1.Sabir BAGHİROV[1], 2.Oleksandr PİTİAKOV[2], 3.Svitlana SHPAK[3], 4. Svitlana KYSLYTSİA[4], 5.Tamara SAKHNO[5], 6.Hryhorii KOZHUSHKO[6]

Azerbaijan Technical University (1)
Kharkiv Polytechnic Institute, Separate Structural Subdivision of "Poltava Polytechnic Vocational College of the National Technical University"(2)
State Enterprise of "Poltava Regional Scientific and Technical Center for Standardization, Metrology and Certification" (3)
National University "Yuri Kondratyuk Poltava Polytechnic" (4, 5)
Poltava State Agrarian University (6)
ORCID: 1. 0000-0001-9411-1374; 2. 0000-0001-9306-4246; 3. 0000-0002-1417-3944; 4. 0000-0002-2431-9900; 5 0000-0001-7049-4657; 6. 0000-0002-7306-4529.

doi:10.15199/48.2023.12.22

Research of Problems Flicker Level of LED Lamps and Luminaires for General Lighting

Abstract. *The paper presents the results of the study of flickering brightness and stroboscopic effect of commercial samples of light-emitting diode (LED) lamps and lamps entering the market from various manufacturers of lighting products. The criteria for assessing the compliance of the flicker level and the probability of detecting the stroboscopic effect are the short-term parameter of flicker and the indicator of the visibility of the stroboscopic effect. The level of flickering was also evaluated in accordance with the recommendations of the standard of the American Institute of Electrical and Electronics Engineers (IEEE). When measuring the flicker parameters in the frequency range up to 80 Hz and the stroboscopic effect with light modulation up to 1.2 kHz, the spectrometer MK 350S was used and the metrics recommended in international standards. It has been shown that most of the tested LED lamps and luminaires for general lighting meet the requirements regarding the safe level of flickering brightness and the visibility of the stroboscopic effect. The studied samples mainly meet the higher requirements recommended in the American standard IEEE 1789:2015. On the basis of the obtained results, the conclusions were drawn that the modern technological capabilities of the production of LED products are able to provide the market in accordance with the established requirements. The achieved level of light flickering of LED sources is lower than that of any other types of sources for general lighting powered by an alternating current network.*

Streszczenie. *W artykule przedstawiono wyniki badań jasności migotania i efektu stroboskopowego komercyjnych próbek lamp z diodami elektroluminescencyjnymi (LED) oraz lamp wprowadzanych na rynek od różnych producentów produktów oświetleniowych. Kryteriami oceny zgodności poziomu migotania i prawdopodobieństwa wykrycia efektu stroboskopowego są krótkookresowy parametr migotania oraz wskaźnik widoczności efektu stroboskopowego. Oceniono również poziom migotania zgodnie z zaleceniami standardu Amerykańskiego Instytutu Inżynierów Elektryków i Elektroników (IEEE). Do pomiarów parametrów migotania światła w zakresie częstotliwości do 80 Hz oraz efektu stroboskopowego z modulacją światła do 1,2 kHz wykorzystano spektrometr MK 350S oraz metryki zalecane w normach międzynarodowych. Wykazano, że większość badanych lamp i opraw LED do oświetlenia ogólnego spełnia wymagania dotyczące bezpiecznego poziomu migotania jasności oraz widoczności efektu stroboskopowego. Badane próbki spełniają głównie wyższe wymagania zalecane w amerykańskiej normie IEEE 1789:2015. Na podstawie uzyskanych wyników wyciągnięto wnioski, że współczesne możliwości technologiczne produkcji wyrobów LED są w stanie zapewnić rynek zgodnie z założonymi wymaganiami. Osiągany poziom migotania światła źródeł LED jest niższy niż innych typów źródeł oświetlenia ogólnego zasilanych z sieci prądu przemiennego. (**Badanie problemów poziomu migotania lamp i opraw LED do oświetlenia ogólnego**)*

Key words: flickering, LED, stroboscopic effect.
Słowa kluczowe: migotanie, LED, efekt stroboskopowy.

Introduction

In 2021, the European Union (EU) Commission Regulation 2019/2020 entered into force [1] which sets new requirements for lighting equipment. One of the features of this Regulation is that it introduces completely new requirements for the safe level of flicker and stroboscopic effect of LED light sources for the first time.

Flickering is a problem inherent in electric light sources powered by alternating current. The problem of flickering has gained new relevance after the widespread introduction of LEDs into lighting technology. Compared to incandescent lamps (IL) and luminescent lamps (LL), the flickering of LEDs is significantly different due to the extremely fast reaction of the change in their light flux to the change in current.

A change in the light flux over time can have both a visual and a non-visual effect on the observer. There are three types of visually noticeable phenomena associated with the change in light flux over time [2]:

-flicker-the perception of visual instability caused by a light stimulus, the brightness or spectral distribution of which fluctuates over time, for a static observer in a static environment;

-stroboscopic effect-change in motion perception induced by a light stimulus the luminance or spectral distribution of which fluctuates with time, for a static observer in a non-static environment;

-phantom array effect (ghosting)-change in perceived shape or spatial positions of objects, induced by a light stimulus the luminance or spectral distribution of which fluctuates with time, for a non-static observer in a static environment.

The general name of these phenomena is proposed in [2]-temporal light artifacts (TLA). Light sources that create TLA not only reduce the quality of lighting (create discomfort), but can pose a health hazard-cause fatigue, eye strain, reduce the performance of visual work, provoke headaches, migraines, create neurological problems such as epileptic seizures, strengthen autistic behavior of children, etc. [3-6].

Currently, several methods are widely used to estimate the level of flicker. At the same time, the following critical characteristics are taken into account [6]:

-MD brightness modulation depth (or flicker percentage), which is defined as:

$$MD\% = \frac{L_{\max} - L_{\min}}{L_{\max} + L_{\min}} \cdot 100 \tag{1}$$

where: $L_{\max}$, $L_{\min}$-are the maximum and minimum brightness values (Fig. 1), FI flicker index, which takes into account the waveform and is defined as:

$$FI = \frac{Area1}{Area1 + Area2} \tag{2}$$

where: Area1, Area2-are the areas under the curve that are above and below the average value of radiation intensity, respectively (Fig. 1), frequency f with which the radiation intensity changes, Hz.

In [7] it is noted that it is now important to understand how the TLA of LED light sources affect human health and how technological factors affect the TLA level of these sources, in particular, pulsations of the output current of rectifiers with different types of filters, the use of dimmers, etc. Information about the level of TLA created by LED lamps and lamps for general lighting supplied to the market is also relevant.

This paper presents the results of research into the level of flickering and the stroboscopic effect of commercial samples of LED lamps and lamps for interior lighting using the criteria and metrics recommended in [1].

A large number of scientific works are devoted to the study of the influence of TLA on the quality of lighting, well-being and health of people. Works [3-7] summarize the results of studies of the influence of brightness flicker on biological processes and the conditions of their occurrence. In particular, it is noted that in the frequency range of 0.05–80 Hz, the risks include convulsions in persons with a diagnosis of epilepsy, as well as some specific neurological symptoms, including malaise and headache. Less obvious biological effects occur under the action of invisible flickering. This is eye strain, fatigue, headache. Point light sources are less likely to cause seizures and headaches than diffuse light that covers most of the retina. Epileptic seizures are most likely to occur at frequencies of 15-20 Hz. Flickering red light with a large modulation depth and alternating red and blue flashes can be particularly dangerous.

Brightness flicker depends on the parameters of the drivers used in lamps and lights, lighting control systems (dimmers) and other external influences (voltage quality in the power grid, electrical interference created by various consumers of electricity, and others). The greatest negative impact of flickering is on the general lighting of residential premises, children's, school and medical facilities, industrial premises with moving machinery and workplaces with intense visual work, etc.

Methods for evaluating the level of light flickering are recommended in the following documents [6, 8-12].

The American IEEE in [6] summarized the data of many independent studies and formulated the following safety criteria for MD modulation levels:

1) at frequencies lower than 80 Hz should not exceed the numerical values (in percent) determined from the expression:

(3) $$MD\% < 0.025\,f$$

2) at f > 80 Hz, the permissible depth of modulation is determined from the expression:

(4) $$MD\% \le 0.08\,f$$

The criteria established by expressions (3, 4) are graphically shown in Fig. 2 [6]. The level of modulation, at which there are no biological effects on the human body, should be 2.5 times lower than that determined by expressions (3) and (4). The flicker index (FI) is used to account for waveform fluctuations. It sets the change in brightness during the period in relation to its average value. For low risk, FI should not exceed a value of 0.1.

Based on the criteria formulated in [6] the following practices are recommended:

1. To limit possible adverse biological effects, the modulation depth should not exceed 0.025 f for frequencies below 80 Hz. In the frequency range of 80 Hz-1250 Hz, the modulation depth should be numerically less than 0.08 f; there are no restrictions on modulation depth above 1250 Hz;
2. If it is necessary to ensure the level of no observable effect level (NOEL)-there is no biological effect on the human body, then the modulations should be reduced by 2.5 times compared to recommended practice 1, i.e.:

-below 80 Hz-the modulation depth should be less than 0.01f;
-in the range from 80 Hz to 3000 Hz-the modulation depth should be less than 0.0333 f %;
-above 3000 Hz-there are no restrictions.

3. (Prevention of photosensitive epileptic seizures). The modulation depth for frequencies below 80 Hz should be less than 5%.

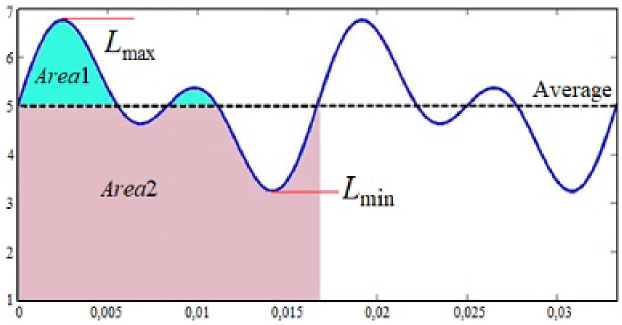

Fig.1. Diagram for determine the depth of MD brightness modulation and FI flicker index

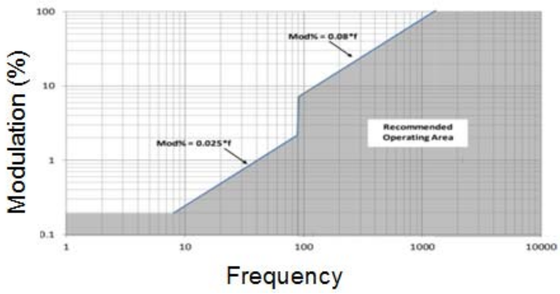

Fig.2. Recommended permissible level of modulation depth depending on frequency

The main drawback of the flicker estimation method given in [6] is that it does not take into account the human perception of flicker depending on the frequency.

In [8], an objective method is recommended for evaluating flicker, taking into account its perception by the observer at different frequencies in the range from 3 Hz to 60 Hz.

In Fig. 3 shows the threshold values of the modulation depth depending on the detection frequency with a probability of 50% [8]. As can be seen from Fig. 3, at a frequency of 15 Hz, an observer can detect a flicker with a relative modulation depth of 0.5%, while at a frequency of 60 Hz, a modulation depth of almost 60% is required to detect a flicker. The resulting modulation values for each frequency are expressed in terms of detection thresholds and denoted as M_{rk}. The perceived modulation corresponding to the threshold value (detected with a probability of 50%) is taken as one.

At values smaller than one, it is practically impossible to detect flickering, and at significantly higher values, it is easy to detect. If the flicker in the interval 3 Hz-60 Hz has different frequencies, then the resulting perception of modulation M_r is determined as:

(5) $$M_r = \sqrt{\sum_k (M_{rk})^2}$$

where k=1, 2, 3 …

The resulting value of M_r is interpreted in the same way as M_{rk} for individual frequencies:

with M_r = 1-threshold values detected with a probability of 50%; at M_r<1-flickers are not visible;

at M_r>1-flickering is easy.

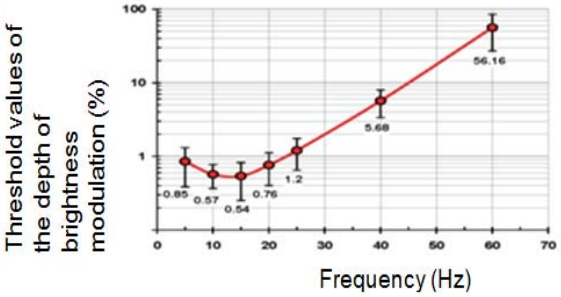

Fig.3. Threshold values of the depth of brightness modulation at different frequencies

In [10], an objective method for evaluating light flickering is described, using a flickermeter, based on standards that establish measurement methods and requirements for devices for accurate perception of voltage fluctuations. Flicker in the frequency range of 0.05 Hz-80 Hz is estimated by the short-term flicker indicator (P_{st}^{LM}), which takes into account the shape and frequency of the wave. The method simulates a person's visual response to flickering light, using a model of a 60 W incandescent lamp as a reference source. The P_{st}^{LM}, the typical measurement time of which is 10 min, characterizes the resistance of the light source to flicker caused by voltage fluctuations. The interpretation of the test results is as follows:
at P_{st}^{LM}=1 the investigated light source has a flickering level that the observer detects with a probability of 50%, such as in incandescent lamps with a power of 60 W;
-at P_{st}^{LM}<1-the light source has a flickering level lower than that of incandescent lamps with a power of 60 W;
-at P_{st}^{LM}>1-the level of flickering is higher than that of incandescent lamps and it is easy to detect.

As for the evaluation of the stroboscopic effect, the objective method of measuring the visibility of the stroboscopic effect (SVM) is proposed in the standard [11]. The conditions for the occurrence of the stroboscopic effect considered in this document are limited to the assessment at illumination of more than 100 lux and at moderate object speeds (<4 m/s). SVM does not assess the health effects of flickering and is not a measure to assess unwanted stroboscopic effects in industry. The method is designed to evaluate TLA in offices, residential premises and similar conditions.

Numerical values of SVM can range from 0 to 9. With SVM=0, there is no light modulation of any kind, while with SVM≈9 the rectangular shape modulation (with infinitesimal pulse duration) is 100%.

SVM is an objective indicator obtained on the basis of laboratory studies and studies on the detection of thresholds for the perception of the stroboscopic effect by people. The sensitivity to the detection of the stroboscopic effect at different frequencies is shown in Fig. 4 [11].

The SVM measurement results can be interpreted as follows:
-with SVM=1-the stroboscopic effect created by light modulation is at the threshold of visibility. This means that the average observer can detect the stroboscopic effect with a probability of 50%;
-if the value of SVM<1, then the probability of detection is less than 50%, and if SVM>1, then the correspondence will be higher than 50%.

It should also be noted that the level of perception of TLA can be much higher than the limit of visibility. Perception depends on the duration of the exposure, the speed of the object and other factors.

Fig.4. Dependence of the relative sensitivity of the perception of the stroboscopic effect on the light modulation frequency

A comparison of the requirements of various normative documents for a safe level of flickering shows that they are the strictest in the standard [6]. Even incandescent lamps with a modulation depth of 12-15% at 100 Hz do not meet the requirements of Recommended Practice 1 of this standard. Therefore, in a number of publications, instead of the MD and FI indicators proposed in [6], it is proposed to use the P_{st}^{LM} [10] to estimate the flicker level, and for the stroboscopic effect, the visibility of the stroboscopic effect SVM [11]. These requirements are less strict, take into account the frequency, waveform and which can actually predict the visibility of flickering and stroboscopic effect.

These levels for LED lamps and general lighting luminaires are: P_{st}^{LM}≤1; SVM≤0.9.

In [12], a new technique for measuring flickering brightness of LED light sources is proposed, which, unlike other techniques, takes into account the amplitude of all frequencies affecting a person and expresses them in a single percentage value.

This unit is called Compact flicker degree (CFD).

Flicker in the range of 1%<CFD<12% is practically imperceptible to humans and corresponds to the flickering of an incandescent lamp. For CFD<1 % there is practically no flickering and the light source is suitable for lighting during filming.

At 12 %<CFD<25% the flicker level is barely perceptible to humans, which satisfies the requirements for lighting public places, but is not suitable for office lighting.

At 25%<CFD<50% flickering is noticeable after prolonged exposure and can cause discomfort. Possible stroboscopic effects. Lighting with this level of flickering is less suitable for general use and long-term work. Suitable for lighting parking lots, underground garages, etc.

At 50%<CFD<75 % the light is classified as hazardous for work and should be avoided. More than 50% of people perceive the stroboscopic effect, feel discomfort and headache.

For CFD>75 % strong stroboscopic effects are perceived by more than 75% of people. Long-term exposure leads to deterioration of the physical condition of people, there is a risk of epileptic seizures. The light is classified as a work hazard and should be avoided. Flickering red light is especially dangerous.

At CFD>100% extremely strong stroboscopic effects occur. Each movement can be recognized only in individual components. The light is classified as hazardous for lighting, but can be used for discotheques.

CFD metrics are quite complex and require calculations using a powerful computer. Currently, this metric is used by individual manufacturers to additionally characterize the level of flickering and stroboscopic effect of their products and is considered promising.

Table 1. The results of measuring parameters of light brightness flickering and the indicator of the visibility of the SVM stroboscopic effect of LED lamps and luminaires

Name Product	Sample Number	P_{st}^{LM}, relative unit	SVM, relative unit	Dominant flicker frequency, Hz	Modulation depth, %	Flicker index, relative units
LED lamps for interior lighting	1	0.0443	0.0096	100	1.95	0.0021
	2	0.0320	0.0013	1020	0.98	0.0044
	3	0.0785	0.0103	100	2.05	0.0020
	4	0.0621	0.0107	100	1.10	0.0022
	5	0.0941	0.2152	100	4.07	0.0205
	6	0.0632	0.0052	100	1.03	0.0014
	7	0.0450	0.0254	100	2.36	0.0032
	8	0.0325	0.0099	100	1.82	0.0033
	9	1.2105*	0.0885	100	4.500	0.1453
	10	0.0910	0.0884	100	5.91	0.0081
	11	0.0280	0.0111	100	1.64	0.0031
	12	0.0780	0.0697	100	2.60	0.0058
	13	0.2130	1.6305*	100	43.3	0.1304
	14	0.4600	2.1507*	100	49.0	0.1740
	15	0.0644	0.0397	400	22.30	0.0326
LED lamps	1	0.3627	0.0219	100	12.9	0.0355
	2	0.2726	0.0212	100	10.8	0.0350
	3	0.0532	0.0107	100	2.0	0.0220
	4	0.0568	0.0121	100	3.3	0.0025
	5	0.0540	0.0115	100	3.31	0.0053
	6	0.0405	0.0415	2208	14.95	0.0353
	7	0.0430	0.0553	1766	14.28	0.0355
	8	0.0791	0.0345	100	3.41	0.0049
	9	0.0316	0.0502	100	1.11	0.0263
	10	0.0459	0.0092	100	2.0	0.0022
	11	0.0430	0.0434	2204	15.73	0.0354
	12	0.9228	0.0214	50	4.01	0.0043
	13	0.0713	0.0423	1286	14.1	0.351
	14	0.0852	0.0317	465	0.32	0.0318
	15	0.0468	0.0096	100	2.0	0.0220

Research into the causes of brightness modulation and its level in LED lamps and-luminaires was carried out in many scientific works, in particular in [6,13-16]. The main causes of flickering are: defects in the design of the drivers, the technology of adjusting light parameters with the help of dimmers using pulse width modulation, fluctuations in the voltage of the power supply network and interference caused by various electrical consumers connected to the power supply network and others.

The factors that determine the visibility of TLA depend on the depth of light modulation, frequency, wave form, as well as on the brightness, color of light, angle of the field of view, and others.

The purpose of this work is to study the level of flicker parameters and the stroboscopic effect of industrial samples of LED lamps and luminaires entering the lighting market.

Results

Commercial samples of LED lamps and luminaires for general lighting from various manufacturers were studied. The P_{st}^{LM} was measured in accordance with the requirements of the international standard IEC TR 61547-1:2020 and the visibility index of the stroboscopic effect SVM in accordance with IEC TR 63158:2018, as well as the modulation depth MD and the flicker index FI in accordance with the recommendations of the standard of the American IEEE 1789:2015.

For complex measurements of flicker and stroboscopic effect, a number of devices have been developed today that provide TLA measurements in accordance with the recommendations of CIE TN 012:2022 [17], in particular, BTS 256-EF [18] and MK 350S [19]. In addition to photometric and colorimetric measurements, the sensors of these devices allow the analysis of flicker parameters, since the diodes used in the sensor can perform measurements in the same way as with an oscilloscope. In addition to calculating flicker parameters, the devices perform a fast Fourier transformation. This makes it possible to detect other frequency components in the signal. The devices display the six most dominant frequency components. With the help of special software, these devices determine both $P_{st}^{LM}$and SVM indicators.

In this paper, measurements of flickering and stroboscopic effect parameters were performed using a MK 350S spectrometer and an integrating photometric sphere in accordance with CIE TN 012:2021 guidelines.

The results of P_{st}^{LM}, SVM, MD and FI measurement of LED lamps and luminaires are shown in Table 1.

*Selected values of P_{st}^{LM}, SVM parameters do not meet the requirements of the EU Commission Regulation 2019/2020

In order to compare the parameters of flickering and the stroboscopic effect of LED light sources with similar parameters of incandescent lamps (IL) and compact luminescent lamps (CLL), commercial samples of these lamps were studied. Some results of the study are shown in Table 2.

As can be seen from Table 1, most of the tested samples of LED luminaires and all LED lamps according to the level of $P_{st}^{LM}$and SVM indicators meet the requirements of the EU Commission Regulation 2019/2020 (P_{st}^{LM}≤1, SVM≤0.9). It should be noted that they are lower than in LR and CLL.

Table 2. The results of measuring parameters of light brightness flickering and the indicator of SVM incandescent lamps and compact luminescent lamps

Name Product	Sample Number	P_{st}^{LM}, relative unit	SVM, relative unit	Dominant flicker frequency, Hz	Modulation depth, %	Flicker index, relative units
Incandescent lamps	1	0.0192	0.4953	100	13.1	0.04110
	2	0.0243	0.3778	100	14.7	0.0338
	3	0.0219	0.4590	100	15.3	0.0392
Compact luminescent lamp	1	0.2619	0.1912	100	7.92	0.0164
	2	0.2605	0.2005	100	8.10	0.0193
	3	0.3441	0.2152	100	10.70	0.0205

As for the compliance of LED lamps and luminaires with the stricter requirements of IEEE 1789:2015, the value of MD brightness modulation for the tested lamps also mostly does not exceed the recommended levels that can create adverse biological effects (MD %≤0.025f for frequencies lower than 80 Hz and MD %≤0.08f for frequencies 80-1250 Hz).

Most luminaires provide the NOEL level (absence of any biological effects on the human body: MD %≤0.001f for frequencies below 90 Hz and MD %≤0.0333f for frequencies 90–3000 Hz).

Flickering of the brightness of LED lamps and luminaires powered from the alternative current network is not a problem of the LEDs themselves, but related to the power supply devices (drivers).Drivers convert alternating current into direct current, among other functions. This conversion is never perfect, always creating a certain ripple in the output current, which in turn creates a modulation of the brightness of the light. Manufacturers sometimes, in order to reduce the cost of LED lamps and luminaires, use cheap, low-quality drivers, so a high level of flickering is primarily a problem of cheap LED products. The disadvantage of LED lamps and luminaires is that the depth of modulation in them, depending on the driver parameters, can be from 0% to 100%, while in IL and CLL with high-frequency electronic devices-no more than 15%. The problem here is that LED products with a high level of flickering brightness do not reach consumers. To solve this problem, established mandatory requirements for the flickering parameters of LED products, which must be monitored and declared by manufacturers. The use of LED lamps and luminaires with flickering parameters set in [1] allows you to ensure sanitary norms regarding flickering recommended for indoor lighting [20].

Today, the efforts of developers and manufacturers of LED products are aimed at increasing energy efficiency while simultaneously ensuring the quality of light-natural color, high quality color rendering, visual comfort, prevention of adverse factors such as light flickering, its photobiological hazard, as well as ensuring a beneficial non-visual effect that does not violate natural biological human rhythms.

The urgent tasks of further improvement of LED lighting are the creation of intelligent lighting systems with automatic adjustment of photometric and colorimetric parameters that provide the necessary indicators of light quality and safety with high energy efficiency and reliability.

Conclusions

1. Factors affecting the biological and psychological effects of flickering light brightness on the well-being and health of people depend on the frequency, depth of brightness modulation, as well as on the waveform of alternating current, brightness and spectrum of light, the angle of the field of view. The negative effect of brightness flicker occurs in the frequency range up to 3000 Hz. The most dangerous is flickering, which is caused in the frequency range up to 80 Hz;
2. The establishes criteria for assessing the level of flickering and stroboscopic effect: P_{st}^{LM}; SVM.
3. The studied commercial samples of LED lamps and luminaires mainly meet the requirements. Modern technological possibilities for the production of LED products are able to provide the market in accordance with the established requirements regarding safe levels of flickering and stroboscopic effect;
4. The level of flickering of modern LED lamps and luminaires for general lighting is lower than that of any light sources powered by an alternating current network, including discharge lamps with high-frequency electronic ballasts.

Authors: Sabir Baghirov, *Email:*sabir.bagirov.61@mail.ru;
Oleksandr Pitiakov, *Email: opitiakov@polytechnic.poltava.ua*;
Svitlana Shpak, *Email: ndcvel.to@gmail.com*; Svitlana Kyslytsia, *Email:* kislicasv@ukr.net;
Tamara Sakhno, *Email: sakhno2003@ukr.net; Hryhorii Kozhushko,Email:* kozhushkogm@gmail.com

REFRENCES

[1] Commission Regulation (EU) 2019/2020 of 1 October 2019 laying down ecodesign requirements for light sources and separate control gears pursuant to Directive 2009/125/EC of the European Parliament and of the Council and repealing Commission Regulations (EC) No 244/2009, (EC) No 245/2009 and (EU), 2019, No. 1194/2012, 32.
[2] CIE TN 006:2016, Visual Aspects of Time Modulated Lighting Systems-Definitions and Measurement Models, 2016, 23.
[3] Lehman B., Wilkins A.J., Designing to Mitigate Effects of Flicker in LED Lighting: Reducing risks to health and safety, IEEE Power Electronics Magazine, 1 (3), 2014, 18-26. DOI:10.1109/MPEL.2014.2330442
[4] Wilkins A., Veitch J., Lehman B., LED lighting flicker and potential health concerns: IEEE standard PAR1789 update, Proceedings of 2010 IEEE: Energy Conversion Congress and Exposition, 2010, 171-178. DOI:10.1109/ECCE.2010.5618050
[5] Fisher R.S., Harding G., Erba G., Barkle G.L., Wilkins A., Photic-and Pattern-induced seizures: A Review for the Epilepsy Foundation of America Working Group, Epilepsia, 46 (9), 2005, 1426-1441. DOI:10.1111/j.1528-1167.2005.31405.x
[6] 1789-2015-IEEE, Recommended Practices for Modulating Current in High-Brightness LEDs for Mitigating Health Risks to Viewers, IEEE, 2015, 80. DOI:10.1109/IEEESTD.2015.7118618
[7] CIE TN 008:2017, Final Report CIE Stakeholder Workshop for Temporal Light Modulation Standards for Lighting Systems, 2017, 25.
[8] Recommended metric for assessing the direct perception of light source flicker, ASSIST recommend, Alliance for Solid-State Illumination Systems and Technologies, 11 (3), 2015, 18. https://www.lrc.rpi.edu/programs/solidstate/assist/recommends/flicker.asp.
[9] NEMA 77-2017, Temporal Light Artifacts: Test Methods and Guidance for Acceptance Criteria, NEMA, 2017, 50.
[10] IEC TR 61547-1:2017, Equipment for general lighting purposes - EMC immunity requirements-Part 1: An objective light flickermeter and voltage fluctuation immunity test method, 2017, 39.
[11] IEC TR 63158:2018, Equipment for general lighting purposes - Objective test method for stroboscopic effects of lighting equipment, 2018, 35.
[12] Erwin P., Shackle P., A new flicker metric and its application to ac led light engines, LEDs Magazine, 14 (4), 2017, 55-66.
[13] Shpak S., Kyslytsia S., Kozhushko G., Sakhno T., Bagirov S., Flickering light and stroboscopic effect from LED lamps and light fixtures, Control, Navigation and Communication Systems. Academic Journal, 2(60), 2020, 135-143. DOI: https://doi.org/10.26906/SUNZ.2020.2.135
[14] Castro I., Vazquez A., Arias M., Lamar DG., Hernando M.M., Sebastian J., A review on flicker-free AC-DC LED drivers for single-phase and three-phase AC power grids, IEEE Transactions on Power Electronics, 34 (10), 2019, 10035-10057. DOI: 10.1109/TPEL.2018.2890716
[15] Neyezhmakov P., Pitiakov O., Shpak S., Baghirov S., Sakhno T., Kozhushko G., Luminance flicker of LED lamps and lighting fittings for general lighting, Ukrainian Metrological Journal, 2022, No 3, 33-42. DOI:https://doi.org/10.24027/2306-7039.3.2022.269747
[16] Perumal S.R, Baharum F., Measurement, Simulation, and Quantification of Lighting-Space Flicker Risk Levels Using Low-Cost TCS34725 Colour Sensor and IEEE 1789-2015 Standard, Journal of Daylighting, 8 (2), 2021, 239-254. DOI: https://dx.doi.org/10.15627/jd.2021.19.
[17] CIE TN 012:2021, Guidance on the Measurement of Temporal Light Modulation of Light Sources and Lighting Systems, 2021, 16. DOI: 10.25039/TN.012.2021
[18] BTS256-EF High Accuracy Flicker Meter and General Lighting Spectral Luxmeter https://www.gigahertz-optik.com/en-us/product/bts256-ef/
[19] MK350S Premium Spectrometer, https://www.uprtek.com/en/product/spectrometers/mk350s-premium
[20] EN 12464-1:2021, Light and lighting-Lighting of work places-Part 1: Indoor work places, 2021, 117.