Optical Testing with a Knife Edge Interferometer

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Abstract. In this paper some experimental results will be presented with a setup that uses a knife edge for producing partial interferograms, with information about the quality of a lens under test. However the same method can be extended to test an optical surface. The knife edge is located near the focal point of the lens, covering almost half of an incident laser light beam. The different observed interferograms correspond to the orientation of the knife edge with respect to the optical axis, and focus of the lens.

1. Introduction

For the testing of optical components in an optical shop the interferometry is one common technique. However, in some methods regularly used, a reference wavefront produced by an auxiliary optics is required, for this reason new procedures are generated with a self reference wavefront. Some examples at testing methods with a self reference wavefront are: the lateral shearing interferometry (Murty, Ronchi) [1], and the point diffraction interferometry [2], etc. In the present work, new process is suggested, and this consists in generating a reference wavefront by use of a knife edge located in a converging beam, before and after of the focus the lens under test. When the knife edge is illuminated, each point of the knife produce a reference wavefront that interfere with the other section of the wavefront produced by the system under test. The advantage of this proposal is to have a simple and powerful testing arrangement. The principle of the testing is based on a Sommerfeld solution for the diffraction from a half plane represented by a knife edge [3]. Therefore a wave therefore diffracted on an edge produces a cylindrical wave. The produced cylindrical wave can be used as a reference wavefront, moving the blade close to the focus, interference fringes are produced by the wavefront coming from the lens and the one from the knife edge. From the fringe pattern the shape of the wavefront under test can be easily calculated, and information of aberrations of the lens can also derived.

2. Interferometer operation

With a collimated beam that illuminates the lens or system under test Fig.1, a beam emerges where all rays converge at the focus of the system under test, and subsequently, continue to spread in the same direction. Ideally the focus should be a point and the wavefronts emerging, from the system under test, should be perfectly spherical; but in reality this does not happen and that is why we need a reference wavefront to find the difference between the real wavefront from the ideal one.

To generate the reference wavefront a razor’s edge is located in a region near the focus of the system being tested. According to the Huygens-Fresnel principle, when the razor’s edge is illuminated, each point on it produces a spherical wavefront, the superposition of all gives rise to a cylindrical wavefront. In turn, this wavefront overlaps with the non-gated
original wavefront produced by the surface or lens under test, and therefore we have partial information interferograms of lens aberration being tested. So what we finally have is the overlapping of a spherical wavefront under test with a cylindrical wavefront reference, giving as result an interference pattern. In fig.2 and fig.3 are shown how the wavefronts interfere, depending upon the knife edge is located before or after the focal point.

**Figure 1. Interferometer operation**

**Figure 2. Amplification of overlapping wave fronts when the knife edge is placed after the focus of the lens under test.**
3. Theoretical analysis

Sommerfeld showed that the diffraction of a plane wave incident on a half-plane (knife edge), produces a cylindrical wavefront [3]. The cylindrical wavefront becomes a reference wavefront for comparison with the real spherical wavefront of the lens under test. The arrangement is very simple, and the knife edge is positioned at a distance of few millimeters, near the focus of the lens that is under testing. Hence an interference pattern can be observed on a screen, located to a some distance from focus plane, see Fig.4.

In order to know the position of the interference fringes on the screen, let’s consider from fig.4 the distance $L_{1,1}$ between the focus and the knife, $L_0$ is the distance between the focus and the observation screen, $L_2$ is the distance at which a dark fringe is observed.

Using geometrical arguments, from same fig.4 and with a little algebra, the optical path difference (OPD) between $AC$ and $AB + BC$ is equal to
$$\Delta_E = \left( \overline{AB} + \overline{BC} \right) - \overline{AC}$$

$$= L_{1,1} + L_{0} \sqrt{1 + \frac{L_{1,1}^2}{L_{0}^2}} - \left( L_{0} + L_{1,1} \right) \sqrt{1 + \frac{L_{2}^2}{\left( L_{0} + L_{1,1} \right)^2}} ,$$

Considering that \((1+x)^{1/2} = 1 + (1/2)x + \ldots\), then

$$\Delta_E \approx \frac{L_{2}^2}{2} \left[ \frac{L_{1,1}}{L_{0}^2 \left( 1 + \frac{L_{1,1}}{L_{0}} \right)} \right] .$$

Now as \((L_{1,1} / L_{0}) \ll 1\), the next equation can be derived

$$\Delta_E \approx \frac{L_{1,1}L_{2}^2}{2L_{0}^2} , \quad (1)$$

where \(L_{2}, L_{1,1} \ll L_{0}\).

On the other hand, we know from interferometry that for the phase \(\delta \varphi = (2n + 1)\lambda\); the conditions for dark fringes will be that the OPD, \(\Delta T\), is equal to \(\Delta T = (n + 1/2) \lambda\) \[3\], where \(n\) is the order of the fringe, and \(n = 1, 2, 3, \ldots\). However, a more accurate condition for the dark fringes \[4\] is

$$\Delta_T = (n + 5/8) \lambda , \quad (2)$$

For checking the experimental results using Eq. 1; the exact or theoretical Eq. 2, derived from the diffraction theory for an edge, a comparison is made between both equations in section 5 in order to have quantitative results.

4. Experimental arrangement

We implemented an experiment (Fig.5), to test a reference sphere lens from an interferometer ZYGO, trade mark. This lens is used as a reference for the manufacture of optical elements in the optical workshop at INAOE. Even that the knife edge was placed before and after the focus for four different rotations \((0^\circ, 90^\circ, 180^\circ\, and\, 270^\circ)\), in this paper it is reported the analysis for the case of the knife edge before focus and located below the optical axis and perpendicular to the paper plane, the reference sphere has an effective focal length of 289.03 mm., 101.6 mm of diameter, and an accuracy of \(\lambda / 10\). Therefore we should expect quantitative and qualitative good results.
5. Experimental results
The results reported here in are for an interferogram with 5 dark fringes, Fig.6, the measurements for the position of the dark fringe is done along a single as it is shown in Fig. 6. Since a He-Ne laser was used as a light source, $\lambda = 632.8 \, \mu m$, and the distances measured are $L_{1,1} = 0.180 \, mm \pm 0.005 \, mm$; and $L_0 = 665 \, mm \pm 1 \, mm$; in Table 1 are listed the values of $L_2$, measured for the five fringes, and the theoretical and experimental, $\Delta_T$ and $\Delta_E$ from Eqs. 1 and 2.

Figure 5. The test is applied to a reference sphere.

Figure 6. Interferogram obtained for 5 interference fringes.
Table 1. Measurements and results.

With these data from Table 1, a polynomial fitting was done for a wavefront polynomial of order 4, written as

\[ W = A x^4 + B x^3 + C x^2 + D x + E \]  

(3)

The numerical values derived for the coefficients of the Eq. 3 are equal to: \( A = B = C = 0.000 \), and \( D = 0.001 \), \( E = 0.077 \). Since the testing was done on a high quality lens, the first order aberrations are corrected (A, B, and C coefficients), and only the defocus and piston are different from zero. In Fig. 7 are the graphs for the variations of the measured wavefront, together with the polynomial fitting.

As can be seen, the numerical analysis has been done only for the meridional plane and only for one position of the knife, but the aim in the future is to obtain information for two knife edge positions in one direction, before and after the focus position to get a full interferograma, and thus to get a more general analysis of the aberrations present in the lens under test.

Figure 7. Graphical representation of the variation of the wavefront.
6. Conclusions
The interferometer requires no reference optics and is insensitive to mechanical vibration, because is a interferometer common path. The interferograms give us the information on the optical quality of the item under test, but it is necessary to overlay information from two adjacent interferograms with the so called Stitching method [5].
The quantitative results shown, so far, are for a single line on only one interferogram; however, provide to the authors; information about all the possibilities of this kind of simple interferometer, once that a full set of fringes are measured on the interferograms, and the stitching method is applied for two or more interferograms.

7. References
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