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Adaptive Headlamp: A contribution for Design and Development of Motorway Light

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ABSTRACT

A major breakthrough in improving visibility, safety and comfort under all driving conditions is given by a headlamp with adjustable light intensity and beam pattern according to the vehicle speed, steering wheel angles and different driving conditions.

The configuration of this adaptive or intelligent headlamp will be achieved in two phases, by implementation of simple functions, i.e. motorway beam pattern, followed by a combination of them in a second phase. For the new adaptive headlamp one should make use of powerful light sources like the Gas Discharge Bulb and of sensors for road surface status, speed and steering wheel angle. The optical design of the adaptive headlamp is more complex than for conventional headlamps and must take into account new requirements like the continuous transition between the low and high beam positions.

In this paper we describe the design and prototyping phases for an adaptive headlamp whose beam pattern and aiming condition can be varied by the use of actuators. The results of the optical simulations are given and compared with the corresponding prototype measurements.

INTRODUCTION

The problem of visibility during night driving conditions is not always considered as an important constraint during the design and development of new vehicles. Very often car-makers reduce the space allocated to the lighting components and define them for design requirements only. Therefore for component suppliers it is difficult to achieve high photometric performances. Under these strict conditions, car suppliers can achieve good performances by means of new lighting techniques (e.g. numerically calculated reflectors) and light sources (e.g. HID bulbs and systems): the new products guarantee a good light flux, as requested by international regulations, but the beam pattern and aiming are fixed. Therefore they do not always provide the best visibility under different driving and weather conditions.

For an overall improvement, it is necessary to dynamically modify the beam pattern and light intensity during driving, and to account for road and weather conditions by means of a wide variety of sensors. A first step in the aforementioned direction is to develop a headlamp which is able to improve visibility during one of the following conditions: rain and fog, on curves, on motorways and in town [1]. The following step will be to implement more than one function, to suit more than one driving condition, and offer a good comfort during transition between driving situations, i. e. transition between low speed and high speed.

This paper will describe the development of a Motorway headlamp able to vary its photometric characteristics with speed. The headlamp will try to reduce the aiming angle and the width of the beam as the vehicles speed increases. These operations will be automatic with the aid of sensors, actuators and electronic boards. The purpose, as for all adaptive functions, is to always provide an optimal beam. This will increase driving safety and comfort. The best visibility characteristics should be obtained without causing dazzling of the oncoming vehicles. Several numerical simulations, laboratory and road tests are being performed to identify the best strategy to achieve the proposed goals.

FUNCTION DESIGN

While driving on a Motorway the high speed and low road lighting require better visibility. In particular when driving at high speed, foreground illuminance is less important, while a high light depth is very useful to detect vehicles running ahead.

Beam modifications must be implemented without dazzling oncoming vehicles: this paper examines the possibility of varying the low beam distribution without trespassing the horizontal line.

It is possible to obtain an increase of illuminance in two ways. The first is to decrease the aiming angle of the light beam and the second is to change the beam shape, to reduce the beam divergence.

Research and experimental activity were divided into two parts:

1. The study and set-up of a system capable of changing the aiming of the beam depending on the car speed.
2. Computer simulations and analysis of optical solutions capable of changing beam shape with the car speed.

VARIABLE AIMING

In varying the beam aiming angle, the attention was focused in the mechanical movement of the reflecting surface. The angle was varied from -1% to 0%.

To test this solution, a prototype was set up, where the reflector movements were implemented by means of stepper motors. The relationship between speed/movements is a linear one: the starting speed was fixed, and several slope parameters were adopted to identify the optimal value.

The system was assembled onto a vehicle and some road testing was carried out. The following variables were chosen in order to carry out a preliminary Design Of the Experiment.

- starting speed
- slope of the movement
- dynamic leveling.

The set parameters are adjustable by acting on the electronic control unit, which was positioned in the vehicle. At this stage, the optical part analysis was ignored and an elliptic headlight with a gas discharge lamp was chosen.

The goal is to establish which starting speed and slope would increase the driver’s comfort. The influence of dynamic leveling on the variation of aiming due to speed increase was also investigated. In some configurations it may happen that dynamic leveling cancels the effect of the applied correction for the speed increase.

Tests were carried out on a two lane track. The participants were divided into drivers, static observers, and dynamic observers (driving a crossing car). All participants were asked to evaluate three different parameters: illuminance, glare and comfort.

According to our test results the best configuration has a starting speed of 90 km/h and a slow variation of aiming, slope = 0.125 (% / 10 km), in order to achieve the 0 % aiming when speed is increased up to 170 km/h: Fig. 1 shows the slope diagram, with four different speeds. The dotted one is the slope that the participants have considered the best, from the point of view of comfort and visibility.

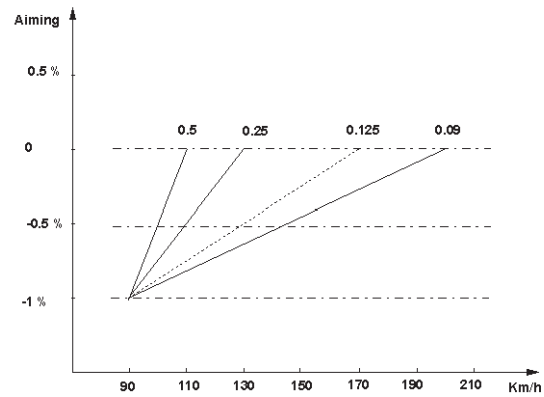

Figure 1. Slope diagram for a starting speed of 90 km/h.

The interaction of this system with dynamic leveling was considered useful in increasing driver's comfort.

VARIABLE BEAM SHAPE

According to the tests carried out on the system described above, the change of aiming is neither optimal nor sufficient yet if we want to obtain a real increase of the driver's comfort.

Further actions are necessary to improve illuminance distribution and the cut off line: a variable beam shape could enhance visibility, together with a variable aiming.

The goal is to obtain a gradual change of the beam shape, starting for example from a low beam configuration. As an example, it is useful to decrease the horizontal divergence and increase illuminance in HV, while the car speed increases. This is because it is demonstrated that at high speed foreground light is irrelevant for safety, while concentrate light in the central part of the screen increases visibility.

As a constrain on this procedure the redirected light shouldn't go above the horizontal line not to dazzle oncoming vehicles.

A preliminary analysis of different procedures was performed taking into account, for instance, the possibility of changing the beam shape with the movements of parts in the reflector structure.[2] [3]

Fig. 2 and 3 represent two different reflectors a parabolic and a segmented one that we simulated with an optical design and analysis software.

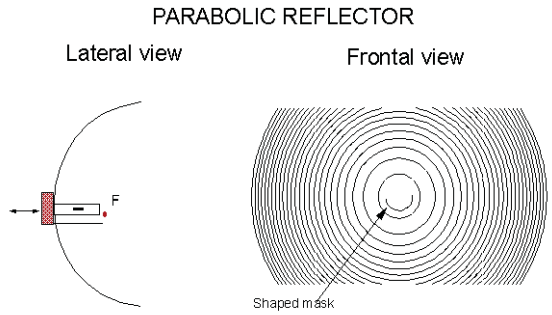

Figure 2. Parabolic reflector.

The low beam configuration for the parabolic reflector was obtained with a shaped mask, fixed to the reflector, that cuts rays from the lower part of the parabolic and models the 15 degree cut-off line. The idea was to reproduce the H4 configuration with a monofilament lamp.

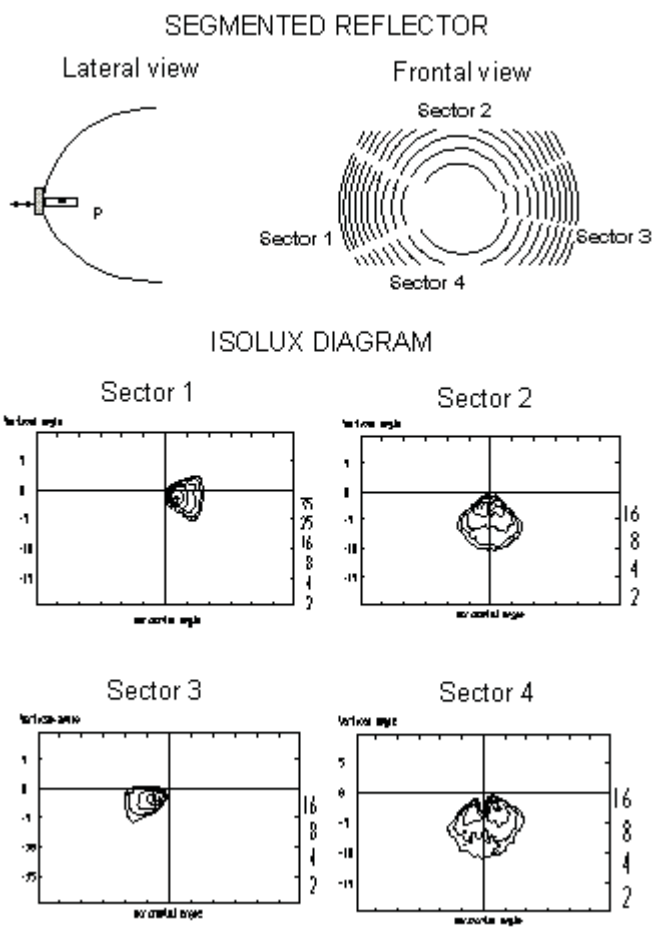

Figure 3. Segmented reflector

Simulations were performed in both cases with a gas discharge bulb D2S because of its high efficiency and low heating. Fig. 4 shows the D2S apodization diagram.

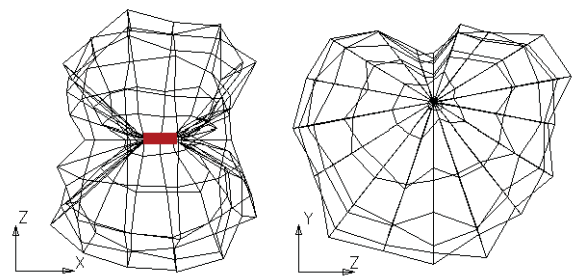

Figure 4. Apodization diagram of the Gas Discharge Lamp D2S (x axis is the optical axis)

A large diameter was chosen for the parabolic reflector to increase the luminous intensity.

Dimensions of parabolic reflector (focus=26 mm):
diameter: 165 mm

Dimensions of segmented reflector:
front section: 150 x 80 mm.

In the case of the parabolic segmented reflector, sector 1 and 2 were tilted around the y axis, with a rotation angle of 1.5 degrees. P1 and P2 are the points about which reflector sectors were rotated as shown in Fig. 5.

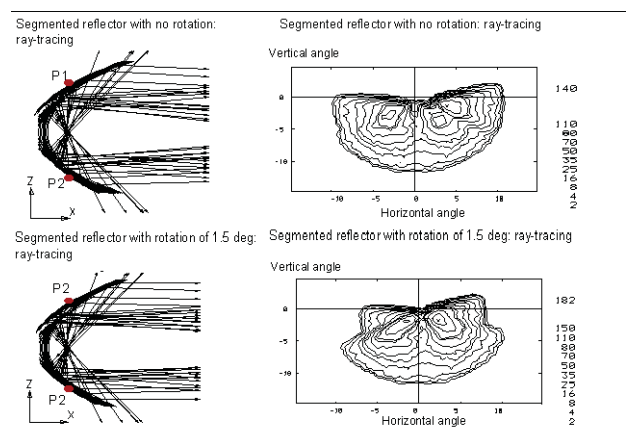

Figure 5. Ray-tracing and isolux diagram of the segmented reflector.

In the case of the parabolic reflector, the reflector lateral segments were rotated around the y axis about points T1 and T2, with a rotation angle of 1.5 degrees, as shown in Fig. 6.

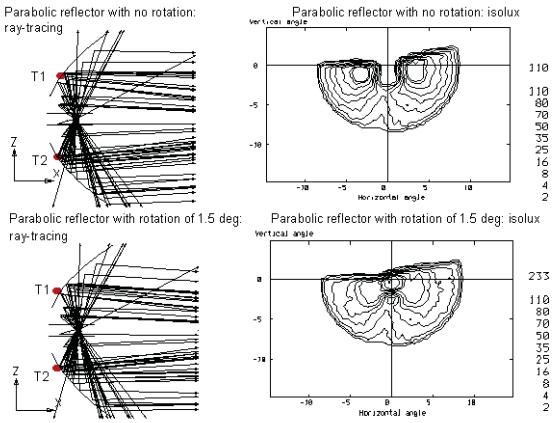

Figure 6. Ray-tracing and isolux diagram of the parabolic reflector.

The isolux diagrams show an increase of the Emax value and, as a consequence, an useful increase of illuminance in HV.

The second solution that we studied in details regarded the effects of source displacement on the beam light distribution, for different reflectors geometries.

Simulations were performed on the displacements of the source near the focus, along the optical axis, for the above systems. Further simulations were performed on an elliptical system (elliptical reflector, obscurator mask and a condenser)

In all cases the source used was the Gas Discharge Bulb, D2S, because hot filaments do break during the movement of the lamp, and because of the high efficiency of the discharge bulb.

Dimensions of elliptic reflector (focus=40 mm):
diameter: 85 mm

A preliminary investigation on the different reflectors efficiency while moving the source along the optical axis was carried out. Our optical design and analysis software evaluated the percentage of the emitted flux collected on an infinite screen positioned 25 m ahead of each optical system.

Fig. 7 shows the graphs of these optical simulations for each different system considered. The shift values (mm) of the light source around the focus are on the abscissa, the percentage values of flux collected by the screen are on ordinate axis.

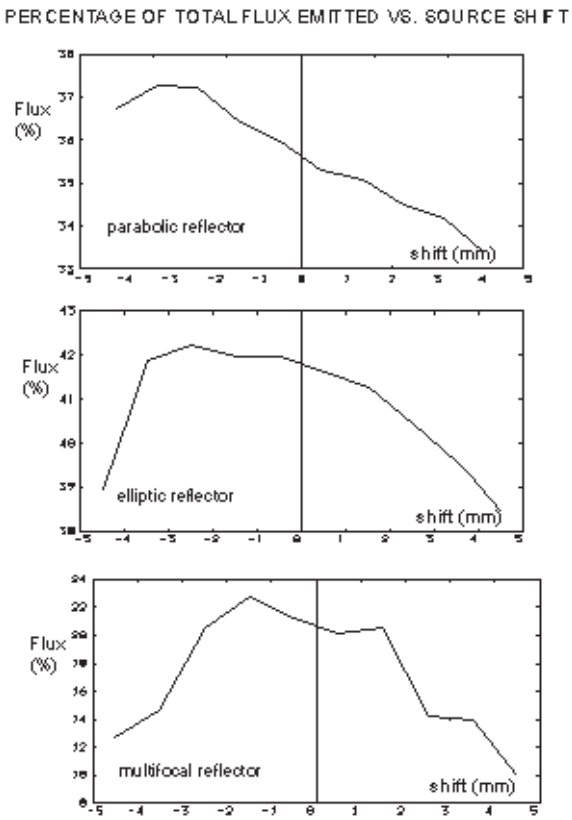

Figure 7. Flux percentage vs. source shift.

When the source is moved from the vertex of the reflector to the outer region (from negative to positive values of shifts), the luminous flux decreases for the parabolic reflector. For both the elliptic reflector and the segmented reflector there is an increase of flux only in a region very close to the focal point.

All the evaluations were done considering only rays collected by a fixed angular portion of the detector screen.

Fig. 8 shows the qualitative changing of the Emax value when moving the source around the focal point (P) of the segmented reflector, around the focus (F) of a parabolic surface and around the focus (F1) of an elliptical reflector.

Three different parabolic reflectors were considered, with the same outer dimensions but with different focus values: 21, 26 and 30 mm.

One can clearly see that maximum illuminance values occur when the source is

i) centered in the focal point in the case of parabolic reflectors,
ii) for positive shift in the case of elliptical reflector
iii) for negative shifts in the case of segmented reflectors.

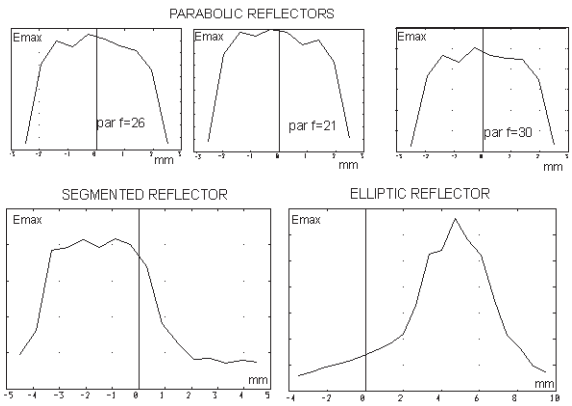

Figure 8. Qualitative evaluation of Emax vs. source shift.

Additional simulations were done on the light distribution and the isolux curves for the segmented, parabolic and elliptic reflector, with different source positions in each case, in order to verify the change of beam shape.

At first the emitting region of the source was centered in the focal point. It was then shifted along the optical axis around the focus F of the parabolic reflector or the point P of the segmented reflector or the focus F1 of the elliptical reflector.

Total shift was 3.5 mm in the parabolic case, 2.6 mm for the segmented reflector and 3.5 mm for the elliptic reflector. The different shift was established on the different geometry characteristics of the optical systems shown.

Simulations were carried out taking into account only reflected light and neglecting rays coming directly from the source, a reflectance of 80% was considered. In all the cases a vertical shift was necessary to project light below the horizontal line.

Diagrams shown in Fig. 9 demonstrate that the segmented reflector considered gives a divergence of 4 degrees with a total shift of the source of 2.6 mm, but a lot of light is projected in the lower region. Parabolic reflector gives a 7 degrees divergence with a total shift of 3.5 mm and the light is concentrated on a small area, with unchanged beam shape. The elliptical system doesn't give an useful divergence variation for our purposes.

Further evaluations will be necessary in order to evaluate not only the variation of the divergence but also the illuminance values, considering appropriate outer lenses for the parabolic and segmented reflectors.

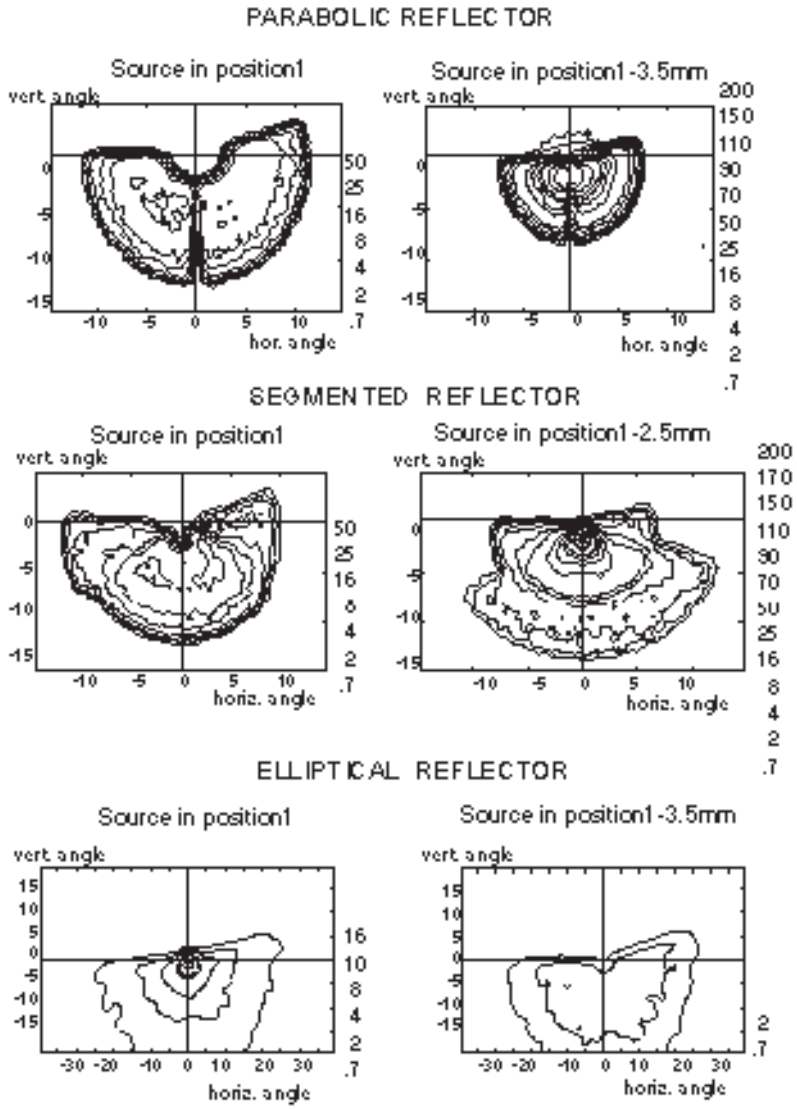

Figure 9. Light pattern for the three different optical systems considered, with some source position shifts around the focal points

CONCLUSION

Some results on the Motorway Light have been presented with HID bulb and systems mounted on a test car. This shows that the movement of the aiming during speed change increases visibility and driving comfort. An improvement of photometric characteristics and optimization of the beam pattern is also required. To reach this goal some simulations were carried out using different optical systems. These simulations are essential to define the most suitable solution for the future.

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