Next generation goniophotometry

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Abstract

In these times of steadily reduced product life times and a rapidly changing choice of available light source it is mandatory to be able to measure the photometric and colorimetric properties of sources and luminaires in an effective, quick and precise way. Modern approaches in computer aided optics design of luminaires demand high-grade measurement data of the sources very early in the development process to support a design of the lighting systems that’s efficient and close to reality.

Manufacturers of sources as well as luminaire makers and vendors need to obtain these information quickly, easily and efficiently. The new approach described in this paper, the next generation goniophotometry, combines the advantages of various conventional goniophotometer methods, comprising much more flexibility, multiple functions and a top of the line precision in only one single device.

Abstract (German)

In Zeiten von immer schnelleren Produktzyklen ist eine schnelle und präzise Möglichkeit Lichtquellen und Leuchten zu vermessen extrem wichtig. Moderne Verfahren zur Leuchtenentwicklung erfordern schon sehr früh im Entwicklungsprozess hochwertige Messdaten um die Entwicklung realitätsnah und effizient durchführen zu können.

Hier müssen sowohl die Hersteller von Leuchten, aber auch die Hersteller oder Anwendern von Lichtquellen, schnell und effizient zu den benötigten Daten kommen. Der vorgestellte neue Ansatz der Goniofotometrie vereint die Vorteile verschiedener herkömmlichen Goniometereigenschaften mit mehr Flexibilität, Multifunktionalität und Präzision in nur einem Gerät.

Introduction

The use of goniophotometers has always been a fundamental measuring method in lighting technology. They have been used for photometric measurements of sources or lumiaires for almost 100 years now.

At the beginning, but also until today, the basic approach with a goniophotometer is the measurement of the angular dependant luminous intensity distribution (LID) of the device under test (DUT) e.g. a luminaire. The detector is a simple photometer measuring in the far field of the DUT.

Forced by the development of steadily more complex as well as more compact lighting systems, but also driven by the use of high performance optics design software packages running on powerful computers, the goniophotometer applications diversified.

This paper introduces a worldwide new technology of using one single device to derive the data of the sources as a seed for the optics design process as well as to perform all the necessary measurements on the resulting products (luminaires, head lamps, signal lamps, etc.) to obtain the well known luminous intensity distribution and much more.

One of the various applications of this goniophotometer approach is the creation of polychromatic ray files to enable the optics engineer to perform optics simulations that are very close to reality in due consideration of the emission angle dependant spectral power distribution of the sources.

Goniophotometer Overview

Traditionally goniophotometers are distinguished in their way how the mutliple rotation axes are linked together as well as how the DUT is rotated in space during a measurement. The different setups are well known and defined in the standards DIN 5032-1, DIN EN 13032-1, CIE 70 or CIE121. These standards categorize the different types in classes ranging from 1,x. 2.x, 3.x up to type 4. Without explaining all of the different types in detail in this paper, let’s have a closer look to three very common setups.

<u>Goniophotometer type 1.1, type A</u>

This goniophotometer type uses a horizontal axis that is fixed in space (zenith axis with red arrow) and a rotated “vertical” axis (azimuth axis with green arrow). The detector/photometer is shown as a black cylinder. In a real setup measuring the far field distribution it is mounted at a much larger distance to the DUT than is shown in the figure.

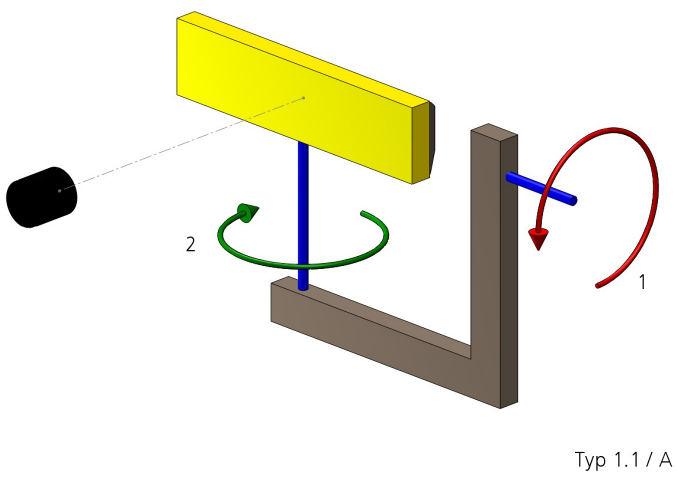

Figure 1: Goniophotometer type 1.1

The second axis is swivelling around the first axis and thus doesn't keep its vertical position.

This is, for example, the common way for the goniophotometric measurement of automotive head lamps. The resulting measurement coordinates and values are located around the equator of the corresponding polar coordinate system. The pole of this polar coordinate sytem points in the direction of axis 2.

Goniophotometer type 1.3, type C

This goniophotometer type uses a vertical axis that is fixed in space (zenith axis with green arrow) and a rotated horizontal axis (azimuth axis with red arrow). The detector is shown as a black cylinder again.

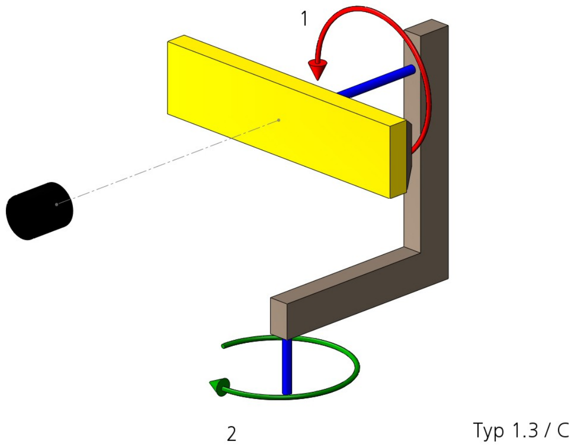

Figure 2: Goniophotometer type 1.3

The second axis is swivelling around the first axis.

This is for example the common way for the goniophotometric measurement of general lighting luminaires. The resulting measurement coordinates and values are located around pole of the corresponding polar coordinate system. The pole of this polar coordinate sytem points in the direction of axis 1.

Goniophotometer type 3.1, type C

This goniophotometer type uses a mirror that rotates around a fixed horizontal axis (lower zenith axis 1 with red arrow) and a second horizontal axis counterrotating with respect to the first axis. This second axis keeps the luminaire in the same operation position regarding the direction of gravity at all times. The first axis is co-linear with the optical axis of the photometer.

A third axis thus keeping its vertical position at all times too, rotates the DUT in different azimuthal positions (azimuth axis with green arrow). The detector is shown as a black cylinder again.

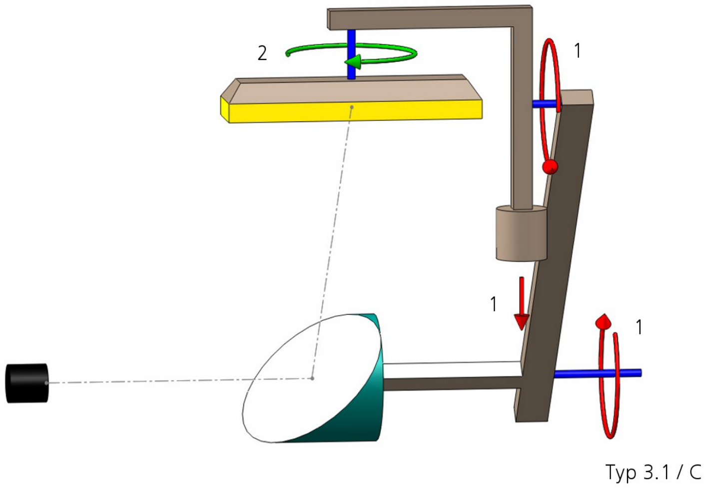

Figure 3: Goniophotometer type 3.1

This is again an example of a common way for the goniophotometric measurement of general lighting luminaires. The The resulting measurement coordinates and values are located around pole of the corresponding polar coordinate system. The pole of this polar coordinate sytem points in the direction of axis 2.

The advantage of this approach is certainly that the DUT keeps its orientation with respect to the direction of gravity at all times during the measurement.
However, a series of disadvantages like the fairly large mechanical structure, trouble with the mirror's flatness, spectral response and dustiness as well as very high system costs make this approach quite often unreasonable. Furthermore, the mirror method suffers from unpredictable and uncorrectable multi-interflexions of light between the luminaire and the mirror. Misreadings might occur.

The mirror goniophotometer lost its importance even more because the influence to the photometric properties of the DUT due to an arbitrary rotation in space decreased tremendously with LED based lighting systems. Convential lighting systems, e.g. based on gas discharge sources, necessarily needed this kind of goniophotometer. LED based systems don't.

This trend is accomodated by recent standardization efforts, too. The fairly new European standard for the measurement of SSL driven systems, EN DIN 13032-4, issued in 2013, explicitly states the arbitrary rotation of the SSL driven DUT during the goniophotometric measurement. Complex and expensive mirror systems are not needed anymore.

Near field vs. far field

Some decades ago a new application arose. So far, the different goniophotometer types mentioned before had been used almost solely in the far field. That means that the detector system (photometer) had been positioned in a reasonable distance to the DUT to reduce the geometrical error in the calculation of the luminous intensity in a range smaller than 1%. In the far field approach, the DUT itself is considered to be a point source without any extent.

The new goniophotometric method of measuring in the near field is motivated by two reasons:

- A demand for systems that are able to measure the luminous intensity distribution of even large DUTs in small space or small distance respectively, but still with a geometrical error small enough to receive reasonable results.
- A demand for much more detailed information about the DUTs. Not only the luminous intensity distribution coming from a virtual point in space, but also the space-resolved information about how and where the light is emitted from the DUT is of significant interest.

While the first application of near-field measurements generates the same information as the traditional far-field approach (the far-field luminous intensity distribution), the second reason is of larger importance.

By using the knowledge of the spatially-resolved emission all around a light source, detailed ray files can be derived for the use in optics design software packages to achieve close to reality simulation results. One typical setup for a near-field goniophotometer is the type 2.1 gonio.

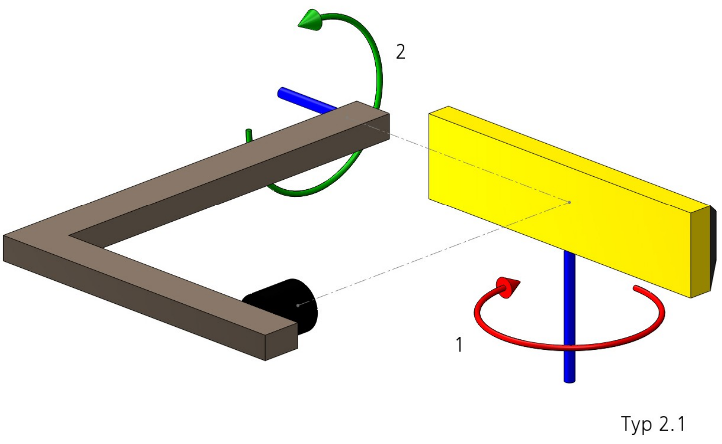

Figure 4: Goniophotometer type 2.1

The DUT (light source or luminaire) is rotated about a vertical axis that is fixed in space (azimuth axis with red arrow) and the detector is rotated about a fixed horizontal axis (zenith axis with green arrow). Contrary to the two setups described before, the axes are not coupled in this goniophotometer type.

A very important fact is that a standard photometer is not suffiicient for the spatially-resolved measurement. An imaging detector like a luminance camera is needed. The amount of data obtained is much higher than with a traditional goniophotometer.

Traditional Goniophotometer summary

In the last sections we see that there are multiple geometric constructions to realize a goniophotometric solution for different applications (e.g. automotive vs. general lighting). Further we see that different kinematic constructions are needed and used for far field and near field measurements.

Next generation goniophotometry

Thinking about the aforementioned traditional goniophotometer systems we see that all of them possess, regardless of their individual type, 1.1, 1.3 or 2.1, five or more axes of movement in total.

- At least two rotation axes for the rotational positioning of the DUT and/or the detector
- Three translation axes for the translational positioning of the DUT to the rotation center of the goniophotometer (typically used for the adjustment before the measurement only)

Furthermore we see that for different applications different mechanical or kinematic constructions are used; 1.1 for automotive, 1.3 for general lighting. Or in other words, nowadays several different machines are used to perform the different applications.

The fundamental new way of realizing goniophotometric measurements is the use of an industry robot to perform the necessary movements and rotations. With a total number of six rotation axes, this machine called “robogonio” is able to realize the mentioned coordinate systems easily in one machine; for far-field and for near-field applications.

Figure 5: Goniophotometer type "robogonio"

Industry robots have been used since quite a bit in production environments. Why didn’t we see the robogonio way of doing goniophotometry much earlier?

For one thing, due to the strongly rising need of robots in the production field, mainly in automotive production, the number of robots produced per year rose tremendously and thus the price of the robots came into a range where it became very interesting for goniophotometer applications. Another reason is that the precision of the robots improved in the last decade to a level comparable or even better than the angular accuracy of the traditional goniophotometers.

A number of significant advantages are coming with this new way of accomplishing goniophotometry:

- Arbitrary coordinate systems, eg. 1.1 or 1.3 or type A or type C goniometer respectively, can be realized with one single machine now.
- The mechanical structure of an industry robot is amazingly stable and rigid with a very high reliability in comparison to the the traditional goniophotometers produced in a comparably low volume only.
- Due to the flexibility of the robogonio axes, the center of rotation isn't fixed anymore and can be choosen arbitrarily in space.
- Multiple, even far distant pivot points can be realized easily in one measurement (e.g. different lighting functions of a complete car head lamp).
- The overall construction is much less restrictive for the measurement of large or long DUTs. As a result the measurement of long luminaire structures can be preformed with the robogonio much easier (e.g. very wide CHMSLs).
- A large number of different robot sizes is available and thus robogonios starting at a payload of 6 kg up to a payload of more than 1000 kg are available.
- Quite fast measurements are possible. A complete 2 pi LID with high resolution can be measured in about 2 minutes.
- The standard DIN EN 13032-4 requests heating up the SSL lighting fixtures in standard working orientation (typically vertically downwards in most general lighting applications) for at least 15 min before measurement. After the heating-up period, the fixture is oriented to point to the detector (typically horizontally). The robogonio is able to realize the heating-up position and the measurement position automatically in one run due to its axial flexibility. A traditional general lighting 1.3 goniophotometer isn't able to fulfil this DIN EN 13032-4 request.

Furthermore, one robogonio machine can be used for near-field and for far-field measurements in one installation. This enables the optics or lighting engineer to gather detailed properties of the tested light sources as a seed to perform the optics design process as well as to measure the luminous intensity distribution of the resulting lighting system with only one device, regardless if a 1.1 gonio (automotive) or a 1.3 gonio (general lighting) is required!

The following figures show the different goniophotometer rotations in the different applications.

robogonio running in type 1.1 mode, (type A mode)

Running in 1.1 mode, the robogonio executes exactly the same rotations like a standard 1.1 goniophotometer.

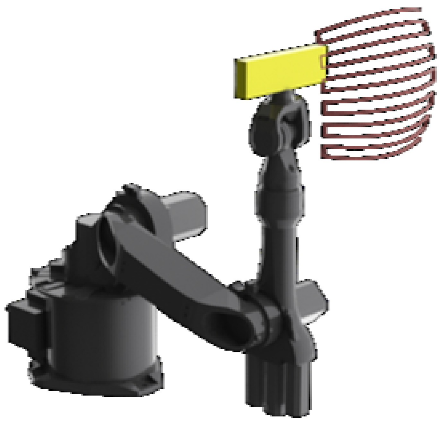

Figure 6: robogonio in type 1.1 mode

Due to the almost unconstrained mechanical structure very large or very wide DUTs can be mounted and measured on the goniophotometer. Bi- or omni-directional fixtures or multi-functional lighting systems with several light exit windows can be measured easily.

robogonio running in type 1.3 mode, (type A mode)

The same machine, running in 1.3 mode now, executes exactly the same rotations like a standard 1.3 goniophotometer.

Figure 7: robogonio in type 1.3 mode

Apparently the lighting system to test can be quite long due to the open non-restrictive mechanics.

robogonio running in type 2.1 mode, (source imaging mode)

In the source imaging mode for the creation of ray sets similar solid angle sections are desired for the measurement. The path of the robogonio is kind of a spherical meander to efficiently gather a high number of luminance measurements on a virtual sphere around the source.

Figure 8: robogonio running similar to type 2.1 mode

non-rotation applications

An application a traditional goniophotometer isn't able to do at all is the motion along an arbitrary path in space. More and more we see elongated and thin light pipes used for various lighting applications in different markets. The luminance of these structures have to be tested during development and even more during production control.

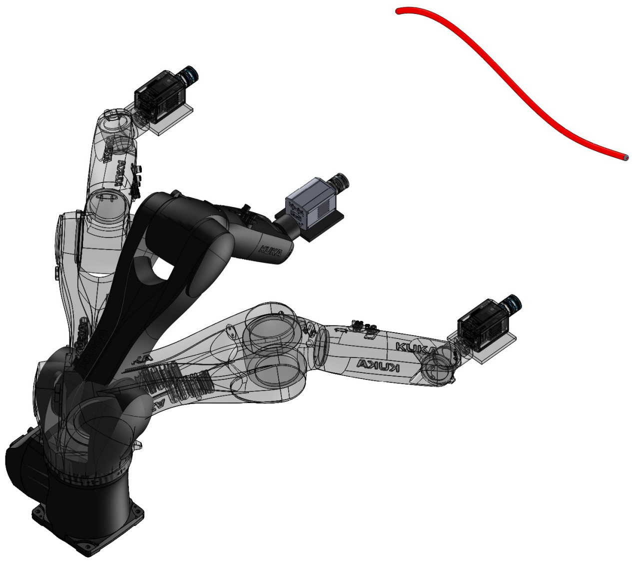

Figure 9: robogonio running in non-rotation mode

The robogonio together with a luminance camera can easily follow the light pipes's path in space to perform this measurement quickly with high spatial resolution. Due to the flexibility of the machine, the geometrical test sequence can be modified very easily for different geometries to be tested.

<u>heating-up according to DIN EN 13032-4</u>

The following figures display how the robogonio can position the lighting system in its standard burning/operating position for the heating-up period (downwards in this example). The changes in the photometric performance are monitored during the heating-up period with an auxiliary photometer.

heating-up ready to measure measuring

Figure 10: robogonio's heating-up procedure

After the heating-up period is finished, the robogonio directs the lighting system towards the photometer with its typical horizontal axis. Changes in the photometric performance due to the change of orientation are corrected by using the auxiliary photometer. Now the goniophotometric measurement with the heated-up DUT can run. Again, according 13032-4, an auxiliary photometer is monitoring for eventual changes in the photometric performance due to the arbitrary rotation of the DUT.

2.3 Conclusion

This paper introduces a fundamentally new way of performing goniophotometric measurements in a much more flexible way than before. The described technology can be used in various different lighting markets. A robot-based goniophotometer is a valuable device during the complete process from optics development up to the production control of lighting systems. The same machine gathers very detailed data of the sources at the beginning of the process and delivers accurate data of the designed lighting systems after production.

All these benefits come with a top of the line angular accuracy and a high end measurement speed to a very competitive price.

The next generation goniophotometer!

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Abbreviations and terms

CA – computer aided

DUT – device under test

LID – luminous intensity distribution

CHMSL – central high mounted stop lamp

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