Diffractive Optics in Automotive Headlamps – New Design Concepts Including a Special Simulation Process

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The chromatic and thermal behaviour of optical materials in headlamp systems leads to aberrations of the light distributions. Both dependencies can be corrected solely by using hybrid lenses. The combination of these two corrections in one element leads to a lens doublet consisting of two materials. Therefore a new design concept including the results of optical simulations of the new lens based on ray tracing is presented.

1 Introduction

The usage of plastics as optical materials in headlamp systems leads to the integration of more complex optical systems in automotive lighting. In contrast to normal glasses, the dispersion and the thermal expansion are much stronger and cannot be neglected anymore [1].

Furthermore, the properties of diffractive optical elements can be used to the design of new functions and optical concepts that cannot be realized by using refractive optics solely [2]. In case of headlamp systems, these functions could be the chromatic and the thermal correction of refractive lenses and the design of a low beam system without any cut-off aperture.

Whereas the chromatic or the thermal correction by hybrid lenses is still used, e.g. in camera systems, it isn't realized in automotive headlamps yet. Therefore, the usage of hybrid lenses for the correction of light distributions needs to be integrated in the optical design process that is containing the optical design and the optical simulation of the headlamp system. Based on this step, the design concept of the athermalization of an achromatic hybrid lens can be realized and analysed.

2 Optical Simulation Process

To analyse the behaviour of hybrid elements containing diffractive structures on the surface of the refractive element, a simulation based on ray tracing is necessary to consider the other elements that are based on geometrical descriptions.

The deflection is calculated by the height profiles considers far field approximations because of the structural dimensions in the headlamp systems. The derivation of the phase profile leads to the direction of the refracted ray [3]. In combination with the diffraction efficiencies transformed into a probability distribution the interference of the elementary waves is calculated. The implementation of this simulation process was analysed by the measurement of diffractive gratings and diffractive lenses.

3 Achromatization and Thermal Behaviour

The chromatic correction based on Abbe's formula [4] can be realized by one hybrid lens that replaces the refractive lens of a projection system as it is shown in figure 1.

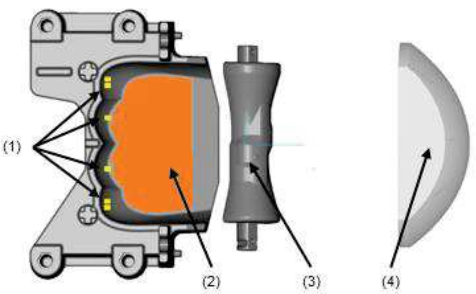

Fig 1 *Top view of a projection headlamp system containing light sources (1), a free-form reflector (2), a cut-off aperture (3) and an aspheric lens (4)*

The results of the optical simulation of this system are shown in figure 2 and figure 3. Firstly, a normal refractive lens is used and the dispersion effects

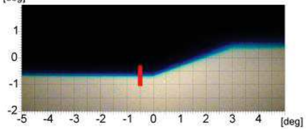

Fig. 2 *Light distribution based on a refractive lens*

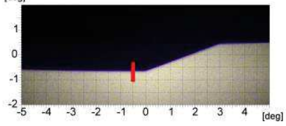

Fig. 3 *Light distribution based on a hybrid lens*

can be shown easily. Secondly, the hybrid lens minimizes the dispersion effects. For the analysis of the cut-off line the luminous intensity is pointed out at x=-0,5°. The results as displayed in figure 4 are demonstrating the increasing gradient of the cut-off line created by the hybrid lens.

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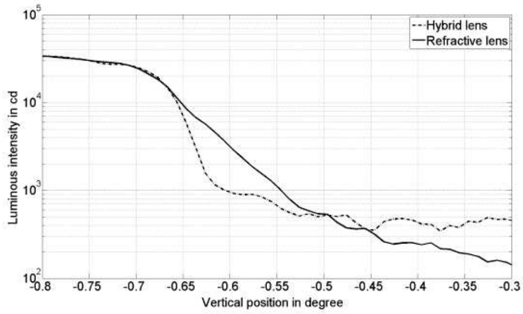

Fig. 4 Section through the cut off line at x=-0,5° of the light distribution based on a hybrid lens and on a refractive lens

In the use-case of automotive lighting, a temperature range of $T_0 - 80°C < T < T_0 + 80°C$ has to be taken into account. Therefore, visual results of the optical simulation of the headlamp system at the highest temperature are shown in figure 5 and 6.

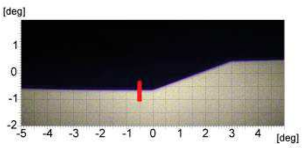

***Fig. 5** Light distribution based on a hybrid lens at T_0*

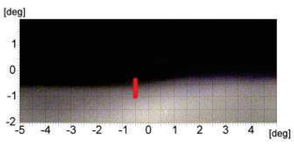

***Fig. 6** Light distribution based on a hybrid lens at $\Delta T = 80°C$*

4 Athermalization of the Achromatic System

To correct the displayed thermal behaviour of the light distribution, a kitted lens doublet of two hybrid lenses containing two different materials can be calculated.

By solving $\frac{d\phi}{dT} = \frac{d\phi}{d\lambda} = 0$, the correction function can be deduced. An optimization process gives the opportunity to decide whether the diffractive or the refractive structures bear most of the lenses power.

This depends on the requirements of the fabrication process and the used materials. The higher the difference of the thermal coefficients the higher can be set the influence of the refractive surfaces.

For the analysis of this principle, a linear dependency of the length extension is assumed. In contrast the change of the refractive index is calculated by using the Lorentz-Lorenz equation [4].

The simulation results of the achromatic lens are the upper bound of the chromatic correction, because to additionally athermalize the light distribution, more elements are needed und leads to aberrations. Because of the additional material, the dispersion is still higher and increases the expected colour fringes.

In figure 7 and figure 8, the results of the optical simulation of the kitted lens doublet are displayed. As expected, the dispersion effects are a little bit stronger than the ones of the achromatic system.

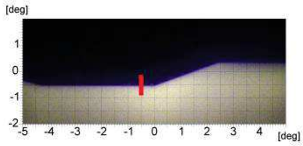

***Fig. 7** Light distribution based on the kitted lens doublet at $\boldsymbol{T_0}$*

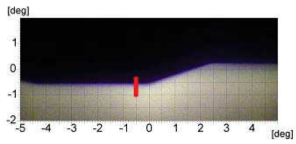

***Fig. 8** Light distribution based on the kitted lens doublet at $\Delta \boldsymbol{T} = \mathbf{80°C}$*

In contrast, the thermal behaviour is reduced dramatically.

Based on figure 9, the analysis of the cut-off line at x=-0,5° shows the benefit of the lens doublet. The gradient of the luminous intensity is even better than the one of the refractive system, although the gradient is not as high as it is for the achromatic hybrid lens.

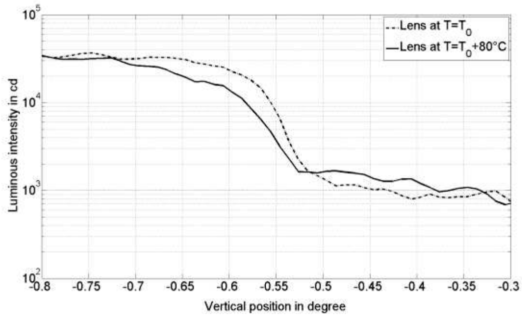

Fig. 9 Section through the cut off line at x=-0,5° of the light distribution based on the kitted lens doublet at two different temperatures

5 Summary

The results of a design algorithm are presented. By this algorithm, a kitted lens doublet containing two different hybrid lenses is calculated. The target of this process is the athermalization of an achromatized light distribution.

The distribution is analysed and defined as upper bound for the athermalization. In addition with cuts through the cut-off lines, it is shown that the concept optimizes the light distribution of a headlamp system. This includes both the chromatic and the thermal correction of the cut-off lines.

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