Multi- Objective Optimization of a LED Heatsink using Evolutionary Algorithm with the Help of CFD Simulations

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Abstract

Light Emitting Diode (LED) devices generate excessive heat during its operation, dissipation of this heat to surroundings is essential for efficient operation of LED unit. Excess of heat from LED unit is dissipated by Heatsink (fins). The volume of the Heatsink should also be as minimum as possible to suit the compact design structure of modern electronic component. In order to obtain the optimal structure size of Heatsink, multiple geometric design parameters that influence the performance of Heatsink are analysed by combining the evolutionary algorithm with computational fluid dynamics. The influences of the geometric variables on the two objective functions are first analysed by commercial code CRADLE scSTREAM through the various samples of design parameters generated by the design of experiments with the help of commercial optimization code EOopti. Using the surrogate model and Multi-Objective Genetic Algorithm (MOGA) the Pareto-optimal solutions are generated. The competitive relationship between the objective functions is depicted in the Pareto front. The values of objective functions obtained from the Pareto front are validated with numerical analysis. The results obtained are within 5% of numerical error. The Pareto solution of objective function values, LED temperature of 65.2474° C and Heatsink volume of 4.53492 x 10^{-5} m^3 is found to be better solution to the application among the Pareto solutions, which has better trade-off relationship with both the objectives.

Keywords— LED Heatsink, Surrogate analysis, evolutionary algorithm,* Multi-Objective Genetic Algorithm, *Pareto solutions.

I. INTRODUCTION

The space limitation in the modern electromechanical systems and energy to drive the cooling units in the electronic systems has demanded the optimization. Following the important work of Mohamed Ali Rehmania et al [1] examined the cooling nature of a Heatsink employed in a definite real-world application. The analysis is accomplished using numerical analysis and the heat transfer analysis of the Heatsink primarily to evaluate Nusselt number. Tamayol et al [2] studied about the two important heat process analysis included in reducing the temperature of the systems i.e., radiation and natural convection. It is obtained that about 50% of the total heat transfer takes through the radiation in case of natural cooling. R. Sam Kumar et al [3] studied numerical analysis of heat sinks which comprise continuous rectangular fins, interrupted rectangular fins and all the configuration models with through holes for electronic cooling. Avram Bar-Cohen & Madhusudan Iyengar [4] analysed about the heat sink design for microelectronic applications like processors which used for high computational effort which are small with minimum material, superior thermal design, minimum pumping power, and consumption. Gaowei Xu.et al [5] developed correlations between fin thickness and fin pitch for optimized cooling of supercomputer chassis with CFD simulation. Christian Alvin et al [6] studied cooling systems which can reduce the operating temperature of LED. The cooling can be achieved having extended surfaces with material of low cost and better reliability.

To study the thermal behavior of LED, commercial code is used to get numerical solution. Min Woo Jeong et al [7] studied the three kinds of heat sinks i.e., a traditional fin heat sink which has no openings, a perforated heat sink in which perforations are provided in the fin base to concentrate improper ventilation between the fins and fin base and the proposed heat sink has altered openings that increases the air flow and the cooling efficiency by employing openings on the fins. Danish Ansari, et al [8] studied, the heat sink with micro-channel with staggered grooves was analysed computationally. Multi-objective optimization was executed with the aid of a hybrid multi-objective evolutionary approach. Daeseok Jang et al [9] investigated a radially configured heat sink, involving radiation and natural convection. The total radiation contribution on entire heat transfer was evaluated by changing the emissivity, and it was estimated that the maximum radiation contribution on the total heat transfer was 27%. G. D. Xia et al [10] studied the geometric sizes of microchannel with arc-shaped grooves and ribs are optimized using the MOEA coupling with CFD. Three-dimensional numerical analysis is performed to demonstrate the influence of a single variable on the two objective variables. Surrogate analysis is performed with the RSA and then MOEA is conducted to find out the Pareto-optimal solutions. NikolayVakrilov et al [11] emphasized the influence of the design geometric parameters of the structure of the heat sink with round pins on the junction temperature of LED system. The study utilised design of experiment (DOE) and thermal simulations to determine the factors that have the greatest impact to improve the cooling capacity and finding the optimal heat sink design.

The present work focus on the optimization of a LED Heatsink, with the help of evolutionary algorithm (MOGA) and numerical analysis (CFD). The surrogate analysis (Kriging method) is performed to generate response surfaces, which are used to evaluate objective function values in between the sampling points of design parameters required for MOGA analysis to search optimal solutions. The global Pareto-Optimal front is explored to get the trade-off analysis between the orthogonal objectives.

2. LED HEATSINK MODEL AND NUMERICAL ANALYSIS

The LED down-light bulb which is the heat source of 12.5 watt rating and is modeled as a rectugular box of size 70mm×28mm×14mm, which consists of a cover around it and also it is modeled with the size of 141.051mm×1141.051mm×56.299mm, and it also has concret slab wall at the top having a dimension of 1000mm×1000mm×15mm. The figure 4.2 shows the setup of LED heat sink. The comercial code scSTREAM is used to model this unit. The figure 1 shows the setup of LED Heatsink.

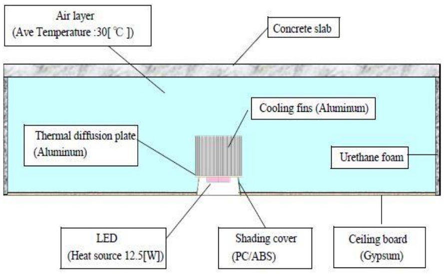

Fig 2.1: Heat sink setup

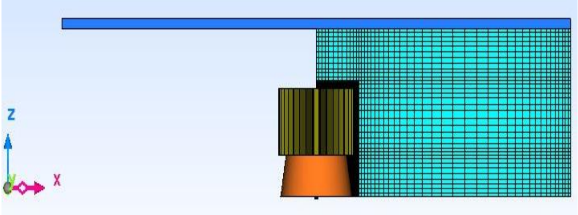

Fig 2.2: Meshed LED Heatsink model

The steady, incompressible and fully developed laminar is assumed and constant heat flux of 12.5 watt is applied at the bottom of the LED Heatsink with constant air properties at 30°C. The governing equations for mass, momentum and energy are solved, to obtain objective function values for the design samples obtained through DOE. Due to the cylindrical profile of the Heatsink, the quarter of the LED Heatsink is selected as computational domain. Adiabatic condition is assigned to the outer thermal boundary. No slip condition is applied at the wall boundaries. The emissivity of the material is 0.6 for the radiation analysis.

3. GEOMETRIC DESIGN VARIABLES AND OBJECTIVE FUNCTIONS.

The five geometric design variables which influence the performance of Heatsink are number of fins, fin height, thickness of hollow shaft, radius of shaft and outer radius of Heatsink volume are selected for the optimization by the Random sampling at the design sites in the ranges 24-48, 80mm-120mm, 2mm-5mm, 25mm-35mm and 65mm-75mm respectively.

The two objective functions, LED temperature and Heatsink volume are selected to optimize LED Heatsink.

4. SURROGATE ANALYSIS AND MULTI-OBJECTIVE GENETIC ALGORITHM.

In the present analysis Kriging method is used to interpolate the geometric design point values between the sampled strength to construct the response surfaces for each of the objective functions. Then MOGA utilizes the response surfaces to search the global Pareto-Optimal solutions with the help of applied suitable conditions of MOGA. After the final MOGA iteration, the response surfaces, distribution of contributions and correlations between the objective functions and total are obtained. The MOGA search strategy generates the Pareto front.

5. RESULTS AND DISCUSSION

The numerical analysis results are validated with the analytical results. Initially 50 geometric design parameter sets are generated by the Random sampling DOE technique and the objective function values are calculated through the CFD analysis. The contribution of design variables towards the objective functions is carried out using analysis of variance (ANOVA).

A real coded MOGA is invoked to generate diversely distributed Pareto optimal solutions with 1024 populations and 1000 generations. The crossover and mutation probabilities are 1and .1 respectively. The average fitness assignment, Fonseca's ranking method, Stochastic Universal Sampling (SUS) and new polynomial mutation method are employed.

The shape of the Pareto front shows that the optimization aims to minimize. Due to the orthogonal nature of the objective functions, upgrading of one objective leads to worsening of the other objective. The optimal solutions in the Pareto front are global Pareto optimal solutions meaning that no solution is superior to solutions in the Pareto front. But the solutions in the extreme ends of the Pareto front can be treated as weak Pareto optimal solutions because of highly orthogonal towards each other objectives.

Three Pareto optimal solutions are selected from the Pareto front in the view of trade-off business. The solution 1 has the lesser temperature value at the expense of high Heatsink volume. The solution 3 has higher temperature value (among the selected Pareto optimal solutions) at the expense of lesser Heatsink volume. So, the solution 2 well suits the trade-off requirement for both the objectives. This approach gives the engineer certain liberty to select economical set of design parameter set to optimize the Heatsink.

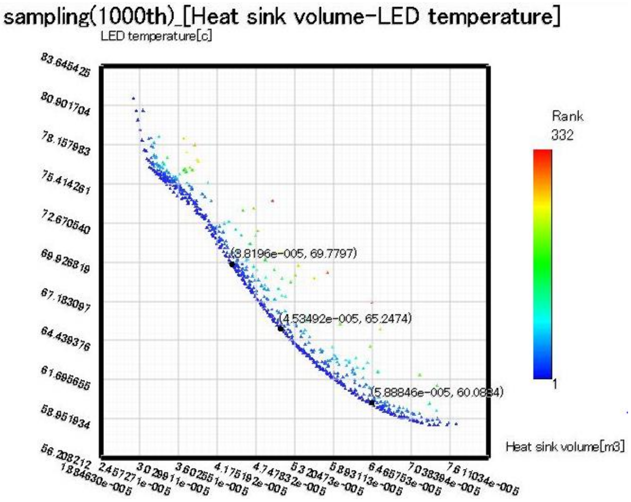

Fig 5.1: The final solutions of MOGA generation

Table 5.1: Comparison of CFD and optimum selected solution no 1

	Solution 1	
	Volume m^3	Temperature °C
Optimization	5.8846 x 10^{-5}	60.0884
CFD	6.018 x 10^{-5}	62.02664
Error percentage	2.1525	3.1248

Table 5.2: Comparison of CFD and optimum selected solution no 2

	Solution 2	
	Volume m^3	Temperature °C
Optimization	4.53492 x 10^{-5}	65.2474
CFD	4.751 x 10^{-5}	66.8391
Error percentage	4.5480	2.3974

Table 5.3: Comparison of CFD and optimum selected solution no 3.

	Solution 3	
	Volume m^3	Temperature °C
Optimization	3.81960 x 10^{-5}	69.7797
CFD	4.006 x 10^{-5}	70.6664
Error percentage	4.6530	1.3255

➢ TEMPERATURE DISTRIBUTION

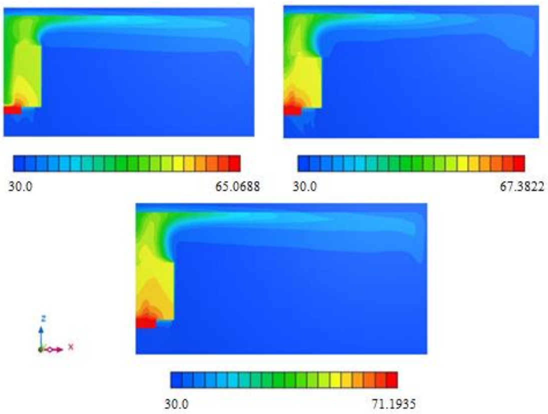

Fig 5.2: Temperature distribution of three optimum solutions

Temperature distribution for three selected optimal solutions are shown in the below figures. It is observed from the contours that the temperature at the base of heat sink , where heat source (LED bulb) is more. It is observed that the as the design parameters especially number of fins, fin height and outside radius of heat sink increases, the LED temperature decreases due to the more scope for heat transfer.

➢ FLOW DISTRIBUTION

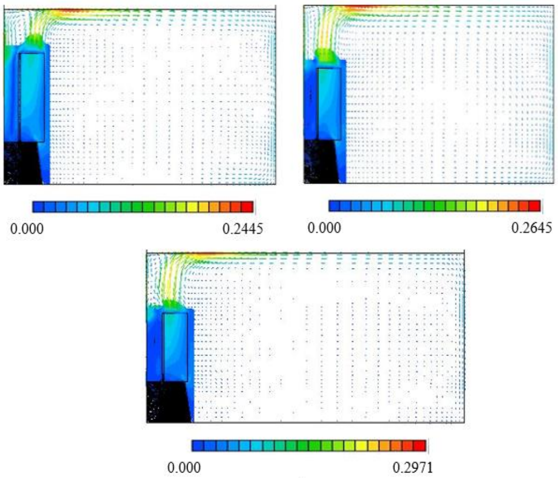

Fig 5.3: Flow distribution of three optimum solutions

The air enters from the bottom side of the heatsink to fluid domain. The entered air comes into contact with heated fin surfaces in the fluid domain, and rises up. The air flows from bottom to top in natural convection due to density difference (buoyancy effect). As it is evident from the contours that velocity of flow increases as the temperature increses, due to more density differece in the air.

6. CONCLUSION

The present work shows the multi-objective optimization of LED Heatsink with the help of MOGA evolutionary approach. Global Pareto Optimal solutions are generated using MOGA coupled with surrogate analysis. All the design parameters have certain effect on the thermal performance of the LED Heatsink. Among the design parameters the number of fins, outer radius of Heatsink and thickness of hollow shaft has significant effect on the LED temperature. The number of fins, fin height and thickness of hollow shaft has major impact on the Heatsink volume. Pareto optimal front depicts the existing trade-off nature of the objectives. The optimal design parameters are sensitive to the LED temperature and LED Heatsink volume.

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