Definition and approximation of the light flux degradation of a LED lamp

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Abstract. Quality control is one of the main functions of the quality management process. Its purpose is an identification of production errors for their prompt elimination and with minimal production losses. The launch of the concept of quality assurance into practice has significantly increased the efficiency of production with a sufficiently high quality of products and services, which has created conditions for the formation of a global market for goods and services. For LED lights luminous flux is the basic parameter that is needed to calculate the illumination of things and to understand the basic parameters of the suitability of the LED lights. In the analyzed articles, the specific time of the beginning of measurements of the luminous flux of the lamp is not given, which is a source of data discrepancies and erroneous results of calculating its light output. Therefore, to eliminate this deficiency in the technical characteristics, the luminous flux should be reduced after a certain stabilization time after power supply. To solve the problem associated with the development of standards for determining the level of degradation of the luminous flux, in this article the technique for predicting the decline of the luminous flux of a LED lamp through the determination of the level of decline in illumination is developed and the approximation of curves is presented.

1. Introduction

The concept of product quality is regulated in the Russian Federation by the state standard GOST 15467-79 "Product quality Management. Basic concept. Terms and definitions", according to which "quality is a set of properties of products that determine its suitability to meet certain needs in accordance with its purpose". If it is necessary to assess the quality of products, it is necessary to compare the parameters of these products, using scientific and technical documentation [1].

The easiest way to find the dynamics of the luminous flux is by an indirect indicator-illumination with an additional measurement of the temperature of the housing and the "hot" points of the LED light source. The value of the illumination decay indirectly reflects the value of the p-n transition temperature of the LEDs in the lamp and, accordingly, the level of light output reduction. Therefore, this parameter can be considered as informative. It is known that illumination is relatively easy to measure, and the luminous flux is difficult and expensive [2]. It is necessary to collect all the light emitted by the lamp and equally take into account the rays in all directions. That is, you need a photodetector in the form of a hollow sphere with the same light sensitivity of each section of its surface. The production of such a photometric sphere and its subsequent calibration is a very difficult task [2].
Another approach is to measure the radiation pattern of the light source by points and integrate it throughout the sphere. But this is not easy: there is a need to place the light source in a dark room of a sufficiently large size with walls close to absolute darkness, as well as to use a goniometric system with two axes and an automatic drive to avoid significant error when manually setting the angles for many points. In this case, there is a need to apply the assumption in special cases. Thus, it is necessary to address the consideration of a planar cosine emitter [3]. A cosine emitter is one whose brightness does not depend on the angle between the normal to its surface and the direction to the observer.

The emission pattern of such an oscillator is determined solely by the geometry – namely, the visible surface area. The ratio between the light flux and the light intensity in the direction of the normal to the plane for a plane cosine emitter exists has the form:

\[ I_o = \frac{\Phi_o}{\pi} \]

To obtain the magnitude of the luminous flux, calculate the product of the illumination value measured at a distance of one meter from the source and the number \( \pi \). If the distance is not equal to one meter, it will have to take into account the law of inverse squares. Also, the light source must be much smaller than the distance to the luxmeter otherwise the application of the law of inverse squares will be impossible [4].

For this case and quite satisfactory accuracy of measurements (10-15%) fit almost any white LEDs without lenses and flat assembly on their basis. It should be noted that for any LED with a lens, as well as for LEDs without a phosphor (for example, RGB), this method is not suitable: their radiation pattern is significantly different from the cosine. Flat fixtures, built into the ceiling and covered with light-scattering glass, also correlate well with the parameters of this model.

In most cases, the procedure can be divided into two main cases of changing the luminous flux of LED lamp over time. The first is the stabilization of the light flux in a relatively short period of time. In the first seconds of switching on and during the first 60 minutes, the luminous flux of the LED lamp can change in short way to 5-10% of the nominal value. Stabilization of the luminous flux is completed after about an hour [5].

The exact time of complete stabilization is very difficult, since random events in the form of background fluctuations in the network voltage constantly occur in the network. To conduct studies with higher accuracy, it is necessary to provide for the stabilization of the network voltage and the placement of the LED luminaire in the chamber with a stable temperature that does not depend on the heating of the LED lamp. Therefore, the stabilization time should be taken into account before conducting research tests of the light characteristics of the LED lamp. The luminous flux is equal to at least 60 minutes from the moment of switching on the LED luminaire, and the measurement of the initial value should be carried out no earlier than 2-5 seconds due to the inertia of the equipment used [5] [6].

Changes of the luminous flux over time are also associated with irreversible degradation processes of vital elements of the LED lamp, responsible for light output and takes a much longer part of the time. This concept is often called degradation of the luminous flux, it should also be associated with the number of cycles on and off the LED lamp.

With the measurement of the illumination from the LEDs by the luxmeter, you should make sure that it has the correct spectral sensitivity curve.

In real conditions of operation, both steady-state modes of a LED lamp operation are possible, for which the formula can be used to determine the value of the illumination decay in the form of:

\[ \hat{\varphi}_{dec} = \frac{E_{beg} - E_{end}}{E_{beg}} \cdot 100\% \]

Modes of operation with the presence of a certain number of cycles turning on and off a LED lamp, then the formula for determining the magnitude of the decline in illumination will be:
\[ \delta_{\text{dec}} = \frac{\sum_{i=1}^{n} E_{i\text{on}} \cdot E_{i\text{off}}}{\sum E_{\text{on}}} \cdot 100\% \]

The error in determining the decay of illumination can be determined by:

\[ \delta_{\text{dec}} = \left( 1 - \frac{\delta_d}{\delta_d + 1} \right) \cdot 100\% \]

where \( \delta_d \) is the relative value of the luminaire light decay measured over time.

On the basis of this expression, it is found that the error in determining the decline of illumination in 5% is 20%. With a decline in the luminous flux of 10%, the error in determining the level of illumination decline is reduced to 10% and only at its limit values we can talk about more accurate measurements [7].

2. Results and discussion

To determine the service life of the LED itself, it is regulated to use the IESNA LM-80-08 and TM-21-11 standards, which prescribe to carry out studies of SOP for 10 thousand hours, and then to approximate the degradation of the luminous flux to 70% and 50% of the decline from the initial value.

Figure 1 shows a curve of the degradation of illumination from the investigated LED lamp. The objective of the tests was to get and study the processes occurring in the electromechanical system of the lamp at the time of its on and off, the impact of on/off cycles on the wear of the system elements and degradation of the luminous flux of the light source [8].

It can be seen that when approximating the obtained values, it is necessary to consider separate segments of the function and apply a partial approximation. In this case, for the resulting graph curve can be divided into three parts and to each segment to apply a linear approximation.

Figure 1. The curve of the degradation of illumination from the investigated LED lamp.

In figure 1 "a" is the first approximation segment with a range of values from 0 to 1200 cycles, "b" is the second approximation segment with a range of values from 1200 to 2500 cycles, "c" is the third approximation segment with a range of values from 2500 to 4000 cycles.

To find the linear regression equations for the segment "a" on figure 1, calculate the coefficients a and b of the linear regression equation:
\[ a = \frac{\sum x_i \sum y_i}{(\sum x_i)^2} - \frac{n \sum x_i y_i}{\sum x_i^2} = \frac{7010 \cdot 11944 - 12 \cdot 6808500}{7010^2 - 12 \cdot 6100100} \approx -0.0842; \]

\[ b = \frac{\sum x_i \sum y_i - \sum x_i \sum y_i}{(\sum x_i)^2 - n \sum x_i^2} = \frac{7010 \cdot 6808500 - 12 \cdot 6100100}{7010^2 - 12 \cdot 6100100} \approx 1044.51. \]

Then the linear regression equation for the segment "a" has the form:

\[ \hat{y}_a = -0.0842x + 1044.51. \]

Similarly, for the segment "b" and "c":

\[ \hat{y}_b = -0.2592x + 1261.6; \]

\[ \hat{y}_c = -0.1164x + 864.3. \]

The average approximation error:

\[ \bar{A} = \frac{1}{n} \sum \left| \frac{y_i - \hat{y}_i}{y_i} \right| \cdot 100\% = \frac{0.2115}{4} \cdot 100\% \approx 5.3. \]

3. Conclusions

Based on the obtained values of the coefficients of the linear regression equation, it is possible to apply a regression line to predict the level of illumination decline depending on the number of cycles of switching on and off of the LED lamp, within the studied number of cycles. Also, to estimate the confidence interval, it is necessary to use the average value of the standard error \( \bar{A} \). The obtained coefficients make it possible to predict more accurately the change in illumination with an increase in the number of operating cycles of the LED lamp. However, it should be borne in mind that the value of the predicted illumination obtained using these coefficients should be corrected for the value of the standard error and measurement errors of equipment and laboratory conditions.

The means of determining the quality and service life of LED lamps are currently not fully standardized and need a significant improvement. As well as the requirements for sampling the test samples, methods for measuring the luminous flux of LED lamps are still under development. Measurement of luminous flux according to MKO 84: 1989 according to GOST R 54815-2011 is not optimized for LED lamps [8]. Additional definitions of service life and methods of its calculation by means of short-term measurements are still discussed.

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