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Development of standard conditions for measuring the illuminance

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Abstract

The main areas for development of standard conditions of measuring the illuminance are proposed, as a result of which the users of the luxmeters will receive characteristic Type B uncertainties for a wide range of standardized operating conditions. Within the scope of work, it is proposed to develop tabular spectral distributions of five groups of light sources. Among them are the following: standard spectra of type A, C, D_{50}, D_{55}, D_{65}, D_{75}; gas-discharge light sources with impurities and phosphors, LED sources based on white phosphor LEDs with correlated color temperatures from 2360 to 8300 K and monochromatic LEDs with emission bands 380–470 nm and 650–760 nm; sources of UV and IR radiation. For the latter group, it is proposed to develop the equipment based on the LED sources of UV and IR radiation as well as to develop a procedure for their use to characterize the non-suppressed sensitivity of the luxmeters beyond V(λ). For UV spectral range, the interval of UV radiation in sections A and B is proposed – from 285 to 380 nm, which allows to take into account the characteristic maxima that exist for the bactericide and erythema. Due to the characteristic transmission cutoff of the glass and the widespread distribution of incandescent lamps, the radiation range from 760 to 2500 nm is proposed for IR range. In addition to the standard type A spectrum, it is proposed to add the standard source with a spectrum in the range from 760 to 860 nm for investigation of the non-suppressed responsivity in the IR region.

In order to evaluate the uncertainty components associated with the periodic component of luminance, it is proposed to implement LED-based equipment and to develop a methodology for its use. In particular, to identify and standardize two main forms of the periodic signal during the study: sinusoidal and rectangular. A sinusoidal waveform with a frequency range from 5 to 300 Hz is required to determine the frequency dependence of the sensitivity of the luxmeter. To estimate the mean luminance values, it is proposed to use a rectangular waveform in the mode with changing duty cycles and a uniform signal distribution.

Keywords: spectrum; radiation; uncertainty; luxmeter; LED.

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Introduction

Lighting is one of the basic human needs. The prevalence of lighting devices is clearly visible in the night images of Earth from the orbit. The most developed areas of the planet are brightly lit. The illumination allows to provide round-the-clock functioning of all spheres of public life, reduces criminogenic tension, which is absolutely necessary for road safety. The quality of lighting affects wellness, performance and, ultimately, human health. A significant amount of lighting means requires a huge range of devices for measuring, accounting, optimizing and saving material and energy resources. The most common measuring instrument for illuminance measurements is luxmeters – devices that measure time-averaged illuminance. Control of the periodic time dependence of illumination on time has also become widespread in recent decades. The eye cannot detect rapid changes in lighting, but it has a negative effect on human well-being and health. Flicker meters are used to record such periodic changes. Very often, flicker meters can perform the functions of a luxmeter. The quality of luxmeters and flicker meters is directly linked to the possibility of controlling and optimizing the lighting costs. When purchasing a device, the customer takes into account own measurement quality requirements. A recognized measure of measurement quality is uncertainty. The measurement uncertainty depends on both the characteristics of the instrument itself and the conditions in which the measurements are carried out. The international community has developed and standardized methods for characterizing the quality of luxmeters, for example [1, 2]. These documents use standardized values for quantitative description of the quality of luxmeters. These values do not represent measurement uncertainties or errors, but help to determine them. Currently, the generally recognized documents of such level for the characteristics of flicker meters do not exist. In order to evaluate the measurement uncertainties, it is necessary to know in what conditions they have been performed. The evaluation of measurement uncertainty is a routine, well-regulated scientific activity. The buyer should not do such work. Convenient and complete information on the quality of products should be made by their manufacturer or seller. The lack of convenient provision of information on the quality of luxmeters inevitably leads to their inefficient use. The obstacle to this work is that the manufacturer cannot know in what conditions the buyer intends to use the device. It seems that the creation of standardized conditions for the observation of lighting, in conjunction with the methods of characterization of luxmeters and flicker meters will allow to provide the consumer with convenient information about the typical measurement uncertainties. It is clear that the creation of such standardized lighting conditions should be based on existing standards [1, 2].

Problem statement

The following characteristics of the luxmeters are connected to the measurement conditions:

- dependence on the spectral composition of radiation, in particular, the response of the device to ultraviolet and infrared radiation, dependence on the nature of the light distribution in space;
- dependence on ambient temperature;
- dependence of the form of signal change on time;
- dependence on the state of radiation polarization.

Part of the measurement conditions, such as the temperature range and humidity in which the luxmeter can operate, is mandatory being specified. Usually acceptable and laboratory measurement conditions are differentiated. The difference in the spatial distribution of radiation is quite fully characterized in the set of illuminance values being used: spherical, hemispherical, cylindrical, semi-cylindrical and planar illumination. The polarization characteristics of radiation from linearly polarized to partial, circular or non-polarized radiation have been traditionally used in everyday practice.

Issues related to the difference in the spectral composition of the illuminance being measured from the spectral composition of the radiation during calibration have been thoroughly studied. For the known spectral responsivity of a luxmeter, it is possible to calculate the difference between the readings of a luxmeter calibrated by radiation with one spectral composition when measuring radiation with another spectral composition. There are standard spectra of radiation [3]. However, they are intended for other purposes and do not fully reflect the diversity of the existing spectrum of radiation sources.

Very often light sources have a noticeable periodic component. The desire to improve the comfort of lighting led to the normalization of the periodic component of illumination, and therefore to the need for its measurement. The presence of a periodic component makes it relevant to specify the response of a conventional luxmeter, designed to measure constant illumination, against partially modulated radiation, with the form of time dependence that can vary greatly. In addition, there are flicker radiation characteristics that should be measured and normalized to ensure acceptable light quality. The presence of various forms of periodic signal change affects the average illuminance measured in different ways.

Today, there are still a significant number of radiation sources based on incandescent lamps. Discharge lamps are also widely used for lighting, the spectra of such lamps are very diverse, but most of them are mercury or sodium lamps with impurities and various phosphors. LED radiation sources are widely implemented, which are practically inertial and have spectra that are significantly different from the existing standard spectra and those of incandescent and discharge lamps. This makes it a relevant requirement to develop standardized time dependencies and additional standardized spectral characteristics of LED radiation sources. The presence of such standards will allow to evaluate the possible measurement uncertainties both for the characteristics of the constant radiation and for the characteristics of periodic radiation.

Light sources with standard spectra

Since there is always some difference of the relative spectral responsivity of the luxmeter from the standard function $V(\lambda)$ (the value of the relative spectral luminous efficiency of monochromatic radiation for photopic vision), a device that has been calibrated by a type A source when working with a radiation of another spectral composition will give distorted readings, that is, be characterized by some type B uncertainty. Uncertainty evaluation for each type of spectrum u_B^s can be performed taking into account the spectral mismatch correction factor and can be written as:

$$u_B^s = \left\{ \left[\frac{\int_{380}^{780} \varphi_A(\lambda) V(\lambda) d\lambda \int_{\lambda\min}^{\lambda\max} \varphi_Z(\lambda) s(\lambda) d\lambda}{\int_{\lambda\min}^{\lambda\max} \varphi_A(\lambda) s(\lambda) d\lambda \int_{380}^{780} \varphi_Z(\lambda) V(\lambda) d\lambda} \right] - 1 \right\} \cdot 100\%, \quad (1)$$

where s(λ) – the relative spectral responsivity of the luxmeter, normalized to one;

$\varphi_A(\lambda)$ – the relative spectral energy distribution of the type A source;

$\varphi_z(\lambda)$ – the relative spectral energy distribution of one of the standard sources;

$V(\lambda)$ – relative spectral luminous efficiency of monochromatic radiation for photopic vision; $\lambda_{\min}$, $\lambda_{\max}$ – the boundaries of the wavelength domain where $s(\lambda)$ is different from 0.

The variety of used radiation spectra is very large. Even the same type of sources, for example, fluorescent mercury lamps, can have significantly different spectra.

It is necessary to select from a variety of sources a limited set of spectra that would be convenient for evaluation of possible measurement uncertainties. There is already a generally recognized set of standard spectra [3, 4]. The standard spectra of type A, C, D_{50}, D_{55}, D_{65}, D_{75} have smooth spectra. The standard spectra of the F_i type have pronounced maxima. The spectra of the set [4] are quite diverse. Due to the widespread use of LEDs, it is necessary to supplement the list of standard spectra with LED sources. LED sources with a relatively uniform radiation spectrum also have two (about 380 nm and about 600 nm), and sometimes three (maximum of about 520 nm is added) pronounced maxima. This allows to obtain sources with a wide range of correlated color temperatures (2700 ÷ 8400 K). Large-scale studies of available types of luxmeters and LED sources were carried out in NSC "Institute of Metrology" [5] and it was found that the calculations by formula (1) for light-emitting diodes and for the above listed spectra of gas-discharge lamps give approximately the same results, however for the LED sources with three maxima results are slightly greater.

It should be noted that this conclusion applies to phosphor LEDs with white radiation. It is clear that for measuring monochromatic radiation for LEDs with one spectral component, or for their combination, devices of such class will have significantly larger deviations. Given that at wavelengths $V(\lambda)$ is significantly smaller than at the maximum, minor deviations in relative spectral responsivity lead to significant measurement errors. The specialized spectra of standard sources are required to evaluate the impact in these domains. It makes sense to limit ourselves to domains where $V(\lambda)$ is less than 0.1 and to take the spectra of actually existing LEDs with an emission band from 380 nm to 470 nm and from 650 nm to 760 nm as the standard spectra of the sources. In the context of using spectral transition factors, it is sufficient to have only the value tables of standard source spectra, as actually existing equipment such sources are not required.

To characterize the spectral responsivity of the luxmeters in the IR and UV regions according to [2], the actually existing equipment is needed, since the used values are calculated by comparing the theoretically calculated luxmeter signals with their experimentally measured signals (which should not be for a qualitative luxmeter at all). Moreover, the logic of calculation is based on the fact that radiation sources in the UV and IR regions certainly have radiation in $V(\lambda)$ domain. The calculation is performed by the source spectrum and the spectral transmittance factor of the filter. The corresponding spectra are tabulated. The constancy of the ratio of signal components from UV, IR and radiation in $V(\lambda)$ domain is determined by both the constancy of the spectral composition of the sources and the constancy of the transmission of the filter. It is clear that the difference between the tabulated spectrum from the real one and the difference between the tabulated spectral coefficients from the real ones negatively affects the accuracy. It makes sense to take LEDs with a spectrum in the UV and IR regions outside the $V(\lambda)$ domain as standard radiation sources. Regarding the spectral range of these LEDs, the interval of UV radiation in regions A and B, i. e. from 285 nm to 380 nm, can be proposed for UV region. This will take into account the characteristic maxima that exist for the bactericide and erythema. Due to the characteristic transmission cutoff of the glass and the widespread distribution of incandescent lamps, the radiation range from 760 nm to 2500 nm should be covered for IR range. The type A source of well-known standard spectrum is already widely used to investigate non-suppressed responsivity in the IR range, but a standard source with a spectrum in the range from 760 nm to about 860 nm should be added to it, as it is in this area that most luxmeters have non-suppressed responsivity. It is clear that for convenience these regions (from 285 nm to 380 nm and from 760 nm to 860 nm) can be covered by a greater number of standard sources. In this case, the perfection of the luxmeter can be directly characterized by measuring the power level of the UV and IR radiation at which the indications of luxmeter appear. Methods for measuring these power levels can also be selected for reasons of convenience.

In summary, there are several groups of standard sources that can be proposed. The first group is relatively smooth sources. The second group is the gas-discharge lamps with impurities and phosphors. The third group is white phosphor LEDs with correlated color temperatures from 2360 K to 8300 K. The fourth group (the most stringent requirements) may consist of conventionally monochromatic LEDs with radiation bands of 380–470 nm and 650–760 nm. These source groups can only exist in form of tables. The last group is the sources of UV and IR radiation with the limits of emission spectra described above. They should exist in the form of real equipment. It is clear that the requirements for the quality of correction of the spectral responsivity of the receivers in these groups are significantly different, so the classification needs to be changed in accordance to this, for example, to specify additionally a group of standard sources. Such a supplement will help users to resolve the relevant question – what uncertainties are possible when working with a photometer.

Sources of standard flicker radiation

The influence of the periodically changing signal is manifested in two directions. The first one is due to the fact that according to [2] the readings of the luxmeter must coincide with the arithmetic average value of illuminance, which changes with time, that is:

$$E_{\text{ave}} = \frac{\sum_{i=1}^{N} E_{\text{i}}}{N}, \tag{2}$$

where E_{ave} – arithmetic average of illuminance, E_{i} – illuminance values, each of which is measured after a short interval of time, N — number of measurements.

The second one is connected to the most common characteristic of flicker radiation (percent flicker) or the flicker factor (K_{p}):

$$\text{percent flicker} = K_{\text{p}} = \frac{(E_{\text{max}} - E_{\text{min}})}{(E_{\text{max}} + E_{\text{min}})} \cdot 100\%. \tag{3}$$

From this formula it is seen that the average illuminance E_{ave} is determined in it as

$$K_{\text{ave}} = \frac{(E_{\text{max}} - E_{\text{min}})}{2}, \tag{4}$$

where $E_{\text{мах}}$ and $E_{\text{мin}}$ — maximum and minimum illuminance with E_{i}.

Thus, if the instrument is both a luxmeter and flicker meter, then as a luxmeter it should determine the average value according to formula (2) and as a flicker meter — according to formula (4). It is clear that these values do not always coincide. The difference is determined not by the frequency, but by the forms of the time dependence of the illuminance. These differences are theoretically analyzed in [6]. These values differ most strongly when there are short-term increases in illuminance or decreases in illuminance with a background steady signal – a form of a square-wave signal. In such cases, the differences can amount to hundreds of percent. The results of the experimental measurements can significantly depend on the frequency of change of illuminance, that is, the practical influence of the form of change of illuminance on the measurement result of illuminance and flickers is greater than the theoretical one. In many cases, light sources have a noticeable periodic component. Field measurements [7] showed that the difference between the average values determined by formula (2) and formula (4) can be more than 10 %. Given that in some cases the allowable level of illuminance flickers is 10 % [8], there is an obvious need to account for these differences.

The development of standard time dependencies should be based on the recommended time dependencies already used in various documents. In [2] it is recommended to use a sinusoidal form of changing the illumination or a form that obtained with a half-disk modulator and a constant light source to characterize the luxmeter bandwidth. It is noted that in the latter case, the average value will be less than half of the illumination generated by the non-modulated radiation of the constant light source.

In [1] it is recommended to use a time dependence form of radiation in the form of peaks lasting 0.5 ms every 10 ms. Such radiation can be obtained from a continuous light source and an opaque rotating disc with a cut-out sector with an angle of 18 degrees. In the first approximation, when using the modulator, trapezoidal pulses are obtained, however, it is obvious that the form of such pulses depends on the ratio of the size of the modulator and the light beam, as well as the distribution of illumination in the plane of the modulator. Given that these parameters are not regulated in the cited documents, there is some arbitrariness in the forms of light flickers.

For the standard radiation flicker sources, the presence of conventional table dependences of illuminance, luminous intensity or luminance over time is not enough. Real sources are required to obtain conventional luxmeter characteristics. The creation of such sources is facilitated by the fact that for LED sources it is quite easy to provide various forms of dependence of light parameters on time. Given the characteristic flicker frequencies of common radiation sources, the requirements for long-term stability for standard flicker sources are reduced. Since the time characteristics of the sources do not depend on the spectral ones, it is possible to use LEDs with any convenient spectrum of radiation. Obviously, the ratio of the variable part of the illumination and the constant one can vary widely. Therefore, only the variable component of illuminance should be standardized. Usually the periodic component of the radiation is smaller than the constant one, so the requirements for the illumination range created by the standard flicker source are significantly weakened. Together, this makes the creation of such sources quite accessible, it is only necessary to agree on common forms of time dependencies.

The sinusoidal form of flickers must necessarily be present as a standard form, since it is used in [1, 2] to determine the frequency dependence of the luxmeter responsivity. It also properly simulates the flicker component of incandescent lamps. It seems that for sources of the standard time dependence of illuminance it is enough to use the frequency range from 5 Hz (magnitude reversed to Blond-Ray constant) to 300 Hz (limit of human eye response to flickers).

Since the difference between the average values of the illuminance determined by the formula (2) and the formula (4) is most manifested in the of illumination type in the form of a square-wave signal with a variable ratio of the radiation period to the flicker duration, it is necessary to use it. Such a form should replace the radiation form received from a constant radiation source by modulating a rotating disc. Probably, for this form of light flickers, it may be possible to limit it to a constant frequency of 100 Hz. Since the form [1] of the time dependence of radiation in the form of peaks of 0.5 ms duration, which repeat after 10 ms, has already been fixed, for reasons of symmetry it should be supplemented by the form of time dependence in the form of constant radiation with short-term irregularities of illumination of duration of 0.5 ms through every 10 ms. Given that the ratio in the form of equal duration of constant and minimum illuminance for the square-wave signal is the only case in which the average values in the formulas (2) and (4) coincide, this form should also be taken as standard. The relative easiness of generation practically any form of illumination by LEDs makes rational taking the type of periodic radiation in the form of square-wave signal with a frequency of 100 Hz and changing duty cycles as the standard form. Control of the consistency of readings with changing duty cycles of flickers will be a good indicator of the quality of the flicker meter.

Conclusions

The performed research allows us to formulate the following proposals for the development of standard lighting conditions, which will provide better information to customers and users of luxmeters. The following actions are required:

1. To supplement the permissible temperature, humidity and polarization ranges available for each particular device in accordance with the general standard conditions of illumination observations, which will allow to compare the devices in terms of uncertainties caused by each of the above listed parameters.
2. To develop tabular spectral distributions of gas-discharge light sources, LED broadband light sources and LED sources of quasi-monochromatic lighting, which will allow to compare devices in terms of uncertainties caused by the variation of the radiation spectrum during calibration and measurement.
3. To develop equipment based on LED sources of UV and IR radiation and to develop a procedure of its application for characterization of the non-suppressed responsivity of luxmeters beyond the area of sensitivity of the human eye.
4. To develop equipment based on LED sources for the creation of standardized time dependences of illumination and to develop a methodology for its use, which will allow to evaluate measurement uncertainties of constant illuminance and flicker factors caused by the periodic component of illuminance.

Performing these tasks will provide customers and users of luxmeters with characteristic Type B uncertainties for a wide range of standardized operating conditions. Greater awareness will lead to more rational choice and more rational use of different types of luxmeters.

Розробка стандартних умов вимірювання освітленості

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Анотація

Запропоновано основні напрямки щодо розробки стандартних умов вимірювання освітленості, в результаті виконання яких користувачі люксметрів отримають характерні невизначеності типу В для широкого спектра стандартизованих умов роботи. В рамках роботи пропонується розробити табличні спектральні розподіли п’яти груп джерел світла. Серед них: стандартні спектри типу А, С, D_{50}, D_{55}, D_{65}, D_{75}; газорозрядні джерела світла з домішками та люмінофорами, світлодіодні джерела на основі білих люмінофорних світлодіодів з корельованими колірними температурами від 2360 до 8300 K та монохроматичні світлодіоди зі смугами випромінювання 380–470 нм і 650–760 нм; джерела УФ і ІЧ випромінювання. Для останньої групи запропоновано розробити апаратуру на основі світлодіодних джерел УФ і ІЧ випромінювання і розробити методику їх застосування для характеризування непригніченої чутливості люксметрів поза V(λ). Для УФ спектрального діапазону запропоновано інтервал УФ випромінювання в ділянках А та В – від 285 до 380 нм, що дозволяє враховувати характерні максимуми, які існують для бактерициду та еритеми. Внаслідок характерної межі пропускання скла та широкої розповсюдженості ламп розжарювання для ІЧ діапазону пропонується діапазон випромінювання від 760 до 2500 нм. Окрім стандартного спектра типу А, для дослідження непригніченої чутливості в ІЧ ділянці спектра запропоновано доповнити стандартним джерелом зі спектром у діапазоні від 760 до 860 нм.

Для оцінки складових невизначеності, пов’язаних із періодичною складовою освітлення, пропонується реалізувати апаратуру на основі світлодіодних джерел і розробити методику для її використання. Зокрема, виділити і стандартизувати дві основні форми періодичного сигналу під час дослідження: синусоїдальну та прямокутну. Для визначення частотної залежності чутливості люксметра необхідна синусоїдальна форма з діапазоном частот від 5 до 300 Гц. Для оцінки середніх величин освітленості пропонується використання прямокутної форми сигналу в режимі зі зміною шпаруватості та з рівномірним розподілом сигналу.

Ключові слова: спектр; випромінювання; невизначеність; люксметр; світлодіод.

Разработка стандартных условий измерения освещенности

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Аннотация

Предложены основные направления по разработке стандартных условий измерения освещенности, в результате выполнения которых пользователи люксметров получат характерные неопределенности типа В для широкого спектра стандартизированных условий работы. Предлагается разработать табличные спектральные распределения пяти групп источников света. Среди них: стандартные спектры типа А, С, D_{50}, D_{55}, D_{65}, D_{75}; газоразрядные источники света с примесями и люминофорами, светодиодные источники на основе белых люминофорных светодиодов с корреллированными цветовыми температурами от 2360 до 8300 К и монохроматические светодиоды с полосами излучения 380–470 нм и 650–760 нм; источники УФ и ИК излучения. Для последней группы предложено разработать аппаратуру на основе светодиодных источников УФ и ИК излучения и разработать методику их применения для характеризации неугнетенной чувствительности люксметров за V(λ).

Для оценки составляющих неопределенности, связанных с периодической составляющей освещения, предлагается реализовать аппаратуру на основе светодиодных источников и разработать методику для ее использования. В особенности, выделить и стандартизировать две основные формы периодического сигнала во время исследования: синусоидальную и прямоугольную. Для определения частотной зависимости чувствительности люксметра необходима синусоидальная форма с диапазоном частот от 5 до 300 Гц. Для оценки средних величин освещенности предлагается использование прямоугольной формы сигнала в режиме со сменой скважистости и с равномерным распределением сигнала.

Ключевые слова: спектр; излучение; неопределенность; люксметр; светодиод.

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