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The Research and Simulation of LED Arrays in Lighting

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Abstract: LED is one of the green light sources in the 21st century, and it has broad prospects in the illumination. In recent years, there have been more and more LED lamps, and designing appropriate LED lamps become very important. The power of a single LED is very small, but lighting requires the uniform flux and illuminance in a certain region, so it is necessary to use LED arrays for increasing the brightness and luminous area, improving the uniformity of illuminance. This paper calculated illuminance of the LED arrays at first, and then according to known functions, the LED arrays were simulated and analyzed. The distribution characteristics of the different LED arrays were obtained by comparing the characteristics of two kinds of LED arrays. Finally, the law of arrays suiting lamps was shown, which will be able to provide the accurate reference for designing LED lamps.

Key words: LED; arrays; simulation

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1 Introduction

LED has inherent characteristics, such as energy saving, long lifetime, shock resistant, fast response. it was predicted that 21st century will be the century of new light sources and green lighting, which will use solid luminous materials as the core. In other words, new light sources and green lighting will be represented by the LED. LED light source has a charming future. For increasing brightness and improving uniformity, LED lamps have been built around LED arrays. This paper calculated illuminance of the LED arrays at first, and then according to known functions, the LED arrays were simulated and the results were analyzed. The distribution characteristics of the different LED arrays was obtained by comparison of the characteristics for two kinds of LED arrays. Finally, the law of arrays suiting lamps was shown, providing the accurate reference for designing LED lamps.

2 LED Lighting and Its Application

LED, short for light-emitting diode, uses the solid semiconductor chips as luminous materials. The illuminance is caused by photon emission through excess energy which is released by carrier's composite in the semiconductor, giving direct red, yellow, blue, green, orange, purple and white light. With characteristics of energy saving, high brightness, low power consumption, and no high-enorgy ray radiation, LED light source, especially, the white LED, has attracted great concern in recent years.

LED applications in lighting mainly include landscape lighting, automotive lighting, traffic lights[1], general lighting, special lighting and security lighting. With continuously improving the efficiency of LED, LED lighting will gradually replace incandescent lighting, going into tens of thousands of households.

3 LED Array Illumination Calculation and Research

3.1 LED Arrays Illumination Calculation

Illumination is the extent to which objects are illuminated. It is the luminous flux per unit area,

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the unit is lux (lm/m^2), stands for the illumination of 1 lm flux in the area of 1 m^2. LED array illumination is linear superposition of single LED illumination. Therefore, we are only concerned with analysis of single LED illumination[2].

The distance which LED usually irradiates is much larger than LED size. In such circumstances, LED can be simplified as a point source which has the space distribution of the light intensity. Characteristics of point sources are that they can issue the light radiation of the same luminous intensity to the surrounding space with 4 solid angle[3]. We assume that surface dS receives LED point source S's irradiation, give that the distance between point source S and surface dS is r, the angle between the optical axis of point source and the normal N of surface is θ, so the illumination on the surface is:

$$E = \frac{d\phi}{dS} = \frac{I\cos\theta}{r^2} \quad (1)$$

LED light intensity distribution is not an ideal cosine distribution, and then the distribution can be expressed as:

$$I(\theta) = I_0 \cos^m \theta$$

When $\theta = \theta_{1/2}$, $I(\theta) = \frac{1}{2} I_0$,

$$m = \frac{-\ln 2}{\ln(\cos\theta_{1/2})} \quad (2)$$

We chose the common LED, which $\theta_{1/2}$ is 7.5°, so $m = 81$.

When the LED irradiates the plane perpendicular to its optical axis direction, the illumination distribution on the plane is as follow:

$$E(r,\theta) = E_0(r)\cos^m\theta \quad (3)$$

Coordinate transformation:

$$E(x,y,z) = \frac{z^m I_0}{[(x-X)^2 + (y-Y)^2 + z^2]^{\frac{m+2}{2}}} \quad (4)$$

Our LED array illumination simulation is based on the above formula.

3.2 The Research of LED Arrays

3.2.1 The analysis of the LED pitch about LED arrays

Because LED is a non-coherent light source, the illumination of the plane is superposition of single LED illumination, so there is (d is the distance between the two LEDs)

$$E(x,y,z) = z^m I_0 \left\{ \left[\left(x - \frac{d}{2}\right)^2 + y^2 + z^2 \right]^{-\frac{m+2}{2}} + \left[\left(x - \frac{d}{2}\right)^2 + y^2 + z^2 \right]^{-\frac{m+2}{2}} \right\} \quad (5)$$

Assume $\frac{d^2E}{dx^2} = 0$, and $x = 0, y = 0$

It comes to

$$d_{max} = \sqrt{\frac{4}{m+3}} \cdot z \quad (6)$$

As shown in Fig. 1, when d is equal to d_{max}, the illumination doesn't drop more near coordinates 0, this distance is more appropriate. For $d > d_{max}$, the illumination near coordinates 0 is nonuiiform.

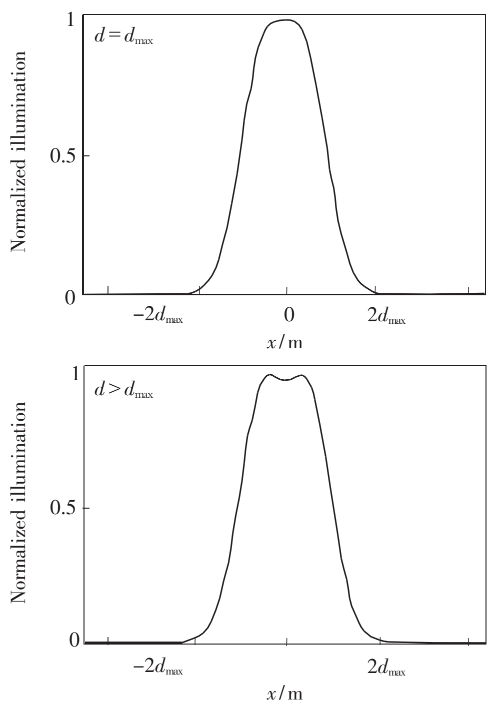

Fig. 1 The simulation of illumination in different d values

3.2.2 The research of LED arrays distribution

LED arrays distribution mainly is concerned in the way of LED arrays distribution, which can be divided into surface distribution and stereo distribution.

Surface distribution includes plane distribution and curved surface distribution. Plane distribution is that LEDs are installed uniformly in flat substrate, forming a luminous source with certain area. Its characteristics are small light area, concentrated light output, uniform light, and high illumination. According to the functional requirements, luminous shape includes rectangular, circular and ellipse. Curved surfaces distribution mainly includes cylinder distribution, spherical distribution and irregular distribution[4].

Stereo distribution mainly includes sphere and cylinder.

Under the given length of this paper, the rectangular distribution and semi-cylinder distribution will be analyzed only here. Stereo distribution is a special case of curved surface distribution, it does not be analyzed here.

4 LED Array Simulation and Comparative Analysis

4.1 The Simulation Results of Rectangular Plane and Analysis

Fig. 2 is the simulation results of 7 × 17 rectangular LED arrays. The distance between arrays and plane of illumination is 6 meters in the simulation (the distance should be changed in different lamps).

From the simulation results in Fig. 2, we can see that the larges illumination around the center is

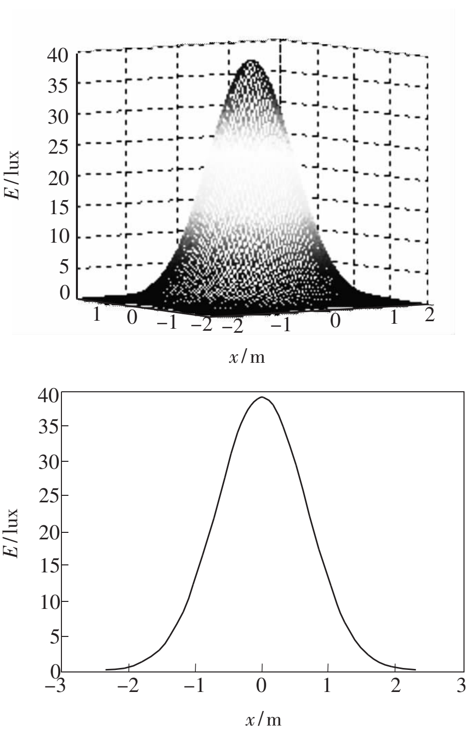

Fig. 2 The simulation results of 7 × 17 rectangular LED arrays

40 lux for 7 × 17 rectangular arrays, and that illumination within the scope of 0.75 m is above the half of the largest illumination. The data indicates that the range of irradiation is more concentrated in the rectangular arrays, and such array lamps should be used in the smaller and more concentrated exposure areas.

4.2 The Simulation Results of the Semi-cylindrical Surface and Analysis

Fig. 3 is the simulation results of 7 × 17 semi-cylindrical arrays, the distance between arrays and plane of illumination is 6 m in the simulation.

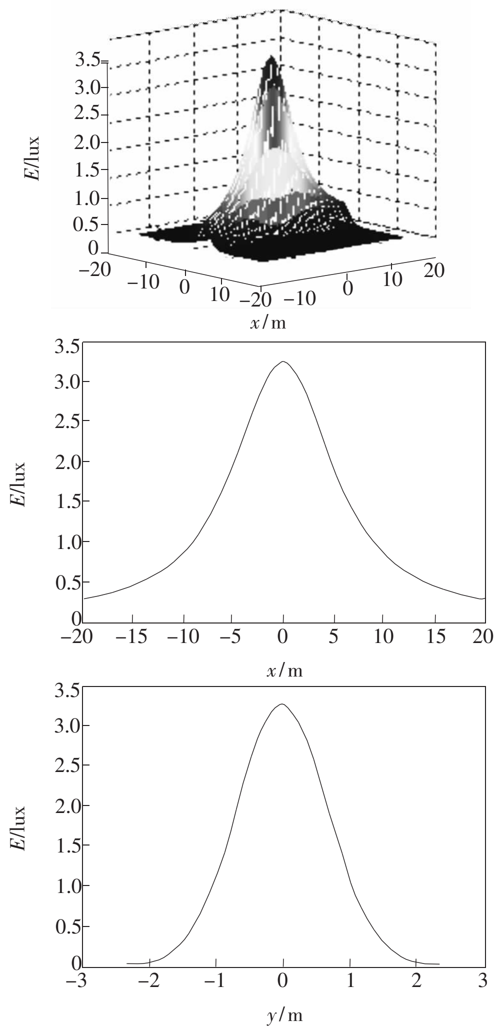

Fig. 3 The simulation results of 7 × 17 semi-cylindrical LED arrays

From the simulation results in Fig. 3, we can see that the largest illumination around the center is about 3.3 lux for 7 × 17 semi-cylindrical arrays, and that illumination between the scope of 7 m in x-axis and the scope of 0.8 m in y-axis is above the half of the largest illumination. The data indicated that the range of irradiation distributes much longer in the semi-cylindrical arrays, and such array lamps should be used in the striped defoliation area.

4.3 The Comparison of Arrays Distribution in the Plane and Curved Surfaces

We analyze the two arrays using the same LED and the same numbers, but we can see from simulation results that the results are very different in illumination and irradiated area. Central illumination reaches to 40 lux in rectangular arrays which represent plane distribution, but exposure areas are much smaller. Central illumination only reaches 3.3 lux in the semi-cylindrical arrays which represents curved surface distribution, but exposure areas are much larger, illumination between the scope of 7 m in x-axis is above the half of the largest illumination.

Comparing simulation results, we can conclude that the characteristics of the arrays which distribute in plane are as follow: small light area, concentrated light output, uniform light, high illumination, which can be used in lighting modules, camera-ready art, mirror front lamp and spotlight. The exposure areas are much larger in the arrays, which distribute in curved surfaces, equip divergent light effects[5], can achieve special result of decorative lighting, and can be used in square lamps and street lamps.

5 Conclusion

In short, this paper emphatically analyze the design and simulation of LED arrays in details, which throw light on designing more perfect LED lamps. It is believed that newer and better technological solutions and products will be endless with the continuous development of LED's technology and design of the LED lamps.

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基于照明的LED阵列研究与仿真

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摘要：LED是21世纪的绿色光源，具有广阔的照明前景。近年来，LED灯具产品开发的种类越来越多，设计合适的LED灯具显得尤为重要。由于单颗LED的功率很小，作为照明来使用，要求在照明区域内具有一定的均匀光通量和照度，所以需要采用LED的阵列形式，加大其发光亮度和发光面积，改善光照的均匀性。该文

首先计算 LED 阵列的照度叠加,进而根据叠加公式对阵列仿真,分析两种 LED 阵列分布的仿真结果,得出不同阵列的分布特点,并比较两种阵列的特点,最后分析出不同阵列分布的适用灯具,为 LED 灯具设计提供可靠依据。

关 键 词: LED; 阵列; 仿真

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