METHOD OF REPRODUCTION OF THE LUMINOUS FLUX OF THE LED LIGHT SOURCES BY A SPHERICAL PHOTOMETER

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Abstract In connection with transition to energy-efficient temporally stable light-emitting diodes (LEDs) lighting, a problem of ensuring the traceability of results of measurement of characteristics of light sources arises. The problem is related to existing measurement standards of luminous flux based on spherical photometers optimized for the reference incandescent lamps with a relative spectral characteristic different from the spectrum of the LEDs. We propose a method for reproduction of the luminous flux, which solves this problem.

1. Introduction
Calibration of photometric lamps in the leading laboratories of the world is performed using spherical photometers [1-4]. They are typically represented as a sphere with a diameter of 1.5 meters or more. Inside they are coated with BaSO₄ or spectralon having close to 1 diffuse reflectivity in the visible spectrum and scattering phase function, close to equal. As an example, Figures 1 and 2 show the spherical photometer of the national primary standard of luminous flux of Ukraine.

Figure 1. Spherical photometer of the national primary standard of luminous flux of Ukraine
A photodiode with a correction filter and milk glass, which reduces the angular dependence of the sensitivity of the receiver, is fixed to the wall of the sphere. At this, relative spectral sensitivity of the spherical photometer can be represented as:

\[ S_{\text{sph.rel}}(\lambda) = S(\lambda) \cdot \tau_{mg}(\lambda) \cdot \tau_{f}(\lambda) \cdot \frac{\rho(\lambda)}{1-\rho(\lambda)} \]  

(1)

Where \( S(\lambda) \) is relative spectral sensitivity of the photodiode, \( \tau_{mg}(\lambda) \) is spectral transmittance of the milk glass, \( \tau_{f}(\lambda) \) is spectral transmittance of the correction filter, \( \rho(\lambda) \) is spectral diffuse reflectance of the wall of the sphere.

Such design allows to install the lamps to be measured inside the sphere and to measure its full luminous flux, provided prior calibration of the spherical photometer by a known directional luminous flux.

Figure 3 shows a diagram of reproducing the unit of luminous flux.

For the calibration of spherical photometers, either reference lamps with known luminous flux (type A source) or measured pre-focused light flux from type A source are used. Then calibrated photometers measure the filament lamps with spectral characteristics close to type A source [1 - 4]. The actinic coefficient of spherical photometer to directional light flux is determined by the expression:

\[ A = \frac{\int_{0}^{780} \Phi(\lambda) \cdot V(\lambda) \cdot d\lambda}{\int_{0}^{780} \Phi(\lambda) \cdot S_{\text{sph.rel}}(\lambda) \cdot d\lambda} \]  

(2)

Where \( \Phi(\lambda) \) is relative spectral characteristic of the directional luminous flux.
The actinic coefficient of spherical photometer to the light flux of the calibrated lamp is determined by the expression:

$$A_I = \frac{\int_{480}^{780} \Phi(\lambda) V(\lambda) d\lambda}{\int_{0}^{\infty} \Phi(\lambda) S_{\text{sph.rel}}(\lambda) d\lambda}$$  \hspace{1cm} (3)$$

Where $\Phi(\lambda)$ is relative spectral characteristic of the luminous flux of the lamp to be calibrated. There will be no significant uncertainty of measurements even with the considerable difference $S_{\text{sph.rel}}(\lambda)$ from $V(\lambda)$ in the calibration of incandescent lamps. As $\Phi(\lambda)$ and $\Phi(\lambda)_l$ will be approximately the same for the incandescent lamps, the actinic coefficients of spherical photometer for directional light flux $A$ and light flux of lamp $A_l$ to be calibrated will approximately be the same.

But during calibration of the LEDs there can be significant problems due to the difference of their spectrum from that of incandescent lamps.

Even a slight change of $\rho(\lambda)$ with time leads to the considerable change of $S_{\text{sph.rel}}(\lambda)$ (this can be seen from the formula (1)), which begins to affect more its difference from $V(\lambda)$, and therefore the difference between actinic coefficients $A$ and $A_l$ increases.

This is confirmed by interlaboratory comparison (IC 2013) conducted by the International Energy Agency (IEA) with the participation of more than one hundred laboratories, which measured the LED sources and found that differences in the measured luminous fluxes were within ± 5%.

2. Method of realisation and transfer of the luminous flux unit to LEDs

Unlike a spherical photometer, the spectral responsivity of the trap-detector [5] with correction filter (Fig. 4 and 5) is well known, close to $V(\lambda)$, and can be investigated on the spectrophotometer radiometric standard. So it can be used to measure the directional luminous flux from the LED source with the accuracy not worse than that from an incandescent lamp.

It is proposed to use a LED lamp that is similar (by relative spectrum of radiation) to that to be measured as a source of directional luminous flux in the circuit in Figure 2 or to use the same lamp in both cases (Fig. 5).
Figure 4. Trap-detector with correction filter

Figure 5. Functional diagram of apparatus for reproduction and transmission of luminous flux to the LED sources

This allows to achieve the same actinic coefficient of spherical photometer for directional luminous flux and the LED lamp to be measured and will provide the necessary accuracy of measurement of luminous flux.
The creation of reference LED lamps is a very difficult task in view of the lack of long-term stability of the luminous flux of these lamps. In this connection, the following design of the reference lamps with high-stable incandescent lamps shown in Figure 6 is proposed for reproduction, transfer, and maintenance of the units of the measurement standards of luminous flux for LED sources. For the reference source of directional luminous flux, we propose to use a correction filter that provides the same spectral characteristic as that of a LED lamp (Fig. 6 (1)).

For the reference lamp that maintains the unit of luminous flux, we propose to use filters that adjust the spectral characteristics of luminous flux to the spectral characteristics of standard LED lamp (Fig. 6 (2)).

![Design of the reference lamps](image)

**Figure 6.** Design of the reference lamps: 1 – for directional light flux; 2 – for measurement inside of the spherical photometer

In this case, the functional diagram of reproduction and transmission of units of luminous flux for LED sources of radiation based on standard filament lamps with corrective filters is shown in Fig. 7.

![Functional diagram](image)

**Figure 7.** Functional diagram of apparatus for reproduction and transmission of luminous flux to the LED sources based on standard filament lamps with corrective filters
3. Conclusion

The proposed method of reproduction and transfer of the luminous flux will allow to reduce the uncertainty of measurements of luminous flux of LED sources to 1%.

References

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