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Design method of a light-emitting diode front fog lamp based on a freeform reflector

Heng Wu [a], Xianmin Zhang [a], Peng Ge [b,*]

[a] Guangdong Provincial Key Laboratory of Precision Equipment and Manufacturing Technology, School of Mechanical and Automotive Engineering, South China University of Technology, Guangzhou 510640, China

[b] Engineering Research Center for Optoelectronics of Guangdong Province, School of Physics and Optoelectronics, South China University of Technology, Guangzhou 510640, China

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ABSTRACT

We propose a method for the design of a light-emitting diode front fog lamp based on a freeform reflector. The source–target mapping is used to establish the relationship between the solid angle of the source and the target plane. The reflector is then constructed based on the non-imaging optics theory and Snell's Law. A feedback function is deduced from the deviation in the simulated light pattern based on the sampling method. The reflector is then regenerated with feedback modifications and the variance is minimized after several feedbacks. A reflector for the automobile front fog lamp is designed for the OSTAR Headlamp LED source whose emitting surface is 2.8 mm × 2.5 mm. Simulation results indicate that the light performance can well meet the standard of the front fog lamps in ECE R19 Revision 7.

1. Introduction

With the rapid development of semiconductor lighting technologies, light-emitting diodes (LEDs) are gradually replacing traditional light sources because of their numerous advantages, and have been widely used in indoor and outdoor lighting, architectural lighting, and so on [1]. However, traditional luminaires cannot work well with LEDs in most cases due to the LED's Lambertian emission character. Hence, a proper primary or secondary optical design is usually needed to redistribute the spatial energy of the LED so that all lighting advantages of LEDs can be put into practice for the high-quality illumination [2–6].

LEDs have been widely used in automobile front headlamps, especially in low-beam and high-beam headlamps [7–16]. However, there are few literatures reported on high-power LED front fog lamps with a small and compact size. Although Jeyachandrabose et al. proposed a method on LED fog lamp, six LEDs were used and each LED together with a reflector formed a modular element [17]. Hamm et al. studied LED fog lamps too, but not mainly on the optical design [18]. Though some LED fog lamps can be searched from the web, they either have a big size or consume more energy. So in this paper we will focus on the design of the freeform front fog lamps based on the high-power LED source with a small and compact size.

In the design of the freeform LED lighting systems, the feedback method has been widely used to optimize the optical performance for the freeform surface. Luo et al. did a deep research on the freeform lens design using the feedback method [19]. In their research, the feedback function was originated from the difference between the simulated illuminance and the desired illuminance. This method works very well in the uniform illumination. However, when it comes to the special nonuniform illumination with a reflector, such as low-beam lamps and fog lamps, different methods need to be employed.

We present a light-emitting diode front fog lamp based on a freeform reflector by optimization in this paper. A new feedback method is shown in details to optimize the optical performance for the reflector based on the sampling method. Firstly, the placement between the LED source and the reflector is determined. Then the source–target mapping is established and a reflector is constructed based on non-imaging optics theory and Snell's Law by numerical calculation [20]. With the feedback function, the reflector is regenerated and the deviation could be minimized after several feedbacks. As an example, a reflector for the automobile front fog lamp is designed for the OSTAR Headlamp LED source whose emitting surface is 2.8 mm × 2.5 mm and results indicate that the light performance can attain the requirements of the front fog lamps. In addition, light efficiency can be improved from 66.17% to 77.86%.

This paper is organized as follows. Section 2 will quickly discuss the ECE regulation for vehicle front lamps. The detailed design principles are given in Section 3. Simulation results are given in Section 4. Finally the conclusions are drawn in Section 5.

* Corresponding author.
E-mail address: scpge@scut.edu.cn (P. Ge).

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2. ECE Regulation No. 19 Revision 7 for vehicle front fog lamps

The ECE regulation R19 revision 7 is applied to front fog lamps, which includes two distinct classes. The first one is Class "B" which is used for the original front fog lamp. For this class, only light sources as specified in Regulation No. 37 are allowed. The second one is Class "F3" which is designed to increase photometric performance. Most importantly, LED sources can be used in class “F3” [21].

As shown in Fig. 1, in the case of Class F3, the beam pattern should have a wide horizontal spread, which is over a width of more than 5° on both sides of the line v. A symmetrical and substantially horizontal cut-off that is 1° below the line h shall be also created. Moreover, the beam pattern should be substantially uniform between lines 1 and 5. Intensity discontinuities between the lines 6, 7, 8 and 9 are not permitted. Variations in homogeneity detrimental to satisfactory visibility in the zone above the line 5 from 10° left to 10° right are not allowed either. In addition, the luminous intensity in the specified points, lines and regions would be measured strictly at the measuring screen 25 m front of the fog lamp [21].

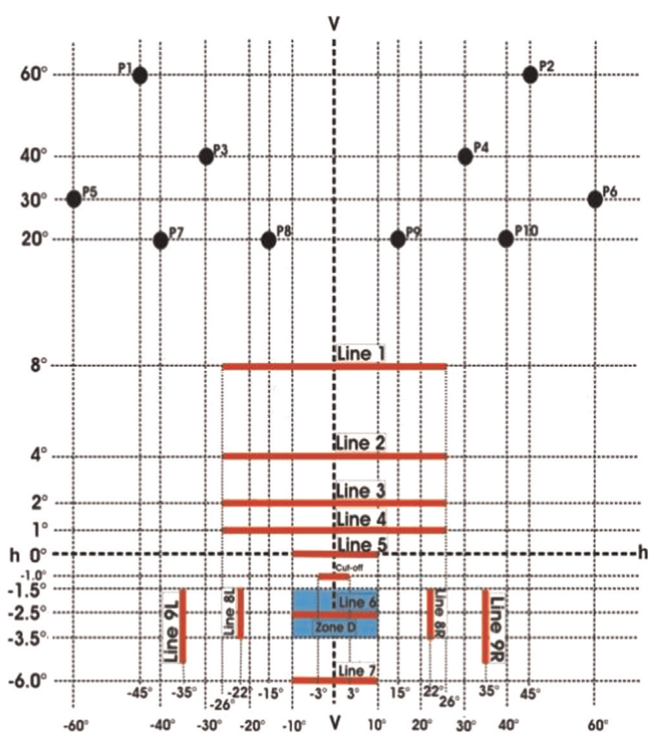

Fig. 1. Light distribution of Class F3 front fog lamp.

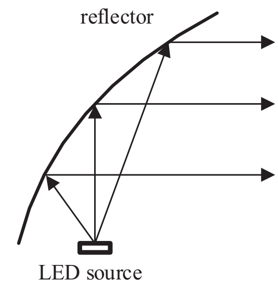

Fig. 2. LED's central axis is perpendicular to the optical axis.

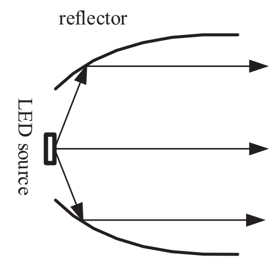

Fig. 3. LED's central axis is parallel to the optical axis.

3. Design principles

3.1. Relationship between the LED source and the reflector

In the design process, there are two types of placement for the LED source and the reflector: (1) the LED's center axis is perpendicular to the optical axis, as shown in Fig. 2; (2) the LED's center axis is parallel to the optical axis, as shown in Fig. 3. Since the LED source has a Lambertian intensity distribution, the intensity in the center is very strong and it weakens toward both sides gradually. As a result, when the parallel placement is chosen, the glare effect can be generated easily, which negatively affects the illumination, and most often this placement is used to produce round and oval light distribution. In contrast, the vertical placement can be a good way to control the angle of the light rays for obtaining the desired light distribution and to suppress the glare effects effectively. Meanwhile, when the vertical placement is adopted, the volume of the reflector is nearly half of that with the parallel placement, which makes the arrangement for the LED modules and the design of reflectors more flexible. Therefore, vertical placement is utilized in this design.

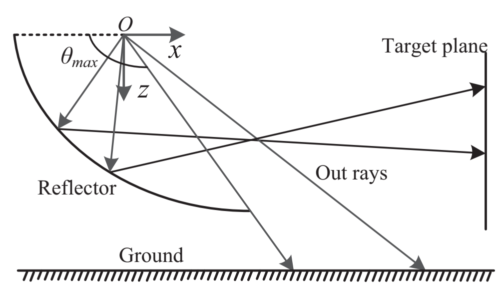

Fig. 4. Schematic diagram of the reflected lighting system.

When the vertical placement is taken, the light pattern is formed by the reflected rays, which deliver the energy emitted from the LED source onto the target plane and produce the required light distribution. Nonetheless, there are some rays that are not reflected because their emitting angle is bigger than the maximum angle that the reflector can control, as shown in Fig. 4. Actually, these rays are not stray lights and do not disturb the lighting performance when Fig. 2 is taken into consideration. In contrast, they can provide some illuminance on the ground, which is helpful for drivers to see the ground condition.

3.2. Establishment of source–target mapping

In this paper, the light is supposed to be reflected onto the target plane to form a rectangular illumination area with a length L and width W. As both the target plane and LED source are of axial symmetry, just half of them are considered. As shown in Fig. 5, the energy distribution of the light source is divided into M, N grids equally, which is specified by coordinates (α_i, β_j) as follows [22]: