

Heat Release Performance of Swaged- and Extruded-Type Heat Sink Used in Industrial Inverter

Jung Hyun Kim, Min Ye Ku, and Gyo Woo Lee

Abstract—In this experiment, we investigated the performance of two types of heat sink, swaged- and extruded-type, used in the inverter of industrial electricity generator. The swaged-type heat sink has 62 fins, and the extruded-type has 38 fins having the same dimension as that of the swaged-type. But the extruded-type heat sink maintains the same heat transfer area by the laterally waved surface which has 1 mm in radius. As a result, the swaged- and extruded-type heat sinks released 71% and 64% of the heat incoming to the heat sink, respectively. The other incoming heat were naturally convected and radiated to the ambient. In spite of 40% decrease in number of fins, the heat release performance of the extruded-type heat sink was lowered only 7% than that of the swaged-type. We believe that, this shows the increment of effective heat transfer area by the laterally waved surface of fins and the better heat transfer property of the extruded-type heat sink.

Keywords—Solar Inverter, Heat Sink, Forced Convection, Heat Transfer, Performance Evaluation.

I. INTRODUCTION

THE development and use of environmentally friendly and renewable energy is necessary for the existence of men because the extensive use of fossil fuel for centuries causes not only facing its exhaustion but also threatening us with climate changes due to global warming and air pollution. The photovoltaic solar energy is expected as one of the most promising sources of renewable energy. A solar cell is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect [1].

While a solar inverter, or PV(photovoltaic) inverter, converts the variable direct current output of a photovoltaic (PV) solar panel into a utility frequency alternating current that can be fed into a commercial electrical grid or used by a local, off-grid electrical network. It is a critical component in a photovoltaic system, allowing the use of ordinary commercial appliances. Solar inverters have special functions adapted for use with photovoltaic arrays, including maximum power point tracking and anti-islanding protection [2]. The insulated gate bipolar transistor or IGBT in the solar inverter is a three-terminal

power semiconductor device primarily used as an electronic switch and in newer devices is noted for combining high efficiency and fast switching. It switches electric power in many modern appliances [3].

The power loss from the IGBT turns into heat and increases the junction temperature inside the chip. This degrades the characteristics of the device and shortens its life. It is important to allow the heat produced from the chip junction to escape outside to lower the junction temperature [4]. That is why the IGBT packed with heat sink system. The selection of proper heat sink depends on the temperature range of the heat source, a required heat release, ambient conditions, and so on.

There are lots of works related with various kinds of heat sink. In 1996, Shaukatullah et al. [5] reported an optimized design of pin fin heat sink for use in low velocity applications where there is plenty of open space around for the air to bypass the heat sink. While, in 2002, Kim et al. [6] investigated the thermal performance of several heat sinks such as extruded, aluminum foam, and layered one. Lee [7] showed the design of a heat dissipation system consisted of a heat source, a heat sink and a fan for the forced air cooling for the 400 kW IGBT inverter. Riu et al. [8] evaluated the performance of a heat sink with strip-shaped fin, and tried to determine the optimal geometry. In 2006, Islam et al. [9] identified the reliability, safety, and quality requirements for a new type of photovoltaic module inverter, and evaluated its performance. The heat sink also used for the cooling of electronic devices. Thru the methods of experiment and numerical simulation, Lee et al. [10] investigated the cooling performance of heat sinks for an electronic telecommunication system by adequate natural convection. Yang et al. [11] also examined the thermal-hydraulic performance of heat sinks having plate, slit, and louver fin patterns. They made a comparison of the associated heat transfer performance and the effect of fin spacing. In 2010 Kim et al. [12] experimentally investigated the effect of tip clearance and bypass flow on the cooling performance of a straight fin heat sink.

In this experiment, we investigated the performance of two types of heat sink, swaged- and extruded-type, used in the inverter of industrial electricity generator. The swaged-type heat sink has 62 fins, and the extruded-type has 38 fins having the same dimension as that of the swaged-type. But the extruded-type heat sink maintains the same heat transfer area by the laterally waved surface which has 1 mm in radius.

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II. EXPERIMENTAL

A. Experimental Setup

Fig. 1 shows the experimental setup used in this study. It consists of a heat sink, three heaters, two fans, a flow duct, data acquisition system, and others. Three ceramic heaters on the heat sink used as substitutes of IGBTs in the inverter. They have a regular power consumption of 538 Watt, and have a dimension of 126 mm x 126 mm in each.

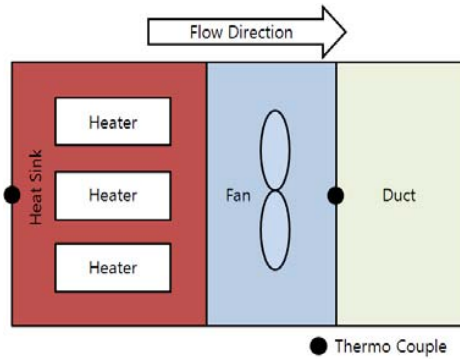


Fig. 1 A schematic of the experimental setup

The cooling air is flowed into the heat sink from the ambient, and then exhausted to the outside thru the duct. Two black dots before and after the heat sink in Fig. 1 are locations of thermocouples for measuring the heat transfer thru the heat sink. The T-type thermocouples (TG-T-36-500, Omega Co.) are made and used after the calibration. The temperatures from the thermocouples were converted to digital data thru the A/D converting module (USB-4718, Advantech Co.).

Two fans used in this experiment have a maximum flowrate (that is, zero pressure drop) of 710 m³/hr in each as shown in Fig. 2. Using the calibration curve presented by the fan manufacturer (Fig. 2) [13] and the measured pressure drop of the fan, we found the flowrates for the 62-finned swaged- and the 38-finned extruded-type heat sink as 517 and 541 m³/hr, respectively. Because of the wider spacing among fins the extruded-type has the lower pressure drop than that of the swaged-type.

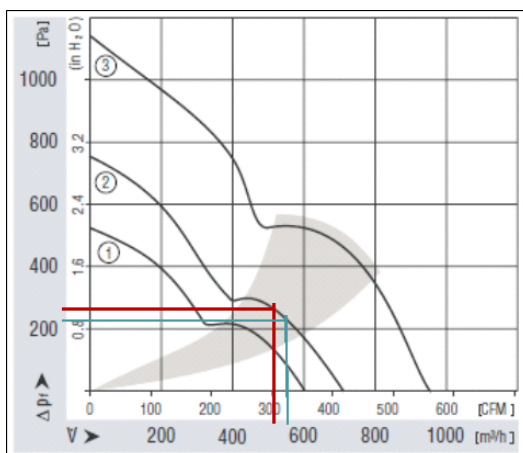
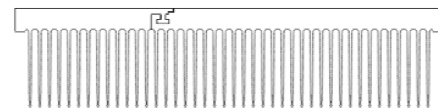


Fig. 2 Performance curve of the fan used in this experiment (No. 2)

The dimensions of the two heat sinks, a swaged- and an extruded-type, are shown in Table I. Both of them are made of aluminum (AL6061). Fig. 3 shows the front view of the two heat sinks. For the swaged-type heat sink, the three parts, fins, upper, and lower plate, were manufactured separately, and then fins were inserted between the plates. While, in case of the extruded-type heat sink, the fins and the upper plate are a single body. Also, it has the lower plate not seen in Fig 3(b). In spite of much less number of fins, due to the small lateral curvatures (radius = 1mm) on the surface of the fins in the extruded-type, both of the heat sinks in Table I have almost the same heat transfer areas, 2.58 m² and 2.62 m², respectively.



(a) Swaged-type heat sink



(b) Extruded-type heat sink

Fig. 3 Schematic diagrams of swaged- and extruded-type heat sink

TABLE I
SPECIFICATIONS OF SWAGED- AND EXTRUDED-TYPE HEAT SINK

	Swaged-type	Extruded-type
Length	325 mm	325 mm
Width	410 mm	410 mm
Height	100 mm	100 mm
Number of fins	62	38
Fin spacing	6 mm	11 mm
Thickness of fin	1 mm	2 mm ~ 3 mm
Height of fin	65 mm	65 mm
Surface area	2.58 m ²	2.62 m ²

B. Experimental Method

In this experiment, the heat sink was cooled down by the forced convection using two fans. The heat release performance of the heat sink was measured using a heat input of the three heaters on the heat sink and an amount of heat transfer thru the heat sink. The measured heat input, that is, the electricity consumption of the three heaters on the heat sink, was 1614.6 Watt. The temperature difference between inlet and exit temperatures of cooling air gave the information about the amount of heat release thru the heat sink.

Temperature measurement was done every 10 seconds. After 1,200 seconds from the operation, the system was fully reached a steady state. Since the steady state, averaged inlet and exit air temperatures and the differences were measured and calculated

during another 1,200 seconds as shown in Fig. 4.

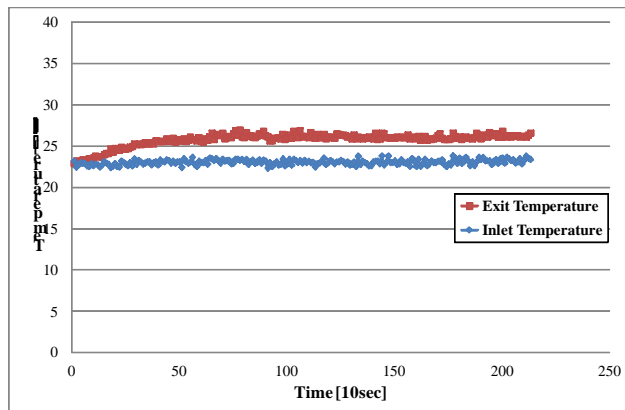


Fig. 4 Inlet and exit temperatures of heat sink with time

Using an equation as below [14], the amount of heat transfer thru the heat sink was calculated. Here, \dot{Q} , \dot{m}_{air} , C_p , and ΔT denote heat transfer rate (W), mass flow rate of air (kg/s), specific heat at constant pressure (J/kg·K), and temperature difference between inlet and exit air of a heat sink (K), respectively.

$$\dot{Q} = \dot{m}_{air} \cdot C_p \cdot \Delta T$$

III. RESULTS AND DISCUSSION

A. Swaged-Type Heat Sink

Fig. 4 shows one of the raw data of inlet and exit temperatures of a heat sink. Based on these raw data, to find out the steady state temperatures we averaged temperatures for 20 minutes after 20 minutes from operation.

In Fig. 5, the averaged steady state temperatures and standard deviations of inlet and exit of the swaged-type heat sink are shown. Also, the temperature differences between inlet and exit for several operations are presented. The averaged inlet and exit temperatures of these averaged temperatures are 22.12 and 25.42 °C, respectively. The standard deviations of these two temperatures are 0.60 and 0.65 °C. The averaged temperature difference and deviation are 3.30 and 0.05 °C, respectively. All the operations show almost the same temperature differences.

Using the equation (1), the measured air flowrate, and the temperature differences in Fig. 5, the amounts of heat release thru the heat sink were calculated as shown in Fig. 6. The averaged heat release and deviation are 1141.7 W and 17.17 W, respectively. Also, the heat release fractions of the six operations are presented in Fig. 7. The lower fraction means heat release thru the heat sink. In case of the swaged-type heat sink of this experiment, about 71% of heat input from the heaters on the heat sink was released thru the heat sink. The other 29% was lost to ambient thru the convection and radiation heat transfer from the heat sink and the heater surface.

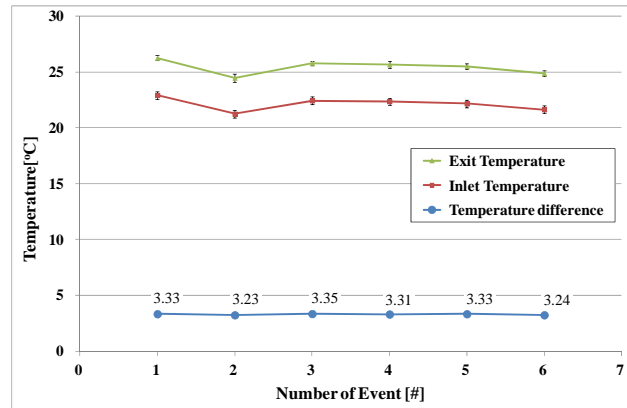


Fig. 5 Averaged temperatures and the temperature differences between inlet and exit of the swaged-type heat sink

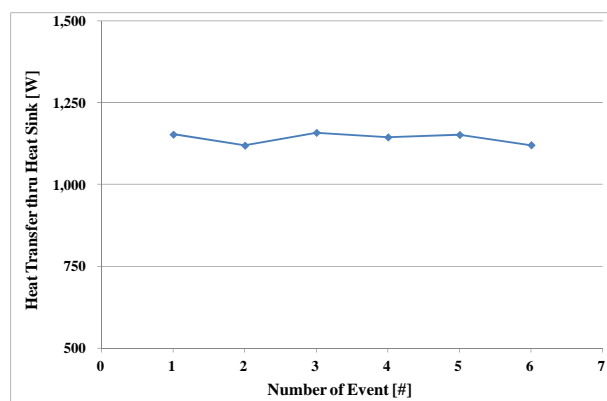


Fig. 6 Amounts of heat release for the swaged-type heat sink

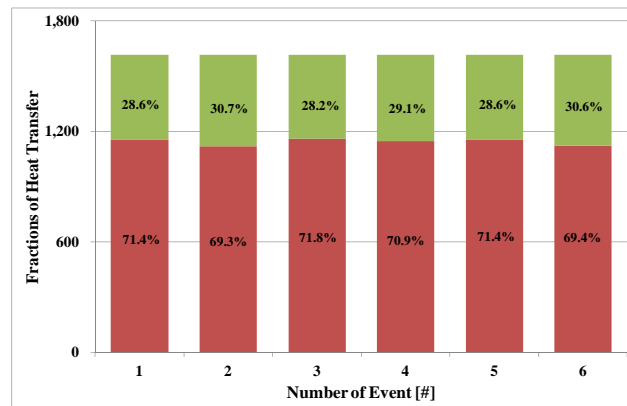


Fig. 7 Fractions of heat release for the swaged-type heat sink

B. Extruded-Type Heat Sink

The same experiment as the swaged-type heat sink was done for the extruded-type heat sink. In Fig. 8, the averaged inlet and exit temperatures and the differences for the several operations are shown for the extruded-type heat sink. The averaged inlet and exit temperatures and the differences for these averaged data are 23.91, 26.75, and 2.84 °C, respectively. The standard deviations of those are 0.47, 0.48, and 0.03 °C, respectively. The temperature difference was somewhat lower than that of the swaged-type heat sink.

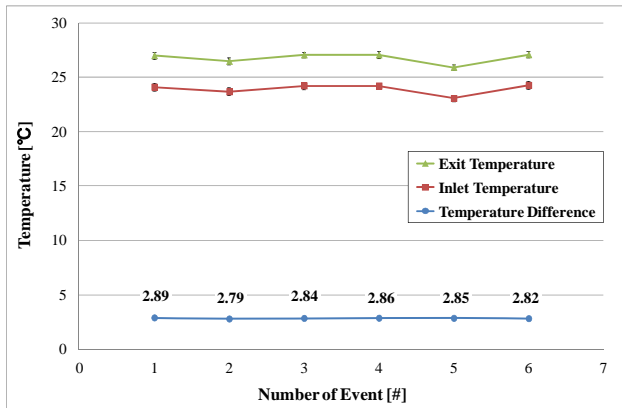


Fig. 8 Averaged temperatures and the temperature differences between inlet and exit of the extruded-type heat sink

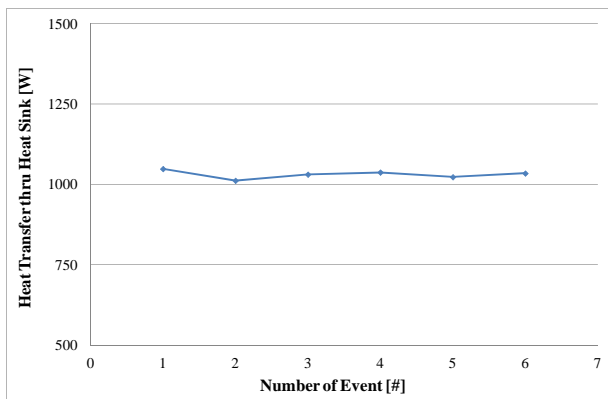


Fig. 9 Amounts of heat release for the extruded-type heat sink

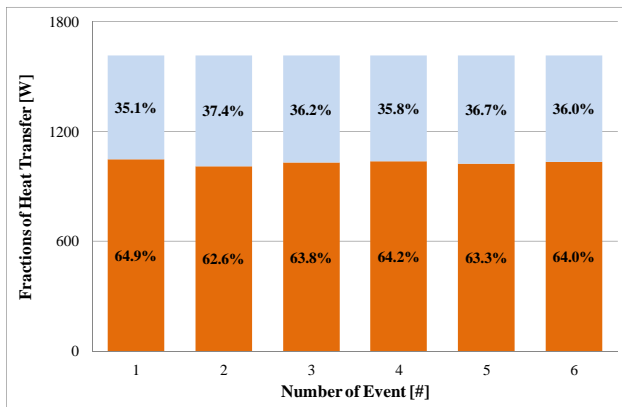


Fig. 10 Fractions of heat release for the extruded-type heat sink

The heat release quantities calculated from data shown in Fig. 8 was seen in Fig. 9 for several operations. It shows almost the same heat release for the cases of extruded-type. The averaged heat release and deviation were 1030.3 W and 12.6 W, respectively. Fig. 10 shows how much heat was released thru the mass flowrate of the heat sink. In case of the extruded-type heat sink of this experiment, about 64% of heat input from the heaters on the heat sink was released thru the heat sink. The other 36% was lost to ambient thru the convection and radiation heat transfer from the heat sink and the heater surface.

IV. CONCLUSION

In this experiment, we investigated the performance of two types of heat sink, swaged- and extruded-type, used in the inverter of industrial electricity generator. The swaged-type heat sink has 62 fins, and the extruded-type has 38 fins having the same dimension as that of the swaged-type. But the extruded-type heat sink maintains the same heat transfer area by the laterally waved surface which has 1 mm in radius. As a result, the swaged- and extruded-type heat sinks released 71% and 64% of the heat incoming to the heat sink, respectively. The other incoming heat were naturally convected and radiated to the ambient. In spite of 40% decrease in number of fins, the heat release performance of the extruded-type heat sink was lowered only 7% than that of the swaged-type. We believe that, this shows the increment of effective heat transfer area by the laterally waved surface of fins and the better heat transfer property of the extruded-type heat sink.

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REFERENCES

- [1] M. Bellis, *Solar Cell*, about.com.
- [2] L. Fraas, and L. Partain, *Solar Cells and their Applications*, 2nd Edition, Wiley, 2010, Section 10.2.
- [3] A. Nakagawa, Y. Yamaguchi, K. Watanabe, and H. Ohashi, *Safe operating area for 1200-V non-latch-up bipolar-mode MOSFETs*, IEEE Trans. on *Electron Devices*, ED-34, pp.351-355, 1987.
- [4] K. S. Oh, *IGBT Basics 1* Fairchild Semiconductor, Application Note 9016, 2001 Feb., p. 15.
- [5] Shaukatullah, H., Storr, W. R., Hansen, B. J. and Gaynes, M. A., 1996, "Design and Optimization of Pin Fin Heat Sinks for Low Velocity Applications," *IEEE Trans. on Components, Packaging and Manufacturing Technology-Part A*, Vol. 19, No. 4, pp. 486-494.
- [6] Kim, J. H., Yun, J. H. and Lee, C. S., 2002, "An Experimental Study on the Thermal Resistance Characteristics for Various Types of Heat Sinks," *SAREK*, Vol. 14, No. 8, pp. 676-682.
- [7] Lee, J.-W., 2004, "Design of a Heat Dissipation System for the 400kW IGBT Inverter," *The Trans. of the KIPE*, Vol. 9, No. 4, pp. 350-355.
- [8] Riu, K. J., Park, C. W., Kim, H. W. and Jang, C. S., 2005, "Cooling Characteristics of a Strip Fin Heat Sink," *Trans. of the KSME(B)*, Vol. 29, No. 1, pp. 16-26.
- [9] S. Islam, A. Woyte, R. Belmans, P. J. M. Heskes, and P. M. Rooij, "Investigating performance, reliability and safety parameters of photovoltaic module inverter: Test results and compliances with the standards," *Renewable Energy*, vol. 31, pp. 1157-1181, 2006.
- [10] J.-H. Lee, J.-M. Kim, J.-H. Chun, C.-H. Bae, and M.-W. Suh, "Development of thermal design program for an electric telecommunication system using heat sink," *Trans. of the KSME(B)*, vol. 31, pp. 947-951, 2007.
- [11] K.-S. Yang, C.-M. Chiang, Y.-T. Lin, K.-H. Chien, and C.-C. Wang, "On the heat transfer characteristics of heat sinks: Influence of fin spacing at low Reynolds number region," *Int. J. Heat Mass Transfer*, vol. 50, pp. 2667-2674, 2007.
- [12] J. W. Kim, S. H. Kim, and J. Kim, "Thermal optimization of a straight fin heat sink with bypass flow," *Trans. of the KSME(B)*, vol. 34, pp. 179-184, 2010.
- [13] Ebm-papst Inc., "Compact fans for AC and DC," *Catalog version 2011*, pp. 62-63, 2011.
- [14] Incropera, F. P., DeWitt, D. P., Bergman, T. L. and Lavine, A. S., 2006, "Introduction to Heat Transfer," 5th ed., John Wiley and Sons.