Advanced Science and Technology Letters
Vol.120 (GST 2015), pp.648-654
http://dx.doi.org/10.14257/astl.2015.120.128

Experimental Study on the Performance Characteristics of an Air-Cooled LED Cooling System for Headlamp of a Passenger Vehicle

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Abstract. For better performance and longevity of LED (Light Emitting Diode) operation in a vehicle headlamp, it is imperative to adopt effective cooling methods to dissipate heat generated. The objective of this study is to experimentally investigate the parametric effect on cooling performance of the air cooled heat sink model used in vehicle LED headlamp for the front side illumination. To evaluate the cooling performance of the heatsink model under consideration, the temperature and thermal resistance at critical points were measured. The input power was varied and the corresponding effects were observed. A comparative study was carried out to assess the effects of forced convection and natural convection. Forced convection is necessary to effectively radiate heat generated during LED usage. In addition, the effect of variation in fan speed was analyzed.

Keywords: Cooling system, Heat sink, LED headlamp, Thermal resistance, Vehicle.

1 Introduction

The headlamp is attached to the front side of a vehicle to provide required illumination for safety and comfort driving during night or insufficient lighting conditions. It is an important safety device and although the operation time might be less during insufficient light conditions, it consumes considerable energy. Current developments in LED technologies have resulted in various interesting applications including usage of LED in a vehicle headlamp for front side illumination. However, during operating condition, LEDs produce a considerable amount of heat. So it is desirable to develop an effective heat dissipation method for the stability, reliability and longevity of LED operation. For better efficiency, the operating temperature of LED must be managed below the maximum operating temperature. Arik et al. [1] discussed about thermal challenges of solid state lighting applications and stressed

ISSN: 2287-1233 ASTL

that the efficiency of the solid state lighting products decreases with the increase in junction temperature. The power loss by LEDs in terms of heat dissipation must be transferred effectively out of the LED chip to the environment. Donahoe [2] discussed about the thermal aspects of LED automotive headlights. Bullough [3] discussed about the energy and environmental implications of LEDs in an automobile industry. Lai et al. [4] discussed about optimum cooling solution for LEDs. Pohlmann et al. [5] discussed about the requirements of LEDs in vehicle lighting applications. Seo et al. [6] conducted the numerical investigation on cooling performance of the heat sink for LED headlamp for automobile. Heat dissipation has been the major bottleneck for developing thermally stable LEDs. So it is important to address the thermal issue using effective cooling systems for stable working of LED headlamp.

For developing effective cooling devices with active air cooling, it is important to evaluate the parametric effect on the cooling performance. The objective of this study is to investigate the cooling performance characteristics of the heat sink model of LED cooling system for the passenger vehicle headlamp. The temperature and thermal resistance at critical points have been measured. In addition, the effects of variation in input power and fan speed on the surface temperature and thermal resistance of heat sink have been discussed.

2 Experimental setup

The experimental setup schematic is shown in Fig.1, which consists of a glass container, a vehicle headlamp LED chip, a heat sink model, a fan, the power supply, thermocouples (T-type), data logger (GRAPHTEC midi LOGGER GL820) and a computer for data processing.

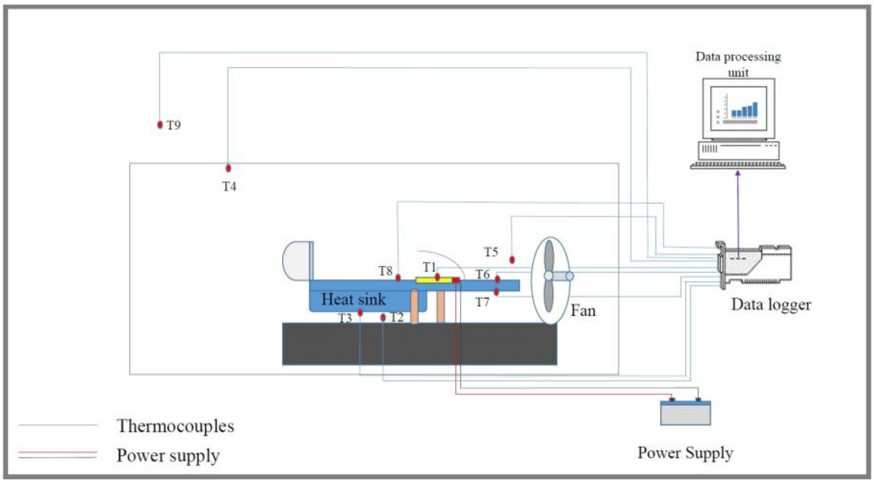

Fig. 1 Schematic of experimental setup with thermocouple locations

One thermocouple is attached to the LED junction to measure the junction temperature. The other thermocouples are attached to measure the temperature of heat sink surface, air temperature near the LED heatsink surface and ambient temperature. Fig.1 shows the relative positions of the different thermocouples. The heat sink model has been mounted on the Aluminum plate with the point support.

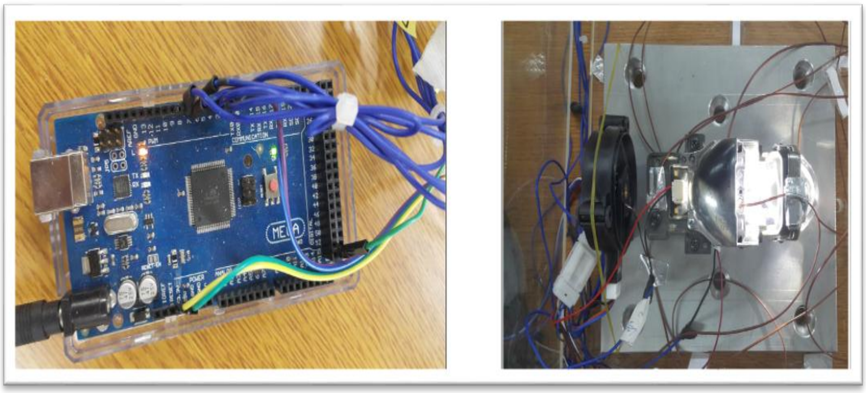

Fig.2 Microcontroller board and experimental setup

For dissipating heat effectively a fan is placed behind the heat sink for an active cooling of the heatsink. The air flows through the heat sink, where it takes away the heat and forced away from the heatsink and lens, making way for low temperature air. This thermal management protects LED from overheating as well as supports defogging of outer lens in cold conditions. This is achieved by moving hot air over the lens which gets heated up. To control and vary the input power and fan speed, a microcontroller board (Arduino MEGA 2560) has been used. Fig.2 shows the arrangement for microcontroller board.

Table 1 Specifications of the heat sink and microcontroller

Items		**Specifications**
Heat sink	Material of the heat sink	Aluminum
	Length of the heat sink (mm)	120
	No. of straight long fins	5
	No. of cross small fins	16
Microcontroller board	Name	Arduino MEGA 2560
	Operating voltage (V)	5
	DC current per I/O pin (mA)	20
	Digital I/O pins	54

Table 2 Test conditions

Items	Specifications
Outdoor temperature (^{o}C)	22
Input current (A)	0.5
Voltage (V)	5.3, 7.25, 8.5, 10.7, 11.5
Fan speed (rev/min)	4030, 5750, 5910, 8650
Time (sec)	1800, 3600

A glass container has been chosen so as to minimize the outside air movement effect on the heat dissipation rate of heat sink. Table 1 shows the details of heat sink and microcontroller. Also, Table 2 shows the test conditions used in this study. The outdoor temperature was set to 22 ℃. The input current was 0.5A and the voltage was varied from 5.3 V to 11.5 V. The cooling fan behind the heat sink for LED cooling system was set to 4030 rev/min, 5750 rev/min, 5910 rev/min, and 8650 rev/min respectively.

3 Results and discussion

The current experimental study investigates the cooling performance characteristics of air cooled heat sink when various parameters are varied. LEDs have been seen as promising option for vehicle headlamp for front side illumination as power consumption and electric to optical efficiency are better compared to HID xenon. One of the major issue to be resolved is thermal management of LED while in operation. LEDs generate large amount of heat which needs to dissipate effectively.

Fig.3 shows the variation of temperature at junction point under the influence of forced and natural convection when the fan speed is being varied from 5910 rpm to 8650 Rev/min while input power is kept constant at 5.75 W for the time period of 3600 seconds. The temperature distribution at junction for natural convection suggests that the heat dissipation is not sufficient for long life cycle of LED. Hence active air cooling has been used. The junction temperature drops significantly when an active air cooling is used. In addition, it is important to observe the effects of different fan speed. Although the fan speed was increased from 5910 Rev/min to 8650 Rev/min, the temperature drop at junction point was found to be 0.7 ºC only after 3600 seconds. This suggests that increase in fan speed alone is not sufficient to develop advanced cooling system and modified heatsink model can be a good option.

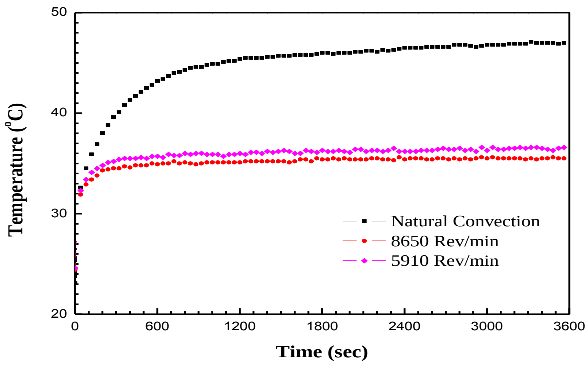

Fig. 3 Junction temperature distribution for different fan speeds at constant input power of 5.75 W

Fig. 4 shows the variation of junction temperature at different input power. The input power was varied from 2.5 W to 5.75 W for 1800 seconds for constant fan speed of 5750 RPM. As the power consumption is increased, the junction temperature also increased due to enhancement in heat generation.

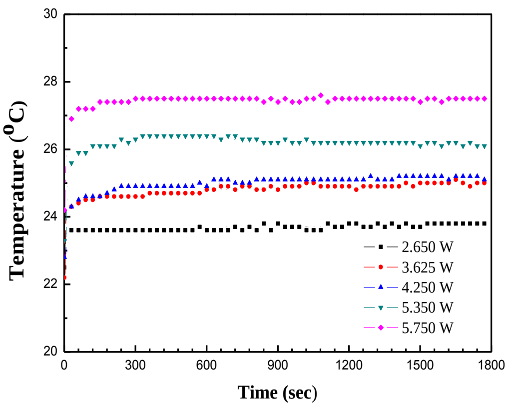

Fig. 4 Junction temperature for different input power at constant fan speed of 5750 rev/min

Fig. 5 shows the temperature distribution at different locations for forced convection with fan speed of 4030 rev/min. For different variety of electronic devices, thermal resistance concept helps to select the proper heat sink. Table 3 shows the thermal resistance variation with different power input.

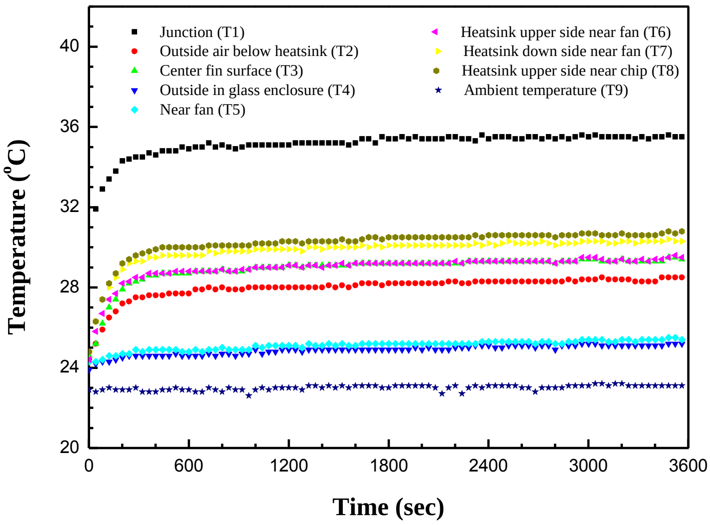

Fig. 5 Temperature distribution at different locations with input power 5.75 W and fan speed 4030 rev/min

Table 3 Thermal resistances with respect to input power

Power input (W)	Thermal resistance after 1800 sec (^{o}C/W)
2.65	0.188
3.625	0.303
4.25	0.352
5.35	0.392
5.75	0.5

4 Conclusions

LEDs are considered promising option in vehicle headlamp for front side illumination. The large amount of heat is generated during LED operation with very small surface area, demanding an advanced cooling system to dissipate large heat flux. In this investigation an active air cooled heat sink model has been used to enhance the heat transfer. Various parameters have been studied for their effects on the cooling performance characteristics of heat sink. Natural convection seems insufficient and forced convection needs to be used to transfer heat effectively. With more power consumption the heat dissipation rate per unit area increases and indicates to develop advanced cooling system to absorb more heat. Although forced convection can dissipate heat more rapidly, there is little temperature decrement was seen when fan speed was increased.

Acknowledgments. This research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Science, ICT & Future Planning(2013R1A1A1062152) and was supported by Business for Establishment Growth Technology development funded Korea Small and Medium Business Administration in 2015 (Grants No. S2359589).

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