Active null-test of personalized progressive addition lenses

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ABSTRACT:

Free-form lenses are continuously being introduced in the market due to their superior performance when compared to classical designs. The control of free-form lens shapes is a mandatory step to evaluate its quality, but also it is often a required part of the fabrication procedures of complex lens shapes. We present an adaptive optics system within an open-loop configuration to serve as a null-test of personalized progressive addition lenses. The system provides a measurement result which is easy and fast to interpret even for a non-expert operator or an automated image processing system.

Key words: active optics, null-test, progressive addition lens, liquid-crystal spatial light modulator.

1.- Introduction

Due to the improvements in optical design capabilities and in the manufacturing tools of free-form optical surfaces, new lenses with complex shapes are a commercial reality. These complex lenses improve the performance of conventional lenses within many optical applications. Some examples of complex lenses are wild-aspherics with curvatures up to 75º [1], aspheric folded lenses within a compact imaging system [2], and progressive addition lenses personalized to the lower and higher order ocular aberrations of a patient [3] or to its pattern of coordinated eye and head movements when looking at an off-axis object [4] [5].

The quality control of the shape of a complex lens is usually performed using mechanical contact profilometers due to the large dynamic range required, despite the extremely high measurement time that it takes to get a good spatial resolution and the danger it represents to the considered surface. Non-contact, high speed testing solutions which do not damage the lens are also nowadays available, including the Shack-Hartmann optical wavefront sensor. However, its limited dynamic range can not typically deal with very complex wavefront shapes involving important local changes in the surface. Moreover, the measurement results which are obtained must be interpreted by an expert operator.

Instead of the methods that directly measure the shape the lens, null-test methods are equally available. They use a known mask to compensate the original shape of lens to give a measurement result which is easier and faster to analyze. These two advantages are especially useful in a production line to get easy and reliable real-time lens quality control. Nevertheless, conventional null-tests are static optical elements (null lenses, phase plates, computer generated holograms, etc.) which are expensive and time-consuming to produce and which match only a particular lens design. Active null-tests based on dynamical devices such as deformable micromirrors or liquid crystal spatial light modulators are a reliable solution to decrease the abovementioned costs.

Following this reasoning, we present an adaptive optics (AO) system within an open-loop configuration as an active null-test of commercial progressive addition lenses that are personalized to the patient's visual strategy.

2.- Active Optics System

The AO principle is based on the local modification of the phase of a distorted wavefront to compensate for its aberrations. Although AO systems can be rather complex, the basic working principle is quite simple. In conventional AO, the distorted wavefront is measured with a wavefront sensor and compensated by introducing its conjugate in the phase correcting device by means of a control system.

Fig. 1 shows the AO system that we have constructed. A 635 nm point light source obtained from a pigtailed laser diode is collimated using a diffraction-limited doublet. The resulting plane wavefront passes through a linear polarizer, crosses the progressive addition lens to be tested, and is directed towards a liquid crystal programmable phase modulator (PPM) [6] by means of a pellicle beam-splitter (BS1) which does not alter the optical path length. The aberrated wavefront is completely compensated (null-tested) by the PPM which is conjugated with a proprietary cylindrical Shack-Hartmann sensor (CSHWS) through a 4:1 telescope system [7]. The sensor, formed by two identical arrays of microcylinders (NA=0.02) oriented along the vertical and horizontal directions, samples the wavefront (previously divided by a second pellicle beam-splitter BS2) in the form of a vertical and horizontal line patterns simultaneously recorded by two identical CCDs. The compensated wavefront is ideally a plane wavefront which is detected by the CSHWS as straight lines. Local deviations of the straight lines –which can be easily and quickly visualized- report spatial errors of fabrication of the progressive lens.

Besides this helpful quick inspection of the detected line patterns, they are also processed by a proprietary line tracking algorithm [7] which computes the average wavefront slope across the microlenses and, from these data, the wavefront is finally reconstructed in terms of the circular Zernike polynomial decomposition [8].

Because of the non temporal dynamics of the samples to be tested and the excellent linear response of the PPM [9] we have chosen to work in an open-loop adaptive configuration (i.e. active compensation). This leads in a faster active null-test process.

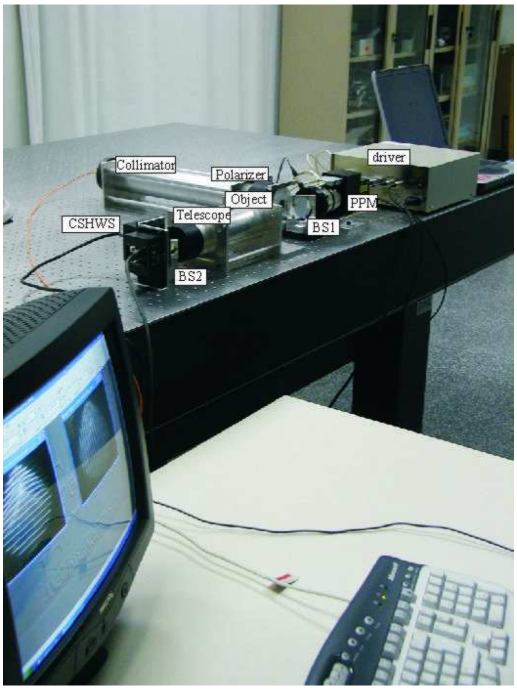


Fig. 1: Active null-test of complex-shaped optical objects, which is applied to personalized progressive addition lenses.

3.- Null-test of a personalized progressive addition lens

We present the results of null-testing a commercial progressive addition lens. The lens has null distance power and 2 D of addition, and its design is customized to wearers who move mainly the head and barely the eyes when doing a near-distance visual task. The null-test is accomplished inside a central circular area of 20 mm of diameter of the lens, depicted in Fig. 2. This circular area contains the 16 mm length power progression corridor of the lens and part of the temporal and nasal sides.

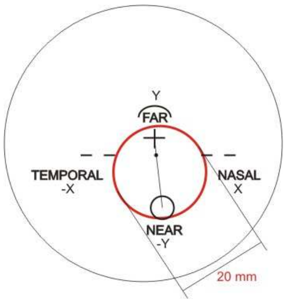
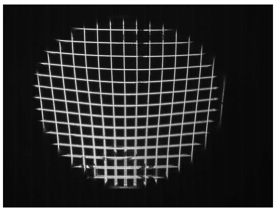
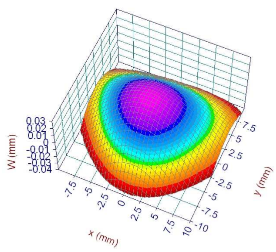


Fig. 2: (In red) Circular area of the personalized progressive addition lens in where the null-test is applied.

First, with the PPM left inactive, the original wavefront transmitted by the lens is measured by the CSHWS. Figs. 3a and 3b show the line patterns detected by the CSHWS and the reconstructed wavefront, respectively. As expected, in the near vision region where the addition reaches 2 D, the width of the lines increases from the diffraction-limited size and are also displaced outside the corresponding microcylinder area of the CCD array.



(a)

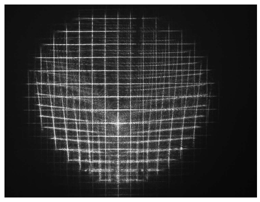


(b)

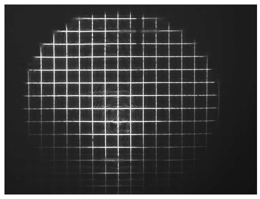
Fig. 3: (a) Line patterns which correspond to the original wavefront transmitted by the progressive lens. (b) Reconstruction of this wavefront.

In a second step, the conjugated wavefront to be introduced in the PPM to perform the null-test is calculated. In this case, due to the large aberration to be compensated, the PPM has low diffraction efficiency [10] due to the high density of phase fringes which need be written. As a consequence, the diffracted original wavefront is superimposed with the compensated wavefront. The "noisy" line patterns are shown in Fig. 4a.

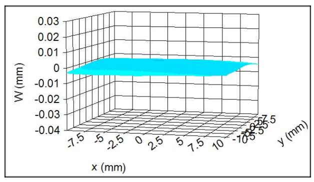
To solve this problem, a pinhole of 300 μm is introduced centered in the focal plane of the first doublet of the telescope. The pinhole blocks the diffracted original wavefront and only the compensated wavefront arrives at the CSHWS. The detected straight line patterns and the reconstructed wavefront are shown in Figs. 4b and 4c, respectively. Its RMS error with regard to a flat surface is 0.080λ (50.8 nm).



(a)



(b)



(c)

Fig. 4: Line patterns that correspond to the compensated wavefront (null-test result) (a) without and (b) with the pinhole filter introduced in the setup. (c) Reconstruction of the compensated wavefront.

4.- Conclusions

An active null-test system which is based on a cylindrical Shack-Hartmann wavefront sensor and a liquid crystal phase modulator has been presented and its performance demonstrated.

Results of total null-testing of wavefronts transmitted by a personalized progressive addition lens with its design customized to wearers who move mainly the head when performing near-distance visual tasks have been shown. Partial null-testing of selected aberrations or local regions is equally possible using the same experimental setup.

Through the simple inspection of the straightness of the line patterns, a quicker identification of possible errors in the shape of the lens could be done. The results obtained showed a RMS difference of the compensated wavefront to an ideal flat wavefront of 0.080λ (50.8 nm), showing the quality of the active null-test developed.

The proposed system lets an easy, fast, and flexible quality control method for complex-shaped optical elements.

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