Improvement of a lamp construction with a highly reflective material

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ABSTRACT
This article is based on a case-study. During the project our goal was to improve a commercial car indoor lamp. To fulfill this goal we used a new component which makes the homogeneity of the escaping light better and increases the efficiency as well. This new optical reflector component was made of a plastic diffuse reflector material with microcellular internal structure. The article presents each phase of product development from the reverse engineering of the lamp to the evaluation of the measurement results. The design includes the conceptual modelling, computer aided optical shape optimization, prototype production and optical tests as well. Involving different software in design results faster iteration thus better presence in the market. As a result, the applied thermoformed reflector component significantly improved the efficiency and the homogeneous light distribution of the product.

KEYWORDS
Product design, Product Development, Improvement, Light Intensity, Homogeneity, Commercial lamp, Reflective

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Eszter Dudás Graduated as Industrial Product Design Engineer (MSc) at Budapest University of Technology and Economics. During the studies, participation in various projects related to lighting led to the interest of the field of lighting techniques including different materials besides examining and solving problems from more aspects.
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1. LIGHT IN THE AUTOMOTIVE INDUSTRY

Light is a commonly used tool in the automotive industry even if we are talking about functional or aesthetical use. There are many different types of indoor lighting equipments. These help the users with different goals. For instance in this case-study we were focusing on a lamp which can be used in various places in the car like the door panel, the glove-box and the trunk. The original construction of the lamp is shown on Figure 1. This multipurpose fitting requires well-designed optical behaviour. The users need to interact with the lamp directly or indirectly as the luminaires help them during their activities. In many cases this means well-calculated bright and shadowless areas. There are high number of standards and testing methods for different luminaires and also for their components which guarantee the required quality such as luminous flux (minimum of 50 lm) (Jármű optika, 2014), thermal stability, low shrinkage, color (from 6/1990. (IV. 12.) KöHÉM in Hungary)(Bonnie Xu, 2017) etc. The main task of a designer is to fulfill these requirements. (CBI, 2017)

In order to improve the distribution of luminous intensity, designers create reflectors with different geometries. A well designed reflector geometry uses the appropriate property of the light source. LED manufacturers make the directivity data of the light source and their test conditions available. The designers use this information even before the luminaire becomes a prototype. During manufacturing in many cases the quality of the reflector surface and its texture require a long design process.

In the presented study our aim was to follow the steps of a product design process and to create a modified luminaire construction with better optical properties. We examined if we could achieve better homogeneity and illuminance with an additional reflector for the mass produced lamp.

2. HIGHLY REFLECTIVE MATERIAL

In many lamp constructions large amount of light does not transmit through the diffuser in the first place. Depending on the material of the diffuser and its optical properties the amount of the reflected and absorbed light can be significant. Using a more efficient reflector allows the previously reflected rays to be used thus the total transmission of the fixture can increase.

We chose a material called MCPET (microcellular polyethylene terephthalate), developed by Furukawa Electric Company (Furukawa, 2016) which has great optical performance. The material was compared to barium sulfate which is a widely used reflector coating material. MCPET has higher reflection value on 550 nm wavelength. It has good physical properties such as high heat resistance and flame resistance. With these properties the material satisfies the requirements of the automotive industry. Besides its high total reflection values it has high diffuse reflection (96 %) as well due to its microcellular internal structure (The behaviour is shown on Figure 2).

3. PRODUCT DEVELOPMENT

3.1 DESIGNING THE REFLECTOR SHAPE

The study contains each phase of product development.

It could be that in the beginning of a project the designers have the real model but do not have the virtual one. For these cases there is a very useful tool called reverse engineering which helps with digitalizing the original product. This can include various tools from a caliper to a 3D scanner. The tools used are determined by the level of details required by the designer. After the reverse engineering, the most important requirements need to be listed. For designing a reflector, the most important features, as it is previously mentioned, are the surface finish and the geometry.

Moreover, optical simulations are based also on the quality of the surface and the geometry. Nowadays, there are various software on market to let the designer create the geometries in a 3D virtual environment. The original geometry can be modified with different modelling techniques. In the case of optical reflectors the top-down modelling technique is a great tool. On Figure 3 we can see few examples of the designed optical reflectors.

After finalizing the model the designer can

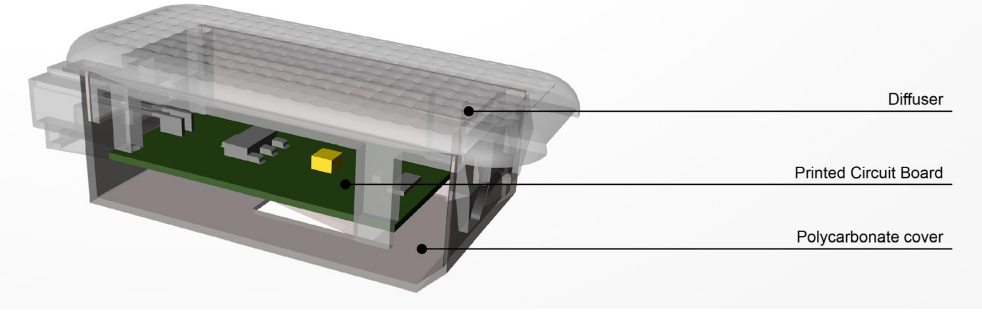

Figure 1 - Examined lamp – consisted of 3 parts

decide which file-format is proper for further examinations in optical simulation software. For our study we used Radiant Zemax. To make the different geometries comparable more simulations need to be done with different layouts, depending on what is the goal parameter we were looking for. In our case our goal was to optimize the overall efficiency and homogeneity. In the case of a trunk lamp simulating the intensity at different angles and distances is important. After the first few, we could see that the assemblies which had the diffuse reflector had higher intensity than the original one. Because of the high diffuse reflectivity of the additional part we had better performance in each measured angle (every 5°).
The simulated light intensity distributions are shown on Figure 3.
For luminaire design, efficiency is the most important. In the optical software the designer defines the properties of the detector, the number of rays and the initial power of the light sources. During ray tracing the program calculates the brightness on each pixel of the detector. Afterwards, the designer uses the values for calculating the efficiency. The results can be seen in various scales.
For validation reasons it is useful to check the results in logarithmic scale as well which is how the human eye perceives light.
The homogeneity examinations can be done in the software too. For comparing different geometries it is useful to normalize the results to the same maximum value.

3.2 PROTOTYPE PRODUCTION

The geometry with the best simulation results can go through a further development process. From the beginning, the designer has to take into consideration the manufacturability as well. The proper technology fits the material, the dimensions of the product and the manufactured quantity. The lamp in our case-study is made with mass production which means that the manufacturer makes thousands of them. This justifies the choice of technology which needs to be fast, productive in a low price.
In our further design process the optical reflector geometry was optimized for matched molding forming technology which is a type of thermoforming. This production method uses two manufacturing tools. In general these tools are made of metal with substracting technology such as milling, lathe machining. With metal molds we can achieve more than a thousand cycles. For making the measurements for our study we only needed a few thermoformed samples. In such case the additive technology can provide suitable quality for the molds. The production takes only a few hours or some days depending on the size and complexity. In this case-study we used 3D printing technology.
After thermoforming and the waste removal the prototype is assembled. If the previous design

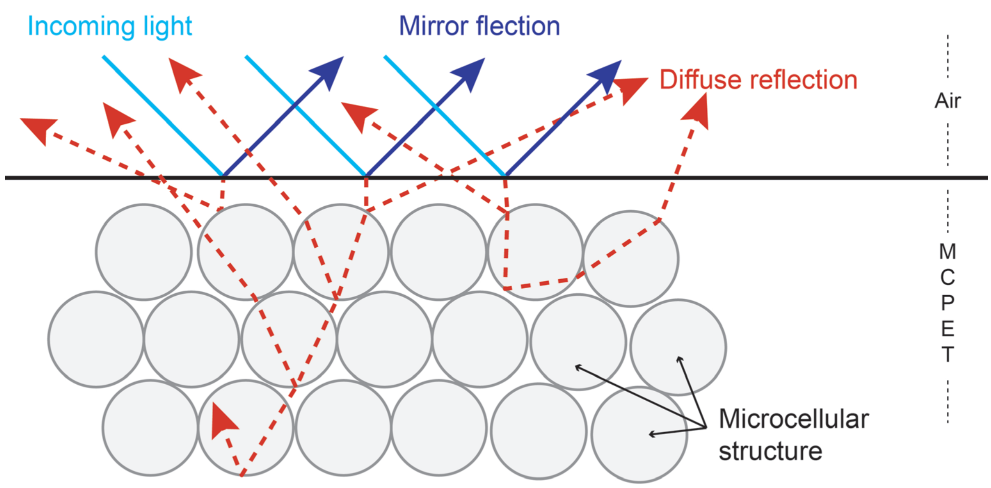

Figure 2 - Internal structure and reflective behaviour of MCPET

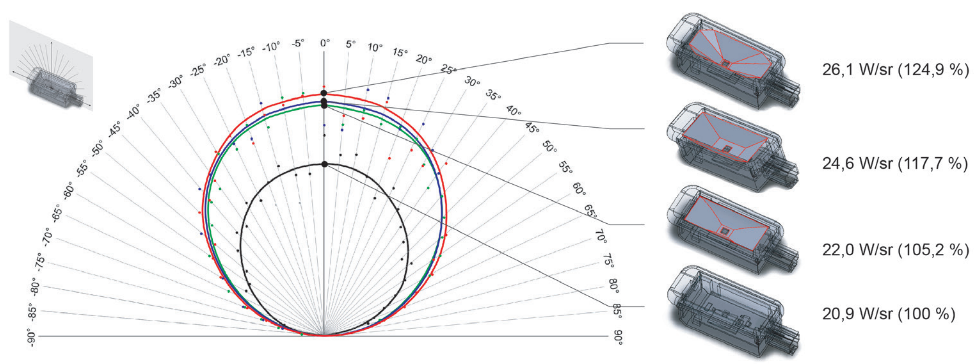

Figure 3 - Results of an optical simulation. The black curve is the result of the original assembly, the other three curves show the results where the samples contained a new reflector geometry

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was precise the component can be installed.

3.3 OPTICAL MEASUREMENTS ON THE READY PROTOTYPE

Optical measurements are used for validation of the simulation results. For achieving reliable results, the measurements are repeated in the same environment multiple times. From the measured values the designer can estimate the noise of the measuring device as well. Afterwards, the proper values are evaluated using various statistical toolset.

In our project to make the results comparable a demonstration device was created. It contains the original lamp assembly and also the optimized one with the optical reflector which provided the best simulation results. This device is shown on Figure 4.

In the evaluation phase we checked the results in two ways. In the previous design phase multiple simulations were carried out for calculating the efficiency. With using an illuminance meter we measured the light intensity distribution. The measuring tool was placed in front of the prototype at 140 mm from the diffuser. Then we measured the light intensity in every 10° from the light source along the longitudinal plane (Shown on Figure 5).

While using the illuminance meter only one lamp was functioning at a time so the other could not have effect on the measured brightness. From the measurement results we could draw the

Figure 4 - Demonstration device for optical measurements and validation

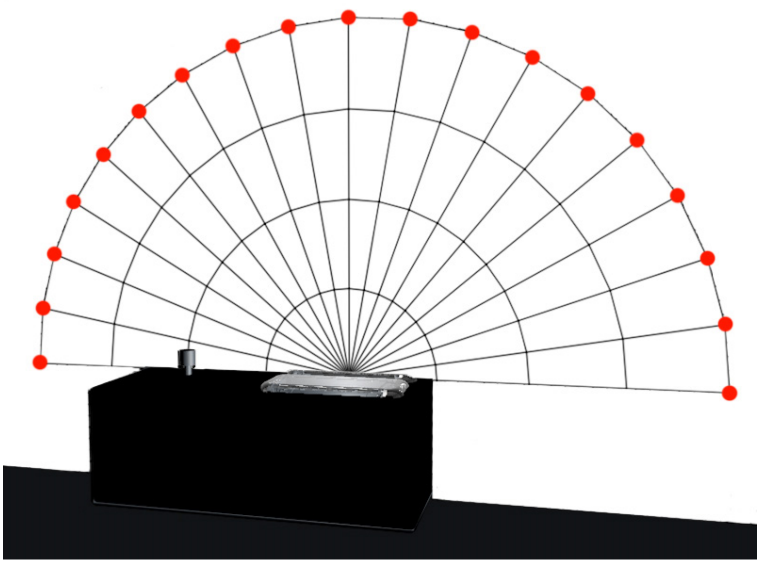

Figure 5 - Illuminance measurement with the demonstration device

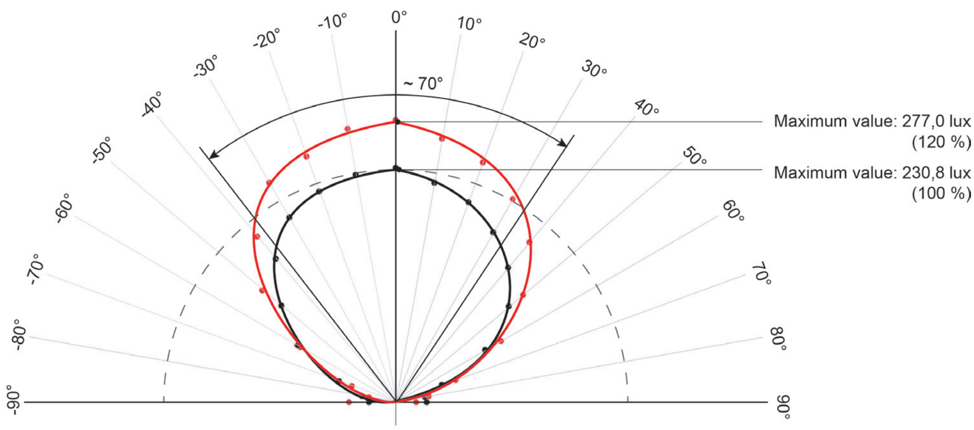

Figure 6 - Measurement results of the two lamps (black: original sample, red: sample with the additional component). Along about 70° range the optimized lamp has greater result than the maximum value of the original one which is presented with the dashed curve.

light intensity distribution curves of both lamps like in the case of simulations. The curves can be seen on Figure 6. The difference between the original and the optimized lamps is significant.
For homogeneity comparison a camera was used. We realized similar results to previous simulations at both samples. The more homogeneous light distribution of the assembly which had the additional reflector component inside is visible on Figure 7.

4. CONCLUSION AND FUTURE OPPORTUNITIES

The study showed us that applying a well-designed optical reflector made of highly reflective diffuse material can result in a 15-20% increased illuminance (the value depends on the testing angle). As it is shown on Figure 6, the optimized version has better properties along about 70° range than the maximum measured value of the original lamp.
The results of the case-study showed that since the development can be divided into phases thus it can stand in the automotive industry as well. As a future opportunity the manufacturers could use fewer number of components for illumination of the same volume for the required level of brightness. It is a great advantage for later design and options.

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CONFLICT OF INTEREST

The authors declare no conflict of interest including financial, personal or other relationship with other people and organizations within three years of beginning the submitted work that could inappropriately influence, or be perceived to influence this work.

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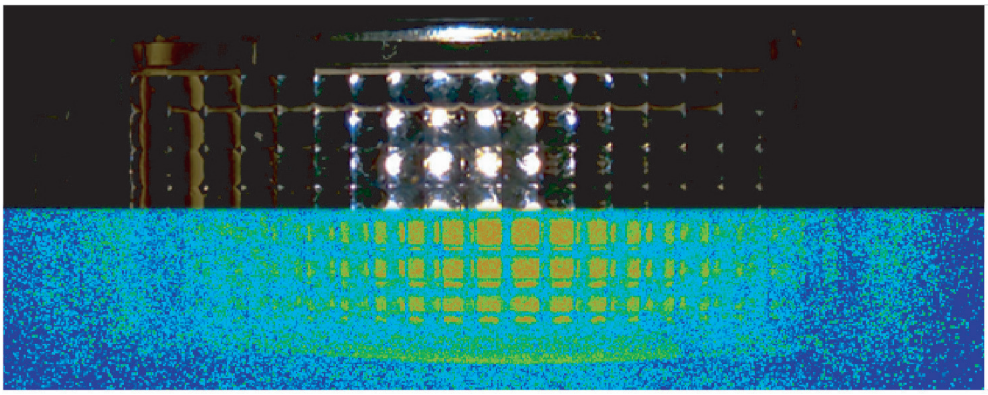

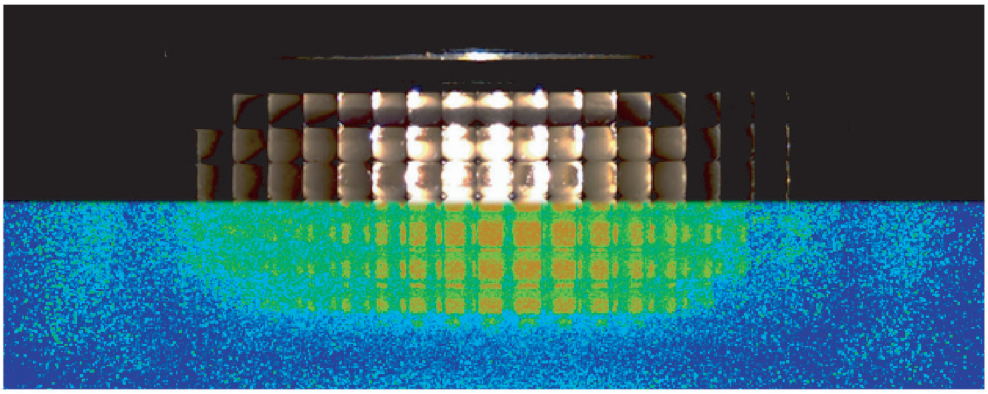

Figure 7 - Comparing the results of the photographs (above) and the simulations (below). The original sample is on the upper hand side picture, the optimized one is on the lower hand side picture.