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Impact of split distance on square pin-fins over natural convection heat transfer enhancement

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Abstract

The component surface temperature of the electronic devices plays a major role in the performance of these devices, thus it needs to keep these surfaces within the permissible temperature limits. Fins, which provide the heat removal mechanism under the natural convection conditions, had been researched very well for optimal shape, location. This research focused on introducing spilt in the fins and its influence over the heat removal process. Fins of various shapes were chosen for this study. The split distance was varied for different configurations. The investigation was extended to varying operating thermal conditions. Experimental study was conducted for these configurations. It has been observed that the splitting of the fins resulted in increase in the heat transfer rate. Split pin-fins increases the area of heat transfer. Also, flow turbulence is created by the split arrangement. The results from split pin-fin were compared against solid pin fin.
Keywords:*Fins, Natural convection*

1. Introduction

Heat sinks are typically divided into forced convection and natural convection heat sinks based on the operating conditions. Forced convection heat sinks dissipate a larger amount of heat due mainly to such flow inducing devices as fans, but their reliability is lower than that of natural convection heat sinks because of these additional devices. Therefore, for high reliability natural convection heat sinks are widely used and low performance may be tolerated. Plate-fin heat sinks and pin-fin heat sinks are two common types of natural convection heat sinks. Out of these, plate-fin heat sinks are easy to design and fabricate, so they are widely used in applications for which cost reduction is a main issue and in-fin heat sinks have omnidirectional performance because of their geometric characteristics, so they are widely used in various orientations heat sink applications. There have been many studies on these two types of heat sink because of their advantages over the other types of heat sink. However, it is not yet known which type of heat sink between the two has better thermal performance in the natural convection mode. Some previous studies have tried to answer this question. Sparrow and Vemurifound an optimal fin population of pin-fin heat sinks by changing the number of fins for the fixed values of the fin diameter. Comparison of the thermal performance of the pin-fin heat sink having the optimal number of fins to that of a plate-fin heat sink under the constraint of the same surface area for both heat sinks showed that the pin-fin heat sink had lower thermal resistance than the plate-fin heat sink, by about 40%. However, the same surface area constraint places an undesirable limit on the thermal performance as the optimum surface area does not have to be the same for each type of heat sink [1]. For a more healthy comparison, therefore, same surface area constraint needs to be removed. Iyengar and Bar-Cohen compared plate-fin heat sinks and pin-fin heat sinks that had been optimized using the least-material method. In this method, the optimum fin thickness (or fin diameter for pin-fin heat sinks) is determined when the fin height is given. Then, the optimum spacing between the adjacent fins is obtained by maximizing the amount of heat dissipated from the array for various values of the spacing. From their analytical results, they found that the optimized pin-fin heat sinks dissipate a larger amount of heat than do the optimized plate-fin heat sinks. However, there are some inherent limitations in the least-material method. This method is effective at reducing the mass of a single fin, but may not provide a mass-minimizing optimum design for the whole array of the heat sink. Therefore, some different approaches are needed to compare the thermal performance per unit mass of both types of heat sink coefficient which have the highest influence on formability. The efficient transfer of heat in many devices, such as electronic components and heat exchangers, is an engineering challenge and a topic of extensive study. In many such devices, fins are used to enhance the heat transfer. All fins operate by increasing the surface area from which the heat transfer can take place; however, a wide variety of configurations and operating conditions are possible.

2. Literature Review

YounghwanJoo, Sung Jin Kim [1] suggested that optimized plate-fin and optimized pin-fin heat sinks thermal performances were compared analytically under fixed volume condition. Pin-fin heat sinks ware proposed with new correlation of the heat transfer coefficient and validated experimentally for the optimization, while plate-fin heat sinks correlation was adopted from previous studies. Total heat dissipation and the heat dissipation per unit mass are two objective functions were used to optimize the thermal performance of the heat sinks. When the objective function is the total heat dissipation, the optimized plate-fin heat sinks perform better than do the optimized pin-fin heat sinks in most practical applications. When the objective function is the heat dissipation per unit mass, on the other hand, the optimized pin-fin heat sinks perform better than do the optimized plate-fin heat sinks in most practical applications. An "infinitely long" fin was proposed by **Abu-Mulaweh**[2] This paper examines the assumption that the heat transfer coefficient is constant and proposes a simple approach to estimate the average total heat transfer coefficient for a long cylindrical fin. The approach makes use of a published correlation for natural convection from a horizontal, isothermal cylinder and a simple model for the radiative heat transfer. A comparison is made to experimental results. Perforated plates and fins represent an example of surface interruption (Kakac et al., 1981; Bergles, 1981, **Al-Essa and Al-Hussien**, 2004) [3] and are widely used in different heat exchanger, film cooling, and solar collector applications. This study examineseffect of surface modifications (interruptions) to the fin on the extent of heat transfer enhancement from a horizontal rectangular fin under natural convection. The perforated fin enhances heat transfer. The magnitude of enhancement is proportional to the fin thickness and its thermal conductivity. Also, for perforated fins, the extent of heat dissipation rate enhancement is a function of the fin dimensions, the perforation geometry and the fin thermos physical properties. Also, the gain in heat dissipation rate for the perforated fin is a stronglydepend on the perforation dimension and the lateral spacing. A comparison of fin performance – in terms of heat transfer rate – between triangular shaped fins and rectangular shaped fins were made by **SandhyaMirapalli**[4].**Santosh Kansal, PiyushLaad**[5] suggested heat sinksare now supplied around the world and are used in a wide range of applications covering audio, electronic cooling, industrial control, telecommunications, defense and more. Heat sinks are widely used in various industrial applications to cool electronic, power electronic, telecommunications, and automotive components. Those components might be either high-power semiconductor devices, e.g., diodes, thyristors, or integrated circuits. To find out best heat sink designs, the fin profiles were investigated for enhancing the heat dissipation rate and some thermal improvements as well as space reduction and material savings were attained. Improvements on heat sink designs are possible by the use of CFD. Eventually it is possible to finish up with a new heat sink design which has better thermal performance and uses less material. **Mehran Ahmadi, GolnooshMostafavi, Majid Bahrami**[6]studied effects of interruptions on vertically-mounted rectangular heat sinks numerically and experimentally. Heat transfer rate will increased by the interruptions by resetting/interrupting the thermal and hydrodynamic boundary layers. Experimental and numerical results showed an increase in heat flux from the heatsink when interruptions were added. Parametric study shows that an optimum interruption length maximized the heat transfer from vertically-mounted rectangular heatsink. A new compact correlation was developed to calculate the optimum fin interruption for the targeted rectangular heatsinks. **Aishwarya A. Patil, Dr. S. G. Dambhare** [7]studied on circular pin-fins. They studied four configurations of split distance for varying operating conditions. The split pin fins resultswere compared against the solid pin-fin. It was observed that by introducing the split in the pin-fins, the heat transfer rate increases significantly.**Kaustubh Pande, OmkarSiras** studied on split hexahedral fins. The split distance was varied for three configurations. The investigation was extended to varying operating thermal conditions. Experimental and Numerical studies (CFD simulations) were conducted for these configurations. ANSYS Work Bench modules were utilized for performing the CFD simulations. The heat transfer rate from the heat sinks for these configurations was compared [8].**Ana Cristina Avelar, Marcelo Moreira Ganzarolli** [9] suggestedan optimum spacing between plates, for numerical and experimental study, in a stack of vertical channels with protruding and not densely distributed two-dimensional heat sources. The SIMPLEC algorithm gives numerical solutions to the full elliptic steady state Navier-Stokes equations. A scale analysis show the existence of an optimum spacing between plates. It was varied the distance between plates and total power dissipated per plate. Comparison of numerical and experimental temperature profiles and optimum plate to plate spacing results gives good agreement.**AnaghaGosavi, P.M. Khanwalkar, N.K. Sane** [10] researched on staggered fin arrays. They concluded that the staggered arrangement with some optimum spacing (which needs to be found out from the experimental study) can be used for augmentation of heat transfer in vertical fins. It can also be concluded that each arrangement has higher value of Nusselt number for higher height. This is due to increased heat transfer area. **Murtadha Ahmed** [11] had investigated the thermal performance of fins considering the influence of heat input and the fin geometry – in terms of perforations. Based on their results, they conclude that the addition of perforation on the fins improve the heat transfer characteristics as compared to the solid fins. This had been observed in both plate-fins and the pin-fins.

3. Objectives

1 Analysis of split-fins over solid pin-fins for heat transfer enhancement in natural convection.
2 Comparison of heat transfer rate for different split distances in pin-fins
3 Plotting heat transfer rate of split- fins for different temperature differences.

4. Project Definition

The heat sink base plate dimensions selected is 100 mm X 100 mm. The heat sink contained a total of 9 fins arranged with in-line fashion. Square cross-sectioned fins are selected. Square fin size is 10 mm X 10 mm. The height of each fin is 80 mm. All fins are arranged at constant pitch in this study. The variations in the fin longitudinal and the lateral pitch will also have major influence on the natural convection flow field and the resulting thermal performance. However, this had not been the scope of this research work and was not investigated in this study. A non-dimensional parameter, C, is introduced to define the split distance. The definition for the same had been provided below.

$$\text{Clearance ratio: } C = \frac{\text{Split distance}}{\text{Side length/dia.}}$$

Table 1

Configuration	Clearance ratio "C" in mm
Base Model	NA
Case A	0.2
Case B	0.3
Case C	0.4

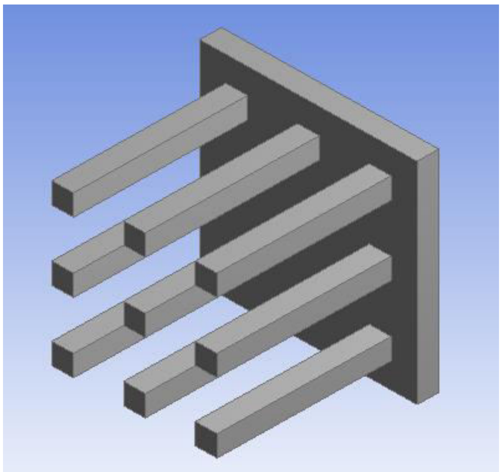

Fig. 1. Solid square pin-fin

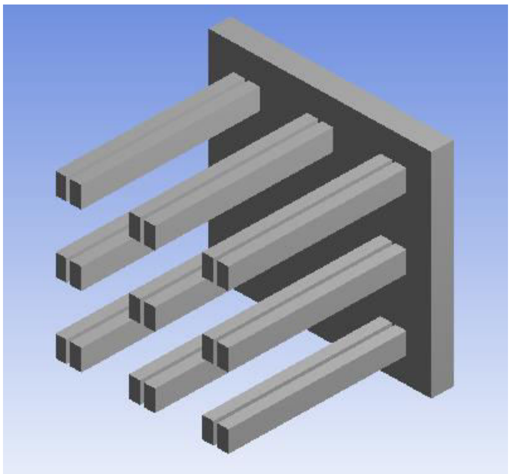

Fig. 2. Split square pin-fin

In this research, the fin geometries with C = 0.2, 0.3 and 0.4 are chosen for the study. Higher values of "C" could mean the split-fins would behave as an individual fins. So, the lower delta configurations were chosen. The heat load is characterized by the following expression, $\Delta T = T_{fin} - T_{ambient}$ in kelvin K. Heat loads of ΔT = 25, 50, 75 and 100 K are imposed and the resulting flow and thermal fields were studied in this research work.

Figure 1 and 2 shows solid and split square pin-fins considered for study.

Figure 3 shows cases considered for the square split pin-fin study.

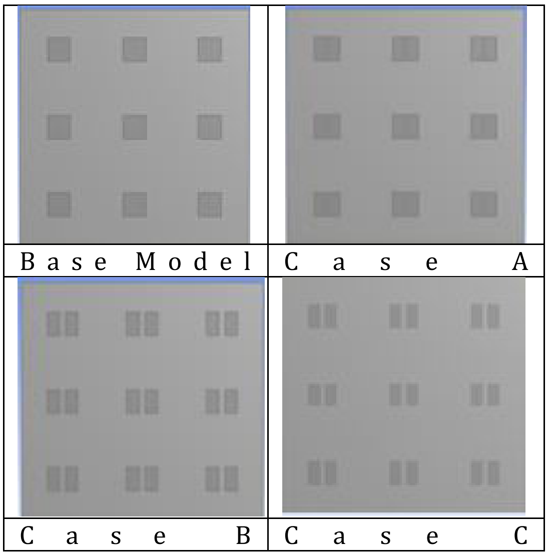

Fig. 3. Split square fins cases

5. Experimental Analysis

Heat sink assembly consists of base plate made of aluminum as a material. Fins used for experiment are also made of aluminum and arranged at constant pitch. Heat is supplied to the base plate using electrical energy. Heater is placed in touch of base plate on its back side. Heat supply is controlled as per temperature difference required. Voltage and current readings can be visualized in voltmeter and ammeter placed in line of electrical supply. Assembly is arranged in vertical position. 4 thermocouples are placed at the rear side of the base plate. Thermocouple readings can be visualized in display placed aside. One thermocouple is arranged for measuring atmosphere temperature. Steady state conditions are ensured before readings are observed. Temperature readings from the thermocouple are noted with the display placed aside. Also, readings from voltmeter and ammeter are noted for calculating heat supply to the base plate. Readings are taken for solid fins and split fins. Readings are taken for 4 temperature differences as discussed earlier.

Experimental setup arranged for the study is shown in the figure 4 below.

Fig. 4. Experimental setup

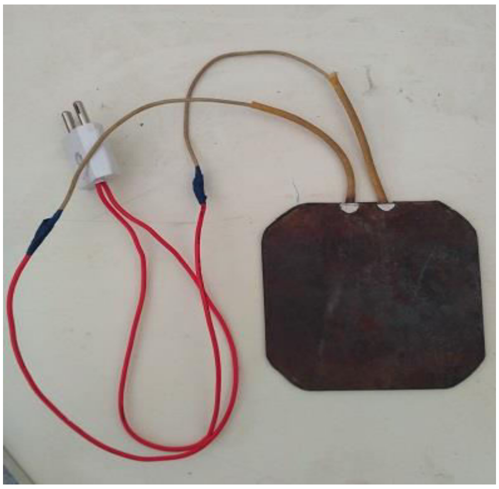

Fig. 5. Mica type heater

Heater used for supply of the heat to the base pate is mica type heater. Heater is square shaped as the dimensions of the base plate to provide uniform heat to the base plate. Mica insulated heaters are constructed of nickel-chrome ribbon type resistance wire wound uniformly around the core and insulated by select quality mica. These heaters are used largely for industrial applications to supply instant heat to base material. Heater used is shown if figure. 5.

With the help of voltmeter and ammeter, heat input to the base plate is monitored.

6. Equations[2]

Heat transfer by conduction and convection is taken into consideration for this study.
Following are the conduction, convection and energy balance equations.

$$\dot{Q}_x = -kA_c \frac{dT}{dx}$$

$$\dot{Q}_{x+dx} = \dot{Q}_x + \frac{d\dot{Q}_x}{dx} dx$$

$$d\dot{Q}_{conv} = hdA_s (T - T_\infty)$$

Energy Balance:

$$\dot{Q}_x = \dot{Q}_{x+dx} + d\dot{Q}_{conv} = \dot{Q}_x + \frac{d\dot{Q}_x}{dx} dx + hdA_s (T - T_\infty)$$

$$\frac{d}{dx}\left(A_c \frac{dT}{dx}\right) - \frac{h}{k}\frac{dA_s}{dx}(T - T_\infty) = 0$$

$$\frac{d^2T}{dx^2} + \frac{1}{A_c}\frac{dA_c}{dx}\left(\frac{dT}{dx}\right) - \left(\frac{1}{A_c}\frac{h}{k}\frac{dA_s}{dx}\right)(T - T_\infty) = 0$$

Where,
Qx- Conduction Heat Transfer
Qconv. - Convective Heat Transfer
Ac- Cross-sectional area of fin
k- Thermal conductivity of material
h- Convective heat transfer coefficient

7. Results and Discussion

Following results are obtained from the experiment.

TABLE 2
HEAT TRANSFER RATE COMPARISON FOR SQUARE CROSS-SECTION FINS

Heat transfer rate (Q), W				
TEMP DIFF, K	BASE MODEL	CASE A	CASE B	CASE C
25	2.24	2.46	2.64	3.04
50	3.57	4.01	4.31	4.90
75	5.07	5.63	6.11	6.88
100	6.21	6.87	7.64	8.33

Results obtained are plotted in graph as shown in fig. 6.

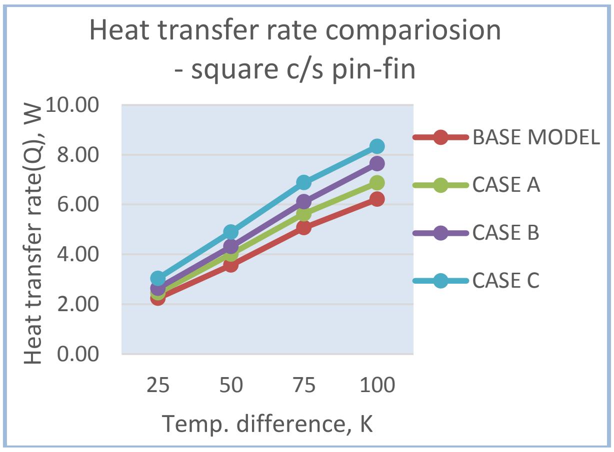

FIG. 6. HEAT TRANSFER RATE COMPARISON FOR SQUARE CROSS-SECTION FINS

From the graph on fig.6, heat transfer enhancement is obtained by introducing the splits in the fins. Heat transfer enhancement for first case is marginal. But, for case B and C substantial enhancement heat transfer observed. These results are obtained for varying temperature differences.

8. Conclusions

[1] Introducing splits in the fins, increases narrow passage, increasing surface area of the fin lead to heat transfer enhancement for the heat transfer under natural convection.

[2] As the split distance increases, heat transfer increases through fin.

[3] Nearly 35-40% heat transfer enhancement is achieved using split pin-fins

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