Simulation and Experimental Analysis of Thermal Management for High-Brightness LED Projector†

Jie Ma，Dalin Dong，Jiaqiang Wang，Xi L， Wei Zhan，Guangquan Wang

LCD innovation application 1 development
Beijing BOE Display Technology Co., LTD., China

Abstract

This paper conducts thermal simulation analysis of LED projector. Through structural optimization, the LCD temperature is lowered to 80°C. The test results show that the LCD temperature reaches 82.5°C, the error between simulation and test is within 5 ℃, which can meet the needs of engineering. The device temperature can be reduced by optimizing the heat dissipation structure.

Author Keywords

Projector; Structure optimization; Thermal simulation; Thermal test.

1. Introduction

LED projectors use LED light sources, LED light sources as temperature sensitive devices have an important impact on the life and reliability of the projector, especially depending on the LED junction temperature. With the increase of LED light source power, the heat generated is also significantly increased, and due to the small area of the LED chip, the heat flux of the LED is further increased, resulting in the temperature of the LED chip. This temperature increase not only reduces the luminous efficiency of the LED chip, but also directly affects the display effect of the projector. Therefore, when applying high-power LED chips, the junction temperature of the LED must be controlled within a reasonable range (below 80 ° C) through an effective cooling system. Therefore, the heat dissipation design of LED has become an urgent problem to be solved.

The design of circulating heat dissipation in optical machine is the difficulty of heat dissipation in projection optical machine. The internal circulation system is in a closed state, and the heat generated by the internal optics is circulated through forced convection heat transfer by a centrifugal fan. The aluminum radiator on the optical machine conducts heat to the outside environment through convection heat transfer. Because the internal circulation system has been in a high temperature state, it is necessary to solve the problem of rapid heat flow and timely heat dissipation, which has become a challenge to be solved urgently.

2. Thermal design of an LED projector

- System parameter

(1) The total power consumption of the system 122W.
(2) The overall size: 254mm*174mm*146mm.
(3) The system inlet and outlet maximum temperature difference is less than 25°C.
(4) The system noise is less than 30dB under normal temperature conditions.

- Main components Thermal Power consumption (W)

Table 1. Thermal power consumption of main components.

Device Name	Quantity	Power dissipation	thermal design specification
LED light source	1	80.5	≤80°C
Light cup	1	3.105	≤95°C
Post fresnel lens	1	3.45	≤70°C（Non-light region）
Insulating glass	1	13.8	≤95°C
LCD	1	13.8	≤85°C
Front Fresnel lens	1	0.345	≤70°C（Non-light region）
Main PCBA	1	7	≤85°C

- Design of heat dissipation scheme of the whole machine

The cooling scheme of the system is designed as follows: the cold air enters from the right air inlet, passes through the heat generated by the upper cover, base and main board of the optical machine, and then passes through the LED cooling module, and finally the hot air is discharged by the left axial flow fan to realize the heat dissipation of the system. The specific diagram is shown in Figure 1.

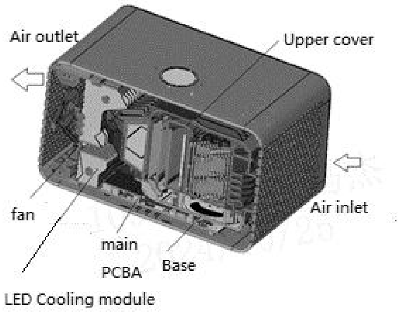

Figure 1. Projector system cooling scheme schematic.

The heat dissipation scheme of the system is divided into two parts: the heat dissipation of the LED light source and the heat dissipation of the internal circulation system of the optical machine. In the cooling scheme of LED light source, the heat pipe cooling module is used, and the heat generated by the LED chip is quickly transferred to the cooling module through heat conduction. As for the internal circulation heat dissipation scheme of the optical machine, because the system is in a closed state, it can only dissipate heat with the outside through heat convection, and its heat dissipation efficiency is limited to a certain extent.

As shown in Figure 2 below, the air generated by the centrifugal fan outlet in the internal circulation system forms three channels through the rear mirror, heat insulation glass, LCD and front mirror (the rear mirror and heat insulation glass are channels C, the heat insulation glass and LCD are channels B, and the LCD and front mirror are channels A). In channel A, the flowing air enters the air inlet of the centrifugal fan through the air duct formed by the middle cover and the LCD; The flowing air in channel B and channel C passes through the air duct formed by the middle cover and the upper cover, and reaches the air inlet of the centrifugal fan in the outer hole and the inner hole on the middle cover, respectively, to form an internal circulation air duct.

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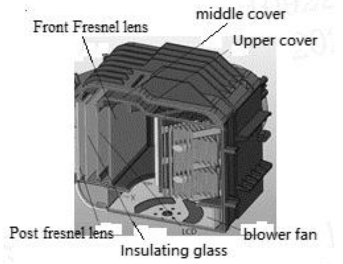

Figure 2. Schematic diagram of circulating heat dissipation scheme in optical machine.

Because the air in the inner circulation can only flow and circulate internally and exchange heat with the outside world through the heat exchange of the upper cover, the upper cover is made of aluminum (thermal conductivity can be selected between 90W/(m • K)~ 210W /(m • K)), so the inner circulation system has been maintained at a high temperature. When operating for such a long time, the performance of the device may be degraded and the life of the device may be shortened.

The transfer of heat usually has three forms, namely heat conduction, heat convection and heat radiation. In this paper, the heat transfer between LED light source and LED cooling module is mainly through heat conduction. The internal circulation system of optical machine mainly transfers heat by heat convection. The heat transfer calculation formula is as follows:

$$\mathrm{Q} = \mathrm{k} \bullet A \bullet \frac{T_1 - T_2}{L} \qquad (1)$$

Where, Q is heat, unit W;

k is the thermal conductivity of the material, in W/(m•K);

A is the area through which heat passes vertically, unit m^2;

T_1 is the temperature of the upper surface (unit ° C), and T_2 is the temperature of the lower surface (unit ° C), $T_1 > T_2$;

L is the distance between the upper and lower surfaces, in m.

The formula for calculating convective heat transfer is as follows:

$$\mathrm{Q} = \mathrm{h} \bullet A \bullet (\mathrm{T_w} - T_f) \qquad (2)$$

Where, Q is heat, unit W;

h is the convective heat transfer coefficient, the unit is W/m^2·K, forced convection heat transfer, h is 20~100W/m^2·K, the actual use of the value of 30 W/m^2·K;

A is the surface area of the convection heat exchanger, the unit is m^2;

T_W is the device wall temperature, unit ℃;

T_f is the fluid temperature ,unit: ℃.

When the ambient temperature is 25℃, it is assumed that the ambient temperature of the inner cavity is 50℃. Using the heat convection formula, the surface temperature T_{LCD} is calculated by taking LCD as an example.

$$\mathrm{T_{LCD}} = \frac{\mathrm{Q}}{\mathrm{h} \bullet A} + T_f \qquad (3)$$

Plug in the value to get:

$$\mathrm{T_{LCD}} = \frac{13.8}{30 \bullet 0.1015 \bullet 0.0628 \bullet 2} + 50 = 86.2$$

The theoretical calculation shows that the LCD temperature reaches 86.2℃.

- Simulation analysis of system cooling scheme

The thermal simulation analysis model of the system was established. In order to improve the analysis efficiency, the model was simplified as follows: (1) the mounting screws, mounting holes and cables of the system were removed, and the rounded corners and curved surfaces were simplified; (2) The heating device, including the LED light source, the rear mirror, the thermal insulation glass, the LCD, the front mirror is simplified into a solid model. Table 2 below lists the materials and thermal conductivity of the main components.

Table 2. Materials and thermal conductivity of components.

Device name	**material**	**Thermal conductivity （W/m•K）**
LED light source	Si	117.5
Upper cover	ADC12	98
Light cup	AL6061	180
Post fresnel lens	PMMA	0.192
Insulating glass	glass	1.05
LCD	glass	1.05
Front Fresnel lens	PMMA	0.192
Base	ADC12	98

The simulation model includes the whole shell, the optical machine and the main board. The optical part includes the external axial fan 12025, the internal blower fan 10018, the external blower fan 6020, and the LED heat sink, the light cup, the optical body, the rear mirror, the heat insulation glass, the LCD, the front mirror and the lens.

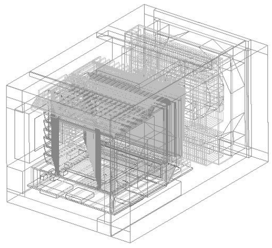

Figure3. Projected optical mechanical thermal simulation model.

- Simulation result analysis

Based on the following simulation analysis, under the ambient temperature of 25℃, the temperature distribution diagram of LCD and thermal insulation glass, the core devices of the optical machine, is shown in Figure 4. The highest temperature of LCD is 85.9℃, exceeding the maximum thermal design temperature of 85℃, which does not meet the design requirements and needs to be optimized. As shown in Figure5, there is obvious wind resistance at the top of the overall inner cavity flow channel, showing a red position, which affects the flow of the air channel in the product and causes the problem of poor internal circulation. The corresponding wind speed on both sides of the LCD and the overall wind speed need to be optimized and improved.

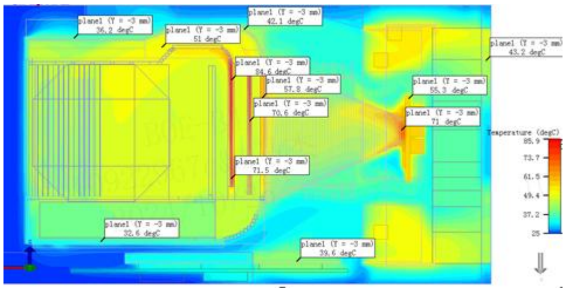

Figure 4. Temperature distribution before optimization.

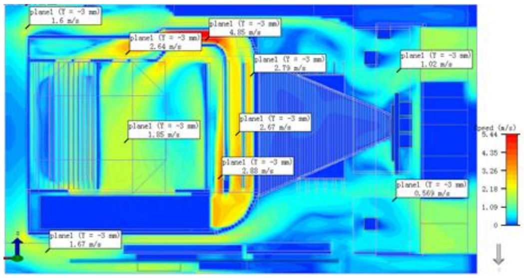

Figure5. Velocity profile before optimization.

- Simulation optimization design

Based on the speed distribution of channel A and channel B, consider increasing the speed of channel B to reduce the temperature of the LCD. The optimization involves adding A sheet of white glass to channel A and dividing channel A into two sub-channels, Channel A1 and Channel A2, by optimizing the base lift damper. Channel A1 is composed between the front lens and glass, and channel A2 is composed between glass and LCD. Such an optimization scheme is designed to increase the speed of channel B, thereby reducing the temperature of the LCD. Through the optimization of the optimized structure, the simulation model is optimized and the simulation analysis is carried out to verify the effect of the optimization scheme.

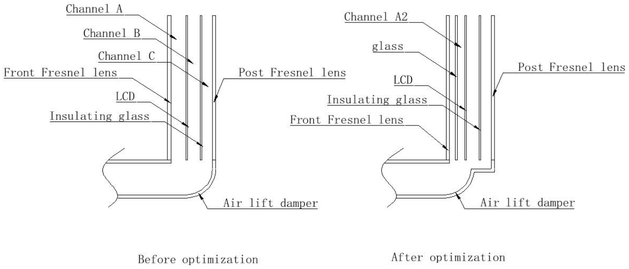

Figure6. Structure comparison diagram before and after optimization.

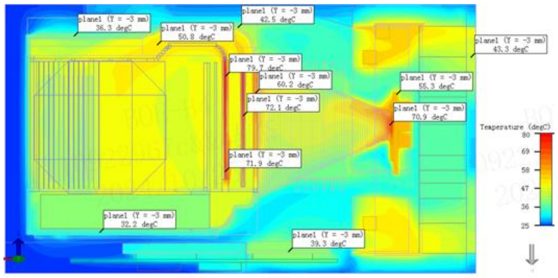

Figure7. Optimized temperature profile.

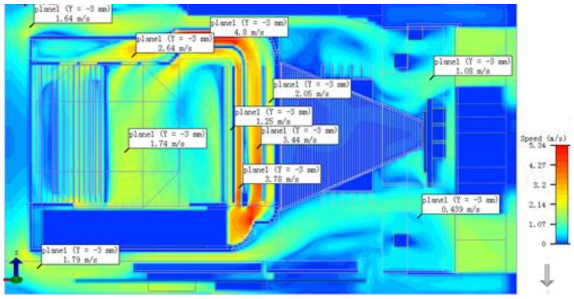

Figure8. Optimized velocity distribution diagram.

By comparison, it can be clearly seen that the temperature of the LCD before and after optimization is reduced by 5.9℃, and the maximum temperature of the optimized LCD is 80 ℃, which meets the requirements of the thermal design specifications. As shown in the following table, the comparison before and after optimization shows that after optimization, the speed of channel B is relatively increased, and the speed of channel A2 is 3.78m/s. Compared with the speed of channel A, the flow rate increases, which helps to reduce the temperature of the device.

Table3. Speed and temperature comparison before and after optimization.

	Item	**Velocity distribution (m/s)**			**Temperature distribution （°C）**	
		Channle A	**Channel B**	**Channel C**	**Insulating glass**	**LCD**
1	Before optimization	2.88	2.67	2.79	77.4	85.9
2	Post ptimization	3.78	3.44	2.05	79.1	80

Simulation temperature data after structure optimization are shown in the following table.

Table4. The LED projection light machine simulates temperature.

Device name	**Simulation temperature/°C**
LED cooper base	55.3
Post fresnel lens	60.8
Insulating glass	79.1
LCD	80
Cavity temperature	50.8
Upper cover	42.5
Air outlet	43.4
Ambient temperature	25

3. Pototype Test verification

- Temperature test

Through the above simulation and analysis, the heat dissipation structure of the projector is determined according to the optimized structure. Figure 9 shows the physical diagram of the structure of the base air lift baffle after optimization. The results show that the optimized design has a good effect on heat dissipation, and the real structure agrees with the simulation results, which provides a reliable basis for the heat dissipation performance of the projector.

Figure9. Optimized base air lift structure diagram.

Figure 10 shows the temperature test platform of the projector. The platform is equipped with a multi-channel temperature inspection instrument, and the temperature sensing line adopts a K-type temperature sensing line, which has a wide range of temperature measurement from -200 ℃ to 1350 ℃ . The temperature sensing wire is mainly made of nickel-chromium alloy material, which has the advantage of low price. The use of this test platform is conducive to the comprehensive testing and evaluation of the temperature performance of the projector.

Figure10. Projection light machine temperature test platform.

The temperature sensor line is arranged on the key device, and the test duration is 1h. After the temperature is recorded, the test data is recorded as shown in Table 5 below.

Table5. An LED projector test temperature.

Device name	Measured temperature/℃
LED cooper base	51
Post fresnel lens outlet surface	64.7
Insulating glass inlet surface	77.5
LCD inlet surface	82.5
Cavity temperature	49.3
Upper cover	44.2
Air outlet	40.1
Ambient temperature	26

It can be seen that the temperature of the device in the optical machine meets the requirements of thermal design. The absolute error between simulation and test is less than 5℃, which can meet the engineering requirements.

- Noise test

The noise test was carried out in a semi-anechoic chamber with an ambient temperature of 26 ° C and the machine was turned on for at least 15 minutes before the test. The instrument used for the test is an FFT analyzer with a frequency range of 20Hz to 20kHz. The location of the microphone is shown in Figure 11, while Figure 11 shows the noise test platform of the prototype. This test setup helps to fully understand the noise performance of the projector and provides detailed test data.

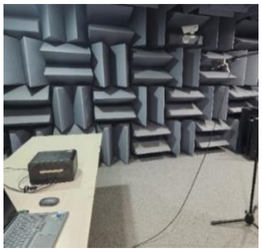

Figure11. Prototype noise test platform.

The test results are shown in Table 6 below. It can be seen that the maximum noise of the equipment at normal temperature is 28.46dB, which meets the design requirements.

Table6. Noise test data sheet.

Machine noise (dB) Base noise 19.8dB				
Right/outlet	Front/lens	Left/air inlet	Back	Max
27.89	28.46	28.15	27.89	28.46

4. Conclusion

- At room temperature, the system inlet and outlet temperature difference reaches the design goal.
- Under normal temperature conditions, the maximum noise level of the equipment is less than 30dB, which meets the design requirements.
- The base air lift baffle structure, which shrinks the arc structure at about the middle position of the insulation glass and the LCD, can increase the air flow rate of channel B and reduce the device temperature.

5. Impact of Your Research

Through numerical simulation, we are able to identify potential risk points within the device before the prototype is manufactured. These risks can be reduced through simulation optimization, providing powerful guidance for the design, manufacture, and testing of mock-ups. This approach helps to improve the efficiency and reliability of the design, ensuring that the equipment can achieve the expected level of performance in practical applications.

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7. References

1. He Yulin, Yang Qingbo, ZHANG Rui, Yang Lina, ZHAO Lun. Thermal design, Analysis and Test of LED Projector [J]. Electronic World, 2012 (03)
2. Yu Jianzu. Thermal Design and Analysis Technology of Electronic Equipment [M]. Beijing: Higher Education Press, 2002