INTRAOCULAR LENS CHARACTERIZATION USING A QUADRI-WAVE LATERAL SHEARING INTERFEROMETER WAVE FRONT SENSOR

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1. Introduction

Cataract surgery is the most frequently performed surgical procedure in adults. It consists in the replacement of the eye crystalline lens by a synthetic intraocular lens (IOL). Therefore IOL manufacturing is a growing and very dynamic market. A few years ago, only simple monofocal bi-convex lenses were implanted. Novel methods for improvement of IOLs in the field of ophthalmology comprise surface shape modifications that differ from perfect spherical geometries of the optical surfaces. Besides correction of spherical refractive vision errors, these surface modifications allow the restoration of the optical properties of the healthy natural human lens. In order to match the implant with the particular optical properties of the patient's optical system, the IOL is designed to exhibit different but well defined optical properties depending on its surfaces geometry.

For instance, to compensate presbyopia, multi-focal lenses have been proposed. Like multifocal glasses, these IOLs have different foci corresponding to near and distance vision.
A lot of measurement tools are available to characterize monofocal IOLs. They are based on contrast measurement (Modulation Transfer Function or MTF). However these methods are not relevant enough to investigate the properties of a multifocal IOL. Wave front sensing is a better solution as the transmitted wave front gives not only information on the optical quality but also leads to optical power maps and allows to determine the foci positions.
At PHASICS, we have developed an measurement tool named KALEO, based on our commercial wave front sensor SID4. Thanks to its acceptance of high numerical aperture beams without any additional relay lens, the measurement scheme is very simple.
In this paper, we will first present PHASICS SID4 technology, named Quadri-Wave Lateral Shearing Interferometry (QWLSI) and the principle of the KALEO measurement machine. We will then show examples of IOL measurements.

2. Quadri-Wave Lateral Shearing Interferometry

In the 90s, the concept of lateral shearing interferometry has been extended to more than 2 waves by Primot and coworkers [1]. This has lead to the invention of multiwave lateral shearing interferometry and, in particular, to the compact quadri-wave lateral shearing interferometer (QWLSI). The principle of this technique is very simple : the wave front is divided in replicas by a diffractive optics (see Figure 1). Each replica propagates and therefore separates from the other ones. In the region where they still overlap, the interference pattern gives access to the phase difference between each couple of diffraction orders. Because they have separated and if the propagation is short enough, this phase difference is proportional to the local phase gradient. Consequently each couple of replica gives an information on the gradient along one direction (which is determined by the two replicas k-vector difference). The phase gradients are recovered thanks to Fourier analysis around each carrier-frequency associated to each replica couple.

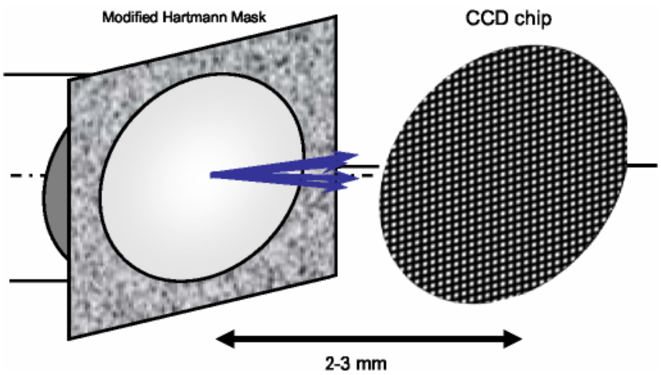

Figure 1. Principle of the Multi-Wave Lateral Shearing Interferometry, illustrated in the case of four wave interference. The beam is incident from the left. It is first diffracted and the interferences are recorded by the CCD chip.

This principle has been applied in laser metrology to 3-wave interferometers [2], which is its simplest variation. The optimization process led to 4-wave interferometers, thanks to the so-called Modified Hartmann Mask (MHM) [3]. This 2D diffractive optics has been designed to concentrate more than 90% of the power in the 4 first +/-1 diffraction orders only. It is therefore a good candidate to make a Quadri-Wave Lateral Shearing Interferometer (QWLSI).In the case of QWLSI, the observed interference pattern is a Cartesian grid of sinusoidal fringes. If the wave front is flat, the grid pitch is the same everywhere in the pupil. If the light contains aberrations, the grid is deformed and the deformations are proportional to the local phase gradients.

3. KALEO measurement machine principle

To characterize small optics, such as IOLs, we have developed the KALEO measurement machine. Its principle is very simple: a calibrated collimated beam propagates through the lens. The transmitted wave front is analysed with a SID4 wave front sensor. If the lens is perfect, it is spherical. The distance to a sphere is then the lens aberrations. From the aberration map, we can simulate the Point Spread Function (PSF) and deduce the Modulation Transfer Function (MTF). We can also generate a curvature map and compare it to the IOL design.

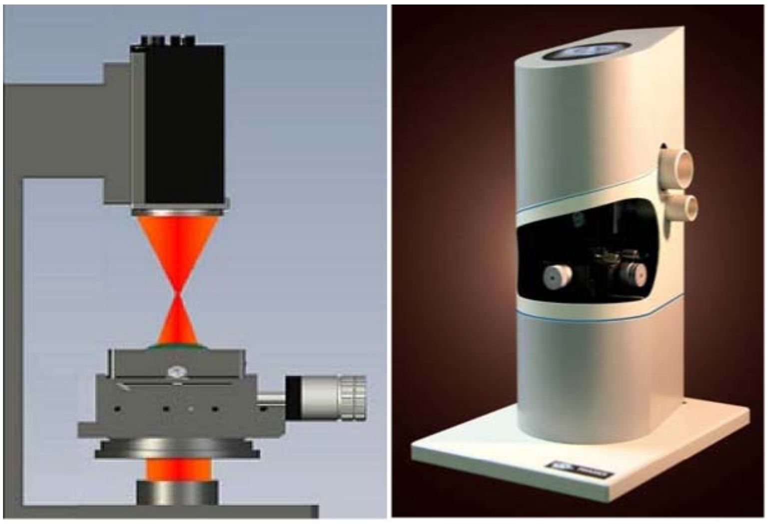

Figure 2 – KALEO measurement machine principle and photograph.

4. Intraocular lens characterizations

This method can be applied to any kind of refractive IOLs, either spherical, aspherical, monofocal or multifocal. An example of such a measurement is shown in Figure 3. With the wave front measurement, we can propagate the wave front in almost any plane. In this case, we can determine the long and short vision foci and deduce their optical transfer functions.

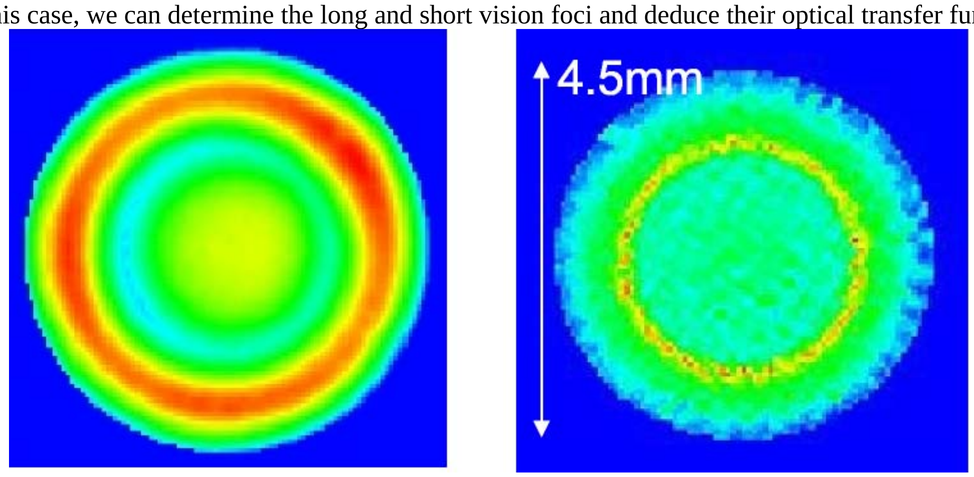

Figure 3 – Measurement of a 26.5D multifocal IOL with the KALEO machine. The analysis pupil is 4.5 mm. In the left, we show the aberration map. In the right, we show an optical power map, with clear regions of different powers.

5. Conclusion

We have shown that wave front sensing is a very good solution to intraocular lens characterization, because a wave front transmitted through a lens carries a lot of information about its optical properties in its focal plane(s). Thanks to its acceptance of high numerical apertures (over 0.3), PHASICS SID4 wave front sensor makes this measurement very fast and simple.

References

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