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A Study On The Thermal Management For High-Efficiency LED Fog Lamps

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Abstract

LED fog lamps have been replacing halogen lamps, but further development is needed to replace halogen lamps in used cars. As such, this study seeks to develop a high-efficiency LED fog lamp as a replacement for existing halogen fog lamps. The body and thermal performance of the fog lamp was optimized through CFD, and a prototype was developed to experimentally verify the performance. The developed high-efficiency LED fog lamp was found to have a junction temperature of 103℃ and a luminous flux of 720 lm.

Keywords*:* LED, Heatsink, Junction temperature, Luminous flux

1. Introduction

Light emitting diodes (LEDs), recognized as a new growth engine, have emerged as a promising light source with their quick response and expression of diverse colors. Some advantages of LEDs compared to existing light sources include a high luminous efficacy, long life, and suitability for miniaturization [1]. Moreover, they provide high color efficiency and hardly any infrared emissions.

However, one weakness of LEDs is that at least 70% of energy is converted to heat, which results in a rapid increase in temperature [2]. The resulting surge in thermal resistance can interrupt the current flow, thus affecting luminous intensity and chromaticity. Chip failure may occur when the junction temperature exceeds 150 ℃, and this cuts shorts the life of LED lamps [3]. These problems have become more severe with the use of high-output LEDs in the modern age. Efficient heatsinks are thus essential in lowering the junction temperature of LEDs.

To resolve the aforementioned issues, Lan Kim et al. [4] performed thermal analysis on an LED array system with heat pipes and found that thermal resistance is reduced by up to 37%. Maaspuro et al. [5] showed that using thermal grease between the LED module and heatsink is the most efficient in reducing chip temperature. Kim et al. [6] compared LED lamp performance using multiple low-output chips with and without heat pipes. Kang et al. [7] determined the relationship between the heat radiating area and fin length of LED heatsinks, and compared the effects of secondary heat sources. Hwang et al. [8,9] predicted junctions based on the heatsink fin temperature of a 10 W LED lamp, PCB physical properties, and the number of low-output LEDs. Through the operational control of the cooling fan, they demonstrated that fan life can be extended by approximately 164.5%. Park et al. [10] succeeded in verifying the performance of 10 W LED fog lamps by optimizing various factors such as the number of LED modules, heatsinks, and fog lamp output.

Research on high-efficiency LEDs have led to the replacement of halogen fog lamps in vehicles with LED fog lamps, as shown in Fig. 1. High costs are involved in replacing fog lamps in new vehicles, but this is not even possible in the case of older models. In addition, the efficiency of LED fog lamps drops significantly due to the difference in light distribution patterns between LED and halogen lamps.

This study seeks to develop an LED fog lamp with outstanding heat dissipation performance at a junction temperature lower than 110 ℃ and better luminous efficiency compared to existing halogen lamps. After optimizing the LED fog lamp body's heat dissipation performance through three-dimensional numerical analysis, a 10 W prototype was developed to experimentally verify the performance.

Fig.1 Existing model of LED fog lamp

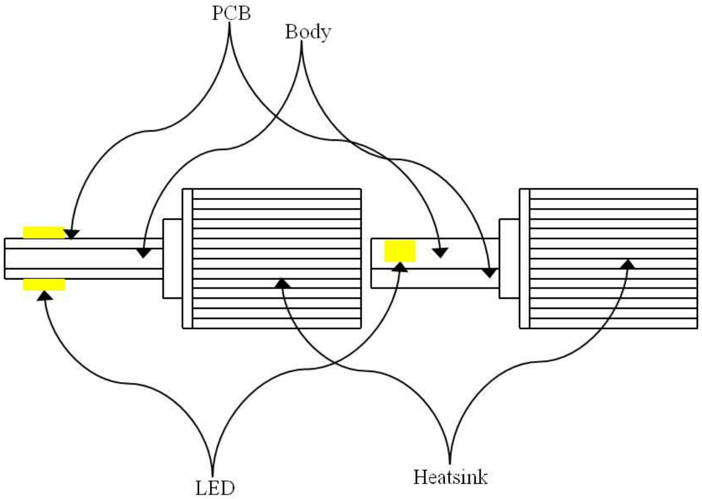


Fig. 2 Schematic of LED fog lamp to be developed

2. Method of numerical analysis

2.1 Numerical analysis model

The three-dimensional numerical analysis model of the LED fog lamp used in this study is shown in Fig. 3. The heating unit was simplified to consist of an LED chip and silicon mold, while the PCB, aluminum body, and heatsink were assumed to be made of aluminum.

The shape of the aluminum body of the numerical analysis model is given in Fig. 4. Depending on the position of the LED, a 180˚ model and a 120˚ model were developed. A PCB was placed on each side of the 180˚ fog lamp and attached in a bent shape with an included angle of 120˚ for the 120˚ fog lamp. 24 rectangular fins measuring 9 mm X 30 mm with a thickness of 1.2 mm were distanced at 15˚ on the heatsink body. The connecting body between the heatsink and fog lamp body, used for installing fog lamps in actual vehicles, was kept as simple as possible. For three-dimensional modeling, the commercial program Catia [11] was used.

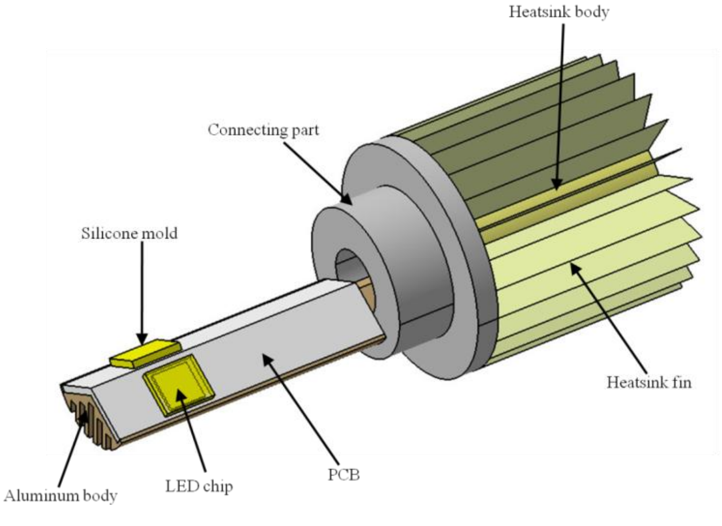
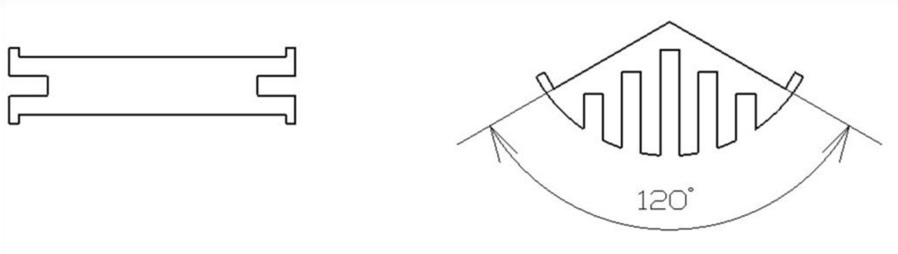


Fig.3 3D modeling of LED fog lamp



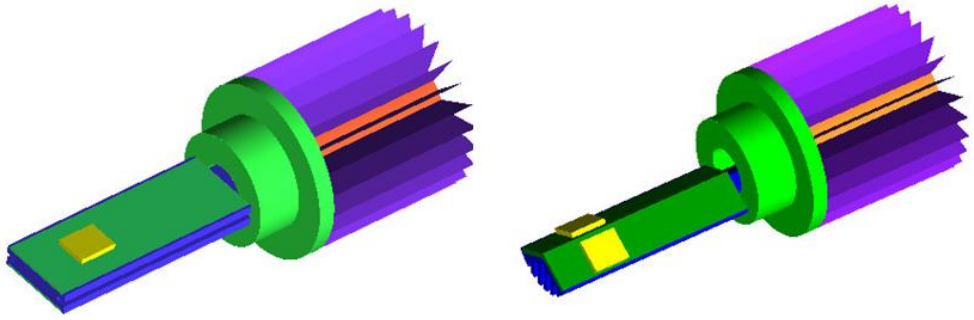
(a) 180˚ model (b) 120˚ model

Fig. 4 Model-specific LED fog lamp's aluminum body shape

2.2 Method of numerical analysis

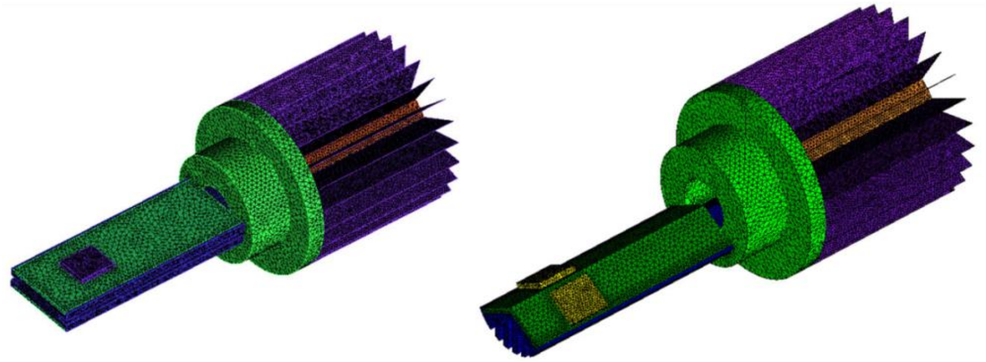
The types of movement considered in this study include three-dimensional, compressive, normal state, and turbulent flow. A k-ε model was employed for turbulent flow modeling. A discrete ordinates (DO) model was selected in consideration of radiant cooling, which is an important factor in fog lamps. The heating value was assumed to be 7 W, which is 70% of the 10 W input of existing halogen lamps. The contact resistance arising from connecting the LED and PCB was 0.5 ℃/W, as stated in the specifications provided by the LED manufacturer [12]. Table 1 presents the details of material properties used in numerical analysis.

The commercial programs used in three-dimensional numerical analysis of LED fog lamps were Ansys Fluent [13] and ICEM-CFD [14]. Fig. 5 shows the result of the three-dimensional modeling of fog lamps. Both the 180° model and the 120° model are comprised of an LED, a PCB, an aluminum body, a connecting part between the aluminum body and heatsink, and a heatsink. The mesh system for numerical analysis is presented in Fig. 6. The same mesh size was used for the two models, but the number of meshes was 620,000 for the 180° model and 580,000 for the 120° model. Polyhedral meshes were employed for more efficient numerical analysis.



(a) 180˚ model (b) 120˚ model

Fig. 5 3-dimensional models of LED fog lamps



(a) 180˚ model (b) 120˚ model

Fig. 6 Mesh system for fog lamps

Table 1. Properties for numerical analysis

	Thermal conductivity (W/mK)	Density (Kg/m3)	Specific heat (J/kgK)
LED chip	130	6170	490
Aluminum	201	2719	871
Silicon mold	0.23	1820	882

2.3 Experimental method

Fig. 7 Prototype of a LED fog lamp

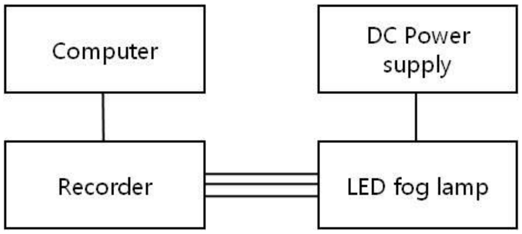


Fig. 8 Schematic of the experiment

To verify the heat dissipation performance of a fog lamp optimized through numerical analysis, a prototype was developed, as shown in Fig. 7. A cream solder was used for minimal heat resistance arising from contact between the LED and PCB. The schematic diagram in Fig. 8 is the set-up for measuring the temperature of the prototype. A T-type thermocouple was used at the solder point of the fog lamp to measure junction temperature. The measured temperature data was sent to a computer via a recorder. The following equation was used to predict junction temperature from the temperature at the solder point.

$$T_j=T_{sp}+\theta\times P$$

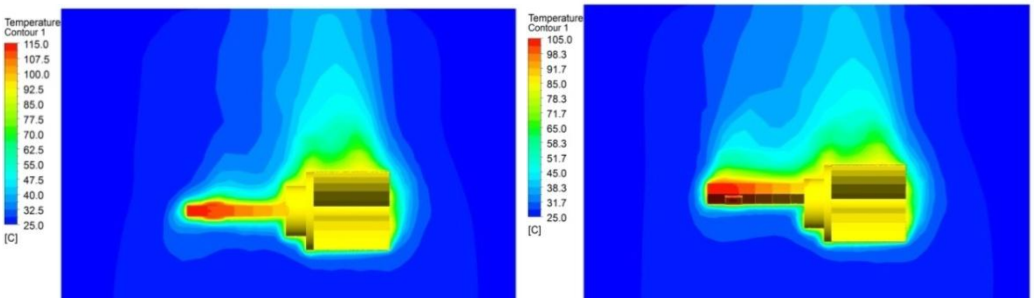
Here, T_j is the junction temperature of the LED, and Tsp is the solder point temperature measured during the experiment. θ is the LED contact heat resistance specified by the manufacturer, and P is the power supplied to the LED. The LED used in this study was supplied with a power of 10 W. Thermal equilibrium is reached after 40 minutes of supplying power to the fog lamp, and junction temperature was measured at this point. A constant voltage of 13.7 V was applied when the surrounding temperature was 25℃, and luminous flux was measured upon reaching thermal equilibrium

3. Results and Discussion

3.1 Analysis of temperature distribution according to fog lamp model

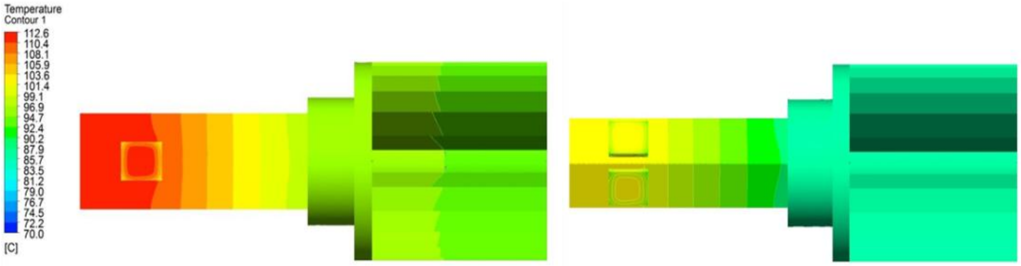
Fig. 9 shows the temperature distribution around the LED fog lamp. Since the 180° fog lamp is in the form of a flat aluminum body attached with a PCB, natural convection occurs less actively near the aluminum body. On the other hand, for the 120° fog lamp, natural convection takes place more actively near its wedge-shaped aluminum body. The 120° fog lamp helps in reducing the heat dissipation load by lessening the amount of heat delivered to the heatsink.

Fig. 10 presents the temperature distribution on the surface of the fog lamp. For both fog lamps, the peak temperature is reached at the LED chip, and the temperature decreases when measured closer to the heatsink. For the 180° fog lamp, the temperature reaches a peak of 112℃ near the LED, and is approximately 94.8℃ at the heatsink fin. For the 120° fog lamp, the maximum temperature is 101℃ near the LED, and about 86.7℃ at the heatsink fin. The peak temperature of the 120° fog lamp is lower than that of the 180° fog lamp because its heat dissipating area is 241% times larger.



(a) 180° model (a) 120° model

Fig.9 Temperature contours around fog lamps



(a) 180° model (a) 120° model

Fig.10 Temperature according to the model contour

3.2 Analysis of junction temperature according to fog lamp model

The junction temperature of the 180° model and the 120° model with the same heatsink is shown in Fig. 11 Here, the junction temperature was obtained from the thermal network model during CFD analysis using the thermal resistance provided by the manufacturer. The junction temperature of the 180° model was estimated to be 114.6℃, which exceeds the manufacturer’s recommended junction temperature of 110℃. This implies that an additional heat dissipating device is needed because of the insufficient capacity of the heatsink. The 120° model, however, satisfied the recommended junction temperature with an estimate of 104.9℃. The 120° model showed improved heat dissipating performance as the aluminum body was designed to be capable of heat dissipation. Because the aluminum body of the 120° model has a volume that is 17% smaller than the 180° model, it is also lighter and more economical.

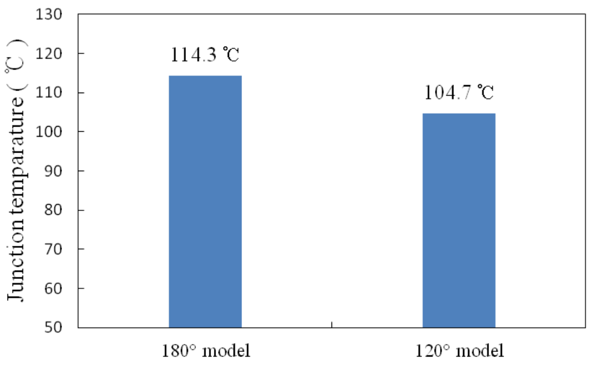


Fig.11 Junction temperature based on the model

3.3 Measurement of junction temperature and luminous flux

Based on the results of numerical analysis for the 120° model, an LED fog lamp prototype was created, as shown in Fig. 6. Table 2 gives the junction temperature and luminous flux for the prototype. Since it is difficult to take direct measurements of junction temperature, temperature was measured at the soldering point, and this was found to be 98.2 ℃. Using the soldering point temperature and thermal resistance provided by the LED manufacture, the junction temperature was estimated to be around 103.7℃. The prototype was successfully developed as the junction temperature satisfies the condition of 110 ℃ or below. The results of numerical analysis were highly accurate, with experimental measurements and estimates differing only by 1℃.

To determine the luminous efficiency of the LED fog lamp, luminous flux was measured when the surrounding temperature was 25℃. The results of luminous flux measurements are presented in Table 2. The luminous flux of the LED fog lamp was 722 lm, or 120% higher than that of existing halogen lamps [15]. This flux is 70 lm/W when converted to flux per input power, which is again far superior compared to halogen fog lamps.

Table 2. Junction temperature and luminous flux for a LED fog lamp prototype

	Power (W)	Ambient temperature (℃)	Soldering point temperature	Junction temperature (℃)	Luminous flux (lm)
Numerical analysis	10	25	-	104.7	-
Experiment	10	25	98.2	103.7	722

4. Conclusion

This study developed an LED fog lamp to replace existing halogen fog lamps. CFD analysis was performed to optimize the fog lamp body, and the performance of the LED fog lamp was verified using an actual prototype. The following conclusions were derived:

1) In this study, the 120° model had better heat dissipating performance compared to the 180°. This is because the 120° model with a PCB-attached aluminum body has a larger heat transfer area despite its smaller volume. The junction temperature of the 120° model was estimated to be approximately 104.7℃, thus satisfying the target

temperature.

2) After developing the LED fog lamp prototype, the LED junction temperature was measured to be 103.7℃. This is lower than the target temperature of 110℃, indicating that the prototype has succeeded in achieving excellent heat dissipation performance. The luminous flux of the LED fog lamp was found to be 722 lm. This becomes 70 lm/W when converted to luminous efficiency, showing that the luminous efficiency of the LED fog lamp is far superior to that of existing halogen lamps.

Further research is needed to develop poly-angle or lens-type LED fog lamps having the same light distribution performance as halogen fog lamps. This study varied efficiency-related factors for linear compressors, so as to design a high-efficiency compressor through full-cycle transient CFD. The following conclusions were obtained:

5. Acknowledgements

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