Proceedings of the ASME 2021
International Mechanical Engineering Congress and Exposition
IMECE2021
November 1-5, 2021, Virtual, Online

IMECE2021-71856

DESIGN AND DEVELOPMENT OF ADDITIVELY MANUFACTURABLE PASSIVE HEAT SINK FOR COMPUTERS

Wondwosen Demisse
Mechanical Engineering,
University of the District of Columbia
Washington, DC, 20008, USA

Pawan Tyagi
Mechanical Engineering,
University of the District of Columbia
Washington, DC, 20008, USA

ABSTRACT

The increasing demand for data use in our community results in a massive data proceeding and computational hours. Those state of art electronics uses much power, which produces an enormous amount of heat may result in overheating. This can affect the device functions, speed and lead to random shutdowns, unusual sounds, crashes, or blue screen errors. Therefore, it is vital to find an excellent and efficient solution for heat generation due to the kinetic energy of the electron's motion. We design additively manufacture heatsink (HS) capable of remove most heat from the system. The HS is designed on Solidworks software and fabricated using EOS M280 Direct Metal Laser Sintering machine at the University of District of Columbia campus. The performance analysis for the HS is performed using COMSOL multiphysics. Results show additively manufacture HSs are highly efficient and could be the future of HS production.

KeyWords: Additive manufacture, heatsink, convection heat transfer, overheating, design

1. INTRODUCTION

It is vital to find an excellent and efficient solution for heat generation due to the kinetic energy of electrons. [1] There are many works made to absorb the heat generated and despite away from the components [2]. One of the way to solve thermal energy management is by using heatsink (HS). They are component that increases the heat flow away from the hot surface of the device. This is accomplished by increasing the device's working surface area and the amount of low-temperature fluid that moves across its enlarged surface area. Those HSs could be a passive HS, active HS, or hybrid. Passive HSs rely on natural convection, which the buoyancy of hot air alone causes the airflow generated across the HS system. The passive HS does not incorporate a fan in the design. It is typically larger than a standard model, using the extra surface area of the device to enhance thermal cooling in compensation for the lack of a fan. [3] Active HSs use forced air to increase fluid flow across the hot area. Forced air is commonly generated by a fan, blower, or forward motion. Hybrid HSs blend some aspects of passive and active HSs. [4][5]

This paper discusses the application of additive manufacture passive HS technology and how we can take advantage of its potential in the field of thermal management.

2. MATERIAL AND METHODS

We design additive manufactured passive HS which works on the principle of natural convection. The design is inspired by the natural movement of heat waves (gradient) from the hot surface to the surrounding. It is obvious on any conventional HS, the temperature will decrease from bottom to top. That means the heat transfer at the lower part of the sink is high. So it is appropriate to add more material to facilitate maximum absorption of heat from the source. While increasing in Z-axis, the thermal heat transfer decreases according to the heat source's distance (l). our design incorporates the dynamics of the heat flow to the material need for the specific area. This will significantly reduce the weight of the HS and material used while manufacturing.

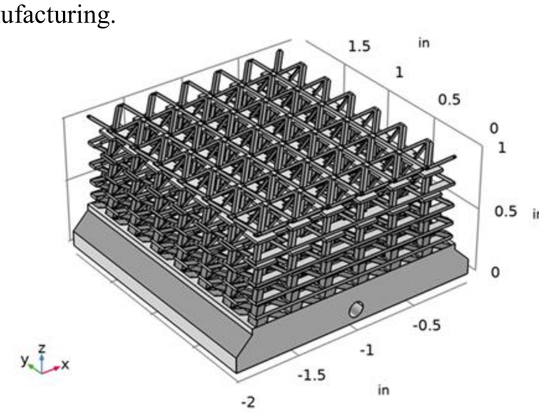

FIGURE 1: Isometric view of the heat sink

HS fins receive heat from an electronic device and dissipate it into the surrounding coolant fluid. It is common to see vertical fins on most conventional HS. Our design incorporates a horizontal fin additional to the vertical fin. The horizontal fins will increase the surface area HS, which increase the convection heat transfer between the environment (air) and HS. Also, increasing the surface contact between the medium helps to maximize the overall efficiency of HS.

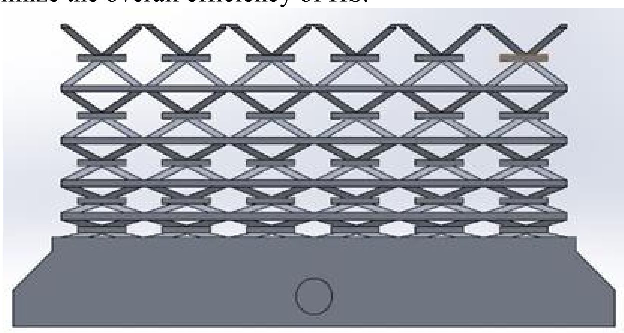

FIGURE 2: Front view design of Heat sink.

While design for additive manufacturing, it is essential to reduce or eliminate the need for supports. One of the criteria while wondering about our final design was a self-supporting HS. In this sense, our design successfully addresses the criteria by putting into consideration of potential and the limit of selective laser melting technology. This self-supporting HS reduces the cost and time wasted by post-processing activity.

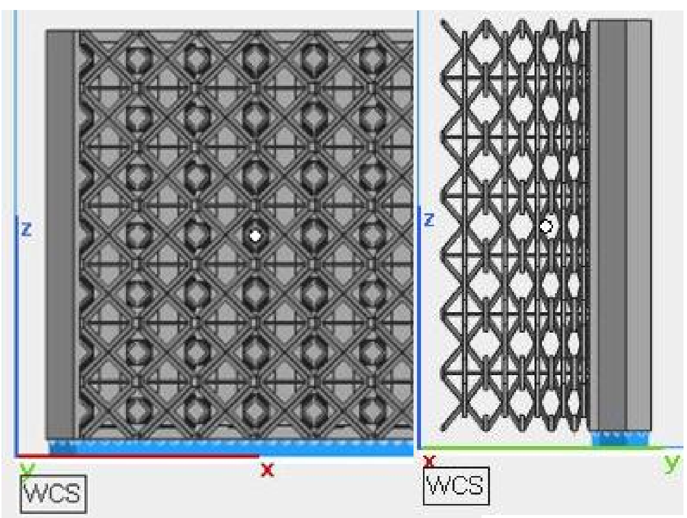

FIGURE 3: Self-supporting design

2.1.1 DESIGN ANALYSIS

Natural convection heat transfer in porous media has long been studied. It is a representative model problem for numerous engineering applications such as electronics cooling, heat exchangers, and various thermal systems [6]. Natural convection is a mechanism of heat transportation in which an external source does not generate the fluid motion. Instead, the fluid movement is caused by buoyancy, the difference in fluid density between two locations, which is most commonly due to a temperature difference between those two locations. The fluid velocity is very low in natural convection, limiting the HS's ability to transfer energy to the environment.

The assumptions we take while designing our HS are

1. Steady-state conduction between the heat source and HS.
2. No heat generation within the HS.
3. Uniform heat transfer coefficient (h) over the entire surface of the fin.

Steady-state conduction is the form of conduction that happens when the temperature difference(s) driving the conduction are constant so that (after an equilibration time), the spatial distribution of temperatures (temperature field) in the conducting object does not change any further. The second assumption specified that there is no heat generation by the HS itself (qg = 0). The final assumption is the thermal resistance of a relatively stagnant layer of the fluid between the heat transfer surface and the fluid medium is the constant entire time.

Conduction heat transfer between the heat source and the HS calculated using Conductive heat transfer can be expressed with "Fourier's Law"

$$q = (k / s) A\, dT = U A\, dT \tag{1}$$

where q = heat transfer (W, J/s, Btu/hr)
k = Thermal Conductivity
s = material thickness (m, ft)
A = heat transfer area (m^2, ft^2)
U = k / s

The natural convection heat transfers between the fine and air calculated as:

$$q = h_c A\, dT \tag{2}$$

where q = heat transferred per unit time (W, Btu/hr)
A = heat transfer area of the surface (m^2, ft^2)
h_c = convective heat transfer coefficient
dT = temperature difference between the surface and the bulk fluid (°C, F)

2.1.2 FIGURE OF MERIT

The figure of merit calculates as follows.

$$\text{FOM} = \frac{1}{(\$heat\ sink.(Ttc - Tamb))} \tag{3}$$

$$\$\ heat\ sink = \$powder * m\ heat\ sink \tag{4}$$

where \$ of powder is \$60/kg
The mass of the HS is 69.19 grams.
\$HS = 69.19 x 10^{-3} kg* \$60/kg
\$HS = \$4.1514
This means the cost of manufacture one HS is four dollars and fifteen cents.

2. RESULTS AND DISCUSSION

The HS weighs only 69.09 grams, which makes it suit the current state of art electronics, and all applications in which weight reduction is crucial. While designing a HS, maximizing surface contact between the medium (air) and the HS highly influences the overall efficiency of HS. Here additive manufacturing plays a significant role in manufacturing intricate and very efficient designs. For comparison, a similar HS with seven vertical fins and manufacture in conventional manufacturing has a 30.95 square inch surface area. In contrast, the proposed design has a surface area of 72.84 square inches, nearly two and half times increase in surface area.

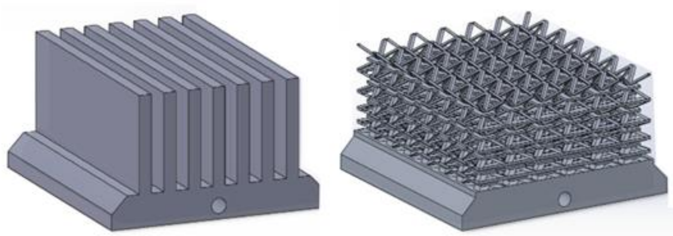

FIGURE 4: Compaction between conventional heat sink and additively manufacture heatsink

The table below is a COMSOL simulated environment which contains T_{copper} is the temperature of the base thermocouple, $T_{junction}$ is the temperature in the base of the HS or flat plate. and $T_{ambient}$ is measured with a thermistor hanging from the roof of the chamber. Those data are recorded by applying different heater power to the HS.

Table 1: Evaluate heatsink performance using different heater power testing points

Heater power (W)	T_{copper} (^{O}C)	$T_{junction}$ (^{O}C)	$T_{ambient}$ (^{O}C)
4.19	43.24	41.05	29.07
8.21	61.93	57.1	30.12
10.27	71.55	64.85	29.53
10.71	66.35	61.75	29.97
15.71	80.51	72.48	29.95
20.49	97.18	87.11	30.04
27.37	119.43	105.51	30.54
30.35	132.03	116.53	28.88

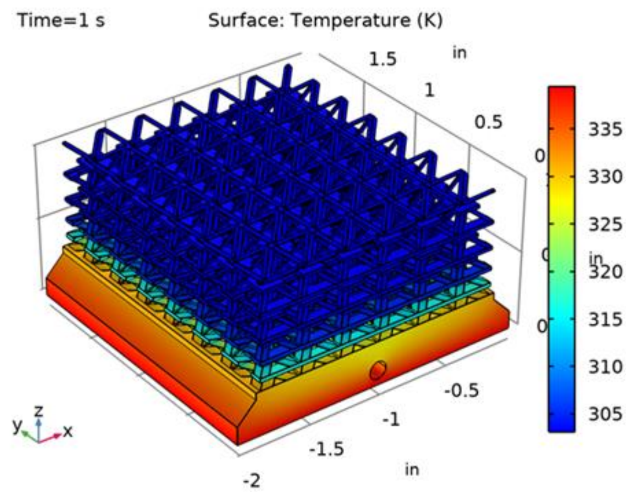

FIGURE 5: COMSOL thermal simulation

From the COMSOL CFD simulation, we have the temperature of the junction on different heater power. To calculate the figure of merit, we modify the equation to

$$\frac{1}{\$heat\ sink} * \sum_{n}\left(\frac{\frac{1}{(T\ tc-Tamb)+\cdots+(T\ tc-Tamb)n}}{n}\right) \quad (5)$$

$$FOM = \frac{1}{4.1514(46.035)}$$

FOM = 0.0523

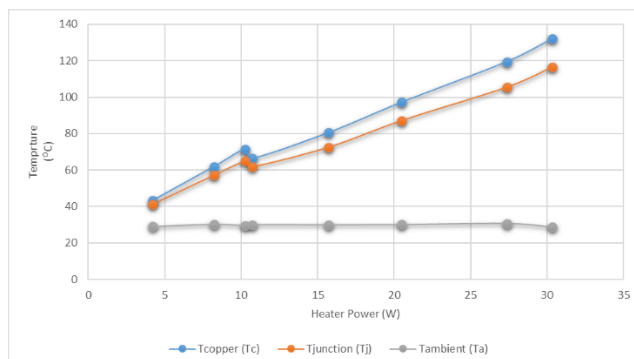

FIGURE 6: Heater Power (W) Vs T_{copper} (T_c), $T_{junction}$ (T_c), $T_{ambient}$ (T_a)

3. CONCLUSION

It is essential for a HS has high cooling rate, excellent vibration dumping and structural integrity for long service life of the electronics. Result show Additively manufacture HS address those challenge with its capacity to print efficient and complex geometry. We believe additively manufactured HS could be the future of electronics cooling.

ACKNOWLEDGEMENTS

We gratefully acknowledge the funding support from the National Science Foundation-CREST Award (Contract # HRD- 1914751), Department of Energy/ National Nuclear Security Agency (DE-FOA-0003945). This work is supported by the Department of Energy's Kansas City National Security Campus. The Department of Energy's Kansas City National Security Campus is operated and managed by Honeywell Federal Manufacturing & Technologies, LLC under contract number DE-NA0002839.

REFERENCES

[1] M. A. Rahmani *et al.*, "Thermal Management and Design Optimization of Heatsink for Cooling Performance Improvement During Transient Heat Generation," *Energy Procedia*, vol. 61, pp. 1665–1668, 2014, doi: https://doi.org/10.1016/j.egypro.2014.12.187.

[2] G. Hetsroni, A. Mosyak, Z. Segal, and G. Ziskind, "A uniform temperature heat sink for cooling of electronic devices," *Int. J. Heat Mass Transf.*, vol. 45, no. 16, pp. 3275–3286, 2002, doi: https://doi.org/10.1016/S0017-9310(02)00048-0.

[3] "What is a Passive Heatsink? (with picture)." https://www.easytechjunkie.com/what-is-a-passive-heatsink.htm (accessed Apr. 26, 2021).

[4] Arrow, "Understanding Heat Sinks: Functions, Types, & More," 2020. https://www.arrow.com/en/research-and-events/articles/understanding-heat-sinks-functions-types-and-more.

[5] A. Abbas, M. M., and C.-C. Wang, "Performance of displaced fin heatsink in natural convection subject to upward and downward arrangement," *Int. J. Therm. Sci.*, vol. 162, p. 106797, 2021, doi: https://doi.org/10.1016/j.ijthermalsci.2020.106797.

[6] D. D. Ganji and S. H. H. Kachapi, "Chapter 7 - Nanofluid Flow in Porous Medium," in *Micro and Nano Technologies*, D. D. Ganji and S. H. H. B. T.-A. of N. S. in N. and N. Kachapi, Eds. Oxford: William Andrew Publishing, 2015, pp. 271–316.

