Analysis of lens aberrations using a retinoscope as a Foucault test

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ABSTRACT

It is presented a quite simple procedure for measuring the astigmatism aberration of lenses by using an optometric and ophthalmic instrument, the retinoscope, as a focimeter.

1. INTRODUCTION

One of the most known methods to evaluate optical systems aberrations is the Foucault test or knife edge test, actually efficient, for instance, to study the concave mirrors for astronomical use. Fundamentally, this device consists on an illumination system, directed to the optical element under study, and an observation system. These systems are placed so the pencil ray that form the image is sectioned by a knife edge that can be displaced both longitudinal and transversally. When the knife edge is near the studied system focus, the observer sees a shadow distribution that has precisely to do with the system aberrations [1]. In practice, the Foucault test is performed for each application with a specially designed device and, therefore, it is not commercially available for general purpose. Unfortunately, this is a severe handicap for its use in educational laboratories of optics. Based on the same optics principles than the Foucault test, although apart developed, there is an absolutely simple optometric and ophthalmic instrument used to measure objectively the refractive state of the eye: the retinoscope.

2. PRINCIPLES OF RETINOSCOPY

The retinoscope is a simple self-luminous hand-held instrument used in a standard clinical procedure to measure objectively the refractive state of the eye. It is composed of a single lens, a light source and a mirror (see Fig. 1).

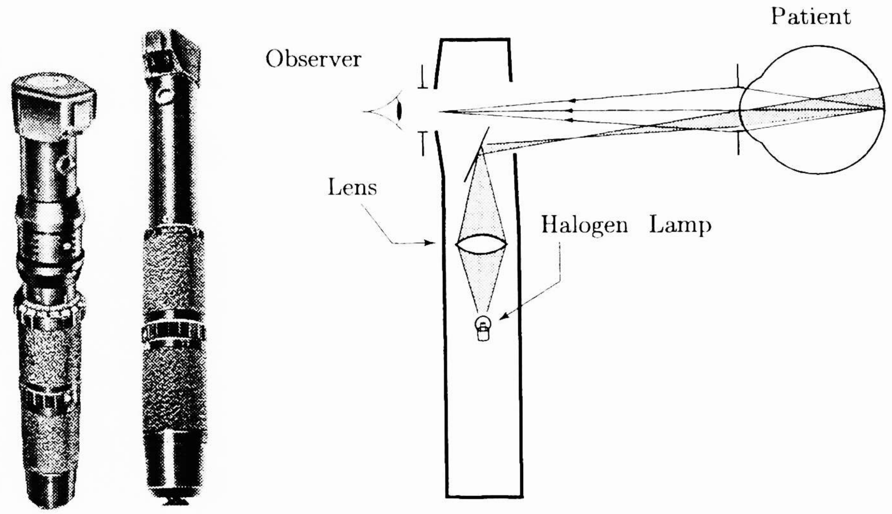

Fig.1 Photograph of a retinoscope and schematic layout of the elements that compose it.

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By performing retinoscopy, the observer views a small patch of light formed upon the patient retina. Depending on the retinoscope light source, this patch can be circular or a slit. By moving the patch in a given direction and viewing the direction in which it appears to move after a double passage trough the patient eye, the observer is able to say whether the patient retina is focused in front, at, or behind the retinoscope. The refractive error of the patient, and therefore his spectacle compensation, is measured by placing lenses in front of his eye until the patient retina is focused at the retinoscope pupil.

In the illumination system (see Fig. 2) the retinoscope forms an out-of-focus patch of light (*A*) upon the patient retina. When the mirror is tilted up, this patch moves in the same direction. The movement direction of *A* does not depend on the eye ametropia value. This patch of light becomes the observation object behind the retinoscope. For the observation system (see Fig. 3) let us consider, for instance, a myope eye whose punctum remotum is located between the eye and the retinoscope. Note that not all the rays originated at the central point of the patch (point *A*) and emerging from the eye pupil arrive to the observer eye. On the contrary, some of them are cut off by the retinoscope pupil. If the retinal patch moves up, its aerial image moves down and the reflex from the retina is seen behind the retinoscope as moving "against" the movement of the mirror. The direction and speed of the reflex movement are the parameters that the observer takes into account to bring the aerial image of the retina to the retinoscope pupil. In this way, the retinoscope works as a focimeter like as the knife edge (or Foucault) test, but, instead of moving the knife edge along the optical axis, the focalization is achieved with the aid of auxiliar lenses (negative in our example, see Fig. 4).

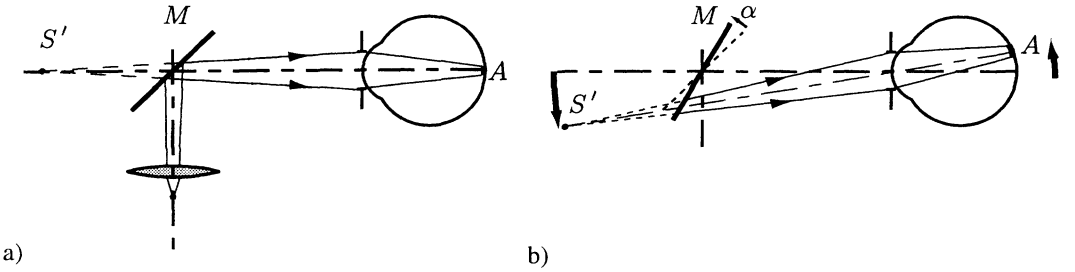

Fig.2 Illumination system. The retinoscope forms an out-of-focus patch of light (*A*) upon the patient retina (see a)). When the mirror is tilted up, this patch moves in the same direction (see b)).

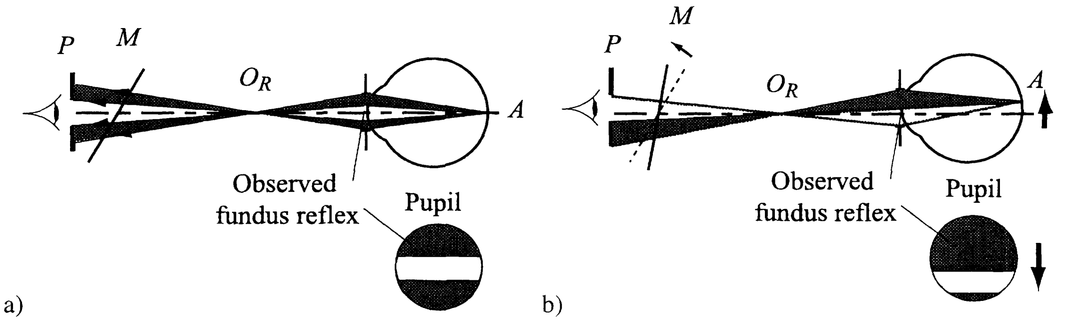

Fig.3 Observation system. Fundus reflex produced by a myopic eye with its punctum remotum O_R between the eye and the retinoscope (see a)). When the mirror is tilted up, the fundus reflex moves in the opposite direction (see b)).

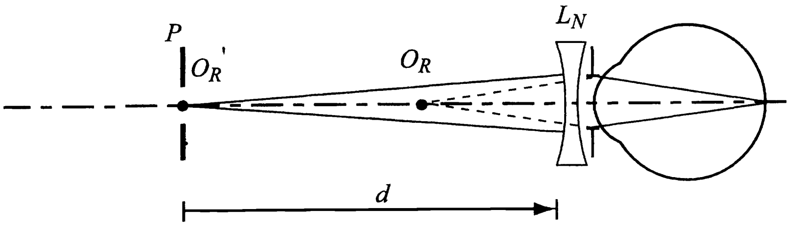

Fig.4 The same as Fig. 3. The neutralization is achieved with an auxiliar negative lens.

When the retina is focused at the retinoscope and by moving it, whole of the retinoscopist field of view appears illuminated or darkened apace and no movement is seen. In retinoscopy this situation is called neutralisation of the reflex movement. If we know the neutralization lens power *N*, then it is very easy to obtain the power spectacle compensation *C*. In order to obtain *C*, the lens *N* can be considered as the sum of two components. The first one is the power of the lens *C*, this one displaces the eye punctum remotum till the infinite. The other is a positive lens of power *W* that brings the image from the infinite until the retinoscope plane. In mathematical terms:

$$N = C + W \tag{1}$$

Probably because retinoscopy and Foucault test do not share a common origin, it is not widely recognized that both techniques are based in the same principle. Therefore, the analysis of lens aberrations can be performed by using a retinoscope as a Foucault test.

3. ASTIGMATISM MEASUREMENT

Let us first consider the experimental setup shown in Fig. 5, where the lens L and the screen all together act as the patient eye of Fig. 1. In order to study the astigmatism of the lens L, this is placed in a graduate rotation stage. In that way, the light that proceeds from the retinoscope impinges obliquely on the lens. For the observation system, a point of the illuminated area on the screen device acts as a punctual object placed at a finite distance (s). Under this conditions, from this punctual object two axially separated images called tangential image (S_T') and sagittal image (S_S') will be obtained, [3].

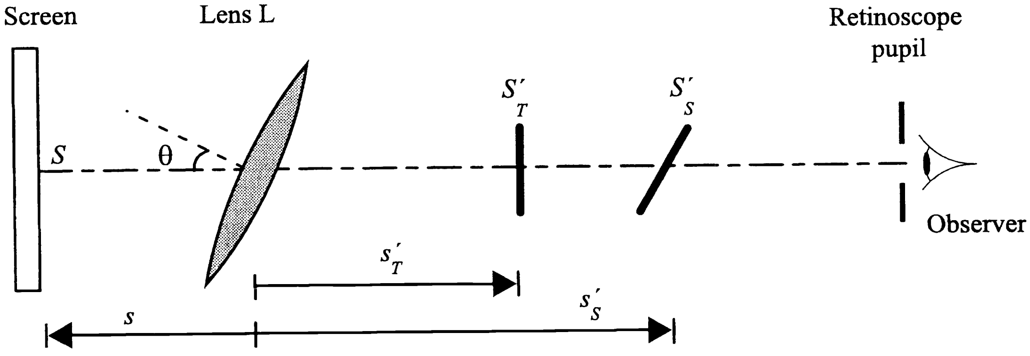

Fig.5 Schematic layout of the experimental setup.

Dealing with an air thin lens, with radii r_1 y r_2 and index n, and treating it as a two spherical diopters coupling, it can be showed that the next equations give the position of this images:

$$
\begin{aligned}
-\frac{1}{s}+\frac{1}{s'_T} &= \frac{1}{\cos\theta}\left(\frac{n\cos\theta'}{\cos\theta}-1\right)\left(\frac{1}{r_1}-\frac{1}{r_2}\right) \\
-\frac{1}{s}+\frac{1}{s'_S} &= \cos\theta\left(\frac{n\cos\theta'}{\cos\theta}-1\right)\left(\frac{1}{r_1}-\frac{1}{r_2}\right)
\end{aligned}
\qquad (2)
$$

where θ and θ' are respectively the incident and refraction angle in the first lens surface, s is the object distance and s'_T and s'_S are the tangential and sagittal image positions. The quotient between the two previous formulas provides:

$$
\cos^2\theta = \frac{(s-s'_S)s'_T}{(s-s'_T)s'_S} \qquad (3)
$$

Moreover, if the object is at an infinite distance, then the Eqs. (2) give the position of the tangential and sagittal image foci and the Eq. (3) is reduced to:

$$
f'_T = f'_S\cos^2\theta \qquad (4)
$$

The experimental setup proposed permits to check the validity of the Eq. (3). To that aim, after selecting the object distance s, fixing the screen and lens position, and changing the incident angle θ, the positions of S'_T and S'_S can be found. So as to obtain s'_T and s'_S, the observer places the retinoscope with its slit vertical near the lens L and moves it along the optical axis until obtain the first meridian neutralization corresponding to S'_T. Performing in the same way but now placing the slit horizontal, the observer continues displacing the retinoscope until achieve the other meridian neutralization corresponding to S'_S.

Eq. (3) shows that the relationship between the tangential and sagittal image positions does not depend on the index n or the shape factor of the lens under study. That has been experimentally checked using the setup of Fig. 5. To be sure of the non-dependence with the shape factor, firstly a plano-convex lens was selected and two sets of measures (both for 10°, 20°, 30° and 40°) were made, the second one rotating it 180°. To preserve the paraxial condition and to avoid a bad quality of the fundus reflex, a pupil of about 5 mm was placed before the lens. In a second step, two lenses of equal power but different index were chosen. Furthermore, in order to work with an infinite distance object, we added a collimating lens and checked the Eq. (4).

This experimental procedure can be easily extended to study other aberrations as, for instance, the spherical aberration or the longitudinal chromatic aberration.

4. ACKNOWLEDGMENTS

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