The freeform lampshade with high luminous efficacy for indoor lighting

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Abstract

This study proposed a designing method for lampshade with free-form surface and fabricated the optimum lampshade structure with 3D printer. Theoretical and measurement results showed high similarity and preserved lower power consumption.

Keywords: free-form surface, lampshade, power consumption, 3D printing.

1. Introduction

LED lighting system, which consisted of a LED chip and a highly efficient concentrator (lampshade) ⁽¹⁻²⁾, is widely used in indoor lighting. The optimum form of the concentrator will be parabolic form and depended on the required illumination pattern. According to the edge ray principle ⁽³⁾, parabolic concentrator will take the form of a shifted and tilted. Therefore, the designing of the parabolic surface will be complicate and spent long designing time.

In this study, we constructed a free-form surface with two oblique surfaces with a small difference incline angle. We derived a formula to describe the relationship between the divergence angle of LED, slopes of two oblique surfaces, lampshade height, and the radius of projection area. Based on this equation, the optimum free-form surface can be obtained with various divergence angle of LED and fabricated with 3D printer. The theoretical prediction and finished lampshade showed similar illumination intensity of 150 lux within the 2 m² in projection area. The luminous efficacy of the proposed lighting system can be better than 150 lm/w.

2. Method

A free-form surface of lampshade was integrated of two oblique planes with a small difference of bevel. The geometrical description of the free-form surface was showed in Fig. 1 and the light beam reflected once/twice by the free-form surface and then incident on to the irradiated surface. The relationship between the beam divergence angle (θ and $\theta_{\max}$) of LED and beam projected points on the irradiated surface (X_{s1} for once reflected beam and X_{s2} for the twice reflected beam) can be represented as

Fig. 1 The schematic diagram of the relationship between beam divergent of LED and projected position on the irradiated surface.

$$X_{s1} = x_{i2} + h \cdot [180^\circ - \theta + 2\theta_{s2}], \quad (1)$$

$$X_{s2} = x_{i2} + h \cdot [\theta_{\max} + 2\theta_{s1} - 2\theta_{s2}], \quad (2)$$

where θ is the divergence angle of LED ($\theta_{\max}$ indicated the maximum divergence angle of LED), h is the normal distance between incident point and irradiated surface,

$$\theta_{s1} = \tan^{-1}\left(\frac{y_2 - y_1}{x_2 - x_1}\right) \text{ and } \theta_{s2} = \tan^{-1}\left(\frac{y_3 - y_2}{x_3 - x_2}\right) \text{ are the}$$

bevels of two oblique surfaces. It is clear that the projection area on the screen will be controlled by the bevels of these two oblique surfaces.

Based on the indoor lighting regulation ⁽⁴⁻⁸⁾ and the divergence angle of LED, two bevels of the oblique surfaces were derived from equations (1) and (2) that can be approximated of 47.6° and 47.7° , respectively. The optimum structure of lampshade can be obtained and showed in Fig. 2.

Fig. 2 The optimum structure of the lampshade with free-form surface.

3. Results and discussions

The semi-finished product of the optimum structure of lampshade was fabricated by 3D printer. After that, reflective paint spraying followed the inner surface polishing and the final product of the lampshade was showed in Fig. 3. Two types of LED, which were warm-white with 6500K (Thorlabs Inc., model: MWWHLPI) and cold-white with 3000K (Thorlabs Inc., model: MWCHLP1), were used for the light source of the optimum lampshade structure. For theoretical simulation of the illumination behavior of the lampshade, the commercial software TracPro 7.7 was adopted to use. The irradiated surface had 2 meter square and located away from the

lampshade about 2 m. The inner surface property of the lampshade set as plastic with absorbing dielectric film and the tracing ray number was 6×10^5 . The lampshade with 10 cm in diameter was used for recessed downlight of indoor lighting and the geometrical dimension of lampshade was indicated in Fig. 2.

Fig. 3 The proposed lampshade with free-form surface and integrated with LED.

Figure 4 showed the simulation results of the lampshade integrated with warm-white and cold-white LEDs respectively. Figs. 4(a) and 4(b) showed the intensity distribution on the irradiated surface of the proposed lampshade with warm-white and cold-white LEDs. The maximum illuminance were 148.1 lux and 179.7 lux for warm-white and cold-white LED configurations, respectively. The diameters of irradiated surface of 90% illuminance maximum were 1.24 m and 1.32 m for the warm-white and cold-white LED configurations. Based on the guidance of the indoor lighting, the projection intensity should be higher than 100 lux within 1 m^2 in projection area with uniformity of 0.4. These simulation results were well satisfied to the guidance.

Fig. 4 The illuminance of the proposed lampshade integrated with different LEDs. (a) warm-white LED; (b) cold-white LED.

We fabricated the lampshade with 3D printer (Zortrax, model: M300) and polished the inner surface and sprayed reflected painting. After that, integrated the LED lamp into the lampshade and measured the distribution curve of luminous intensity by goniophotometer (Sensing Optonics Corporation, model: GMS 1800) which showed in Fig. 5.

Fig. 5 Goniophotometer for measuring light distribution curve.

Figure 6 showed the measurement results of the distribution curve of the luminous intensity by goniophotometer. Fig. 6(a) showed the maximum illuminance 165.4 lux of the warm-white LED lamp and Fig. 6(b) showed the maximum illuminance 212.8 lux of the cold-white LED lamp. The diameters of irradiated surface of 90% illuminance maximum were 0.92 m and 1.04 m for the warm-white and cold-white LED configurations. Compare to the simulation results, the maximum illuminance of the measurement results exhibited

higher values than the simulation results. But, the diameters of irradiated surface of 90% illuminance maximum were smaller than the simulation results.

Fig. 6 The measurement results of the proposed lampshade integrated with different LEDs lamp. (a) warm-white LED; (b) cold-white LED.

Fig. 7 The 3D scanner for bevels measurement of the final product of lampshade.

To figure out the bevels changed of two oblique

surfaces, we used the 3D scanner (GOM, model: ATOS core 3D) to measure the inner surface of the final product of lampshade. The measurement system and measured results was showed in Fig. 7. The values showed in the reconstruction surface indicated the surface toward or outward to the central axis of the lampshade. Positive value indicated the surface toward to the central axis and caused more rays concentrated in the center of the irradiated plane. We also constructed the lampshade with the measurement data coming from the 3D scanner and re-simulated the illuminance behavior which showed in Fig. 8. The maximum illuminance were 174.7 lux and 219.3 lux for warm-white and cold-white LED configurations, respectively. The diameters of irradiated surface of 90% illuminance maximum were 0.88 m and 0.76 m for the warm-white and cold-white LED configurations. The comparisons were summarized in Table 1 and Table 2.

Fig. 8 The illuminance of the re-simulated lampshade integrated with different LEDs. (a) warm-white LED; (b) cold-white LED.

To consider the efficacy requirement, the lm/W should

be higher than 65 lm/W for downlight luminaires⁽⁸⁾. In this study, the lm/W values were 117 lm/W and 158 lm/W for warm-white and cold-white LEDs, respectively. It is obvious that the proposed lampshade exhibited lower power consumption and totally satisfied the requirement.

Table 1 Comparison of optimum illuminance of lampshade

	Simulation	Measurement	Re-simulated
Warm-white	148.1 lux	165.4 lux	174.7 lux
Cold-white	179.7 lux	212.8 lux	219.3 lux

Table 2 Comparison of the diameter of 90% illuminance

	Simulation	Measurement	Re-simulated
Warm-white	1.2 m	0.92 m	0.88 m
Cold-white	1.28 m	1.04 m	0.76 m

4. Conclusions

In this study, an optimum lampshade for the downlight luminaire was designed and fabricated. The structure can be suitable for both warm-white and cold-white LED lamps and preserved lower power consumption. The optimum lm/W value can be reached to 158 lm/W which is three times higher than commercial product.

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