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Design peculiarities of light-emitting diode devices

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Abstract

The operation of light-emitting diode (LED) devices has identified a number of peculiar features of the angular distribution of light intensity. The use of several light-emitting diodes results in an unevenly bright light-emitting surface of a lighting device. When lighting devices operate under vibration conditions, certain circumstances may occur when highlight or lowlight areas appear and are continuously observed on screen. The authors have simulated model conditions of dark screen areas occurred as applied to the light flux being formed by light-emitting railway headlights.

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Keywords: light-emitting diode (LED); lighting devices; railway headlight; numerical modeling; ray tracing; intensity distribution

1. Introduction

The most common use of LED light sources has allowed one to identify their disadvantages. Some organizations, implementing LED lighting devices [1], as well as some railway employees have reported a number of disadvantages [2] of LED color-light signals such as, for example:

- the phantom effect (at sunrise and at sunset, vehicle operators and transport drivers feel seeing spots, dots, lines or fragments of high-intensity or low-intensity surfaces);
- blurring boundaries of illuminated objects;

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- the effect of hot spots, uneven illumination (spottiness) and bad color rendering [3].

These disadvantages may be explained by technical reasons.

However, in railway transportation sector, both an observer and a light source undergo different vibrations. In medical literature, we have the notion of human vision persistence – a human eye's response time to photostimulation. From reliable medical sources it is known that the eye's response time to photosimulation depends on many factors such as:

- the observer's age [4];
- the observer's vibrations [5-6]. It is found that under vertical vibrations of a human being, from 7 to 75 Hz, a human eye would focus on a blurring contour and phantom vibrations of an object under observation [6];
- the relative speed of movement of the observer or of the object under observation [7];
- spatial orientation of the observer's look and head [8].

In our opinion, all these factors indicate that everyone can individually identify disadvantages of LED-based lighting. That's exactly why we haven't found any recorded images of spottiness or blurring of the LED-based illuminated object.

A railway headlight is subjected to vibrations whose frequency spectrum varies from 1 to 150 Hz [9]. In this case a LED-carrying substrate would sustain vibrations by means of brackets shaped in the form of metal strips. The brackets serve as waveguides. We consider that one of the factors of the spottiness effect in illuminated zones might be the standing waves appeared on the LED carrying substrate's surface. As the result of this, on the substrate's surface in areas corresponding to standing-wave loops, an individual LED-based light flux has a least spatial deviation from its original position. At sections corresponding to standing-wave nodes, the LED-based light flux has the largest spatial deviation amplitude. Screen areas illuminated by LEDs located within the standing-wave nodes can have a low lighting level. This fact along with the low color rendering index (Ra) [10] can result in the fact that individual screen areas will be either darkened or unusually white (the phantom effect) if compared to the general background of the illuminated screen. Methods and software of classical computer optics [11-16], and modern design tools for LED structures [17-19] don't let us investigate the influence of vibrations over the radiation pattern being formed.

The purpose of this paper is to propose a method for determining vibration conditions on the LED-based substrate's surface that would result in shadowed or abnormally bright segments being appeared on the illuminated screen.

2. Problem description

The occurrence of light-emitting surface deformations, resulting in uneven illumination of the screen, was defined on a solid model of the LED-based headlight [20] (Fig. 1). Physical and technical characteristics (modulus of elasticity, Poisson's ratio and density) of each component of a headlight 3D model corresponded to physical and technical characteristics of structural elements of the headlight applied by the Russian Railways [20]. A source of substrate vibrations is provided by two brackets located symmetrically from one another. The LED-carrying substrate in the headlight structure is made of a perforated aluminum sheet 3 mm thick. The substrate contacts with two brackets over rough surfaces. The authors recognize that the refraction of acoustic waves depends on the following factors:

- a magnitude of static contact-exerted pressure and elastic characteristics of contact bodies [21];
- microroughness sizes of contact surfaces [22];
- an angle of wave incidence at a rough surface contact [23].

In this case, the amplitude of the refracted longitudinal wave is always less than the incident wave amplitude at the rough surface contact [21].

The frequency spectrum of possible substrate vibrations coincided to the spectrum of railway vibrations [9].

It remains an open question on what frequency a standing wave is formed at the substrate's surface. We suppose that to excite large-amplitude vibrations of the substrate's surface, it is necessary to use several vibration harmonics. In order to increase the vibration amplitude applied to the substrate's surface, we suppose that vibration harmonic frequencies must be multiples or close to multiples. Besides, the phases of substrate's surface vibrations generated