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Concept and implementation of H-V goniophotometer for fast measurement of luminous intensity distribution in C-γ system

***Abstract**. This article presents on-the-fly goniophotometer for fast luminous intensity measurements both in C-γ system and in H-V geometry realized in BOSMAL Automotive Research and Development Institute Ltd. Technical parameters achieved were compared with classic goniophotometer and commercially available solutions on the market. The factors affecting the accuracy of the measurement were analysed, obtained photometric data were validated.*

***Streszczenie.** Artykuł opisuje goniofotometr do szybkich pomiarów rozsyłu światłości w systemie C-γ i geometrii H-V opracowany w Instytucie Badań i Rozwoju Motoryzacji BOSMAL Sp z o.o.. Osiągnięte parametry techniczne odniesiono do klasycznego goniofotometru oraz zestawiano z osiągami komercyjnych rozwiązań dostępnych na rynku. Przeprowadzono analizę czynników wpływających na dokładność pomiaru oraz walidacje uzyskanych wielkości fotometrycznych. (**Koncepcja i realizacja goniofotometru H-V do szybkich pomiarów rozsyłu światłości w systemie C-γ**)*

Keywords: lighting technology, goniophotometer, fast luminous intensity distribution measurement
Słowa kluczowe: technika świetlna, goniofotometr, szybkie pomiary rozsyłu światłości

Introduction

Luminous intensity distributions are the most important properties of the luminaires. Photometric data included in photometric files are the basis for calculating required illuminance levels by lighting designers for indoor rooms and outdoor areas. Most common method for getting luminous intensity distributions is measurement using system based on goniometer and photometer's head called goniophotometer. In classic goniophotometer luminous intensity measurements in a given direction are performed point-by-point on specified angular grid, hence data acquisition time may last up to several hours depending on the number of measuring points. This measurement procedure is the effect of the hysteresis of the photoreceiver and the lack of synchronization between the goniometer rotation and mentioned photometric head. For this reason attempts are made to develop new, more efficient and flexible measuring methods. Nowadays, there many innovative measurement system solutions based on imaging luminance measuring device both in far and near field. In near field photometry, photometer's head is usually replaced by imaging photometer [1,2]. This solution allows to calculate photometric quantities like luminous intensity distribution and luminous flux from luminance distribution of lighting elements of the luminaire. Moreover, this type of goniophotometer reduce significantly dimensions of whole measurement system, however this test method is less accurate and may be used only for limited group of luminaires or light sources. Another interesting technical solution for measurements in far field is a system using imaging photometer, goniometer and transmission or reflection screen [3,4]. This method allows to obtain in short time spatial luminous intensity distributions with angular resolution up to 0.01° depending on measurement system geometry and equipment. Due to the very high angular resolution of obtained luminous intensity distributions, method is useful when testing front high and low beam vehicle lights. However, this method has some limitations: large dimensions of the test bench, the knowledge of spectral reflection or transmission coefficient of the screen and distribution of reflected or transmitted light via the screen (BRDF function) [3].

The next innovative measurement system is called "robogonio" due to the similarity to industrial robots. This solution allows near-field and far-field measurements of lighting devices in any geometrical system, but it is very expensive due to the complexity of the system [5].

Also on-the-fly goniophotometers appear in various configurations that often use additional spectroradiometer to increase accuracy and collect more data about lighting device [6].

In this article on-the-fly goniophotometer for fast spatial luminous intensity distribution measurements both in C-γ system for general lighting and H-V geometry for automotive lighting is presented.

Testing of luminaires for general lighting using H-V goniophotometer type

Depending of tested object, goniophotometers with different technical solutions and geometries are used [7]. A large part of the luminaires with LED light sources have negligible influence of their orientation on the luminous flux emitted [8]. It means that their orientation during the tests in most cases may be arbitrary and gives the opportunity to use a goniophotometer with a rotating tested object. An example of such a measurement system may be the H-V goniophotometer used usually for automotive lighting devices– Fig. 1.

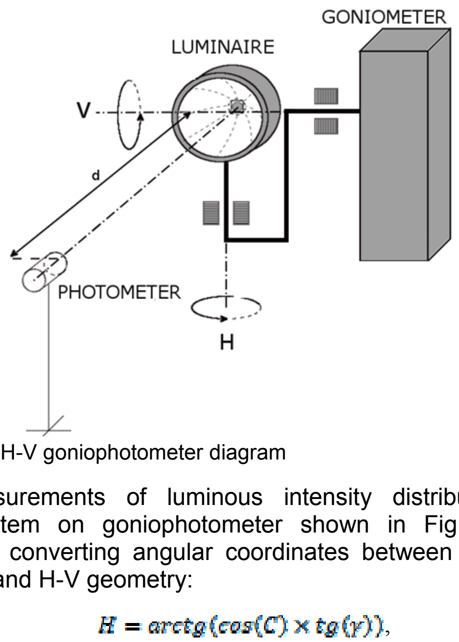


Fig.1. An H-V goniophotometer diagram

Measurements of luminous intensity distribution in C-γ system on goniophotometer shown in Fig. 1 are possible converting angular coordinates between the C-γ system and H-V geometry:

(1) $$H = arctg(cos(C) \times tg(\gamma)),$$

(2) $V = \arcsin(\sin(C) \times \sin(\gamma))$,

where: C,γ – direction of luminous intensity measured in C-γ system specified by half-plane C and γ angle; H,V – direction of luminous intensity specified by angles H (horizontal) and V (vertical).

In practice, measurements in the C-γ system on the H-V goniophotometer are characterized by a relatively long measurement time. The calculated H-V angles from the C-γ angular grid takes inconvenient values, and goniometer must often be positioned in two axes at once. What is more, the practical range of the angle V on the H-V goniophotometer is limited to a range of about from -90˚ to 90˚ due to the technical properties of the measurement system, hence it is not possible to obtain luminous intensity distribution of luminaire emitting light in the whole space at once. However, the measurement of luminous intensity in the C-γ system on the H-V goniophotometer is also possible when modifying the measurement geometry as shown in Fig. 2. This solutions based on rotation of native geometry of H-V goniometer by the 90˚ in V-axis significantly simplify the relationship between H-V geometry and C-γ system :

(3) $C = V - 90^{\circ}$,

(4) $\gamma = -H$.

Realization of the on-the-fly C-γ goniophotometer

Measurement system presented in this article was achieved applying geometry shown in Fig. 2 and implementing the on-the-fly goniophotometer developed in BOSMAL Research and Development Institute Ltd.
In order to synchronize photometer readings with rotation of goniometer the real-time controller as a core of the whole measuring system was implemented.

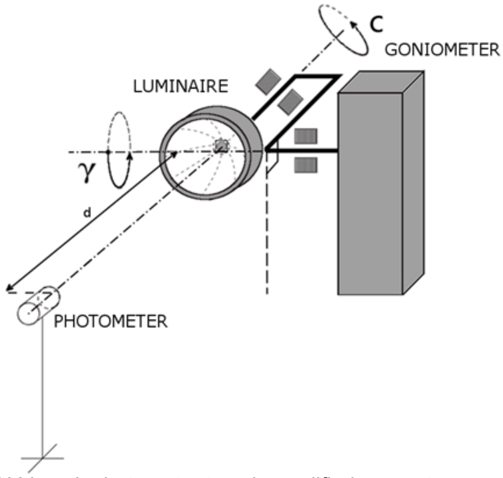


Fig .2. H-V goniophotometer type in modified geometry

The main parts of the system are:

- fast photometer with refresh frequency rate up to 10 kHz developed in BOSMAL Research and Development Institute Ltd. [9];
- 16-bit rotating encoders;
- EtherCAT module and programming stepper motors controllers for goniometer rotation control;
- other components like: data acquisition modules, stepper motors, transmissions.

Communication between the real-time controller with the module that manages goniometer motion and angle readings from the rotating encoders are carried out via the EtherCAT interface, which allows to transfer data between devices in real time. The modular diagram of realized on-the-fly goniophotometer was shown in Fig. 3.

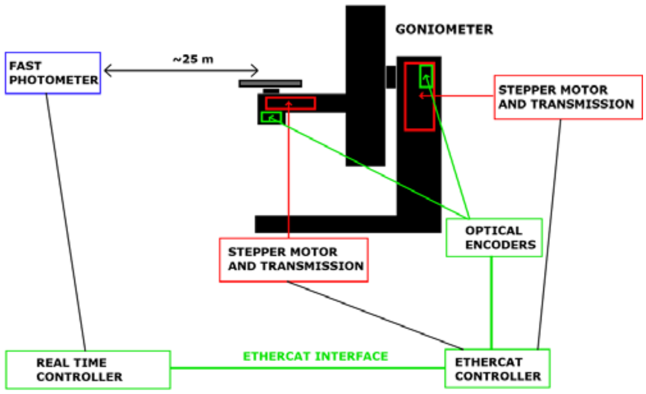


Fig.3. Block diagram of the on-the-fly goniophotometer

The software has been created in such a way that allows perform measurements both in H-V geometry and C-γ system. The final parameters of on-the-fly goniophotometer:

- scanning angular speed for C semi-planes up to 50°/s;
- C and γ resolution up to 0.01°, reproducibility <0.05°;
- γ angle range up to 150°;
- smooth accelerating and breaking during rotation;
- refreshing frequency of photometer from 200 Hz to 10 kHz.

Additional features and capabilities included in the software:

- remote control;
- observation photometric and electric parameters during lamp stabilization;
- automatic lamp pre-heating;
- point-to-point measurement on any measurement grid (also generated in .txt files);
- .ldt and .ies files generation;
- measurement of PWM light sources in on-the-fly and point-to-point measurement mode;
- goniophotometer coupling with DC, ADC power supply and power analyser;
- delayed start;
- automatic power disconnection;
- capability of goniospectroradiometric measurement on any grid,
- capability of measurement of effective intensity at any grid of flashing light sources;
- possibility of an auxiliary photometer implementation;
- automatic creation of luminous intensity charts and relative spectral distribution charts for goniospectroradiometric measurements.

The results of comparative tests

To show on-the-fly goniophotometer efficiency, the testing durations for exemplary luminaires on different angular grids were compared in Table 1. The applied scanning speed of on-the-fly goniophotometer was 15 ˚/s.

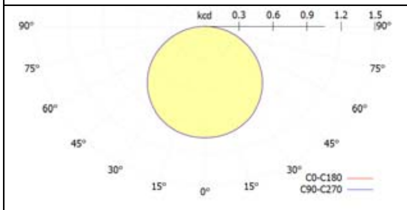
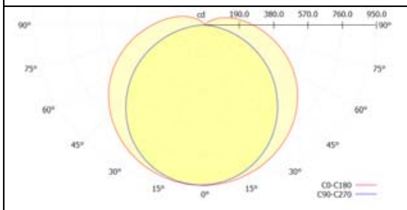
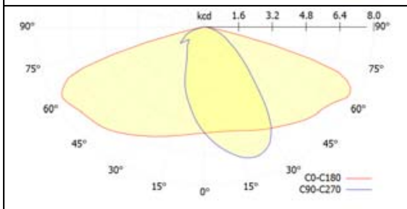
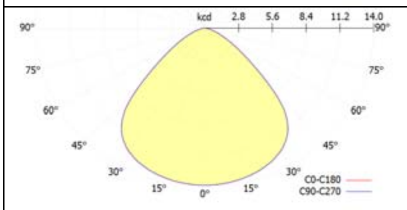
Table 1. Measurement duration for various angular grids

Angular grid			Measurement duration [min]	
number of C planes	γ angle range	number of meas. points	classic gonio-photometer	on-the-fly gonio-photometer
24	0˚- 90˚	1104	110	24
24	0˚- 150˚	1824	180	40
360	0˚- 90˚	32760	-	49
360	0˚- 150˚	54360	-	79

Moreover, in order to validate tests results obtained using on-the-fly goniophotometer, photometric quantities of various luminaires were compared. For this purpose, luminous fluxes calculated from luminous intensity distributions measured using both on-the-fly and classic goniophotometer were shown in Table 2 (“classic” – results obtained using classic goniophotometer, “on-the-fly” – using on-the-fly goniophotometer, Dev. – deviation between test results in %). The relative expanded uncertainty of luminous intensity measurement using classic goniophotometer: ±5% (for p≈0.95 and k=2 for normal distribution). The differences in the obtained luminous fluxes are insignificant

As a result of rapid reduction of the measurement time using on-the-fly goniophotometer, it becomes possible to obtain luminous intensity distributions with high angular resolution in a short time. For this purpose, luminous intensity distributions of exemplary lighting devices with high angular resolution in H-V geometry were presented in Figs 4 and 5.

Table 2. Comparison of luminous fluxes obtained using on-the-fly and classic goniophotometer

Luminous intensity distribution	Φ[lm]		Dev. [%]
	on-the-fly	classic	
	3674	3673	<0.1
	3557	3560	0.1
	16790	16710	-0.5
	30280	30400	0.4

Factors affecting measurement accuracy

Goniophotometer presented in this article allows to shorten the measurement duration several times, although, this solution is characterized by many factors affecting the accuracy of luminous intensity measurement. A very helpful analysis with practical guidelines about applied scanning speed of the “on the fly” goniophotometer was carried out in the article [6].

However, the following factors must be taken into account when determining the speed of goniometer rotation. Firstly, the rotation of luminaire with high angular velocity may disturb its temperature which can cause the luminous flux variations. For this reason, it is important to adjust proper scanning speed for tested luminaire. This is particularly important when testing lighting devices susceptible to temperature changes, e.g. with heat sinks and metal housing elements.

To estimate the effect of cooling resulting from the motion of the luminaire, a series of measurements with different rotational speeds from 5 ˚/s to 50 ˚/s were made. These tests were performed on plastic linear luminaires 150 cm length with total power up to 40W. The average external surface temperature of the luminaires after stabilization was near to 40˚C. Estimated luminous flux sensitivity on temperature changes of tested devices were 0.4 %/˚C (at 25 ˚C). The luminous flux relative differences calculated from luminous intensity distributions measured with scanning speed of 5 ˚/s, 15 ˚/s, 30 ˚/s and 50 ˚/s was lower than 0.5 % (the level of repeatability of the measurement system). However, a broader analysis for luminaires of various designs should be carried out.

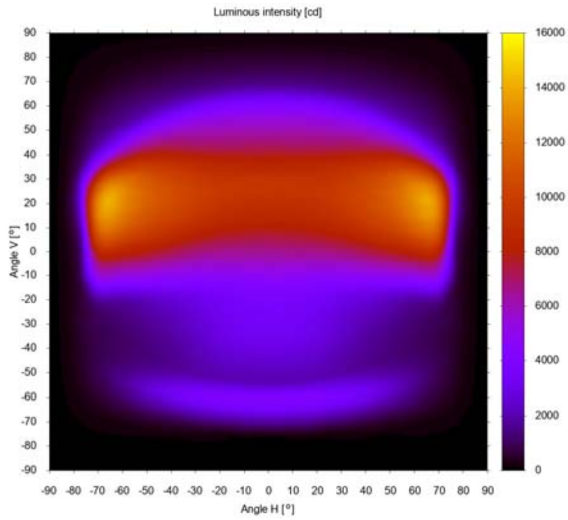


Fig .4. Luminous intensity distribution of road lighting luminaire – resolution 0.5˚

Table 3. Exemplary commercially available goniophotometers with on-the-fly measurement mode

Parameter	BOSMAL gonio-photometer	Instrument Systems AMS 5000*	LMT GO-H 1660*
angular resolution	0.01	0.01	0.01
angular reproducibility	<0.05°	<0.03°	0.01
photometry type	universal (CIE Type A and C)	CIE Type A	CIE Type A
axis drive	stepper motor	servo	DC motor
maximum scanning speed	up to 50°/s	up to 50°/s	up to 60°/s
scanning speed control	continuously controlled	16 selectable speeds	7 selectable speeds
smooth acceleration / deceleration	yes	no data	no data
measurement of PWM controlled light sources	yes (also in on-the-fly mode)	yes	no data
maximum sample mass	40 kg	80 kg	50 kg
remote control	yes	yes	no data

*technical data taken from the manufacturer's website or information brochures

Another problem is the light flickering. When measuring luminaires with significant luminous flux fluctuations over time caused by an alternating supply voltage, it is necessary to use an algorithm that calculates the average value of luminous intensity from one pulse cycle, which worsens the accuracy of luminous intensity measurement. This issue may also be omitted decreasing the scanning speed of the on-the-fly goniophotometer.

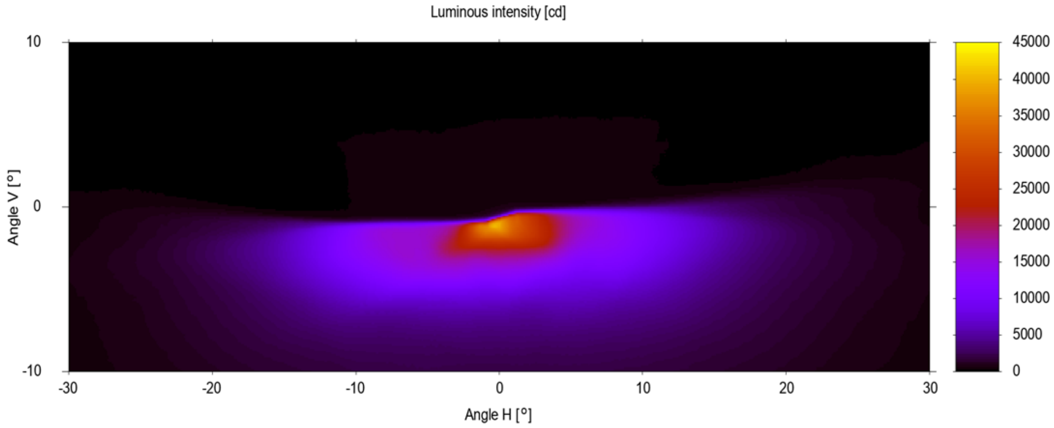


Fig.5. Luminous intensity distribution of headlamp (passing beam)– resolution 0.1˚

Conclusion

The use of the on-the-fly goniophotometer shortens the luminous intensity distribution measurement time significantly. The reduction of measurement duration allows obtaining photometric data on measurement grid with thousands of points with an angular resolution up to 0.1 ˚ in several dozen minutes. This feature is very useful when testing lighting devices with complex optics and irregular, luminous intensity distribution that changing sharply.

Going further, presented goniophotometer enables luminous flux measurement of luminaires with different shapes and luminous intensity distribution, while the same measurements using integrating sphere may require additional calibration to achieve the same accuracy.

On the other hand, on-the-fly measurements are more difficult and additional effects may appear that affect the accuracy of the measured values. Therefore, more experienced personnel to adjust scanning speed properly is needed. Mentioned problem can be also solved developing auxiliary photometer to track luminous flux changes during goniophotometer scanning

The next issue which can be taken to continue the topic is estimation of measurement uncertainty for high scanning's speeds. Therefore, the uncertainty of measurement for a wide group of luminaires with different speeds of rotation of the goniometer axis is needed.

Now there are more and more commercially available goniophotometers with on-the-fly measurement mode. For this reason, the key technical parameters of exemplary solutions were compared in Table 3. Most features of selected goniophotometers are similar, however there are many additional features and development possibilities to suit market needs.

On-the-fly goniophotometer realized in BOSMAL Automotive R&D Development Institute Ltd. is distinguished by possibility of measurement both lighting devices for automotive industry and luminaires for general lighting – measurement may be performed in two geometries. Furthermore, presented goniophotometer has many additional features. One of them, is an implemented algorithm which allows to measure lighting devices with flickering or PWM controlled light sources. In this case, the on-the-fly measurement works in slower mode and there is a need to know the signal parameters eg. time period, pulse width, ON time, OFF time etc. but this can be easily measured by implemented plug-in. This feature is very helpful performing measurements eg. on rear automotive lamps with LED light sources whose individual lights have several functions. For example, when the same light is used both for rear position and stop lamps but with various power supply mode using PWM current control.

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