УДК 656.251 **DOI**: 10.18664/ikszt.v27i3.265540

ZMII SERGII, associate professor,
SIROKLYN IVAN, associate professor,
PANCHENKO VLADYSLAV, associate professor,
SOTNYK VASYL, associate professor
(Ukrainian State University of Railway Transport)

Energy effective Technologies on Transport: Safety of Appliance of LED Railway Signals

For about 50 years the LED technology of visual information transfer is world-known, in spite of it, there is a row of unsolved questions of implementation of LED railway signals till present. This article is devoted to the analysis of topical issues on introduction of LED signals on railway transport, in particular: modes of operations of railway signals, influence of the atmospheric phenomena on the transmission of signal, unconcern of new technology as compared to glow lamps etc. There have been separately analysed the possible failures of LED matrix elements and the choice of the most rational structure of matrix has been grounded from the point of view of the railway signal functioning safety.
Keywords: *railway signal; safety of LED matrix circuit; LED temperature dependency; LED intensity shift.*

Introduction

Energy efficiency of the railway automation systems frequently enough conflicts with the safety of their work. One of the examples is the introduction of LED railway signals. Unlike other types of transport, on a railway transport the traffic-light is only a part of a more global railway traffic control system.

The traffic-light signaling is one of links of providing the traffic safety, and thus is an important element that must always be in good condition. According to failures statistics, in the construction of railway signals the least reliable element is an incandescent lamp which works as a source of light. To solve this problem the special strategies of technical support of these knots have been implemented on the railways of Ukraine, but those are of no desirable result in practice. One of the options to increase the reliability of lamps is substituting the light source with the light-emitting diodes.

Additionally, the introduction of LED technologies should become one of links as finding the ways to improve the reliability of railway transport and reducing the cost of maintaining infrastructure and its other components remains an urgent task. Active development of sensors and technologies for monitoring as well as the development of information processing techniques have opened up new opportunities to improve the technical maintenance system in railway transport. A new approach in the construction of forecasting systems, hardware operating life management and maintenance planning has been termed PHM (Prognostics and Health Management). The development of scientific basis of PHM approach application for rail transport is an urgent task at the moment.

In the second part of research the analysis of basic topical scientific tasks to introduce the LED railway signals has been executed on the basis of comparison of advantages and lacks of traditional and new technologies. In the third part the questions of choice of railway signals construction complete set have been examined from the point of view of correct light perception and atmospheric factors influence. In the fourth part the question of connection circuit of LED matrix elements is exposed from the point of view of their failures and their influence on traffic safety. Basic job performances and issues to be researched have been brought in the conclusions.

Main of advantages and disadvantages

At present on Ukrainian railways in traffic-lights the incandescent lamps of ЖС12-15 and ЖС12-25 types are used as a light source. The basic lack of these lamps is low durability 1500-2000 hours, that results in not only their systematic replacement, but to the of trains delays as well [1]. Besides basic mode of operation, when lamps are supplied from the source of 12V 50 Hz, the night mode of tension decline to 9 – 10.5 V is additionally used. Under such mode except for the intensity of radiation in incandescent lamps the temperature of lamp filament decreases to 300 – 400К [2], that influences the spectrum of radiation on Wien's displacement law (1):

$$\lambda_{max} = 0.002898/\mathrm{T}, \tag{1}$$

where λ_{max} is wave-length with maximal intensity, m;
T is temperature, K.

This defect can be compensated by using the signals on the basis of monochromatic light-emitting diodes, however among the substantial lacks of the latter there is ambient temperature sensitiveness. Many research works are devoted to this matter [3, 4, 5]. From Fig. 1 it is evident, that yellow is the most sensible color to this phenomenon.

As the options of compensation of this phenomenon in [3] the adaptive control of light-emitting diodes set of different wave lengths has been suggested. In particular, the adaptive control of yellow and orange radiation intensity in accordance with the lamp temperature makes it possible not to abandon the rationed spectrum of radiation. On the assumption of many elements and complication of technology realization the question of its behavior safety at failures is actualized. It is especially topically in hard requirements to the circuits of railway automation of Ukraine.

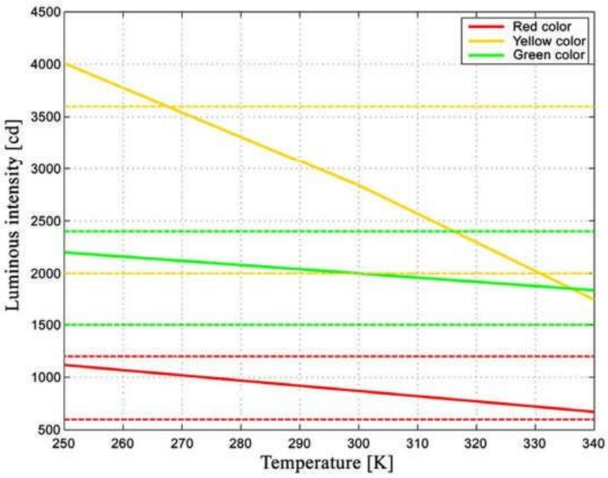

Fig. 1. Intensity of diagram as a function of temperature

Another option of compensating the temperature influence is the use of different technologies of light-emitting diodes for different colors. GaN LEDs are principally used as small wavelength sources (UV, violet, blue, green), offering an inherent higher efficiency than the AlInGaP technology, which is still implied to provide wavelengths in the opposite side of the spectrum. At least for yellow the technology of GaN is more acceptable [6, 7].

But in [2] but in epy number of other sources, as priority it is suggested to use the universal matrix of white light-emitting diodes with the use of existent lens complete sets (doublet) for forming the necessary color of signal (Fig. 2). The latter decision is potentially more economically expedient for the railways of Ukraine, where almost 99% systems of automation are out-of-date, and the trackage is one of largest in the world.

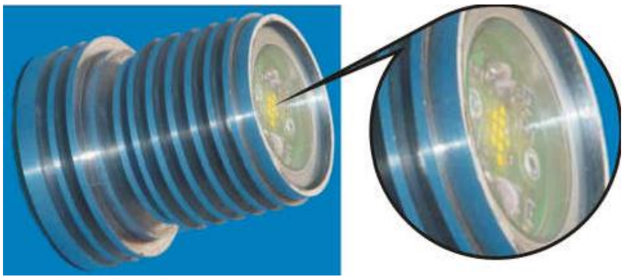

Fig. 2. LED lamp for to set in a doublet of railway signal

Despite the fact that the construction of LED lamp allows to even realize the imitation of double-filament incandescent railway lamp, the question of LED circuit matrixes construction remains open with safe behavior at failures. This question is topical, for in a incandescent lamp only one a possible breakdown is accepted – it is the breakage of tungsten filament, and in the semiconductor elements of LED matrix there are at least two of those.

Safety of switching-on circuits of incandescent lamps

When refusing incandescent lamps and replacing those with the other source of light – LED lamp, it is necessary to take into account that existent schematics must not be subject to the change. The change of schematics is acceptable at new building and reconstruction when the train traffic of is stopped or is of low intensity, taking the special terms of traffic into account. Making alteration in the conditions of normal train traffic requires agility from the auxiliary personnel, that might result in errors at assembling works and increase of their time that can result in the delay of trains and to the violation of traffic schedule.

Basic conception of safe charts construction of switching on the lamps on railway signals consists in that switching of traffic-light lights is executed by the contacts of the 1-st class reliability relay with control of the actual lamps ignition. To switch on the lamp a certain combination of contacts of controlling relays creates an electric circle with the source AC current with voltage 220 V, loading for which is the primary winding of the transformer (СОБС, СТ). The secondary winding is adjusted to voltage 12 V to which a incandescent lamp is connected, consistently with which the winding of firing relay is switched on. This relay controls the integrity of incandescent lamp filament as follows: when set by the station duty officer of the route, the centralization blocking system forms a command on switching on a certain display, under the good condition of incandescent lamp and circle of supply, the secondary winding of alarm transformer will be loaded with a incandescent lamp, the current of which will flow through the low-resistance winding of control relay; at burning out or absence of lamp, the circle of secondary winding of transformer appears broken (mode of idling), controling relay is deenergized, by what the lamp falure is fixed [1].

The given principle of schematic actions has been used on the railways for over 40 years, their reliability and safety has been well-proven by experts and confirmed by a considerable operating life on main and industrial transport.

The dangerous lamp failure on a railway signal is the disparity of display of instruction on signaling [8], i.e. actual ignition for more than the display is allowed. The switching of this failure is fixed on control relays and schematics only based on one possible failure – burning out (breakage) of lamp filament.

Safety of LED matrixes charts

In its turn the light-emitting diode has two types of failures – the breakage of one or both electrodes or their short circuit. The breakage can be permanent and periodic (for example, dependency upon the change of temperature). Thus in case of breakdown a light-emitting diode is able to work in the pulse-mode or consume the current not radiating light. However, a short circuit differs with that the diode is actually non-luminous, however, it is impossible to control the breakdown with the existent schematics.

A light-emitting diode is a semiconductor element, belongs to the elements that have a symmetric breakdown, i.e. the probability of breakdown as a short circuit or breakage are approximately equal to each other Qsc ≈ Qb and approximately in an even amount are distributed between these two probabilities [9].

To determine the probability of each of possible dangerous failures it is necessary to define the possible options of switching on the light-emitting diodes. The analysis of functioning features of light-emitting diodes, railway signals construction and lens complete sets has defined that the most rational charts of switching on are multiple series or series-parallel switching. Let's consider the multiple series (Fig. 3).

With such switching on, the short circuit of any diodes results in fading of those diodes switched in parallel to the one with breakdown. That is, at the short circuit of one of diodes the column (link) where it is located will be redeemed.

As known from [10] the circuit breakdown probability is determined.

$$Q = 1 - [1 - (1 - e^{-\lambda t})^n]^m \ , \qquad (2)$$

where λ is the intensity of the light-emitting diode breakdown, 1/hour;

t is the term of exploitation; n is the number of in-parallel light-emitting diodes in one link;

m is the number of links.

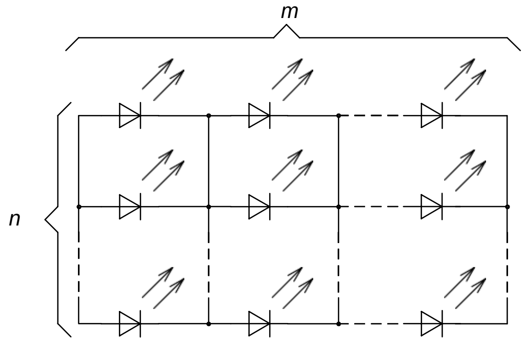

Fig. 3. Circuit with the parallel-series switching on the light-emitting diodes

It has been obtained on the analysis results (2), that the breakdown probability will arrive at a minimum value at *m = 1* and *n* = ∞. From the practical point of view the increase of the number of in-parallel light-emitting diodes in one link of more than 8 does not carry considerable reduction of probability, and the influence of parallel links number is nonsignificant (Fig. 4) here.

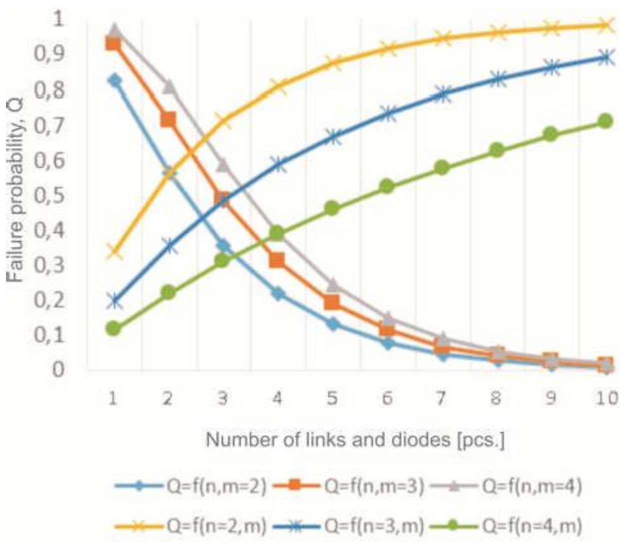

Fig. 4. Dependence of probability of refuse is on the amount of links and diodes in every link

Will consider the consistently-parallel method of connection of light-emitting diodes (Fig. 5).

At such connection of light-emitting diodes and presence of stabilizing of currents in every successive circle the short circuit of electrodes to the light-emitting diode will not result in substantial changes, an element that said no will not light only. At a precipice be what diode, a successive circle will leave off to shine, where this diode is. There will be an insignificant increase of current in other circles, that at presence of stabilizing will not result in death all chart.

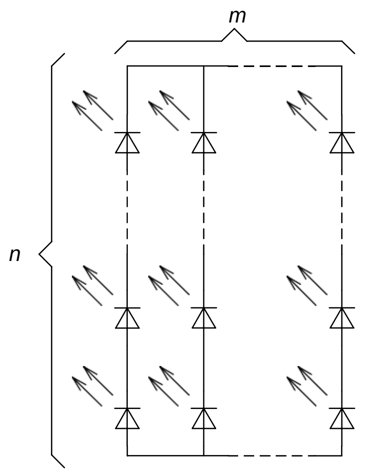

Fig. 5. Circuit with the series-parallel switching of light-emitting diodes

The lack of this circuit consists in that when one light-emitting diode in the circuit starts working in the blinking mode, all the light-emitting diodes in series connection start blinking data, which might distort the visual perception of signal.

As it is known from [10] the circuit breakdown probability is determined

$$Q = (1 - e^{-\lambda t n})^{m}, \qquad (3)$$

where λ is the intensity of the light-emitting diode breakdown, 1/hour;

t is the term of exploitation;

n is the number of in-parallel light-emitting diodes in one link;

m is the number of links.

It has been obtained on the results of analysis (3), breakdown probability will arrive at a minimum value at $n = 1$ and $m = \infty$, that is a reverse situation (Fig. 6) compared to one considered before.

At increasing the number of light-emitting diodes in series connection in one link (n), the breakdown probability also increases, and at an increase the number of links (m) decreases. At $n = 1$ the circuit degenerates into circuit with multiple series connection (see Fig. 3).

From the practical point of view, the increase of the number of parallel mode links more than 5 does not carry considerable reduction to probability, and the influence of series light-emitting diodes number is nonsignificant (see Fig. 6).

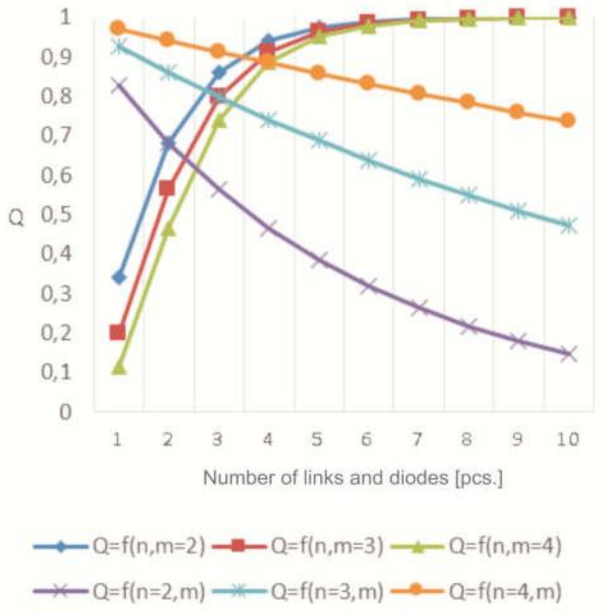

Fig. 6. Dependence of breakdown probability on the number of links and diodes in each link

At the values of $n = 2$ and $m = 5$ is most rational both from the point of view of breakdown probabilities and from practical possibility of physical location in a lamp, and it is suggested to use for a series-parallel circuit connection of light-emitting diodes.

Conclusions

The search of the ways to increase the reliability of railway transport, to increase its energy efficiency and to reduce the charges on infrastructure maintenance and its other components belong to the most topical tasks of railway industry in the world.

For increasing the energy efficiency of railway automation circuits, namely for application of LED railway signals, two basic questions have been considered: dependence of spectrum of radiation on the temperature of lamp and safe behavior of matrixes at failures.

On the first question it has been defined, that the priority decision is the use of light-emitting diodes of complete spectrum in the complex with present lens complete sets. For solving the problem of compatibility of LED lamp with the lens complete set of railway signals, it is necessary that LED lamp were placed in certain focus, thus the form of their location must repeat the form of the glowing filament. The simplest decision is a linear layout circuit that is series connection or parallel mode of diodes. At the location of diodes as a square matrix or other figure, it is necessary to envisage the additional measures of focusing the light stream that promotes complication and cost of producing such lamps.

On the second question, having investigated two most widespread charts of LED matrixes construction, it has been determined, that at a certain correlation between n and m it is possible to apply both variants of circuits. However, if the number of parallel and series diodes is identical, the circuit with the parallel-series connection has the smaller breakdown probability (see Fig. 3), which is recommended for application in the lamp for the railway signals. The number of light-emitting diodes will depend on their physical sizes, and sizes of sublayer for their location in the lamp.

References

1. V. Sapozhnikov "Ekspluatatsionnyie osnovyi avtomatiki i telemehaniki" [Operational fundamentals of automatics and telemechanics]: Moscow: Marshrut, 2006, [in Russian].
2. B. Abramov, S. Nikiforov, A. Ivanov, P. Penzev, and H. Muhov. Svetodiodnaya lampa dlya zheleznodorozhnyih svetoforov [LED lamp for railway traffic lights], Poluprovodnikovaya svetotehnika [Semiconductor Lighting] №3, 2010, pp. 47 – 52 [in Russian]
3. G. Schirripa Spagnolo, D. Papalillo, A. Martocchia, "LED Applications in Railway Signals: Wavelength and Intensity vs Temperature Variation", Journal of Transportation Technologies, № 2, 2012, pp. 78-83
4. D. G. Todorov and L. G. Kapisazov, "LED thermal management," Electronics' 2008, Sozopol, 24-26 September 2008, pp. 139-144.
5. A. Groh, S. Brückner and T. Q. Khanh, "The Temperature-Dependent Changes of the Photometrical and Colorimetrical Parameters of Today High Power LEDs," Proceedings of the 7th International Symposium on Automotive Lighting, Munchen, 25-26 September 2007, pp. 622-629.
6. T. Mukai, M. Yamada and S. Nakamura, "Characteristics of InGaN-Based UV/Blue/Green/Amber/Red Light-Emitting Diodes," Japanese Journal of Applied Physics, Vol. 38, No. 7A, 1999, pp. 3976-3981. doi:10.1143/JJAP.38.3976
7. T. Suski, P. Perlin and B. Monemar, "Gallium Nitride (GaN) I," In: J. I. Pankove and T. D. Moustakas, Eds., Semicondutors and Semimetals, Academic Press, San Diego, 1998, p. 279.
8. "PTE na zaliznitsyah Ukrayini" [PTE on the railways of Ukraine], Kyiv, Transport of Ukraine, 2003 [in Ukrainian].
9. V. Kustov "Osnovi teoriyi nadiynosti ta funktsiynoyi bezpechnosti sistem zaliznichnoyi avtomatiki" [Fundamentals of the theory of reliability and functional safety of railway automation systems]: Kharkiv UkrDAZT, 2008 [in Ukrainian].
10. J. Menčík "Concise Reliability for Engineers", InTech, 2016 doi:10.5772/62354

Змій С. О., Сіроклин І. М., Панченко В. В., Сотник В. О. Енергоефективні технології на транспорті: безпечність застосування світлодіодних залізничних сигналів.

Анотація. Вже близько 50 років світлодіодна технологія передачі візуальної інформації відома у всьому світі. Незважаючи на це, до цього часу залишається ряд невирішених питань впровадження світлодіодних залізничних сигналів. Дана стаття присвячена аналізу актуальних питань впровадження світлодіодних сигналів на залізничному транспорті, зокрема: режимів роботи залізничних сигналів, впливу атмосферних явищ на передачу сигналу, нецікавості нової техніки порівняно з лампами розжарювання тощо. Окремо проаналізовано можливі відмови елементів світлодіодної матриці та обґрунтовано вибір найбільш раціональної структури матриці з точки зору безпеки функціонування залізничного сигналу.

Ключові слова: залізничний сигнал; безпечність світлодіодної матриці; температурна залежність світлодіода; змінна інтенсивності світлодіода.

Надійшла 15.06.2022 р.

Змій Сергій Олексійович, *канд. техн. наук, доцент, декан факультету «Інформаційно-керуючі системи та технології», Український державний університет залізничного транспорту, Харків, Україна. E-mail: zmii.sergii@kart.edu.ua ORCID ID: http://orcid.org/0000-0002-7974-5181*

Сіроклин Іван Миколайович, *кандидат технічних наук, доцент кафедри автоматики та комп'ютерного телекерування рухом поїздів, Український державний університет залізничного транспорту, Харків, Україна. E-mail: seroklin@kart.edu.ua ORCID ID: http://orcid.org/0000-0001-9978-8261*

Панченко Владислав Вадимович*, кандидат технічних наук, доцент, кафедра електроенергетики, електротехніки та електромеханіки, Український державний університет залізничного транспорту, м. Харків, Україна. E-mail: vlad_panchenko@ukr.net ORCID ID: htts:// orcid.org/0000-0003-4822-7151*

Сотник Василь Олександрович*, кандидат технічних наук, доцент кафедри Автоматика та комп'ютерне телекерування рухом поїздів, Український державний університет залізничного транспорту, Харків, Україна. E-mail: sotnyk.va@gmail.com ORCID ID https://orcid.org/0000-0002-8039-1392*

Zmii Sergii*, Candidate of Technical Sciences, Associate Professor, Dean of the Faculty of "Information and Control Systems and Technologies", Ukrainian State*

University of Railway Transport, Kharkiv, Ukraine. E-mail: zmii.sergii@kart.edu.ua ORCID ID: http://orcid.org/0000-0002-7974-5181

***Siroklyn Ivan,** Candidate of Technical Sciences, Associate Professor of the Department of Automation and Computer Telecontrol of Train Traffic, Ukrainian State University of Railway Transport, Kharkiv, Ukraine. E-mail: seroklin@kart.edu.ua ORCID ID: http://orcid.org/0000-0001-9978-8261*

***Vladyslav Panchenko**, PhD, Associate Professor, Department of electroenergy, electrical equipment and electromecanics, Ukrainian State University of Railway Transport, Kharkiv, Ukraine. E-mail: vlad_panchenko@ukr.net ORCID ID: htts:// orcid.org/0000-0003-4822-7151*

***Sotnyk Vasyl**, Candidate of Technical Sciences, Associate Professor of the Department of Automation and Computer Telecontrol of Train Traffic, Ukrainian State University of Railway Transport, Kharkiv, Ukraine. E-mail: sotnyk.va@gmail.com. ORCID ID https://orcid.org/0000-0002-8039-1392*