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Design of Light Source in Optical Measuring Equipment for Wave Slope Field on Sea Surface

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Abstract Light source is a very significant lighting component, and plays a crucial role in the optical measuring process for wave slope field on sea surface. Rational selection of light source is one of the important factors for ensuring accuracy and layout of the system. Based on the advantages compared with short-arc xenon lamp as lighting in luminous efficiency, durability, reliability, safety and consuming power, LEDs are becoming the preferred candidate for many lighting applications that require uniform illumination distribution. An assumption that applied LEDs as light sources of the measuring device is presented, the feasibility has clarified by theoretical calculation and optical software simulation.

Key words: light sources; LED modeling; LED arrays; illumination uniformity
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1 Introduction

The wave slope field on sea surface is a type of wave structure naturally formed, and embodies the kinematic characteristics of short-wave on sea surface. Fig. 1 shows the slope measuring principle with color encoding method[1,2]. The light source evenly illuminates color coding plate, which is located in the focal plane of the Fresnel lens. The cone-shaped beams with different colors, which are emitted from different points on the plate, are collimated into parallel rays in different directions by Fresnel lens. 3CCD camera, the distance from mean sea surface is 4m, receives near-vertically upward and colorful rays which are refracted through undulant seawater. Finally we get the slopes of all points on sea surface by the recorded image date processing. For the measuring device, lighting source system under the flume is a very significant portion. In 2001, Shi Bo-xuan[1] applied the short-arc xenon lamp as lighting source of optical measuring equipment for sea surface microstructure. Based on several advantages in luminous efficiency, durability, reliability, safety, and power requirements, we present an assumption that using LEDs as light sources of the equipment. We get the quantity of required LEDs, the optimal LED-to-LED spacing and the optimum configuration of LED array by formula derivation, and assume the color-coded plate as a flat screen parallel to the surface of the LED array. Finally we simulate illumination distribution on the screen by optical software to verify feasibility of the assumption.

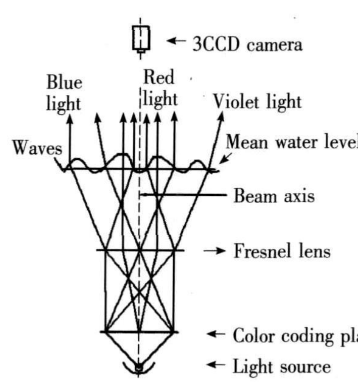

Fig. 1 Sketch for slope measuring principle of wave slope field on sea surface with color encoding method

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2 Requirements and Selection of the Light Source

For the measuring device, lighting source system is a very significant portion and has an important influence on measurement accuracy. We must take into account several factors when choosing the type of lighting sources.

1) Radiation spectrum of the lighting source is continuous and the distribution over the visible regions is as uniform as possible.

2) Ensuring the value of illuminance on the imaging system beyond the minimum required by 3CCD camera imaging.

3) Good stability of light source in filming process for real-time measurement.

4) lower thermal dissipation and longer operating life owing to inconvenience to replace and high luminous intensity.

The rapid development of light-emitting diodes (LEDs) over the past few years has surpassed the characteristics of conventional lamps (e.g., incandescent lamps, metal halide lamps, high-voltage mercury lamps) in luminous efficiency, durability, reliability, safety, and power requirements. Comparing with the short-arc xenon-lamp, LEDs simplfy the mechanical structure and aviod additional cooling system. Considering several requirements and several advantages of LEDs, we propose to use the high power LED that is named xlamp 7090-XRE and manufactured by CREE corporation as the source of the equipment, which has a typical luminous flux of 100 lm at 350 mA current and a viewing angle of 90°[3].

3 Calculation of Optical Illumination

In order to illuminate the color coding plate as uniformly as possible, we mount a reflector at the bottom of light source on which there is a piece of frosted glass. Two pieces of plexiglass plates are used for clamping and fixing the color coding plate. The measurement is processed in laboratory, and the undulated seawater is simulated by freshwater. Fig. 2 shows the light transmittance of parts of the device.

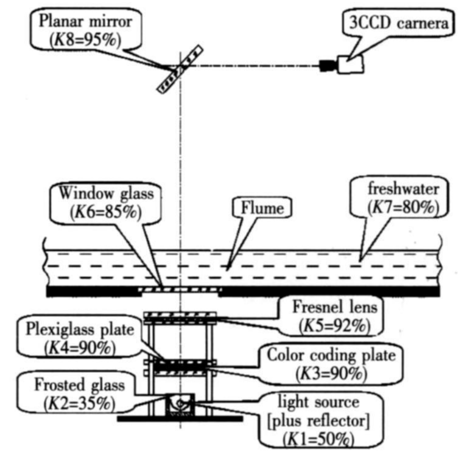

Fig. 2 Parts of the measuring equipment and the values of light transmittance ($K1 \sim K8$) correspondingly

The rays from each point on sea surface are with 15° cone angle. 3CCD camera, the distance from mean sea surface is 4 m, receives near-vertically upward and colorful rays, between which and sea surface the value of relative aperture is (1/5)[4,5]. Assuming Φ is luminous flux of the light source, then the illuminance on the photosensitive surface of 3CCD camera is

$$E = \Phi \cdot k1 \cdot k2 \cdot k3 \cdot k4^2 \cdot k5 \cdot k6 \cdot k7 \cdot k8 \cdot [(1/4)/\tan(15°)]^2 = 0.066\Phi, \quad (1)$$

According to indices of 3CCD camera, the value of illumination required for the F5.6 is approximately 200 lx. Then the luminous flux of the light source is

$$\Phi = E/0.066 = 200/0.066 \approx 3\ 000 (\mathrm{lm}), \quad (2)$$

4 LEDs As Light Sources

4.1 Calculation of the Number of LEDs

Assuming the target value of luminous flux is 3 000 lm, then the number of needed LEDs is

$$n = \frac{\Phi}{\Phi_0} = \frac{3\ 000\ \mathrm{lm}}{100\ \mathrm{lm}} = 30 \quad (3)$$

4.2 LED Modeling

When utilizing computer modeling as a design and evaluation tool, it is critical to start with an appropriate representation of the LED source, and the LED model generates an output distribution as close to an actual source as possible. On account of employing 30 LEDs and accurate models inducing complicated computation, we adopt a traditional method for LED sources modeling which doesn't consider the detailed physical structure of the LED, but rather define the surface property of a disk-shaped object by ray generation of accurate photometric measurements or specified light output of the LEDs.

The LED die is defined with its original geometry, the radius of which is 1 mm. It can be considered to be a top surface emitter, as the LED die side surface emission could be regarded to be negligible. The output illuminance distribution of Cree xlamp 7090-XRE can be obtained from typical spatial radiation pattern of technical datasheets. These distribution parameters are converted to surface absorptance and specular transmission of the top surface of LED die. The surface absorptance is defined by the relative intensity of every distribution angle, and the surface specular transmittance can be described with margin that 1 subtracts the value of surface absorptance[6]. Then, the surface property is applied to the top surface of LED die, and the source angular is selected to surface absorptance.

Fig. 3(a) shows the wireframe representation of Cree xlamp 7090-XRE model. The irradiance on a

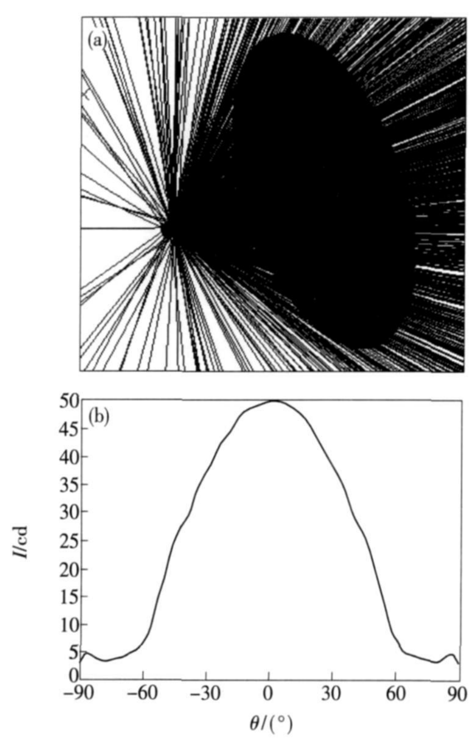

Fig. 3 (a) Wireframe representation of Cree xlamp 7090-XRE model; (b) Simulated rectangular candela distribution.

flat screen, at distance z from the LED die is simulated and represents the uniformity of illumination on the color coding plate, the radius of which is 200 mm. Fig. 3(b) shows the rectangular candela distribution plot acquired by 500 000 rays tracing.

Fig. 4 shows the irradiance map and its profile. In Fig. 4(b), the solid line and the dash line, respectively, express the vertical and horizontal directional profile for the irradiance map.

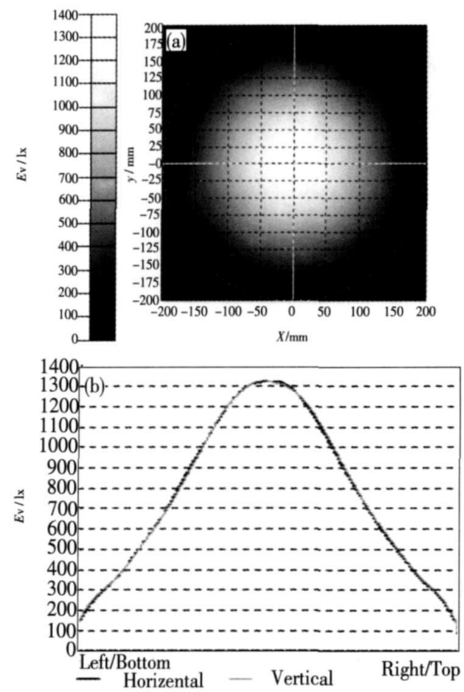

Fig. 4 Simulation for the illumination system of one LED source. (a) Irradiance map; (b) Profile of the illuminance map.

4.3 Design of Uniform LED Arrays

Although a LED source is not a perfect Lambertian emitter, the irradiance distribution is also a cosine function of the viewing angle, and the LED emitting region is usually less than 1mm on a side, so that we can treat LEDs as point sources with the inverse square law[7~19]. A practical approximation for the irradiance distribution is given by

$$E(r, \theta) = E_0(r)\cos^m\theta, \quad (4)$$

where θ is the viewing angle and $E_0(r)$ is the irradiance (W/m^2) on axis at distance r from the LED and $\theta = 0°$. The value of m depends on the relative position of the LED emitting region from the curvature center of the spherical encapsulate, and the number m is given by the angle $\theta_{1/2}$ (a value typically provided by the manufacture, defined as the view angle when irradiance is half of the value at 0°);

$$m = \frac{-\ln 2}{\ln(\cos\theta_{1/2})}, \tag{5}$$

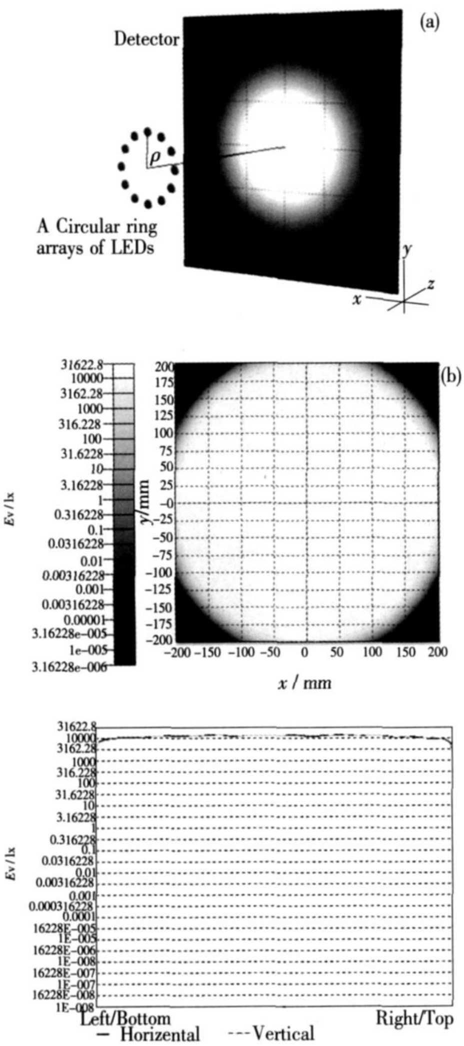

Fig 5　Circular ring LED array. (a) Diagram of an array. (b) The uniform irradiance distribution of this array when $N = 30$, $m = 2$ and $\rho = \rho_{max} = 141.4$

We transform (5) into Cartesian coordinates (x, y, z). The irradiance over every point (x, y) on a flat screen at distance z form the LED array may then be expressed as

$$E(x, y, z) = \frac{z^m I_{LED}}{[(x - x_0)^2 + (y - y_0)^2 + z^2]^{(m+2)/2}}, \tag{6}$$

the viewing angle of Cree xlamp 7090-XRE is 90° causing $m = 2$, and we adopt the pattern of circular ring LED array to simulate the illumination system. We consider the case of a circular ring array of LEDs with radius ρ. The irradiance E is given by the sum of the irradiance for $N \geqslant 3$ LEDs

$$E(x, y, z) = z^m I_{LED} \sum_{n=1}^{N} \left\{ \left[x - \rho\cos\left(\frac{2\pi n}{N}\right) \right] + \left[y - \rho\sin\left(\frac{2\pi n}{N}\right)^2 + z^2 \right]^{-(m+2)/2} \right\}, \tag{7}$$

Differentiating E twice and setting $\partial^2 E / \partial x^2 = 0$ at $x = 0$ and $y = 0$ eventually yields the maximally flat condition

$$\rho_{max} = \sqrt{\frac{2}{m + 2}} \cdot z \tag{8}$$

Fig. 5(a) shows a circular ring array of 30 LEDs. Fig. 5(b) shows the uniform irradiance pattern of this array for selected values of $m = 2$, $z = 200$, and $\rho = \rho_{max} = 141.4$ mm. As seen from Fig. 5(b), the near-perfect uniformity of illumination on the flat screen validates the feasibility of the hypothetical proposal that applying LEDs as light sources of the optical measuring equipment.

5　Conclusion

In this paper, the high power LEDs 7090-XRE are applied as light source of the optical measuring equipment for wave slope field on sea surface by requirements of the light source and calculation of luminous flux. As well, we adopt the pattern of circular ring LED array, derive the optimum LED-to-LED spacing and simulate the illumination system by optical software Tracepro. The simulation results validate the feasibility of the proposal. Based on obvious advantages of LEDs over xenon lamp, including longer lifetime, smaller size and lower thermal dissipation, LEDs can replace the xenon lamp as light source of the optical measuring device.

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海面波浪坡度场光学测量装置的光源设计

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摘要: 在海面波浪坡度场光学测量系统中,光源是一个非常重要的照明元件。合理的设计和选用光源,是保证系统精度和布局的重要因素之一。比较传统光源短弧氙灯的明显优势,如低能耗,寿命长,更好的安全性和稳定性等,本文提出了采用 LED作为本系统光源的设想,确定了所需 LED个数和 LED阵列方式,并经过计算和光学软件模拟,验证了本设想的可行性。

关 键 词: 光源; LED建模; 阵列; 照明均匀性

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