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Study on the Development of a Compact and High-efficiency LED Fog Lamp for Passengers Cars

S. J. Park
Grauate student, Department of Mechanical Engineering Kongju National University, Korea, mnsj1984@kongju.ac.kr

Y. L. Lee
Corresponding Author, Professor, Department of Mechanical and Automotive Engineering Kongju national University ,Korea ylee@kongju.ac.kr

Abstract
The life time and luminous efficiency of LED light source are superior to the halogen or HID light sources. In this study, a light and compact LED fog light has been studied by downsizing the existing 10W LED fog. To this end, 3-dimensional CFD analysis was performed to optimize the heat dissipation performance of the LED fog lights. As a result, it was found that there is no problem in heat dissipation performance if a heat pipe is adopted.

Keywords: LED, LED fog lamp, Thermal design, CFD

Introduction

LED lamps have recently become an alternative to filament and halogen bulbs and are also widely used in the automotive industry. The reason behind these trends is that parts and components with features of low power consumption, high intensity, and high efficiency have become necessary not only in electric and hybrid cars but also in general automobiles.

Using LED lamps provides a number of technical advantages: less waste produced due to increased durability, improved fuel efficiency, fast response, and enhanced safety by high color temperature. In the case of replacing halogen bulbs, it can also prevent deterioration of the housing unit due to the high temperature of the bulb. In addition, LED lamps have higher luminous efficiency compared to HID lamps, and do not need a high capacity generator as required by HID or halogen lamps.

Since fog lamps for cars have relatively shorter light distribution areas and broader illumination ranges, developing a replaceable LED fog lamp for cars is relatively easier. However, a replaceable LED fog lamp that can entirely substitute for the halogen fog lamp does not exist at present because the LED fog lamp has not yet satisfied the thermal performance criteria. Thus, an LED fog lamp that meets the thermal performance standard should be developed first before a replaceable LED fog lamp can be developed.

Unlike the thermal management system for the conventional LED, a LED fog lamp has several constraints. First, an electrical fan for thermal dissipation cannot be installed. Second, there is a limited space due to a standardized lamp size and use of a bracket. Therefore, the surface area, structure, and coating material of a heat sink are the major factors determining the thermal performance of the LED fog lamp.

Research on LED fog lamps and headlights has been conducted for more than ten years. Kang et al.[1] designed a thermal management system for a LED headlight and conducted a performance test for the system using the Computational Fluid Dynamics (CFD) method. Lee et al.[2] suggested a roadmap for high brightness LED headlight technology and the related market. Yuan et al.[3] showed the effect of contact thermal resistance on LED junction temperature and Laia et al.[4] studied a cooling system using fluid for LED lamps for automobiles. Wang et al.[5] studied cooling of automobile headlamps employing white LEDs. Hsieh et al.[6] suggested the optimal design for thermal diffusion of a high output LED using the Finite Element Method (FEM) in combination with the Simplified Conjugated Gradient Method (SCGM).

This study aimed to develop a compact, highly efficient and long-life LED fog lamp that can replace the existing halogen lamp[7] by downsizing the LED fog lamp and optimizing its thermal performance. To this end, a LED fog lamp was designed using a CFD(computational fluid dynamics) analysis.

Numerical analysis

Fig. 1 shows a schematic view of the existing 10W LED fog lamp. Consumption power of the LED module was assumed to be 10W and the number of heatsink fins is 25. Fig. 2 represents the major specifications of the LED fog light. To predict the heat dissipation performance according to the number of modules, a numerical analysis was performed by increasing the module number from 2 to 4 as in Fig. 3. In addition, a heatsink as in Fig. 4 was adopted for thermal performance and a heat pipe was considered to enhance thermal performance further, as in Fig. 5. The heatsink and the body of the LED lamp was assumed to be aluminum that has high conductivity. Outside air temperature is 25 ° C, PCB substrate is copper and the heat pipe was assumed to be the thermal conductivity 5,000 W/mK. Furthermore, convective heat transfer coefficient is 0.5 W / m2K, the thermal resistance between the LED chip and the PCB is 2 °C/W, the target junction temperature 110 ° C. LED module is assumed to be lumped-capacity object. Three-dimensional modeling was performed by Catia[8] and numerical analysis was conducted using Ansys[9].

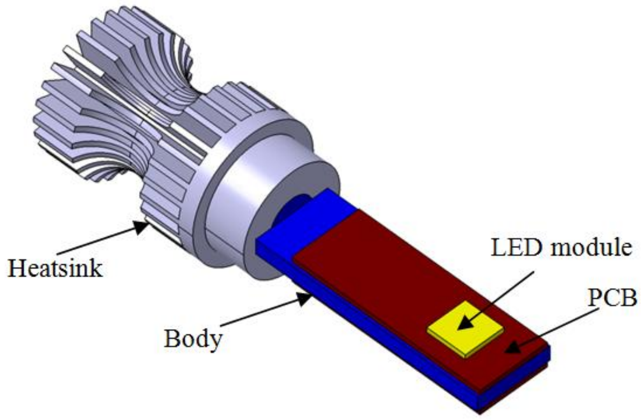


Fig.1. Schematic of the LED fog lamp

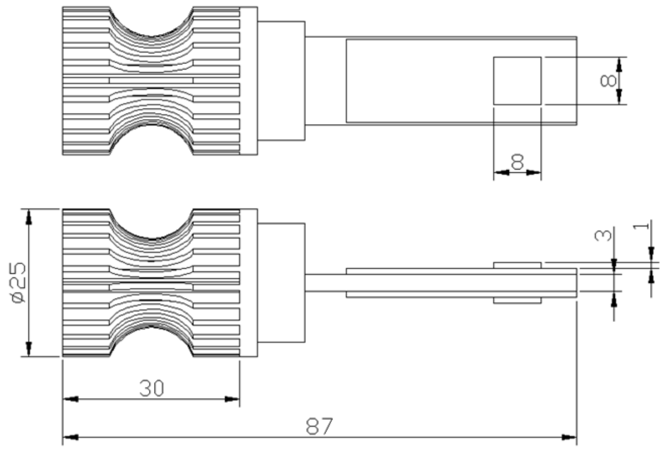


Fig.2 Specification of the LED fog lamp (unit:mm)

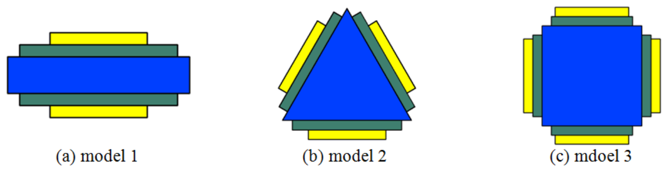


Fig.3. Numerical models with the number of LED modules

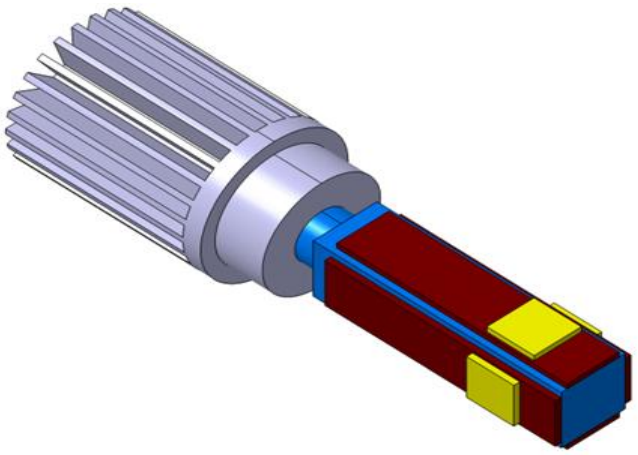


Fig.4. LED fog lamp of model 4

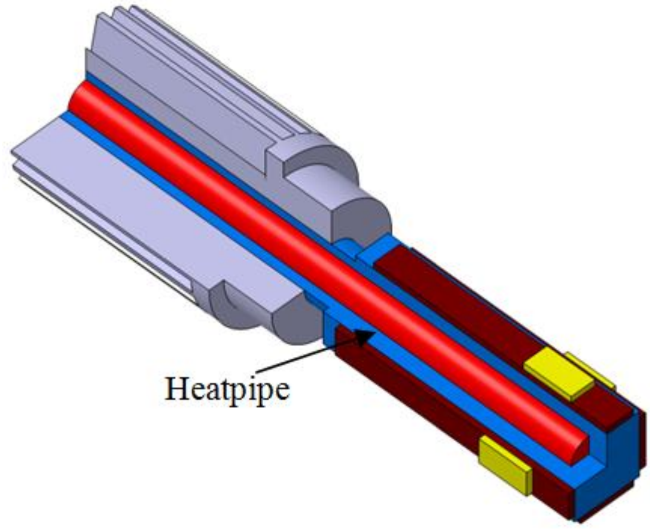


Fig.5. LED fog lamp with a heatpipe

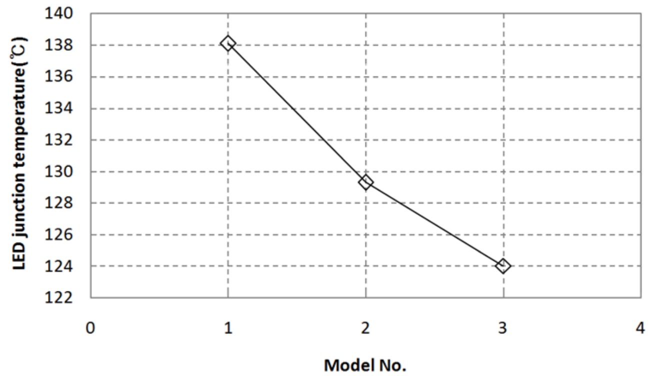


Fig.6. Variation LED junction temperature with the number of LED modules

Results and Discussion

3.1 Thermal analysis of LED fog lamp with module number

Fig.6 shows the variation of LED junction temperature with the number of LED modules. The junction temperature is 138°C for model 1, but it decreases to 124°C for model 3 where the module number increases to 4. This corresponds to about 10% reduction in junction temperature . Therefore, multiple LED modules has better thermal performance since they have the effect of heat spreading compared to a high-power LED module. In general, if the temperature of a LED chip becomes higher than 120 ~ 140 °C, the lifetime of the chip rapidly reduces, and chip short and color change can happen. Therefore, an additional method for thermal management is necessary even for a model 3 where module number is 4.

3.2 Thermal analysis of LED fog lamp with heatsink shape

Fig. 7 represents the variation of LED junction temperature with heatsink shape. Heat dissipation area of model 4 is maximized compared to model 3 and the junction temperature of model 4 becomes 112 °C lower by 12 °C than that of model 3. This results from the fact that heat capacity and heat dissipation area of model 4 increase about 12% and 30%, respectively. However, additional thermal management needs for better performance since the LED junction temperature is still higher than the target temperature, 110 °C.

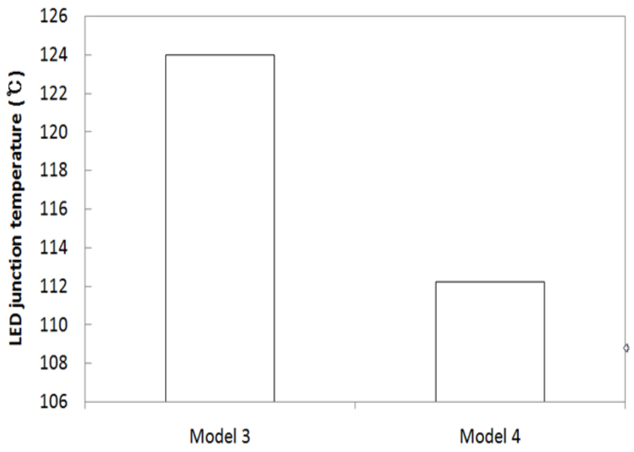
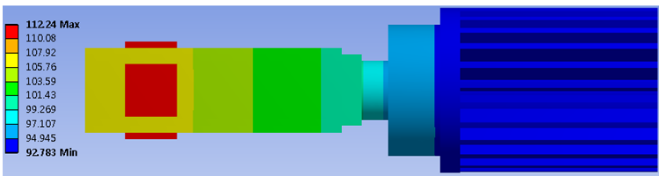
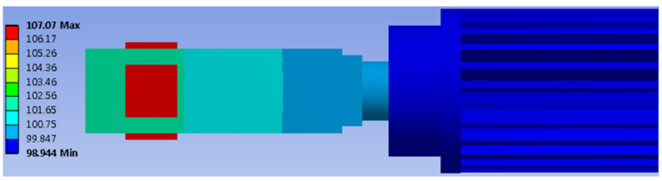


Fig.7. Variation of LED junction temperature with models



(a) Model 4



(b) Model 5

Fig.8. Temperature contours of LED fog lamp model 4 and 5

3.3 Thermal analysis of LED fog lamp with a heat pipe

An additional thermal management device, a heat pipe, was introduced and Fig. 8 indicates temperature contours for model 4 and model 5. Model 5 is same as model 4 except an installed heat pipe. In the case of model 4, the temperature difference between the heat sink and the LED chip is approximately 19 °C while model 5 shows much less temperature difference, about 8 °C. This means that a high-conductivity heat pipe transfers the heat generated by the LED module to the heat sink very effectively, resulting in s higher heatsink temperature and a lower junction temperature. The junction temperature of model 5 decreases to about 107°C, lower than the target junction temperature, 110°C. Therefore, it was able to secure a sufficient heat dissipation performance by additionally applying a heat pipe to model 4.

Conclusion

In this study, a compact, high-efficiency and long-life LED fog lamp was studied through 3-dimensional CFD. Conclusions drawn from this study are as follows:

(1) The compact, high-efficiency and long-life LED fog lamp can be developed by optimizing the LED module number and heatsink shape, and by adopting a heat pipe. The optimized model shows the junction temperature of 107°C, lower than the target temperature, 110°C.

(2) The new compact LED fog lamp has 17% less volume compared to the existing 10W-class LED fog lamp and it can therefore be applied to almost every vehicle without causing any installment problem.

In the future, it is necessary to experimentally validate the thermal performance through prototypes of the compact LED fog lamps.

Acknowledgement

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