)$$

C. *Overall Surface Efficiency*

The efficiency of fin and surface area depend on fin geometry. Assuming that fin shape is rectangular the single fin efficiency can be expressed as:

$$\eta f = \frac{\tanh(mL)}{mL} \quad (3)$$

Where L is fin length, η_f is the fin efficiency and

$$m = \sqrt{\frac{2h}{k_f t_f}}$$

where k_f is the fin conductivity, t_f is the fin thickness.

In contrast to the fin efficiency η_f, which characterizes the performance of a single fin the overall surface efficiency η_o characterizes an array of fins and the base surface to which they are attached [8]

$$\eta_o = 1 - \frac{NA_f}{A_t}(1-\eta_f) \quad (4)$$

Where N is the number of fins in array and each of surface area A_f.

D. *Determine Heat transfer rate*

The total rate of heat transfer by convection from fins may be expressed as

$$q_t = hA_t\left[1 - \frac{NA_f}{A_t}\left(1-\eta_f\right)\right](T_s - T_a) \quad (5)$$

Where T_s is temperature of surface of heat pipe and T_a is the ambient air temperature.

III. DESIGN OF EXPERIMENT (DOE)

Design of Experiment (DOE) software program is used for the design of experiments, statistical analysis, modeling and optimization. Depending on a selected criterion and a given number of design runs, the best design is created by a selection process.

The optimality of a design depends on the statistical model and is assessed with respect to a statistical criterion, which is related to the variance-matrix of the estimator. Specifying an appropriate model and specifying a suitable criterion function require both an understanding of statistical theory and practical knowledge [9].

In this study, the analysis depends on the analytical results instead of experiments to obtain the maximum removed heat transfer rate.

Factors Definition

Define This program was implemented based on the analytical results rather than the results of experiments. The two significant factors considered are fin thickness (A) and fins number (B), as presented in Table 1. Each independent variable is varied over three levels. The low, center, and high levels of each variable are designated as −1, 0, and +1, respectively. Additionally, in this design, the response factor is heat transfer rate. For more details, see Elnaggar [9].

TABLE I. INDEPENDENT VARIABLES OF CCD DESIGN

Level of value	Fin thickness (A) (mm)	Fins number (B)
-1	0.4	44
0	0.7	50
1	1.0	56

IV. RESULTS AND DISCUSSIONS

Fig. 2 shows the effect of thickness of fin on heat transfer rate. It was found that the heat transfer rate increases as a result of the increase in thickness of fin (varied from 0.1 mm to 1 mm with increment of 0.1 mm). It is also noticeable if the increase in the thickness of the fin continues, this will result in an increase in the heat transfer rate. However, the increase in the fin thickness reduces the spacing between the fins.

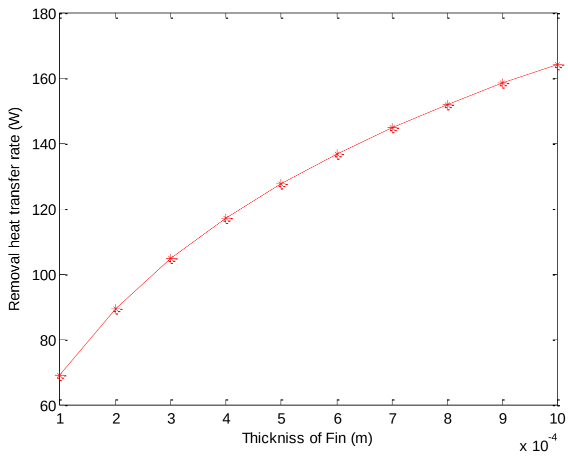

Fig. 2. Heat transfer rate vs. thickness of fin.

Fig. 3 shows the relationship between the thickness of fins and single and overall fin efficiency. Fig. 3 indicates that the increase in the thickness of fins leads to an increase in both single and overall surface fin efficiency. It is also clear that the overall surface fin efficiency is significantly higher than the single fin efficiency because the overall surface fin efficiency depends on the array of fins and fins number as shown in equation (4).

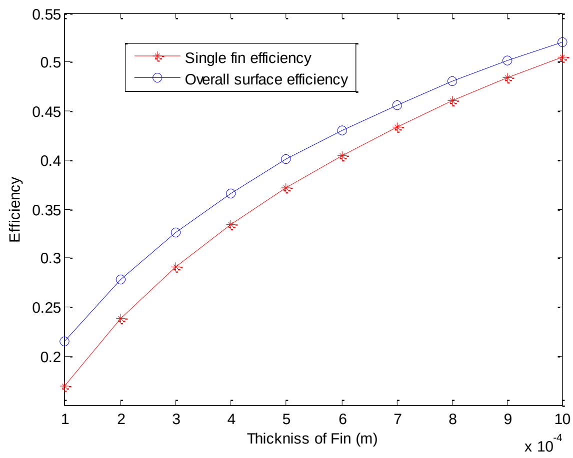

Fig. 3. Single and overall surface fin efficiency vs. thickness of fin.

Although the fins significantly increase heat transfer from heat pipes, considerable improvement could still be obtained by increasing the number of fins. In Fig. 4 illustrates the results of computing the increase in convection heat transfer rate (q) as a result of increasing the number of fins (N), by fixing the fin thickness at t=0.4 mm, 0.7 mm and 1.0 mm. Fig. 4 also illustrates the increase in the number of fins by reducing the space between fins. The maximum allowable number of fins is 56. This decrease in the distances among the fins results in an increase of fins surrounding temperature and prevent the cooling fluid to reach all cooling fins and thus permits poor heat transfer rates from the heat source. Moreover, Fig. 4 shows that the convection heat transfer rate (q) increases nearly linearly with the increase of number of fins (N).

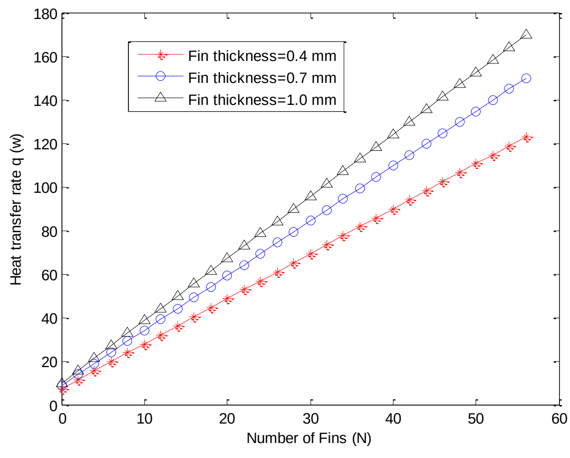

Fig. 4. Heat transfer rate vs. Number of fins at t= 0.4 mm, 0.7 mm and 1.0 mm.

The response surface model created for predicting effective heat transfer rate has been considered sensible[10]. The final regression model, in terms coded factors, is expressed by the following second-order polynomial equation:

Heat transfer rate = $-9.551+52.723t + 1.568N + 1.304(t)(N) - 34.207t^2$ (6)

Where N is the fins number and t is fin thickness in mm.

This equation can be used to make predictions about the heat transfer rate for given levels of fins number N and fin thickness t.

Equation (6) is used to visualize the influences of operating variables (i.e., fin thickness and fins number) on heat transfer rate (Fig. 5). The curvature of 3D surfaces indicates that the fin thickness and fins number have major effect on heat transfer rate. In other words, increasing the fin thickness leads to an increase in heat transfer rate and increasing the fins number also leads to increase in heat transfer rate.

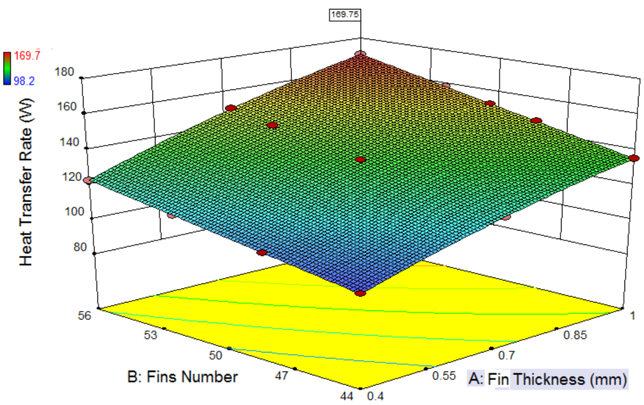

Fig. 5. 3D surface plots of Heat transfer rate as function of heat fin thickness (A) and air Fins Number (B).

V. Conclusion

Analytical investigation of the effect of fins number and fin thickness on the performance of heat sink was presented. The results have revealed an increase in the rate of heat transfer when both fin number and fin thickness were increased. However this increase in heat transfer rate was found to be significantly further when increasing fins number than fins thickness. In fact, increasing the fin thickness leads to a decrease in the number of fins and distances among the fins. This decrease in the distances among the fins results in an increase of fins surrounding temperature and prevents the cooling fluid to reach all cooling fins and thus permits poor heat transfer rates from the heat source. Therefore, this study may be extended for an optimal fin arrangement design requires harmonization among these contradictory features having in mind maximizing the removal heat transfer rate.

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