Calculation of the Thermal Mode of the LED Device

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Abstract—The problem of heat removal from the substrate of LED light sources is considered. Modern methods of cooling of LEDs are reviewed. The calculation method is given and the radiator area for passive heat removal is calculated. The radiator was selected according to the given criteria.

Keywords—LED; radiator; heat removal.

I. INTRODUCTION

Recently, the problem of heat dissipation has been put at the forefront when designing LED Lighting Devices. The reason for this is the nature of the LEDs. For a long time, LEDs considered "cold" light sources, because when working, the crystal itself is hardly heated. In fact, when operating the LED DS, only 5% of the heat is emitted in the form of thermal radiation, but the rest of the heat released by the crystal, which is more than 90%, is transferred to its metal substrate due to thermal conductivity.

The calculation of the thermal mode plays an important role in the quality of the LED's operation and its lifetime. Without a heat sink, the LED can overheat and malfunction. Also, as the temperature rises, the luminous flux decreases and the color of light changes [1].

That is why accurate calculation of heat removal from the crystal of LED is required.

II. SETTING OBJECTIVES

To cool LED light sources, aluminum radiators are commonly used, which are designed for natural convection. Such radiators solve two major cooling problems: heat removal from an LED source and heat dissipation into the environment. The intensity of convection and radiation increases with increasing temperature, so that at a constant power of the heat flux from the LED light source, the radiator is heated only to a set temperature at which the total power of convection and radiation is equal to the power of the radiating light from the radiator.

The intensity of convection and radiation is proportional to the area of the radiator participating in the heat exchange. The surface area of the radiator heat exchange is less than the surface area of the radiator. If you increase the radiator area by plates or pins, the distance between these elements must be taken into account. If the distance between the pins is less than 4mm, it will not give the expected cooling effect.

III. RESEARCH METHODOLOGY

There are two methods for calculating the radiator for an LED:

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design, the essence of which is to determine the geometric dimensions of the structure at a given temperature;

- check, which involves acting in reverse order, that is, with known parameters of the radiator, you can calculate the maximum amount of heat that it is able to effectively dissipate.

The application of this or that variant depends on the available raw data. In any case, accurate calculation is a complex mathematical problem with many parameters. In addition to the ability to use the reference literature, take the necessary data from the graphs and substitute them in the appropriate formulas, you should take into account the configuration of the rods or edges of the radiator, their orientation, as well as the influence of external factors. Also worth considering is the quality of the LEDs themselves. Most often, in Chinese-made LEDs, the real characteristics differ from those stated.

To calculate the heat sink for high-power LEDs, you can use the source method [3].

Modern LEDs have an efficiency of about 30-40%, that is, on average 60-70% of the power consumed is converted to heat. In the XLampThermalManagement document, CREE recommends using the assumption that 75% of the power consumed is converted into heat; The power to be dissipated is calculated as follows (1) [3]

\[ P_t = 0.75 \cdot V_f \cdot I_f \]  

where \( P_t \) is the thermal capacity (W); \( V_f \) is a direct voltage drop across the LED (B); \( I_f \) - current through LED (A).

During the work, the thermal calculation of the CREE CXA1507 LED was carried out (Fig. 1).

![Figure 1. Mechanical characteristics of the CXA1507 LED](image1)

This LED belongs to the class COB (clip-on-board) and is mounted on the radiator (Fig. 2).

![Figure 2. Installation of CXA1507 LED on the radiator](image2)

The equivalent scheme for calculating the thermal regime for this case consists of thermal resistance "transition-contact pad of the LED", thermal resistance "contact pad - thermal conductive material", resistance "thermal conductive material-radiator" and thermal resistance "radiator-air" (Fig.3)

![Figure 3. Equivalent circuit for LED CXA1507](image3)

**IV. RESEARCH RESULTS**

The calculation was performed for an ambient temperature of 25°C and 55°C. For the optimum lifetime of the LEDs, it is necessary that the temperature of the heat-conducting surface of the substrate does not exceed 85°C [4].

Assuming that the LED operates at a transition temperature of 85°C and at maximum current, using a software PCT calculator from CREE, we obtain a voltage value for a given transition temperature at maximum current (Table 3.3). As a thermal conductive material, a thermal paste such as KPT-8 is commonly used, and thermal conductivity is assumed to be 0.7W/(m·°C).
To determine the value of maximum thermal resistance between the LED contact and the air, you can use the schedule provided in the LED documentation (Fig. 4).

**TABLE I. DATA FOR THE CALCULATION OF THE LED CXA1507**

<table>
<thead>
<tr>
<th>№</th>
<th>Initial data</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Transition temperature, °C</td>
<td>85</td>
</tr>
<tr>
<td>2</td>
<td>$I_0$, A</td>
<td>0.37</td>
</tr>
<tr>
<td>3</td>
<td>$V_f$, V</td>
<td>36.77</td>
</tr>
<tr>
<td>4</td>
<td>$P = I_0 \times V_f$, W</td>
<td>13.61</td>
</tr>
<tr>
<td>5</td>
<td>$P_r = 0.75 \times P$, W</td>
<td>10.02</td>
</tr>
<tr>
<td>6</td>
<td>Contact area of the LED, mm$^2$</td>
<td>251.22</td>
</tr>
</tbody>
</table>

Figure 4. Maximum thermal resistance between contact and air

The graph shows that at 25°C the maximum resistance is 6°C/W, and at 55°C - 3.5°C/W. Let the thickness of the thermal paste layer be 0.1 mm. The value of thermal resistance is calculated by the following expression

$$Q_{\text{tim}} = L / (k \cdot A)$$  \hspace{1cm} (2)

where $Q_{\text{tim}}$ is the thermal resistance of the heat-conducting material (°C/W); $L$ is the thickness of the layer (m); $K$ - thermal conductivity (W/m·K); $A$ is the contact area (m²).

Hence $Q_{\text{tim}} = 0.8$°C/W.

Given all of the above, for a temperature of 25°C, the radiator resistance should be less than 5.2 °C / W, and at 55°C 2.7°C/W.

For example, you can use the MechaTronix LPF6768-ZHP radiator, whose thermal resistance is 2.1 °C / W (Fig. 4).

CONCLUSIONS

The calculation of the thermal mode plays an important role in the quality of the LED's operation and in its lifetime. Without a heat sink, the LED can overheat and malfunction. Also, as the temperature increases, the luminous flux decreases and the luminescence changes.

The problem of heat removal from the substrate of LED light sources is considered. Modern methods of cooling of LEDs are reviewed. Requirements for the design and parameters of the heat sink system of the LED luminaire were formulated on the basis of the analysis of existing systems, taking into account the experimental studies of the heat transfer properties of radiators of different design.

The calculation method is given and the radiator area for passive heat removal is calculated. The radiator was selected according to the given

**REFERENCES**