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Measurement of Total Flux and Divergence of LED Radiation

Mihail V. Kirgetov[1], Eduard V. Kuvaldin[1,*], Anna A. Shulga[1]

[1]*Metrology department, S. I. Vavilov State Institute, St. Petersburg, Russia*

Abstract: *Three methods for measuring the total radiation flux of LEDs are described. There are recommendations for elimination measuring difficulties and measurement errors. A new method of measuring divergence of LEDs radiation was developed. The method uses generalized power and generalized beam diameter which are available for easy calculation. Specific recommendations for manufacture of installation units are described.*

Keywords: *Measurement, LED, radiation power, divergence, total flux*

1. INTRODUCTION

LEDs without built-in lenses emit in a wide angle reaching up to 180 degrees. The beam divergence of LEDs with lenses is 20 – 40 degrees. The easiest way to measure total radiation flux of LED is using a nearby radiation detector with a large receiving surface area. However, high power of LED radiation leads to a nonlinear mode of radiation detector operation. Glass filters in front of detector are impossible to use, because it is impossible to measure their transmittance in divergent radiation with a previously unknown divergence. The power meter of calorimeter type is suitable for this purpose. In most calorimeters the receiving element is located at some distance from input window. This limits field of view of device and does not allow to capture total flux of LED radiation. The standards [1,2] recommend two methods for measuring total radiation flux of LEDs. It provides General requirements for measuring devices and calculation formulas in form of integrals. In practice of measuring recommendations of standard is not enough. The measurement of radiation divergence is usually carried out by methods developed for laser radiation. These methods are suitable for measuring divergence of radiation at a great distance from source. Using of these methods for measuring divergence of LED radiation requires new methods of processing the measurement results. The article considers additional requirements for measuring devices, the order of measurements and methods of calculations.

2. MEASUREMENT OF LED TOTAL RADIATION FLUX

Order of measurements and calculations by three methods of measurement is presented below.

2.1. Method of calorimeter

Three main methods of measuring the total radiation flux of infrared LED with maximum radiation at the wavelength of 880 nm were examined. LED has a lens with diameter of 5 mm and operates in continuous radiation mode. A 3 mm diameter diaphragm could be placed in front of lens at a distance of 5 mm from lens. The whole structure is placed in a round case.

Measurement of calorimeter is performed by means of direct measurements. The receiving element of the calorimeter is made in form of a cone with a base diameter is 15 mm and depth of the entrance window is approximately 15 mm. This limits the divergence of measured radiation sources. Therefore, LEDs with diaphragms were measured. The conversion of LED radiation power without diaphragm was calculated by multiplying on conversion factor. The values of coefficient were obtained by measuring in an aluminum sphere with a diameter of 80 mm. The inlet of sphere was larger than inner ring in LED case. Flux Ratio without diaphragm and with diaphragm was 4.13.

2.2. Method of Photometric sphere

The method presents measuring LED radiation flux according to standard [1,2]. All recommendations for sphere construction are stated in standard. An aluminum sphere with a diameter is 35 mm and with a diameter of inlet and outlet holes is 5 mm and an internal screen was used in experiment. The radiation power was measured behind outlet hole of sphere with photodiode. Before measurement it was necessary to calibrate the sphere. LED radiation was reduced by diaphragm thus to obtain indication on photodiode without sphere at maximum linear measurement limit. This limit corresponded to photodiode load resistance of 100 kOhm. After that indication n_1 was taken. Then photodiode was installed behind outlet of sphere, and the diaphragm remained in front of inlet of sphere and n_2 indication was taken. Attenuation coefficient of radiation by sphere k is $k = n_2 / n_1$. Measured attenuation coefficient in sphere was 0.0030. It is enough to measure the most LEDs.

2.2.1. Method of recalculation of radiation flux from the radiation pattern

The LED was installed on the turntable thus to obtain maximum signal from photodiode by turn and tilt of LED. Long black cylinder, bounding field of view, was installed before photodiode. The distance L between receiver and emitter was measured. Calculations were carried out according to goniophotometer method from standard [1]. Equation from standard for calculating radiation flux is valid only for uniformly bright distribution of LED radiation. This roughly corresponds to emission of LED without a lens with open large emitting surface. Limits of integration in standard's equation are not defined. Calculation for LED with lenses and diaphragms was carried out by averaging radiation power at angle of 180 degrees.

Photodiode current I_d of maximum LED's radiation was measured. Flux in photodiode P_d was calculated via a responsibility of photodiode S_λ according to formula $P_d = I_d / S_\lambda$. Illumination on photodiode is $E = R_d / A$, where A is receiving area of photodiode. Luminous intensity is $I = E / L^2$. This is relative distribution of radiation flux in one plane of cross section of radiation pattern. Conventionally, it is called radiation intensity at maximum of LED radiation pattern I_0, since measured value is proportional to radiation intensity in this direction. Then average power of radiation in hemisphere was calculated with measured spatial distribution. Thereby the sum of all indications is divided by number of intervals in 180 degrees at selected step of indication. Then ratio k_1 was calculated by dividing average radiation power P_{av} on maximum radiation power in distribution I_0. If entire average flux in hemisphere is concentrated in solid angle of 1 steradian, it will be 2π times larger, and total value of correction factor will be $k = k_1 2\pi$. Then average power of radiation in angle of 1 steradian is equal to $I_0 k$. If it assumed that radiation of LED in mutually perpendicular planes of cross-section of radiation pattern is symmetrical, the total flux will be proportional to average radiation power in these planes. In this case, flux is $P_d = I_0^2$.

3. MEASUREMENT OF DIVERGENCE RADIATION OF LEDS

Measurement of divergence radiation of LEDs with lenses was carried out according to GOST 26086 – 84 [6]. There are two methods in the GOST: method of focal spots and method of two diaphragms. In both methods a diameter of scattering spot is measured: in the first – in absolute units, in the second – in relative units. For measuring divergence of LEDs both methods are suitable. There is presented the second as the most simple and not requiring expensive equipment. Before LED measurement specified additional requirements were set by diaphragm which eliminates scattering light or restricting the width of radiation diagram. The flux to be measured passes through this diaphragm with precisely measured diameter d. In the case of measuring the divergence by method of two diaphragms slit with detector behind it are installed at a distance L from the diaphragm (Fig. 1). The distance L is chosen thus the slit covers whole radiation flux. The width of slit is chosen so that passed flux is within linear mode of detector. The slit is moved in a plane perpendicular to optical axis of installation. The displacement step determines numbers of reference points in measurement. At each movement the radiation flux behind slit is measured.

In this way distribution of power density of LED radiation at the slit plane was determined. This distribution is characterized by a three-dimensional figure with the spatial coordinates x, y and power P along z coordinate. In the standard's method of measurement [4] this figure is obtained by multiple measurements at different points of plane by movement of diaphragm with detector behind it. To estimate the equivalent diameter, a cross-section of figure with a plane at some level from maximum power is being made. These calculations are time-consuming and result depends on given power reference level. Usually the reference level is not corresponding to physical meaning of divergence concept.

Detector signal depends on slit allocated area of distribution spot and on radiation power falling on the area. Dependence of power distribution from slit displacement coordinate is characterized by a two-dimensional graph in which the area of distribution spot allocated by slit is plotted along x-axis and radiation power along y-axis. On the x-axis, instead of area, sequence number of sampling could be plotted while moving slit in measurement time. This graph (Fig. 2) is similar to shape of voltage pulse or optical radiation power.

Power and pulse duration are uniquely characterize any power distribution of radiation in Figure 2, if these parameters are calculated by equations of generalized power P_g and generalized pulse duration t_g that are used in radio electronics [3] and adopted in the Russian standard for pulse photometry [4].

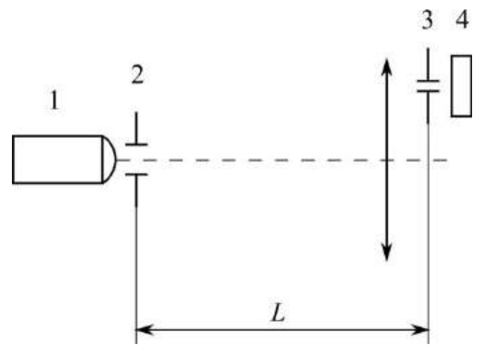

Figure 1. *Scheme of installation. 1 – LED, 2 – diaphragm, 3 – slit, 4 – photodiode*

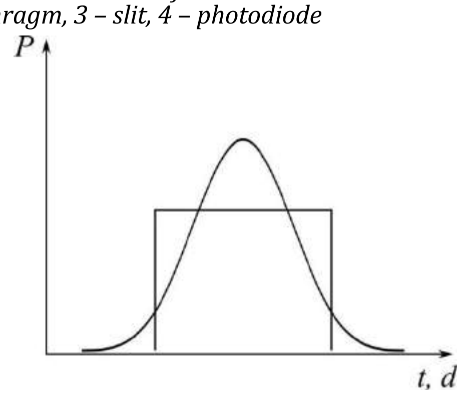

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Figure 2. *Real distribution of power and equivalent rectangular envelope*

In this case, the pulse duration t_g is replaced by diameter d_g of equivalent rectangle and height is replaced by generalized power P_g [5]. The area of real distribution and equivalent rectangle in Figure 2 are equal and proportional to radiation energy W during scanning. In a real three-dimensional distribution figure in slit plane, diameter d_g is equal to replacing diameter of cylinder. Parameters P_g and d_g or t_g uniquely characterize any real power density distribution at plane of slit distribution spot. Diameter d_g is minimum diameter of diaphragm through which entire flux will pass in case there is no additional scattering. This takes place at a great distance from radiation source. In this case power reference level in three-dimensional distribution figure is set automatically.

Parameters P_g and d_g are similar to generalized amplitude and generalized duration of electrical pulses, which properties and methods of calculation are discussed in detail in [3]. The generalized power and generalized duration of radiation pulse of arbitrary shape and arbitrary power density distribution over pulse are power and duration of equivalent radiation pulse having a rectangular envelope, the same power density at any point in its section and equal to measured pulse energy W and power square [3].

These calculations are conveniently carried out in the Excel program on computer as follows.

The measured power distribution on surface of slit plane is placed in a column B, scale of movement in mm within presence detector signal in column B is put in a column A. Sum of samples equal to radiation energy W in Figure 2 is calculated in column B. Each value in column B is squared and placed in column C. Sum of counts in column C corresponding to integral of power square is calculated. Calculation of generalized power P_g is made by dividing the sum of column C on the sum of column B. Sum of column B is put in square. The result is square of energy W^2. Generalized diameter d_g in units of discretion of samples is calculated by dividing energy in square W^2 on generalized power P_g. The resulting value of generalized diameter in unit's withdrawal of samples is multiplied on difference between any two adjacent values in column A. This permits to receive scale of movements in mm. All formulas are written in advance; therefore the measurement will immediately get final result. It is sufficient to calculate only generalized duration during measurement in the installation which replaces generalized diameter of scattering point. The concept of generalized power is not used in this installation, since relative measures of radiation fluxes are made. The generalized power is used only in intermediate calculations. The divergence of radiation D in radians in accordance with requirements of standard [6] is determined by formula $D = (d_g - d) / L$. Presented method is implemented in immediate vicinity of radiation source.

4. CONCLUSION

Considered methods of measuring radiation flux were used to measure the described LED. The total radiation flux of LED was measured with and without a built-in diaphragm. Ratio of fluxes without diaphragm and with it was equal to 4.13 in method of calorimeter. The ratio in method of measurement radiation flux through radiation pattern was obtained a value of 3.85. As a result total radiation flux by different methods were 5.4 mW in the case of calorimeter measurements, 7.5 mW in measurements of radiation pattern and 6.2 mW in measurement in sphere. Maximum divergence was 0.34. If this discrepancy is considered that maximum scale of measurement results is equal to confidence limit of random error of measured value ε, the mean square deviation from arithmetic mean $S = \varepsilon/t$, where t – Student coefficient. At the confidence probability P = 0.95 and number of measurements n = 5, t = 2,776. Since the scope of measurement results in this case is included in non-excluded systematic error of absolute measurements, the RMS S can be considered as boundary of error of measured value Δ without taking into account the sign. Then $S = \varepsilon / t = 0.1122$ and error of these measurements is $\Delta = \pm 0.061$.

The proposed method of measuring divergence uses a simple installation and allows quickly getting measurement result. The method could provide automating measurement process.

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