Experimental Study on Thermal Performance of Longitudinally-Finned Heat Sink Integrating Piezoelectric Fan

Liang Yu [1], Ying Huang [1, *], Xinjun Li [2]

[1] Shanghai Aircraft Design and Research Institute, Shanghai, China

[2] School of Energy and Mechanical Engineering, Nanjing Normal University, Nanjing, China

* Corresponding Author Email: huangying011@nuaa.edu.cn

Abstract. An experimental investigation is performed to research the heat transfer performance (HTP) of a longitudinally-finned heat sink integrating piezoelectric fan. This piezoelectric fan (PF) is actuated at its first-mode resonant frequency of 51Hz and excitation voltage of 220V. The influence of PF orientation on the thermal resistance of finned heat sink is revealed under different channel flow velocity ranging from 0m/s to 8m/s. The results show that the presence of the PF has a positive effect on HTP enhancement of finned heat sink, which is tightly dependent on the channel flow velocity, PF orientation. In general, the role of PF on improving the HTP of finned heat sink behaves in the situations of low channel flow velocity, especially under free convection situation. When the PF is located tightly close to the front edge of heat sink, its orientation appears to be an important factor affecting the HTP of finned heat sink.

Keywords: Piezoelectric fan, longitudinal fins, heat sink, thermal resistance, heat transfer enhancement.

1. Introduction

Effective heat dissipation is the key to avoid inefficiency or damage of electronic systems. Although air-based cooling technology usually cannot provide the same cooling capacity as liquid-based cooling, it is still widely used in the thermal management of electronic systems due to its many advantages, such as high reliability, low cost and simplicity. In order to improve the air-based cooling performance, considerable efforts have been made to explore effective methods to enhance forced air flow heat transfer. Pin-fin sink is a very popular radiator because it can increase the heat transfer area and improve the convective heat transfer coefficient [1-3].

In order to reveal the flow characteristics caused by, a lot of studies have been carried out. Due to its pseudo-jet impact, a large number of studies have been carried out on the HTP of PF [4-9]. However, as far as we know, in the case of forced channel flow, few studies have been conducted on the thermal and hydraulic performance of finned radiators with integrated PH.

For addressing this issue, an experimental investigation on HTP of longitudinally-finned heat sink integrating PF in the presence of channel forced flow is made in the current study. The influences of PF arrangement related to the longitudinally fins and the channel flow Reynolds number are mainly considered.

2. Experimental Setup

The experimental device used in the current study is shown in Fig. 1. It is basically composed of four main components: PF operating system, test part, data sampling unit and the forced channel flow supply channel.

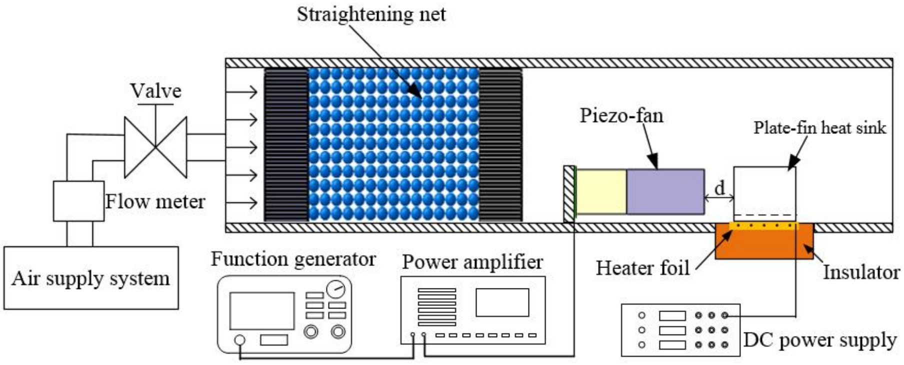
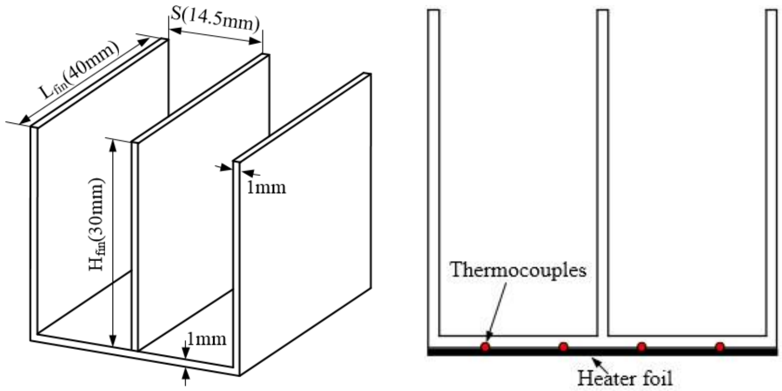


Figure 1. Schematic diagram of experimental setup

The longitudinally-finned heat sink used in the experiment is made of aluminum alloy plate with a thickness of 1.0mm. Three fins are used for this heat sink, as shown in Fig. 2(a). The fin length (L_{fin}), fin height (H_{fin}) and fin pitch (S) designed as 40mm, 30mm and 14.5mm, respectively. A heater foil is adhered tightly on the base of heat sink for providing uniform heat flux, as seen in Fig.2(b). A total of 36 T-type thermocouples are mounted on the interested surfaces in four rows along fin pitch direction. Each row has nine thermocouples uniformly distributed along longitudinal direction. All thermocouples are connected to the data sampling unit.

A thick Styrofoam thermal-insulation layer is used to surround the heater foil for eliminating heat loss. The heat loss from the back of heater foil to the ambient is reasonable to be neglected.

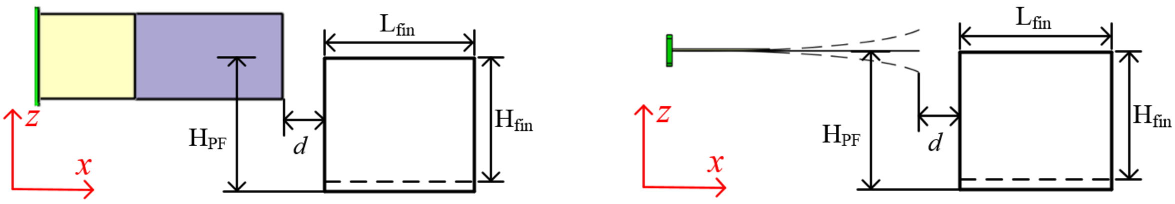
For comparison, a plain heat sink without fins is also adopted for investigation, which is made of the same material as the finned heat sink.



(a) schematic (b) thermocouple locations

Figure 2. Schematic diagram of heat sink with thermocouple locations.

A single PH in integrated in the finned heat sink. The arrangement of PF related to the fins is similar to that used by Li et al. [10]. The PF is set in either vertical or horizontal mode in the front of heat sink, as seen in Fig. 3. In the vertical case, the distance between the center of PF and the heat sink base plate is denoted as H_{PF}. While in the horizontal case, the distance between the neutral position of vibrating fan and the heat sink base plate is denoted as H_{PF}. The distance between the fan-tip and front edge of heat sink is denoted as d. In the current study, d/L_{fin} is varied as 0.1, 0.5 and 1.0 and H_{PF}/H_{fin} is varied as 0.6 and 1.0.



(a) vertical configuration (b) horizontal configuration

Figure 3. Configuration of piezoelectric fan

As seen in Fig. 4, the PF used in current experiment is the same as that used in our previous works [9, 11].

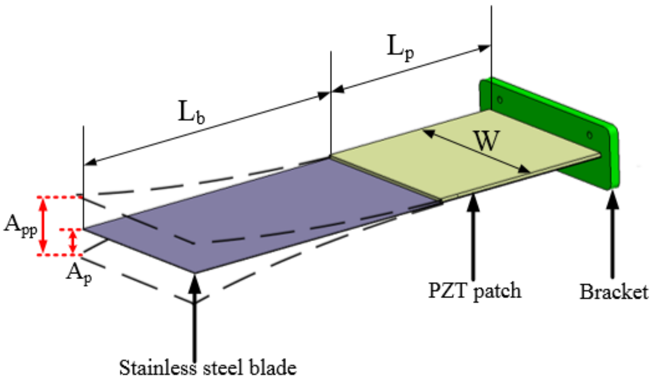


Figure 4. Schematic geometry of piezoelectric fan

3. Comparison Between Plain and Finned Heat Sink (HS)

Fig. 5 shows the averaged thermal resistances of the plain and finned HS without the presence of PH. For the plain HS, the thermal resistance in the situation of free convection (or without the presence of channel flow) is about 38 K/W. As the increase of channel flow velocity, the thermal resistance of plain heat sink decreases rapidly due to the convective heat transfer enhancement of forced convection related to the free convection. When the channel flow velocity is increased to 3.75m/s, the thermal resistance of plain heat sink is about 16K/W. The equivalent heat transfer coefficient of plain HS is about 2.5 times of that in the situation of free convection. When the channel flow velocity is increased to 8m/s, the thermal resistance of plain heat sink is about 10K/W. Accordingly, the equivalent heat transfer coefficient of plain HS is about 4 times of that in the situation of free convection.

For the finned HS, the thermal resistance in the situation of free convection is about 6.3 K/W. It is sure that the fins play a significant role on improving the HTP of HS due to tremendous enlargement of heat transfer area. As the increase of channel flow velocity, the thermal resistance of finned heat sink is reduced monotonously. In comparison with the plain heat sink, the influence of channel flow on improving the HTP of finned HS seems weekly. For example, when the channel flow velocity is increased to 8m/s, the thermal resistance of finned heat sink is about 2.3K/W.

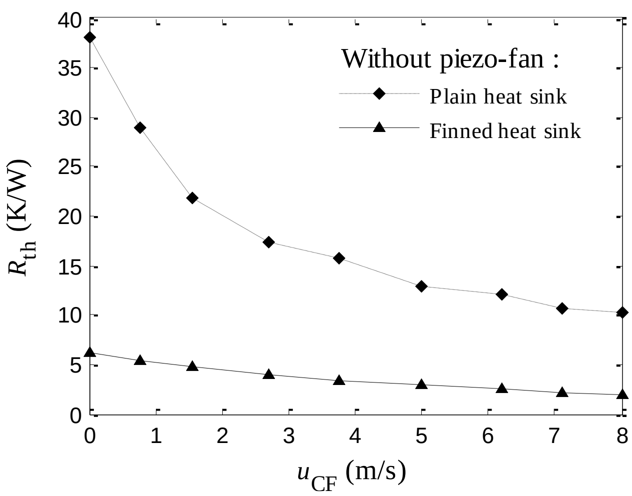


Figure 5. Thermal resistance of heat sink without the presence of piezoelectric fan

4. Effect of Piezoelectric Fan on Thermal Performance of Finned Heat Sink

To illustrate the effect of PF on HTP of the finned HS, a direct comparison is firstly presented for a specific piezoelectric fan orientation, such as vertical arrangement with d/L_{fin}=0.1and $H_{\mathrm{HP}}/H_{\mathrm{fin}}$=1.0. Fig.6 shows the thermal resistances of the finned HS integrated with the PF. It is seen that the piezoelectric fan indeed plays a role on improving the thermal performance of finned heat sink in the situations where the channel flow velocity is less than 7m/s, especially under free convection situation. Under free convection situation, the thermal resistance of the finned HS is decreased from 6.3K/W to 5.0K/W by integrating a piezoelectric fan, producing about 20% reduction related to the pure finned heat sink. Under a channel flow velocity of 0.78m/s (or $\mathrm{Re}_{\mathrm{CF}}$=4000), the thermal resistance of the finned heat sink is decreased approximately 10% by integrating a PF. As the increase of channel flow velocity, the role of PF on improving the thermal performance of the finned HS is weakened. Two causes are responsible for this feature. On one aspect, the equivalent heat transfer of finned HS is higher under a stronger forced flow channel. On the second aspect, the fan-tip displacement for this specific PF is suppressed seriously under a stronger forced flow channel.

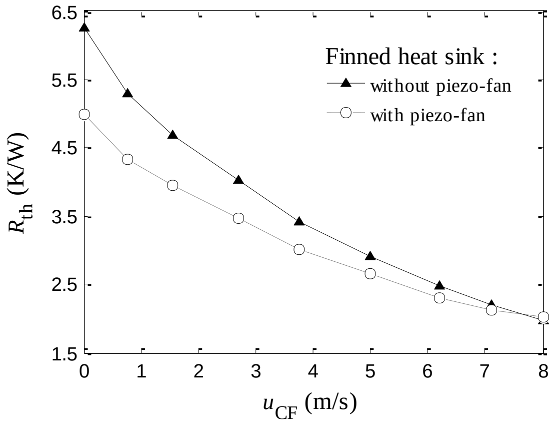
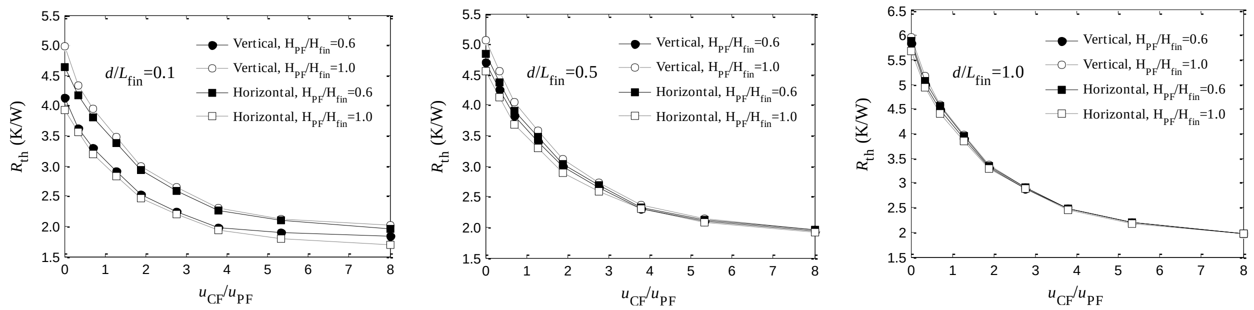


Figure 6. Thermal resistances of finned heat sink with and without piezoelectric fan (vertical arrangement with d/L_{fin}=0.1and $H_{\mathrm{HP}}/H_{\mathrm{fin}}$=1.0)

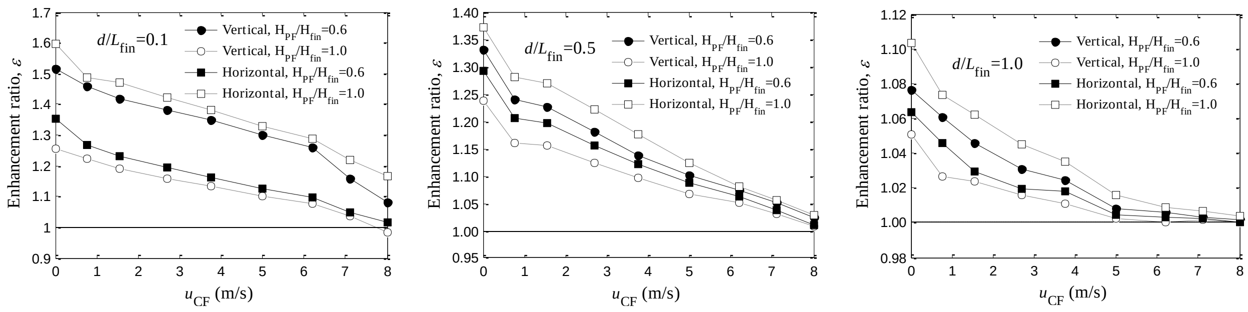
Fig. 7 presents the effects of PF orientation on the thermal resistance of finned HS. It is found that the piezoelectric fan orientation has an obvious influence on the thermal resistance of finned HS when the piezoelectric fan is located tightly close to the front edge of HS, as seen in Fig. 7(a). For $H_{\mathrm{PF}}/H_{\mathrm{fin}}$=0.6, the vertical arrangement of piezoelectric fan seems to be achieve smaller thermal resistance of finned HS than the horizontal arrangement of PF. While for $H_{\mathrm{PF}}/H_{\mathrm{fin}}$=1.0, the case is opposite. When the PF is located at d/L_{fin}=0.5, as seen in Fig. 7(b), the influence of piezoelectric fan orientation on the thermal resistance of finned heat sink is weakened. When the PF is located far from the front edge of HS, as seen in Fig. 7(c), the influence of piezoelectric fan orientation on the thermal resistance of finned HS almost disappears.



(a) d/L_{fin}=0.1 (b) d/L_{fin}=0.5 (c) d/L_{fin}=1.0

Figure 7. Effects of piezoelectric fan orientation on thermal resistance of finned heat sink

Fig.8 shows the heat transfer enhancement ratio with PF under different configurations and locations. The heat transfer enhancement ratio (ε) is defined as the ratio of equivalent heat transfer coefficient of finned HS under the action of PF related to the situation without piezoelectric fan. It is confirmed that in the vast majority of instances the vibrating piezoelectric fan could improve the HTP of the finned HS.



(a) d/L_{fin}=0.1 (b) d/L_{fin}=0.5 (c) d/L_{fin}=1.0

Figure 8. Heat transfer enhancement ratio of finned heat sink by integrating piezoelectric fan

Under a certain arrangement of $H_{\text{PF}}/H_{\text{fin}}$ and a certain channel flow velocity u_{CF}, the increase of the distance between the fan and the front edge of HS (d/L_{fin}) will decrease the ε of the finned heat sink gradually. For instance, when in horizontal arrangement with $H_{\text{PF}}/H_{\text{fin}}$=1.0 and u_{CF}=0m/s, the ε is about 1.6 under d/L_{fin}=0.1. When d/L_{fin} is increased to 1.0, the ε is decreased to 1.1, which is relatively decreased about 30%.

With regard to the influence of $H_{\text{PF}}/H_{\text{fin}}$ on the HTP of finned HS, it is noted that influence of $H_{\text{PF}}/H_{\text{fin}}$ is opposite for the different arrangements. In vertical arrangement, the increase of $H_{\text{PF}}/H_{\text{fin}}$ will decrease the ε. But in horizontal arrangement, the increase of $H_{\text{PF}}/H_{\text{fin}}$ will increase the ε. For example, under d/L_{fin}=0.1 and u_{CF}=0m/s, when $H_{\text{PF}}/H_{\text{fin}}$ increases from 0.6 to 1.0, the ε in the vertical arrangement is decreased about 17%. While the ε in the horizontal arrangement is increased about 18.5%.

It is also confirmed that the ε decreases monotonously with the channel flow velocity. Especially, when the channel flow velocity reaches about 8.00m/s, the ε is generally closed to 1. In this situation of strong channel flow, only one piezoelectric fan orientation (such as horizontal arrangement with d/L_{fin}=0.1 and $H_{\text{PF}}/H_{\text{fin}}$=1.0) makes the ε greater than 1.1.

In general, the presence of the PF has a positive effect on heat transfer enhancement of finned HS, which is tightly dependent on the channel flow velocity, PF orientation.

5. Conclusions

This paper summarizes the experimental results of HTP of longitudinally-finned HS integrating a PF. The influence of PF orientation on the thermal resistance of finned heat sink is revealed under different channel flow velocity ranging from 0m/s to 8m/s. The following conclusions are obtained:

(1) The piezoelectric fan indeed plays a role on improving the HTP of finned HS in the situations of low channel flow velocity, especially under free convection situation. As the increase of channel flow velocity, the role of PF on improving the thermal performance of the finned HS is monotonously weakened.

(2) The piezoelectric fan orientation is an important factor affecting the HTP of finned HS under some situations where the PF is located tightly close to the front edge of HS. The vertical or horizontal arrangement of PF shows different influence, dependent on its relative location to the longitudinally-finned heat sink.

References

[1] LEDEZMA G, BEJAN A. Heat sinks with sloped fins in natural and forced convection [J]. International Journal of Heat and Mass Transfer, 1995, 39: 1773-1783.

[2] BAHADUR R, AVRAM B C. Thermal design and optimization of natural convection polymer pin fin heat sinks [C]// IEEE Transactions on Components and Packaging Technologies, 2005, 28: 238-246.
[3] FENG Li-li, DU Xiao-ze, YANG Yong-ping, et al. Study on heat transfer enhancement of discontinuous short wave finned flat tube [J]. Science China-Technological Sciences, 2011, 54: 3281-3288.
[4] KIMBER M, GARIMELLA S V, RAMAN A. Local heat transfer coefficients induced by piezoelectrically actuated vibrating cantilevers [J]. Journal of Heat Transfer-Transactions of the ASME, 2007, 129: 1168-1176.
[5] LIU Sheng-fu, HUANG Ren-tsung, SHEU Wen-jenn, et al. Heat transfer by a piezoelectric fan on a flat surface subject to the influence of horizontal/vertical arrangement [J]. International Journal of Heat and Mass Transfer, 2009, 52: 2565-2570.
[6] LIN Chien-nan. Analysis of three-dimensional heat and fluid flow induced by piezoelectric fan [J]. International Journal of Heat and Mass Transfer, 2012, 55: 3043-3053.
[7] TAN Lei, ZHANG Jing-zhou, TAN Xiao-ming. Numerical investigation of convective heat transfer on a vertical surface due to resonating cantilever beam [J]. International Journal of Thermal Sciences, 2014, 80: 93-107.
[8] FAIRUZ Z M, SUFIAN S F, ABDULLAH M Z, et al. Effect of piezoelectric fan mode shape on the heat transfer characteristics [J]. International Communications in Heat and Mass Transfer, 2014, 52: 140-151.
[9] LI Xin-jun, ZHANG Jing-zhou, TAN Xiao-ming. Experimental and numerical investigations on convective heat transfer of dual piezoelectric fans [J]. Science China-Technological Sciences, 2017, 60: 1-10.
[10] LI Huang-yi, CHAO Shung-ming, CHEN Jing-wei, et al. Thermal performance of plate-fin heat sinks with piezoelectric cooling fan [J]. International Journal of Heat and Mass Transfer, 2013, 57: 722-732.
[11] LI Xin-jun, ZHANG Jing-zhou, TAN Xiao-ming. Convective heat transfer on a flat surface induced by a vertically-oriented piezoelectric fan in the presence of cross flow [J]. Heat and Mass Transfer, 2017, 78: 1008-1022.