Visualization of the Cargo Orientation in Space under Movement by a Tower Crane in Low Visibility Conditions

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Abstract. This article discusses the problem of improving safety on the construction site and the efficiency of the tower crane operators. It is proposed to introduce into operation LED lighting devices to ensure the visualization of the orientation of the load in space. For this purpose, during the work the indicators of the visibility range of the light glow of halogen and LED lamps in fog conditions at the construction site of the Lakhta Center were compared.

1. Introduction

A tower crane is a special type of lifting device often used in the construction of high-rise structures, such as skyscrapers. Operation of tower cranes is associated with certain risks, that is because safety is a top priority. Employers are required by law to provide safe working conditions for all workers at the construction site, including during operating cranes. [1-2]

The main occupational risks at the construction site include injuries from contact with a power line, crane overload, a fall, the influence of weather conditions, or manual lifting. [3,4]

The rational choice of special lifting mechanisms and the consideration of all harmful and dangerous factors affecting the driver of tower cranes can improve the efficiency of work performed and reduce the risk of emergency situations at the construction site. [5]

During the construction of the Lakhta Center skyscraper, workers had to deal with various peculiar properties of working conditions associated with increased height of the building under construction and unfavorable climatic factors characteristic of St. Petersburg, which created special working conditions at this height. [6]

2. Methods

To achieve the goal of the study, the following chain of methods was used: problem statement; study of literature, documents and results of activities, analysis of the weather archive in St. Petersburg with the identification of the number of foggy and rainy days for 2018, calculations; inductive-deductive method; specification; hypothesizing. [7-11]

To improve the working conditions of workers at the Lakhta Center construction site, literature was studied on the nature of fog and its effect on visibility.
The calculation of the range of visibility of light halogen and LED devices in the conditions of low bill, arising on the construction site of Lakhta Center due to thick fog, heavy rain or low clouds was carried out. [12-13] Further, a comparison of the efficiency and cost-effectiveness of these types of lamps was carried out. [14]

The next step was the synthesis of facts obtained about the working conditions of crane operators of tower cranes and the formulation of a hypothesis about reducing the risk of emergency situations when using LED lighting devices.

The harsh climate of the northern capital greatly complicated the workflow at the Lakhta Center construction site. The typical of this region high humidity, as well as the close proximity to water Finskiy zaliv cause thick fogs in the autumn-winter period, when the surface of the land is much lower than the temperature of the open surface of the water. High humidity significantly reduces the required temperature difference to achieve a “race point”. The appearance of cyclones and anticyclones with high humidity causes the process of mixing air masses with different thermo-hygrometric properties, which in turn plays an important role in the formation of clouds and fog at considerable heights. As the skyscraper grew, low clouds created additional difficulties to ensure the safety of lifting operations. The lack of visibility of cargo movement, as well as low illumination at the construction site at certain sites made it difficult for the work process, creating the risk of an emergency and a threat to the lives of workers at the construction site. In order to eliminate dangerous situations, well-coordinated work was carried out on the walkie-talkie of the crane operator and slinger to ensure that the risk of an emergency is reduced and to prevent accidents. To create a more accurate visual orientation of the cargo in space in order to exclude the possibility of its damage and unplanned movement, posing a threat to the lives of surrounding workers, it is proposed to install signal and lighting devices using carabiners directly on the slings that secure the cargo, and also to mark with these devices the cargo receiving area. The most effective will be a light device emitting red light, as it is the brightest, most contrasting and quickly captured by the human eye in conditions of poor visibility. [15-17]

For the analysis of the visibility range of the proposed signal-lighting devices LED and halogen type (one LED light has the following light characteristics: $\Phi_l=260\, \text{lm}$, $\Omega=105^\circ$; halogen light bulb: $\Phi_h=400\, \text{lm}$, $\Omega=160^\circ$) shall take the following calculated data: $\text{MOR}=80\, \text{m}$; $E_p=10^4 \, \text{lx}$. The visibility range of a black dot object is 100-10 meters. [18]

Light intensity is calculated by the formula $I=\Phi/\Omega$, where $\Phi$-light flow; $\Omega$-is the solid angle in which the luminous flux is enclosed. [19]

Thus, the LED device of 5 lamps will have a current strength of $I_l=530\, \text{cd}$; halogen device of 5 lamps $- I_h=385\, \text{cd}$.

The range of visibility of the lights of the signaling system $S$ is calculated from the ratio following from the Allar law: [18]

$$E_p = \frac{I}{S^2} e^{-\sigma \cdot S}, \quad \text{where}$$

(1)

$E_p$ - threshold illumination on the observer's eyes when visual perception of point sources of light by luminous intensity $I$;

$S$ – visible range of light;

$e$ – the basis of natural logarithms;

$\sigma$ – is the attenuation index, which determines the meteorological optical range (MOR).

To calculate the range of visibility of the lights of light-signal systems, the relation (1) is transformed taking into account the well-known dependence following from Koshmider's law ($\text{MOR} = 3/\sigma$), [17] specifically:

$$E_p = \frac{I}{S^2} e^{-\frac{3 \cdot S}{\text{MOR}}} \quad \text{or} \quad S^2 = \frac{I}{E_p} e^{-\frac{3 \cdot S}{\text{MOR}}} \quad \text{(2)}$$

Using the relation (2), the visual range of the lights of light-signal systems is calculated by the method of iterations after the following transformations:
After performing the calculations using the online program, the visual range of the LED lights was equal to 150 meters, and halogen values to 141 meters. \[ 2 \lg S = -\lg E_p + \lg I - \frac{3S}{MOR} \cdot lge, \]  \[ (3) \]

Mark \[ 2 \lg S = A, -\lg E_p + \lg I = B_1, \quad \frac{3}{MOR} \cdot lge = B_2 \]  \[ (4) \]

receive \[ A = B_1 - B_2 \cdot S. \]

These results indicate that within 140 meters, the visual perception of the light system attached to the cargo line with the human eye will be feasible. This confirms the feasibility of using these devices in order to improve the visualization of the orientation of the load in space.

However, in order to facilitate the operation of the light device, it is necessary to use wireless power, which implies the choice of sufficiently powerful types of batteries (eg AA-3 pcs.) or rechargeable batteries (eg Li-Ion-1800 mAh). [21] Under these conditions, safe and long-term operation of the device is possible only with the use of led lamps, since they have a low degree of heating, are able to operate at a wide temperature range from -30°C to +60°C and most importantly, they operate at a power consumption of 13 times less, than halogen lamps (LED -3 W, halogen -40 W), which significantly extends their service life. [22-24]

According to average data, there are about 37 foggy days each year in St. Petersburg, and 49 rainy days (with precipitation levels ranging from 7 to 23 mm / 12 h.). This explains the relevance of this work. Poor visibility due to natural phenomena is a common problem for many cities in the world, for different regions, the indicators of visibility range of LED devices may vary. Fog is not the only dangerous climatic factor, so a detailed study of the influence of natural phenomena is necessary for effective and safe work on the construction site.

Figure 1 shows a diagram of the proposed installation of lighting devices on the slings that secure the load, and figure 2 shows the placement of LEDs in a compact housing - 7×5 cm with a carabiner.

\[ \text{Symbol of the light device—●} \]

Figure 1. The scheme of the proposed installation of light devices on the lines.
Figure 2. The option of placing the LEDs in a compact case is $7 \times 5$ cm with a carbine.

3. Conclusion
Signal LED device, due to its light characteristics, has the greatest visibility in dense fog. This will allow creating a more accurate visualization of the orientation of the load when it is moved by the tower crane in conditions of reduced visibility. In this way, the risk of deformation of the load and the occurrence of accidents will be reduced. Provide visualization of the cargo offered by placing on the lines of the LED installation.

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