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A STRUCTURED LED MULTI LINEAR LIGHT FOR GROOVE MEASUREMENT OF A SPECTACLE FRAME

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ABSTRACT

Nowadays, eyeglasses are not only a vision aid, they also are fashion and design articles for the customers. The customer preference for various forms of spectacle frames grows and is served by the different frame manufacturers. This development leads to an increased effort for the production of adapted eyeglass lenses because of the huge range of the different designs and their manufacturing inaccuracies [1]. Therefore it is absolutely necessary to know exactly the coordinates of the ground of the spectacle groove for grinding the glasses well.

One non-contact possibility is the triangulation principle. Therefore often a laser line generator is used. But also a structured LED linear light is possible. For this the linear light has to have a defined width, brightness and sharpness. The linear light on the object, here the groove of the frame, is changed by its surface and is detected by a digital image processing [2]. If more information should be detected within one image a multi linear light could be used. Due to this also a structured LED based light source is an economically priced alternative to a multi laser line generator. Consequently, the focus of this research lies on the necessary width, brightness, sharpness, length and depth of focus of the linear light generated by a LED light source for high-precision measuring. This research has been carried out by extensive computer-aided simulations.

Index terms – multi linear light, structured LED light source, triangulation, detection of 3D surfaces.

1. INTRODUCTION

A frequently used method for measuring distances and surfaces is triangulation, typically using a laser as the light source [3].

If the beam sent out is a point, only the distance can be measured. But if the beam is structured into a more complex geometric shape, e. g. a line, surfaces can also be measured.

In order to use the principle of triangulation, the laser source, the detector and the object are arranged in a triangle.

A directed laser beam spot will be reflected at the object onto the detector, e. g. a CCD camera. The position of the object point can be calculated from the known geometry of the optical setup [2].

The widespread use of laser beams is limited by the occurrence of speckles which limits the line width [1].

The speckle patterns depend on the surface and the material and may lead to the fact that precise measurements are not possible, such as for example in the case of highly reflective metal and polished surfaces (see Fig. 1).

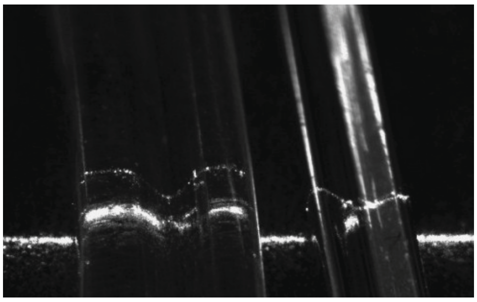

Fig. 1: A plastic and a metal frame with its groove, illuminated with a laser line generator (from left to right)

2. GROOVE MEASUREMENT OF A SPECTACLE FRAME

The groove of the spectacle frame is conduced to hold the eyeglasses in the frame by form closure. It has got a depth of up to 0.7 mm. But it has to be measured with an accuracy of 10 µm in order to keep the glasses strainless. For the other parameters of groove measurement see Table 1. Today the groove is measured by a tactile procedure. This has got several disadvantages due to the contact force between the stylus and the groove, see also [1].

Table 1: Criteria for groove measuring [1]

Criterion	Specification
light source	LED red colored
width	≤ 500 µm
length	10 mm
depth of focus	≥ 5 mm
illuminance	0,1 lm/mm²
low cost	< 350 €
working distance	< 50 mm

Groove and surface measurement is a typical task for the triangulation principle using a laser generator. The laser beam illuminates the object under test and diffuse or specular reflections are monitored from that point with a detector. The distance between the light source and the detector is known, so the groove can be measured.

The laser generator as the light source is very expensive and has got some other handicaps in comparison to a LED based light source [2], see also Table 2. First of all a high accurate measurement is not possible if there are speckles on the object under test.

These interference patterns due to the coherence of the laser light causes influences on sharpness and homogeneity of the linear light, which cannot be measured correctly.

Table 2: Typical properties of LEDs and Laser diodes [4]

Property	LED	Laser diode
wave length (color)	NIR, red, yellow, green, blue, UV, white	NIR, red, blue, UV
power (typical)	500mW	visible: 50mW
spatial coherence	highly multi-mode	single transversal modus (speckle)
time coherence	incoherent ($\Delta\lambda > 10$ nm)	coherent ($\Delta\lambda < 0{,}1$ nm) (speckle)
dimming	linear	not linear, laser threshold
modulation	MHz	GHz

On the other hand a linear light could also be generated by a structured LED. The diversity of power, spectral color, structural shape and so on allows a solution to nearly all measuring tasks. In some cases this is possible only by changing the source of light, the LED.

But the illumination of the LEDs is shared in all directions. For this reason high power LED need an attachment optic for building a powerful point light source to solve this measuring task. Also the beams have to be parallel and bundled before they can be modeled by optical systems with apertures, slits and lenses [4].

3. A STRUCTURED LED LINEAR LIGHT

The illumination of LED is distributed in all directions (see Fig. 2 – left hand side). A solution for creating a powerful point light source, which is needed for almost all classical optical setups, is using an aperture for creating a point light source. The big disadvantage of this optical system is the loss of nearly 90% of the illumination.

Another solution can be achieved by attaching an optical device on the LED (see Fig. 2 – right hand side).

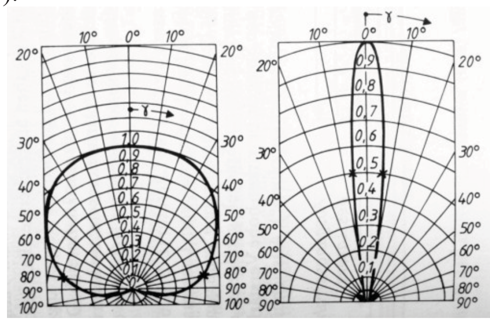

Fig. 2: Directional characteristic of different LEDs [4]

One prerequisite, a point light source has already been mentioned. Another condition is that beams have to be parallel and bundled before modeling by optical systems with apertures, splits and lenses. Secondary radiation has to be reduced by apertures. The elementary way to bundle LED light is using a biconvex lens as collimator. Therefore the LED has to be placed in the focal point of the biconvex lens [4].

When optical systems are designed, it is customary to use simulation programs, e. g. ZEMAX. This allows the simulation of dimensions and the theoretical testing of the developed system.

There are different basic setups to generate a line light:

- projection of a slit
- beam molding with a cylindrical lens
- beam molding with a parabolic reflector
- a combination of them

Different simulations with the optical program ZEMAX showed that the best assembling for forming a linear light based on a LED source is an optical system consisting of a split and a cylindrical lens (see Fig. 3).

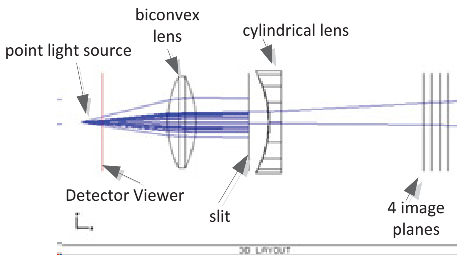

Fig. 3: ZEMAX 3D-Layout

The split has got a width of 300 µm and a length of 12 mm. It projects the linear light on the object under test. Its width is constant over the whole depth of focus. The cylindrical lens is used for beam expansion [2].

4. A STRUCTURED LED MULTI LINEAR LIGHT

With a single linear light the groove of the spectacle frame could only be measured on one position. Because of the curve of frame the ground of the groove should be measured at more than one location. This is easily done, if there is not only one but a multi linear light on the object under test [4]. This will also be monitored by the detector, normally a CCD-matrix-camera.

ZEMAX allows applying special parameters of the optic elements used e. g. the lens diameter, the radius of the lens and so on. These data are stored in catalogs that are available in ZEMAX. The results of the data can be seen in the NSC Shaded Model (see *Fig. 4*).

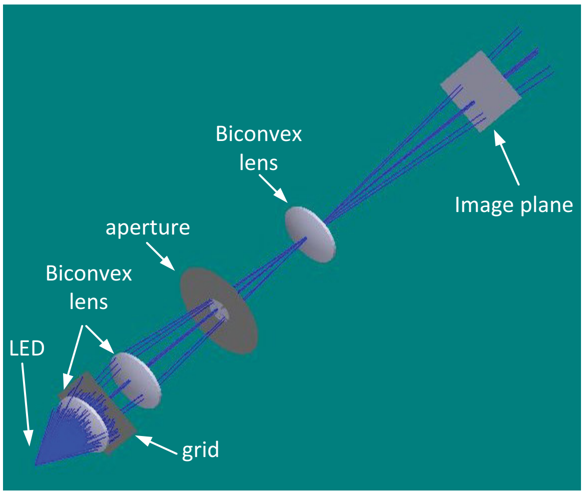

Fig. 4: ZEMAX NSC – Shaded Model – telecentric assembling to generate multi linear light lines

The Peak illuminance is shown in the Inverse Grey Scale Detector Viewer in Fig. 5. With it the homogeneity of the linear line is represented.

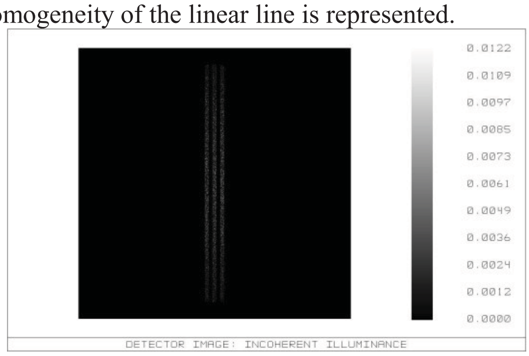

Fig. 5: ZEMAX – Inverse Grey Scale DV of a multi linear light

In Fig. 6 the Cross Section Row Detector Viewer represents a cross section through the linear line and the Cross Section Column Detector Viewer in Fig. 7 shows a longitudinal section through the line.

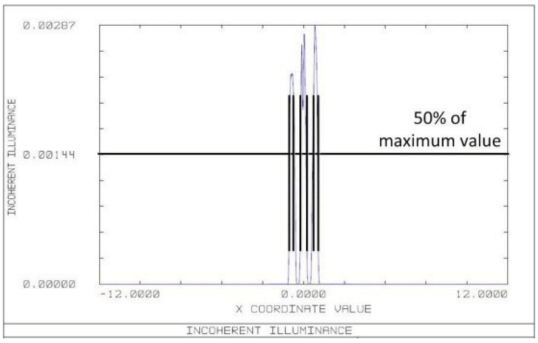

Fig. 6: ZEMAX – Cross Section Row DV – line width

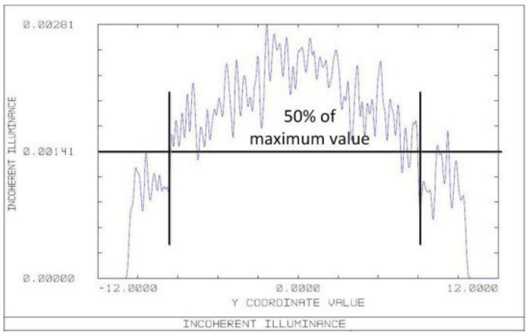

Fig. 7: ZEMAX – Cross Section Column DV – line length

With this information it is possible to get the geometrical dimensions of the width and the length of the linear line. The significant criterion of the line data has been the 50% value of the maximum peak illuminance.

In the simulation the grid had a width of 250µm and a length of 20mm and projected the linear light on the image plane [4].

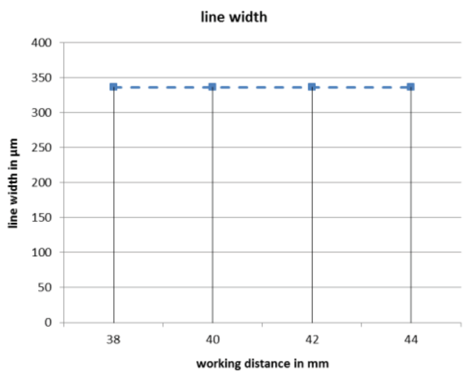

Fig. 8: Line width

Fig. 8 shows that the line width is constant over the whole working distance in the simulation. The line length increases with larger working distance (see Fig. 9).

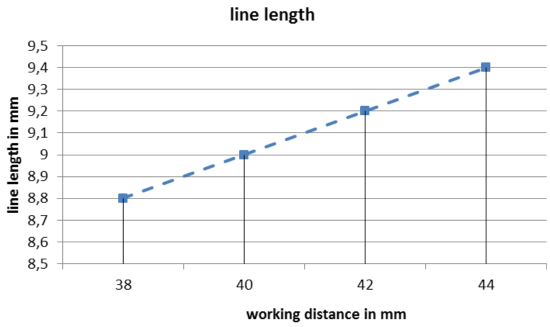

Fig. 9: Line length

5. REALISATION OF A STRUCTURED LED MULTI LINEAR LIGHT

For creating a multi linear line the slit has to be changed to an optical grid. After simulation the assembly was realized in practice. The realized optical system consists of an LED Vishay TLCR100 red colored, a biconvex lens for beam collimation, a grid and the telecentric system which consists of two biconvex lenses and an aperture. As a detector a monochromatic CCD-camera with 1360x1024 pixels was used. The technical principle of the optical system is shown in *Fig. 10*.

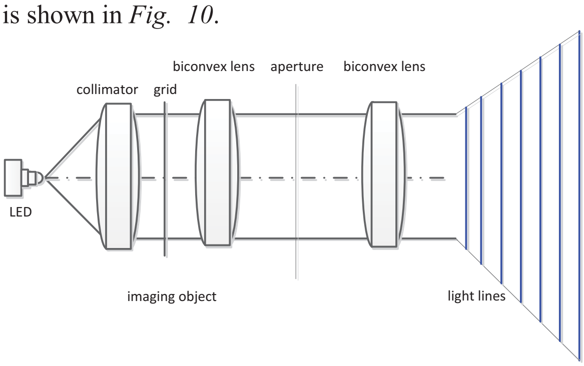

Fig. 10: Multi linear light out of a telecentric assembling [4]

The teclecentric assembly is necessary to create a huge depth of focus.

The analysis of the results in terms of the images was carried out by grey scale value analysis in Matlab.

For that the adequate LED had to be found. To provide for optimum sharpness of the line and a maximum line length, the viewing angle of the LED must be as small as possible. The light intensity is the most important aspect for the selection of the LED next to the viewing angle.

The LED Vishay TLCR5100-red was used. This LED has a size of 5 mm, a viewing angle of 18° and an intensity of 11 cd. Under normal circumstances as light source red colored laser diodes are used. That is the reason red colored LED are used for investigations. Also red color light sources are used to avoid color failure because of using white light sources.

Fig. 11 and Fig. 12 show the evaluation of the lines generated. In this case 3 lines have been created.

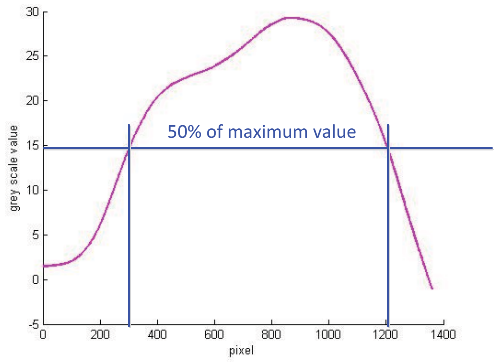

Fig. 11: Realized longitudinal section through the line

For this purpose the conversation of the pixel values is necessary. In the case of cross section for the determination of the line width 1024 pixels were used, so one pixel equals 0.024 mm. For the determination of the longitudinal section through the line 1360 pixels were used to create the image. One pixel equals 0.025. E. g. the line width was determined with 13 pixels which correspond to 320 µm.

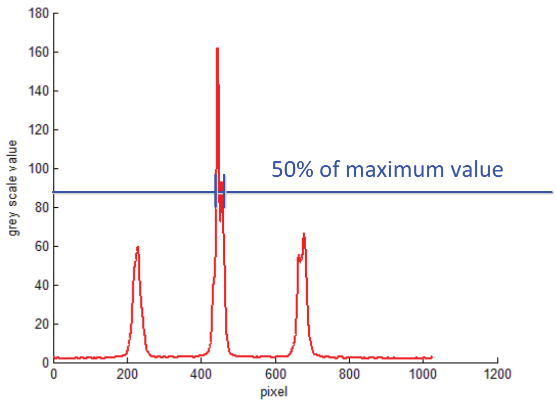

Fig. 12: Realized cross section through the line

At the point of the pixel with the highest grey scale value a longitudinal section and a cross section were made through the line. These measurements were repeated reproducibly. In addition to the simulations the sharpness of the line was determined by an extraordinary algorithm. Therefore the maximum increase in the edge angle was identified (see Fig. 16 and Fig. 17). It may be noted that the lines produced an outstanding sharpness and were thus well suited for measuring systems.

It is the aim that both edge increases of the linear line possess an identical rise and steep edges. For the application as a measurement system it is necessary that the linear line has a high degree of sharpness. This is indicated by a steep edge increase.

The results of the line geometry are shown in Fig. 13, Fig. 14 and Fig. 15. The line width is nearly constant over the whole working distance and it is smaller than 500µm. The line length increases due to the expanding optical effect of the whole optical system as expected. Furthermore the Peak illuminance was analyzed to get information about the illuminance of the lines.

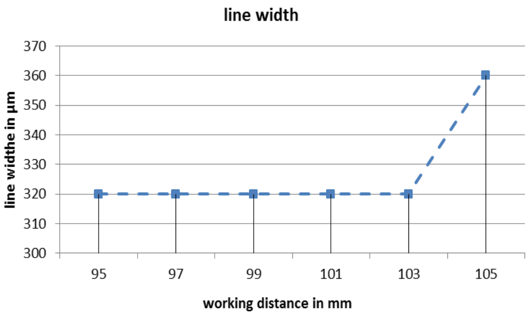

Fig. 13: Width of the multi linear light.

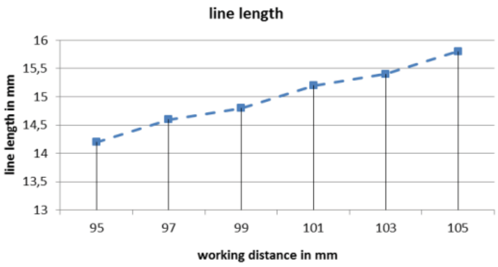

Fig. 14: Length of the multi linear light

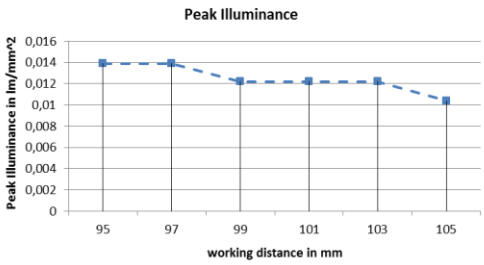

Fig. 15: Peak Illuminance of the multi linear light

Additional in Fig. 16 and Fig. 17 the rising of edges was analyzed. Especially for the line width it is very important that the lines have a great sharpness.

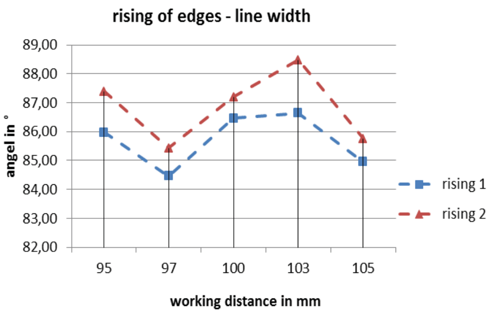

Fig. 16: rising of edges – line width

In Fig. 16 all values of the angles are larger than 84° and this is a very good value for using the generated lines for measuring tasks.

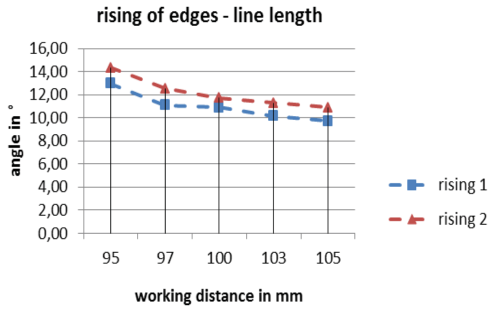

Fig. 17: rising of edges – line length

The information of the rising of edges of the line length is useful to get information about the usable line length. The deviations of the results of the simulation are partly due to the image plane, which could not be precisely aligned orthogonally to the beam path. The noise of the camera image causes deviations of the measurements. The fluctuations of the measurement results in comparison to the simulation show that the adjustment of the alignment of the elements for the test with a LED line generator must be very precise [4].

The simulation results in ZEMAX were generated under ideal circumstances which could not be realized in practice as well as in the simulation. Nevertheless the simulation is a very good tool for creating optical systems in practice.

6. CONCLUSIONS

Finally it can be established in what cases it is appropriate to use an LED light instead of a laser source for generating a linear light.

In general, both laser and LED line generators can be used in measurement systems. If economic efficiency is to be the main aspect, it is also recommended to use LED line generators. On the other hand, whenever a huge depth of focus is required, the use of laser line generators can be recommended.

The development of the LED line generators is not completed yet. Thus in the development of novel high-power LEDs there is much potential for such measurement tasks. Moreover, particular attention is focused on special optics which can be placed on LEDs (see Fig. 18) [5].

These optics can realize a better shaping of the beam to reduce the stray radiation of the emitted light.

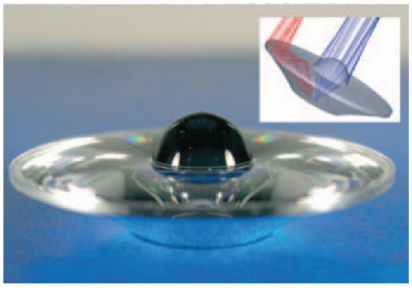

Fig. 18: Diamond turned prototype of a refractive/reflective concentrator [5]

All in all, the high demands for generating a structured LED linear line, such as depth of field, line width and line length are reasonably easy to realize by using optical devices like LEDs, cylindrical lenses and apertures but they have to be designed for a special measuring task.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

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