OPTIMIZATION OF A 3-D HIGH-POWER LED LAMP Orthogonal Experiment Method and Experimental Verification

by

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The temperature distribution in a 3-D high-power light emitting diode lamp is affect by multiple factors, the orthogonal experiment method is adopted to elucidate three main factors, an experiment is designed to verify the main finding, which is useful for an optimal design of the light emitting diode lamp.

Key words: *light emitting diode lamp thermal characteristics, orthogonal test analysis, finite element thermal analysis*

Introduction

In the latest decade, the electro-o tic convesion efficiency of the light emitting diode (LED) was about 10-15%. The temperature distribution of high-power LED lamps has greater negative influence on the efficiency [1-3]. Much literature focused on experimental method to reduce the maximum temperature of radiator of high-power LED lamps [4-7], additionally a 3-D numerical model was used in open literature to study the steady-state temperature distribution [8]. Though both experiment and numerical simulation can lead to some useful results, the main factors affecting the temperature distribution were ignored. This paper adopts the orthogonal experimental design method to analyze three main factors, *i. e.*, the thickness of the fin, the thickness of the base plate and the degree of density structure, which have huge effect on the radiator temperature. The experimental results are used for the orthogonal algorithm so that a reliable result can be obtained. This method not only reveals the main factors affecting the heat dissipation, but also overcomes the disadvantage of large-scale experiment.

Analysis model

The structure of a single LED lamp is shown in fig. 1, while its 3-D model for the finite element analysis is shown in fig. 2, the 3-D model of high-power lamps with 77 LED lights is shown in fig. 3 and the structural analysis of lamps is shown in fig. 4. The radiator is composed of 27 fins arranged at equal distance and adopts natural-convection cool down. The heat transfer coefficient of the radiator air is 2.5 W/m°C, the thermal generation rate of the chip is 3.2 W/m^2 [9].

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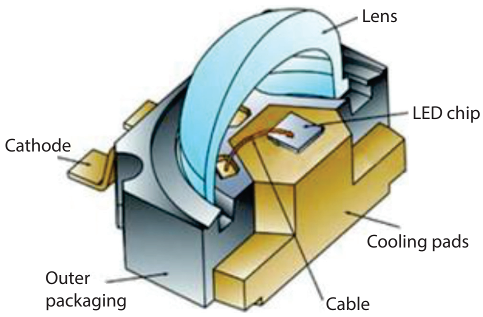

Figure 1. The structure of a single LED lamp

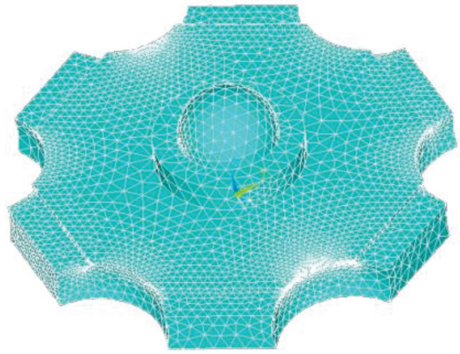

Figure 2. The 3-D model of LED in simulation diagram

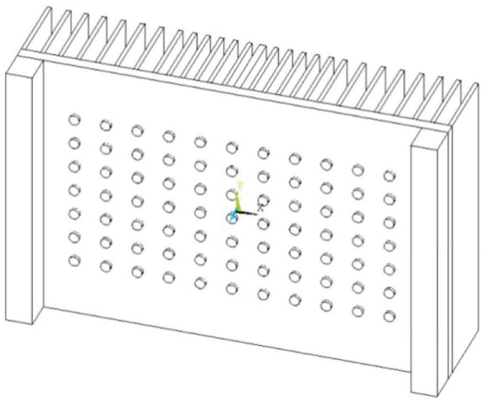

Figure 3. The 3-D model of high-power LED lamps

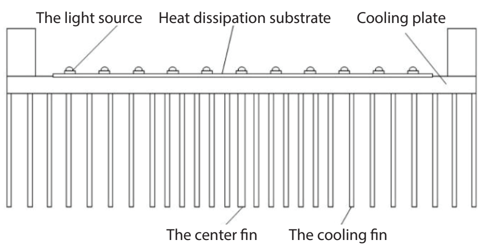

Figure 4. Structural drawing of high-power luminaires

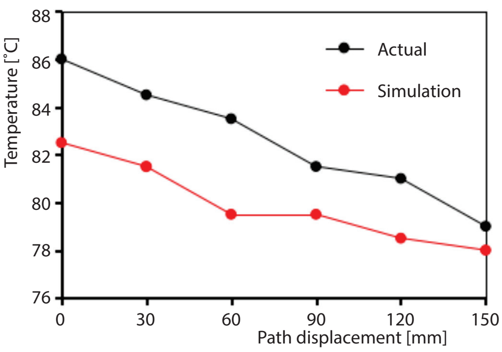

Figure 5. Contrast chart

The results of finite element thermal analysis were compared with the measured values of the infrared thermal imaging instrument TI-10. The comparison figure is shown in fig. 5 [10-13].

According to the results of the comparison in fig. 5, it is known that the temperature error between the measurement and the simulation is 1.135-3.467 °C, while the error rate is only 2.7%. The main reason is that the simulation environment and photoelectric conversion rate are both idealized. The reliability of simulation is verified, which establishes the foundation for the further optimal design of experimental scheme [14, 15].

Experiments

Case 1. Determinations of radiator orthogonal experimental factors

The orthogonal test design refers to a test design method that studies multiple factors and levels, which can achieve the equivalent results with the least number of tests and a large number of comprehensive tests, to obtain the influence of various factors on the results and the optimal combination according to the corresponding range analysis method [16].

In the radiator optimization test of LED lamps, the thickness of radiator center fin, the thickness of base plate and fin structure with different density are taken as the test indexes.

Secondly, to determine the test level, the thickness of the central fin affects the distance between the central fin and the side fin, and the distance affects the performance of heat transfer to the air. The value of the thickness of the central fin needs to be moderated. The values are 3 mm, 4 mm, and 5 mm in the experiment.

The thickness of the base plate affects the performance of the lamp body temperature transferred to the radiator. According to the overall size and structure of the lamp body, the values are 9 mm, 10 mm, and 11 mm.The density of the intermediate fins affects the air convection, and the spacing of the intermediate fins needs to be determined within a reasonable range, otherwise it will produce the opposite effect. In the experiment, three types of fin structures with non-equal spacing are selected, as shown in figs. 6-8. To sum up, the table of three-factor and three-level orthogonal test of radiator is shown in tab. 1.

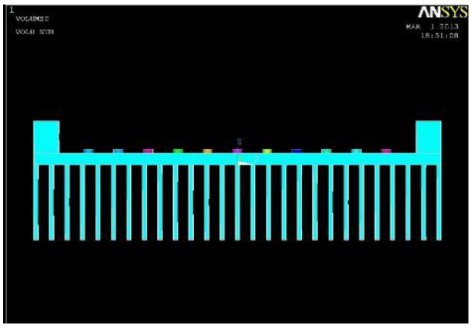

Figure 6. Type I

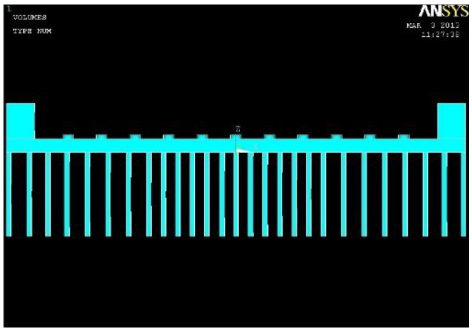

Figure 7. Type II

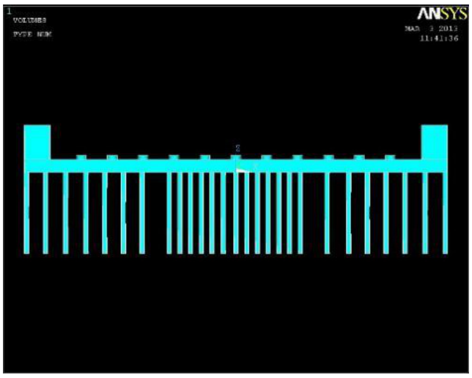

Figure 8. Type III

Table 1. Three factors and three levels of radiator

Factors level	*A* Thickness of central fin [mm]	*B* Thickness of bottom plate [mm]	*C* Fin density type
1	3	9	I
2	4	10	II
3	5	11	III

Case 2. Design of orthogonal experimental table

Orthogonal table is a set of regular design table. The L9 (34) orthogonal table is selected according to three factors and three levels of radiator to arrange the experiment, which indicates that nine experiments need to be done, and four factors can be observed at most, while each of which has three levels [17].

Finite element software was used to conduct nine experiments, respectively, which obtains the maximum temperature of the heat dissipation model, as shown in tab. 2.

Table 2. Experimental arrangement and results

Factors nunber	*A* Thickness of central fin, [mm]	*B* Thickness of bottom plate, [mm]	*C* Fin density type	Model maximum temperature, [°C]
1	3	9	I	74.625
2	3	10	II	79.422
3	3	11	III	82.516
4	4	9	II	80.781
5	4	10	I	76.134
6	4	11	III	76.975
7	5	9	III	78.144
8	5	10	I	72.387
9	5	11	II	74.674

Case 3. Analysis of design results of orthogonal experimental table

Orthogonal table was selected for experimental design. After the experimental results obtained by simulation, mean value t and range R were used to analyze the data. The analysis results were shown in tab. 3.

Table 3. Experimental results analysis table

Factors value	*A* Thickness of central fin	*B* Thickness of bottom plate	*C* Fin density type
T_1	236.563	223.146	223.146
T_2	233.89	227.943	234.877
T_3	225.205	234.165	237.635
t_1	78.85	74.38	74.38
t_2	77.96	75.98	78.29
t_3	75.07	78.06	79.21
R	3.79	3.67	4.83

The values of three factors and three levels of the radiator will not affect each other. It is concluded from the experimental data in tab. 2 that the maximum temperature of the model in *Experiment 5* is the lowest.

Through the magnitude of the range value, R, it was concluded that there was a significant different effects of the factors in this experiment, the factor C in tab. 3 was the highest and the factor B the lowest, that is, the type of the fin density is the most important factor affecting the model temperature, followed by the thickness of the central fin and the thickness of the base plate.

Table 2 shows the average values of radiator temperatures for each factor, *A*3, *B*1, and *C*1 are the level values with the greatest influence among all factors, and they are the optimal combination of factors. After improvement, the simulation results of the radiator are shown in fig. 9.

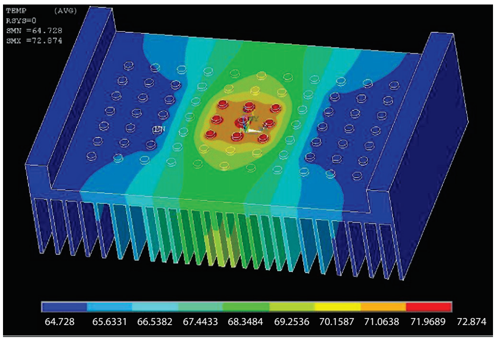

Figure 9. Temperature distribution of improved radiator

Results and discussion

The optimal combination was obtained from the experiment. According to the simulation results in the fig. 9, the maximum temperature of the optimal model was 72.874 °C, while the maximum temperature of the model before optimization was 82.633℃, reducing the temperature by 12%. The results show that the optimal model can be obtained by the orthogonal experiment, and the maximum temperature of the model can be reduced. The results presented in this paper are expected to aid in the development of thermal design guidelines for the 3-D high-power LED lamps.

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