Short Free-Standing Pole LED Luminaire and Lens Design for Road Lighting

İsmail Serkan ÜNCÜ, Mehmet KAYAKUŞ

Abstract

Road luminaries are required to provide the luminance specified in the standards according to the road characteristics. For this reason, the light from the light source should be directed according to the desired conditions. While the range of minimum average road surface luminance recommended for different classes of road are provided; at the same time, it is desirable to be economical. In this study, a freeform lens and LED luminaire design with high luminous efficacy, low glare and uniform luminance distribution with a height of 1.5 m and a distance of 7 m between poles were designed for M3 road standards. First of all, lens design was made by using optical and illumination design software. Also, lens manufacturing and luminaire production were made as a result of the success of the design simulation test. The success of the LED luminaire in providing CIE standards has been measured on the designed road. In addition, the advantages and disadvantages have been determined by comparing with High Pressure Sodium Vapor (HPS) lamps.

Keywords: Optics design, lighting, road lighting, LED, luminaire design.

1 INTRODUCTION

The energy spent on road lighting is increasing day by day. Lighting represents 15-20% of the world yearly electricity [1]. Public (predominantly street) lighting contributes 2.3% to the global electricity consumption [2]. Many studies have been carried out to evaluate road lighting in terms of energy efficiency due to these high energy requirements and costs [3-8].

In the selection of the lamp to be used in road lighting, the luminous efficacy, life and luminous flux must be considered. HPS luminaires have been widely used for road lighting because of their high efficacy. However, it’s impossible to control all the light rays emitted from a large size HPS...
source within the effective region, resulting in light pollution and energy waste [9]. Lighting technologies based on light emitting diodes (LEDs) are a promising innovation for street lighting [10]. The rapid development of LEDs, especially their increasing luminous efficacy makes them viable light source offering potential for energy savings. LEDs also provide other advantages such as reduced maintenance costs, longer service life, the possibility to control the illumination levels and reduced light pollution. However, LED lighting still has some disadvantages. The lack of standardization, temperature dependence and high price of the luminaires, restrict their application and wider adoption in road lighting applications. In addition, the technical data provided by the seller or manufacture of the luminaire is often inadequate for comprehensive comparison [11].

There are many LED luminaire models used in road lighting. Each LED luminaire has its own advantages and disadvantages. The most important features of LED luminaires are the lens or reflector parts of the luminaires. Standard lenses and reflectors are used in the market for LED luminaires to be used in lighting. Companies do not prefer to produce original lenses or reflectors for each project. Ding et al. [12] stated that in order to achieve the targets in lighting design projects, the distribution of the light flux from the LED should be done again.

LEDs cannot provide the required density distribution on their own. In order to achieve the targeted lighting distribution with LEDs, the density distributions must be used with a secondary lens [13-17]. Wang et al. [18] mentioned the importance of using secondary optics in LED applications. The light distributions of the LED cannot directly meet the requirements of specific applications; it has uneven light distribution curves. Secondary optical (free-form lens) is an optical technology that provides high design freedom in LED luminaire applications and provides lighting control in LED lighting design [19-23].

A standard street lamp should be highly efficient and provide low glare to protect drivers from dangers. Nowadays, it is recommended to use a secondary lens to provide these conditions [9,24-27]. Wang et al. [25] designed a smooth free-form lens that controls the intensity of street lighting to reduce glare. Lee et al. [26], design a luminaire which has a cluster of LEDs with TIR lenses are put inside a reflective box for high optical efficiency, high optical utilization factor, low glare, and illuminates the street with high uniformity. In addition, many work is done to improve the operating performance of LEDs [28-29].

In this study, design and manufacture of led luminaire with high efficiency factor, low glare rate and homogeneous light distribution were performed for international M3 road standards. Placement of luminaires on the road: The 1.5 m height led luminaries are placed 7 meters side-by-side and 7 meters mutually on the road as shown in Fig. 1.
2 METHOD

Optical design programs are used in lens design. These programs simulate the light distribution of the lens by calculating the movement of light. Design results can be tested and optimized before production. Thus, a significant amount of time and money can be saved according to the trial and error method. Zemax, Lighttools, ASAP, Trace Pro, Photopia, Optisworks lighting optics are some of the optical design programs that can be designed.

The LED luminaire is intended to be the most ideal in terms of energy consumption, efficiency factor, lamp life, color rendering, low glare and maintenance coefficient. In the first stage, optical lens design for road lighting has been done by using Zemax software. In the second stage, prototype lens mold was produced and six lenses were manufactured by using this mold. In the third stage, led luminaires were manufactured for road lighting by using produced lenses and supplied armature equipment (LED module, coolant surface and LED driver circuit).

2.1 Lens Design for LED Luminaires

Firstly, the brand and model of the LED to be used are determined and the light distribution file of this LED is defined as the light source in Zemax. In this study, high power acrich series LEDs of Seoul semiconductor was used. Optical design in Zemax lighting design program is done in two different design modes. These are sequential mode and non-sequential mode. In this study, lens design was performed in non-sequential mode. In non-sequential mode, the positions and axes of objects can be different. The light emitted from the light source is reflected or broken through these objects and reaches the defined detector. These detectors allow us to predict how the optical design creates a light distribution.

The measurement results in Zemax program include light intensity and spectrum distribution in polar coordinate system. The designs made with these light sources are very close to reality. Colour temperature and colour rendering values are seen at the design stage with the light intensity to be illuminated on the surface to be illuminated as a result of the optical design.

In Zemax detectors are used to analyse design results. These detectors are determined according to the design purpose. Fig. 2 shows the light source and the defined detectors. Polar detector and surface detector are defined in the design. Polar detector surrounding the light source; the surface detector is at a certain distance from the light source. The estimated light intensity curve of the LED light source designed with these detector applications can be calculated. The measurement results of this detector can be output as .ise or .ldt file. It is possible to analyse these outputs in lighting design programs such as Dialux.

For the analysis of the lens, the optical properties of the raw material must be defined in Zemax. One of the materials in the Zemax library can be selected for this operation. If a new material is to be used, it can be analysed by identifying its optical properties such as light refractive index, light
transmittance. In addition, the surface of the lens, the surface of the design, surface roughness (sandblasting), tissue (skates, single) to be applied to the surface must be defined.

### 2.2 Evaluation of the Design

After the first analysis, it is evaluated whether the design meets the determined targets. An optimization process is performed to improve the design performance. In the optimization process, the target values such as smoothness, light intensity and distribution angle are defined on the detectors. Then values that can be changed from lens design parameters are defined as variable. The program calculates the merit function (error function) according to the objectives. The merit function shows the difference between the current performance of the design and the defined target values.

Before starting the production process for the designed lens, it was tested in the simulation by using Dialux program. The results of the analysis of the lens design from the Zemax program are taken out as a .ies or .ldt file extension. These files contain the light distribution curve provided by the lens. The light distribution curve of the lens designed in Fig. 3 is shown.

In the Dialux program, the number of luminaires, the placement of the luminaires on the road and the desired illuminance and luminance levels on the road are determined. In the DiaLux program, the M3 road system was chosen to perform the simulation test. In addition, the road information was entered in the test system:

- Road width: 7 m
- Number of lanes: 2
- Asphalt: R3
- Maintenance factor: 0.89
- Average luminance coefficient (qo): 0.07

The information about the luminaires pole is given below:

- Distance between the poles: 7 m
- Pole distance: 1.5 m
- Light centre height: 1.5 m
- Boom inclination: 10°
- Boom length: 0.65 m

According to the designed road and illumination, the simulated lighting values resulting from the simulation created in the DIALux program are shown in Fig. 4 as a color scale.

Fig. 5 shows the luminance curves according to the observer-1. Fig. 5-b shows the luminance curves according to the observer-2.

Table 1 shows photometric information according to observer 1 and observer 2.
3 EXPERIMENTAL RESULTS AND ANALYSIS

After the tests were successful, the mold was made for the production of the lens. The lens can be produced as needed by using this mold. In this study, 6 lenses were produced.

The other parts that make up the luminaire (LED lamp, safe, electrical connections and pole) are brought together and they are finished. The final version of the luminaire is shown in Fig. 6.

Portable, adjustable angle, 1.5 m high lighting pole designed for testing on different roads. The features of the LED luminaire developed are given in Table 2.

Led luminaires were mounted on the poles and then they were tested on the road. 6 luminaires are placed on the road in accordance with the standards shown in Fig. 1. The luminaires on the test road are shown in Fig. 7.

Photometric measurements of the LED luminaires were done by using the luminance meter. A comparison of the measured values and international standards is shown in Table 3.

One of the biggest advantages of the armature developed is that it consumes less energy while providing ideal lighting values. The way to determine the economic advantages of the LED luminaire is illuminated by the existing High-Pressure Sodium (HPS) lamps. Fig. 8 shows the illumination of the road by using HPS lamps.

As a result of the measurements performed, illuminating the same road with led luminaires provides an advantage of about 37% compared to HPS. Luminance measurements of the road illuminated by HPS were performed. Comparative luminance measurements of LED and HPS lamps are given in Fig. 9.

In view of this graph, it is seen that the LED lamp is much more advantageous than the HPS in terms of luminance smoothness. The road lighting with HPS lamp creates very dark and very bright areas. LED lamp is used in road lighting more evenly distributed lighting occurs. Thus, more uniform illumination can be provided with the LED lamp. This important factor increases driving comfort.

4 CONCLUSION

In this study, a long-lasting, high luminous efficacy, uniform luminance distribution, low-glare, economical LED luminaire has been developed in accordance with international standards for M3 road class.

Today, LED luminaires used in road lighting are between 45-240W; HPS luminaires consume 150-450W of energy. The developed LED luminaire provides approximately 37% energy efficiency compared to HPS luminaires. This value is important for street lighting which constitutes a large part of electricity consumption.

It has been found that the LED lamps provide a more homogeneous luminance distribution on the road than the existing HPS lamps. Since HPS lamps provide illumination over poles with a height of 8-12 m and are required to illuminate larger areas, it is difficult to provide homogeneous
illumination. In the developed system LED luminaires are at 1.5 m high poles, so that smaller areas are illuminated. Thus, LED luminaires provide more homogenous illumination than HPS luminaires. In this study, the overall uniformity ($U_0$) and longitudinal uniformity ($U_1$) of road surface luminance of the developed LED lamp are twice as good as HPS.

REFERENCES


Figure Captions

Figure 1. Placement of luminaires on the road
Figure 2. Light source and detectors
Figure 3. The light distribution curve of the lens
Figure 4. Lighting colour scale
Figure 5. Luminance curves according to the observer-1 and observer-2
Figure 6. Final version of the luminaire
Figure 7. Luminaires on the test road
Figure 8. Lighting with HPS lamps
Figure 9. Comparative luminance measurements of LED and HPS lamps

Table Captions

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### Table 1. Photometric values according to observer-1 and observer-2

<table>
<thead>
<tr>
<th></th>
<th>Observer 1</th>
<th>Observer 2</th>
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<tbody>
<tr>
<td></td>
<td>Lm (cd/m²)</td>
<td>U₀</td>
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<tr>
<td>Actual value according to calculation</td>
<td>1.03</td>
<td>0.49</td>
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<tr>
<td>Required value according to class</td>
<td>≥1.00</td>
<td>≥0.40</td>
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<tr>
<td>Fulfilled/ Not fulfilled</td>
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### Table 2. The features of the LED luminaire

<table>
<thead>
<tr>
<th>Feature</th>
<th>Value</th>
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<tbody>
<tr>
<td>Power (W)</td>
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<tr>
<td>Color Temperature (oK)</td>
<td>4000</td>
</tr>
<tr>
<td>Luminous Flux (lm)</td>
<td>4000</td>
</tr>
<tr>
<td>Luminous efficacy (lm/W)</td>
<td>155</td>
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<tr>
<td>Color Rendering</td>
<td>&gt;70</td>
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</table>
### Table 3. A comparison of the measured values and international standards

<table>
<thead>
<tr>
<th></th>
<th>$L_m$ (cd/m$^2$)</th>
<th>$U_o$</th>
<th>$U_1$</th>
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<tr>
<td><strong>International standards</strong></td>
<td>≥1.00</td>
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<td>≥0.50</td>
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<td><strong>Observer (O)</strong></td>
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<td>O1</td>
<td>O1</td>
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<tr>
<td></td>
<td>O2</td>
<td>O2</td>
<td>O2</td>
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<tr>
<td><strong>Measured value</strong></td>
<td>1.40</td>
<td>0.42</td>
<td>0.24</td>
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<tr>
<td></td>
<td>1.64</td>
<td>0.38</td>
<td>0.22</td>
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<tr>
<td><strong>Fulfilled(√)</strong></td>
<td>√</td>
<td>√</td>
<td>-</td>
</tr>
<tr>
<td><strong>Not fulfilled (-)</strong></td>
<td>-</td>
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</table>

#### ABBREVIATIONS

- **LED**: Light Emitting Diod
- **CIE**: Commission internationale de l'éclairage
- **HPS**: High Pressure Sodium
- **TIR lens**: Total Internal Reflection lens
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