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Prediction of the Service Life of LED Lamps Based on the Extrapolation of the Luminous Flux Conservation Factor

Abstarct. *The paper presents the results of research into the luminous flux conservation factors of commercial samples of light-emitting diode lamps for general lighting during tests of up to 6.000 and 10.000 hours, as well as the results of their service life assessment based on the extrapolation of the values of the luminous flux conservation factor until the moment when this coefficient in 50% of the lamps will decrease to 70% of the initial value. The measurement of the luminous flux of the lamps was carried out every 1000 hours operation of the lamps in the mode with switching cycles: 150 minutes on at full power, after which the lamps are turned off for 30 minutes. Selection of the empirical curve of the luminous flux conservation factor should be performed by finding the initial constant and rate of change of the luminous flux using the method of least squares. The forecast of the service life, according to the recommendations of the IEC 62612 standard, was carried out for four times the test time according to the test results up to 6 thousand hours and 10 thousand hours. It is shown that the service life of lamp samples which can be declared based on test results, is up to 6.000 hours is at least 24 thousand hours (calculated 27.2 thousand hours). Forecast based on tests up to 10 thousand hours is about 36.500 hours, which is 3.500 hours less than declared by the manufacturer(.*

Streszczenie. *W artykule przedstawiono wyniki badań współczynników zachowania strumienia świetlnego komercyjnych próbek lamp diodowych elektroluminescencyjnych do oświetlenia ogólnego podczas testów do 6000 i 10000 godzin, a także wyniki oceny ich żywotności na podstawie ekstrapolacji wartości współczynnika zachowania strumienia świetlnego do momentu, gdy współczynnik ten w 50% lamp spadnie do 70% wartości początkowej. Pomiar strumienia świetlnego lamp wykonywano co 1000 godzin pracy lamp w trybie z cyklami załączania: 150 minut pracy z pełną mocą, po czym lampy są wyłączane na 30 minut. Doboru empirycznej krzywej współczynnika zachowania strumienia świetlnego należy dokonać poprzez znalezienie stałej początkowej i szybkości zmian strumienia świetlnego metodą najmniejszych kwadratów. Prognozę żywotności, zgodnie z zaleceniami normy IEC 62612, przeprowadzono dla czterokrotności czasu badania według wyników badań do 6 tys. godzin i 10 tys. godzin. Wykazano, że żywotność próbek lamp, którą można zadeklarować na podstawie wyników badań, wynosi do 6000 godzin, czyli co najmniej 24 tysiące godzin (obliczono 27,2 tysiąca godzin). Prognoza na podstawie testów do 10 tys. godzin to około 36.500 godzin, czyli o 3.500 godzin mniej niż deklaruje producent.) (* ***Przewidywanie żywotności lamp LED na podstawie ekstrapolacji współczynnika zachowania strumienia świetlnego***)

Key words: light-emitting diode lamps, prediction, service life, luminous flux conservation factor
Słowa kluczowe: lampy diodowe, prognoza, żywotność, współczynnik zachowania strumienia świetlnego

Introduction

Light-emitting diode (LED) lamps are extremely reliable light sources. The service life of these lamps in real operating conditions can amount to tens of thousands of hours, so one of theproblems is resource tests, which with traditional approaches used for incandescent lamps and discharge lamps would be 3-4 years. It is clear that the results of such tests cannot be effective ly used for operational management of product quality by the manufacturer and evaluation of product quality by consumers and independent conformity assessment bodies. Therefore, research and improvement of methods of accelerated assessment of the service life of LED lamps and luminaires is an urgent task.

The EU Commission Regulation 2019/2020 [1], which establishes requirements for the eco-design of light sources for general lighting, obliges manufacturers to provide information on the service life of these sources, including for LED lamps and luminaires. In order to shorten the test period, accelerated methods for estimating the service life of LED light sources were recommended for the first time in [1]. The service life for these light sources means the time (in hours) from the start of their use and the moment when 50% of the lamps under test have a luminous flux conservation factor (LFCF) that gradually decreases to 70% of the initial value. It is also called L_{70} B_{50} service life.

Currently, there is not enough information on the conformity of the service life of LED lamps and luminaires declared by the manufacturers with the actual test results, therefore it is also relevant to study the coefficients of the conservation of luminous fluxes of commercial samples of LED lamps and luminaires during the service life and to evaluate their service life based on these studies.

Analysis of literary data

At the first stages of the use of LED lamps and luminaires, there were no standardized methods of testing them for their service life. The first recommendations for evaluating this parameter for LED light sources were developed in the USA [2]. The service life was defined as the period of time during which the light source provides a given amount of luminous flux.

Later, in international standards [3,4], it is also recommended to estimate the service life of LED lamps based on the extrapolation of the LFCF up to 70% of the initial value. According to [2,3], the recommended duration of tests of LED lamps and modules should be at least 6 thousand hours. The forecast of the service life of LED lamps is made on the basis of extrapolation coefficients of the conservation of the luminous flux not increased for a time that exceeded four times the duration of the tests. Thus, based on the results of tests up to 6.000 hours, with a positive result, it can be concluded that the batch of lamps has a service life of at least 24.000 hours [3]. The recommended method of predicting the service life based on the LFCFs is the selection of an empirical exponential curve to describe the obtained experimental data. Further extrapolation of this selected function to the moment of time, where the luminous flux decreases to the minimum acceptable level (for example, 70% of the initial value of the luminous flux) allows us to estimate the value of the useful line of service. This curve can also be used to estimate the value ofluminous flux at given future points in time (for example, 30.000 hours or 40.000 hours).

The experimental data used for extrapolation are first normalized to unity (100%) at 0 burning year for each sample within the given sample and then averaged at the skin point of the luminous flux measurement. For tests lasting from 6 to 10 thousand hours, only the last 5 thousand hours should be used for prediction. For tests with a duration of more than 10.000 hours, only the data of the last 50% of the full duration of the test should be used to select the empirical curve. In other words, all experimental points between D/2 and D must be used. For example, if the test duration was 12.000 hours, use all experimental points between 6.000 and 12.000 hours. If there is no experimental point at D/2, then the largest moment of time must be included in the data approximation. That is, in this case (for a study duration of 12 thousand hours), experimental points from 6 to 12 thousand hours were used for data obtained after every thousand hours.

The selection of the empirical exponential curve of the LFCF can be performed using equation:

(1) $$X_{LMF}\left(t\right)=B\exp\left(-\alpha t\right)$$

by finding the value of *B*-the predicted initial constant, and α-the constant rate of decrease of the luminous flux using the method of least squares. After calculating the constants *B* and *α*, the desired value of the time required to reach the given level of luminous flux is calculated from equation:

(2) $$L_p=\frac{\ln\left(100\times\frac{B}{p}\right)}{\alpha}$$

where: *p* is a given level from the initial luminous flux.

Thus, at the recommended critical level of 0.7 from the initial flow, we have:

(3) $$L_{70}=\frac{\ln\left(\frac{B}{0,7}\right)}{\alpha}\quad .$$

Selection of the empirical curve using the method of least squares is carried out as follows: taking the logarithm of both parts of equation (1) we have:

(4) $$\ln X_{LMF}\left(t\right)=\ln B\exp\left(-\alpha t\right)$$

Then, denoting y=ln X_{LMF} (t), m=-α, b=lnB we get the equation of a straight line:

(5) $$y=mx+b$$

For a set of *n* experimental points on the graph (x_1, y_1), (x_2, y_2)..., (x_n, y_n), where n-total number of averaged experimental points x_k= t_k , y_k=ln X_{LMF}, where *k* = 1, 2, ..., n, we will determine the value by the method of least squares *m* and *b*, will give accordingly:

(6) $$m=\frac{n\sum xy-\sum x\sum y}{n\sum x^2-\left(\sum x\right)^2}$$

(7) $$b=\frac{\sum y-m\sum x}{n}$$

After carrying out the necessary calculations and inverse transformations, we find:

(8) $$B=\exp(b),\alpha=-m$$

Using equation (3) based on data *B* and *α*, you can calculate the service life of the lamps.

As for the evaluation of the service life of LED lamps and luminaires according to [1], it does not provide for calculating the service life, but on the contrary, the reliability of the data declared by the product manufacturer is evaluated by comparing the LFCF determined experimentally after 3 thousand hours of testing and calculated by $X_{LMF,\ MIN}$ (%), based on the manufacturer's data.

LFCF after 3.000 hours according to [1] is calculated equation:

(9) $$X_{LMF,MIN}\ \%=100\cdot e^{\frac{3000\cdot\ln(0.7)}{L_{70}}}$$

where: 3000 is the burning time of light sources during tests, hours; L_{70} is the service life declared by the manufacturer.

The method of testing LED light sources involves:

1. Initial measurement of luminous flux before switching cycles;
2. Switching cycles: The source must be operated for 1200 complete continuous cycles. One complete switching cycle consists of 150 minutes of turning on the light source at full power, after which the source is turned off for 30 minutes. The recorded operating time (ie 3.000 hours) includes only the periods of the switching cycle when the source is on. The total test time is 3600 hours;
3. Final measurement of luminous flux after 1200 switching cycles;
4. For each of the sample units that did not fail, you need to divide the measured final luminous flux by the initial one. Determine the average value of all tested samples that did not fail and calculate the average value of the LFCF.

The purpose of this work was to experimentally determine the luminous flux of commercial samples of LED lamps with recommendations [3], predict the service life of these lamps based on tests of different durations, and evaluate the declaration of service life by the manufacturer in accordance with recommendations [1].

Research results

We have conducted studies of the coefficient of conservation of luminous flux during the burning process of a batch of lamps with a power of 10 W in the amount of 10 pieces. The lamps were tested in accordance with the recommendations [3]. The luminous flux was measured every 1000 hours lamp burning according to the standard [5].

The parameters of the lamp during the measurement of the luminous flux were stabilized-the supply voltage during the measurement of the luminous flux in the photometric sphere with a diameter of 1 m was maintained with an accuracy of ± 2%. The results of measuring the LFCF after 1000 hours and calculation results are listed in Table 1.

The received forecast of the useful life of the LFCF up to 70% of the initial value based on tests up to 6 thousand hours for the researched batch of lamps is 27.2 thousand hours. According to [3], the service life forecast based on test results is up to 6.000 hours can be declared only for four times the test time. So, we can state that the study of a batch of lamps has a useful life of no less than four times the time of tests, that is, 24 thousand hours. To obtain a more accurate forecast, it is necessary to conduct tests up to 0.25 of its declared value. Since the manufacturer declared an average service life of 40.000 hours for this batch of lamps, it is advisable to extend the test to 10.000 hours.

Test results up to 10.000 hours and the results of calculations based on the data of the last 5 thousand hours of tests (from 6.000 hours to 10.000 hours) are shown in Table 1. Using equation (3), we calculate the useful life of the test results up to 10.000 hours. It is 38.5 thousand hours, that is, by 3.5 thousand hours smaller than declared by the manufacturer.

For this batch of lamps, tests were also conducted to determine the LFCF and to evaluate the service life declared by the manufacturer in accordance with the requirements [1]. The average value of the LFCF after 1200 cycles of restarts (3 thousand hours of lamp burning) is 95.8%. The calculated value of $X_{LMF,MIN}$ carried out using equation (9) is 97.4%. If the calculated value of X_{LMF} is greater than 96% for comparison, according to the recommendation [1], 96% is accepted. Since the experimentally determined LFCF is lower than the calculation made on the basis of the declared service life of 40.000 hours, this gives grounds for asserting that the real service life will be slightly lower than that indicated by the manufacturer. This was also confirmed by tests up to 10.000 hours. The predicted service life based on tests and calculations is 36.500 hours.

Table 1. The results of measuring the LFCF (up to 6 thousand hours, up to 10 thousand hours) and calculations when determining the empirical curve using the method of least squares

Time (hours)	Luminous flux conservation factor X_{LMF} (%)	ln X_{LMF} (t)	A constant rate of luminous flux reduction α	Predicted initial constant B	The calculated value of the service life L_{70} (hours)
1000	0.98643	-0.014			
2000	0.96866	-0.032			
3000	0.95804	-0.043			
4000	0.94873	-0.053			
5000	0.93046	-0.072			
6000	0.92451	-0.078			
			-0.0000129889	0.996871241	27200
6000	0.92451	-0.078			
7000	0.915	-0.091			
8000	0.909	-0.101			
9000	0.901	-0.108			
10000	0.895	-0.115			
			-0.0000090405	0.9739816607	36500

Conclusions

1. Methods of predicting the service life of LED lamps based on experimentally determined LFCFs for a period of 6.000 hours with further extrapolation of data for a time four times longer than the test period allows to significantly reduce testing costs.
2. To evaluate the service life of lamps with a burning duration of more than 24 thousand hours, it is necessary to conduct tests up to 0.25 of the value of the declared or expected service life.
3. For tests lasting from 6 to 10 thousand hours, only the last 5 thousand hours should be used for prediction. In tests of more than 10.000 burning hours, the data of only the last 50% of the full duration of the tests should be used to determine the empirical curve.
4. The results of the forecast of the service life of the tested commercial samples of a batch of LED lamps during tests of up to 6 thousand hours allow us to declare a service life of no less than 24 thousand hours, in tests of up to 10 thousand hours of burning approximately 36.5 thousand hours.
5. The coefficient of conservation of the luminous flux of the lamps, determined experimentally after 1.200 restarts (3.000 burning hours) in accordance with the requirements of the EU Commission Regulation 2019/2020 is 95.6%, which is less than the calculated value for the service life of 40.000 hours declared by the manufacturer, obtained according to the methodology of this regulation. This means that the actual service life of the tested lamps is lower than that indicated by the manufacturer. This is also confirmed by the extrapolation of the LFCF to the level of 70% from the initial value based on tests up to 10.000 hours in accordance with IEC 62612 recommendations.

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