Optics and Lasers in Engineering 113 (2019) 47–54

Contents lists available at ScienceDirect

Optics and Lasers in Engineering

journal homepage: www.elsevier.com/locate/optlaseng

Bironchigram processing method for quantitative evaluation of optical focusing mirrors

Gustavo Rodríguez[a,*], Jesús Villa[a,*], Rumen Ivanov[b], Ismael de la Rosa[a], Jorge Luis Flores[c]

[a] Unidad Académica de Ingeniería Eléctrica, Universidad Autónoma de Zacatecas, Av. Ramón López Velarde 801, Zacatecas 98000, Mexico
[b] Unidad Académica de Física, Universidad Autónoma de Zacatecas, Calz. Solidaridad, Esquina Paseo de la Bufa s/n, Zacatecas 98060, Mexico
[c] Departamento de Electrónica, Universidad de Guadalajara, Av. Revolución 1500, Jalisco 44840, Mexico

ARTICLE INFO

Keywords:
Image processing
Optical testing
Surface measurement

ABSTRACT

Since its proposal the Ronchi "ruling" test has been considered as the most remarkable technique of the Schlieren family. Despite being based on fringe pattern generation and commonly interpreted in a qualitative way, it was capable of achieving outstanding results in the detection of aberrations in optical surfaces. Given its theoretical straightforwardness, experimental simplicity and economic affordability in comparison to other methodologies in the field, in the present work is addressed the lingering issue of how to extract quantitative information from digital captures of this test. Such task was accomplished taking advantage of the improved Ronchi test with a square grid, from which it was possible to develop a mathematical model with foundation in the Fourier theory to describe its observations. Thereupon, it was devised a novel iterative algorithm grounded in Fourier phase measuring able to compute fairly accurate wavefront gradient estimations from a single "bironchigram" sample with grid defocus. This procedure is complemented by a mandatory integration algorithm that is based on the regularization theory. The overall proposed methodology was put to test in a large aspherical mirror, estimating a surface aberration profile with a P–V (peak to valley) ratio of 155 nm, value well in accord with the one reported by the commercial interferometric system used for validation.

1. Introduction

The Ronchi test was proposed in 1923 by the Italian physicist Vasco Ronchi. Since then, this procedure has been considered as one of the most powerful tools at the disposal of amateurish telescope makers. This methodology allowed a comparatively faster, simpler and/or cheaper optical testing of large focusing mirrors, critical during its figuring process [1].

A basic Ronchi test apparatus can be roughly described as the combination of a semi-punctual light source and an optical target consisting of a series of clear and opaque straight stripes alternating at a fixed spatial frequency [2], nowadays simply known as a "Ronchi ruling".

As a result of being a direct derivation of the Foucault "knife-edge" test, the merit of the Ronchi test thus lies solely in the substitution of the knife-edge for a Ronchi ruling to be used as the system light transfer function. This simple interchange grants both richer and more detailed visual information all over the specimen surface, making the evaluation considerably less subjective.

In the past many works were dedicated to better understand, generalize and improve several aspects of this technique. Among the most remarkable variations can be named the null Ronchi test, designed to increase the sensitivity of the procedure and its correlation with the Hartmann test [3,4]. Later on, the single side-band Ronchi test was proposed to substantially reduce the Talbot diffraction, diminishing effect commonly present in lateral shear interferometry at the time [5]. This was followed by the fringe scanning (phase measuring) Ronchi test, devised to handle the testing of fast aspherical (large aberration) surfaces with the aid of synchronous phase detection [6,7]. Finally, the extended source Ronchi test appeared to enhance the contrast and fringe visibility of the ronchigrams by taking advantage of the self-imaging phenomenon and the superimposition of multiple mutually incoherent Fresnel diffraction patterns [8].

Despite all this efforts, the methodology would never entirely escape the veil of subjectivity in which all optical testing techniques based upon generation of shadow patterns are commonly shrouded. As the years passed, all the Schlieren tests were almost completely abandoned in favor of other procedures considered as vastly superior at least in terms of precision, as is the case of interferometry [1,9].

More recently, the whole influence of the Ronchi test has been confined to the employment of its fixed periodicity grating as a complementary device in the implementation of several other optical procedures. For example, it was proposed an alternative model for the interpreta-

* Corresponding author.
E-mail address: jvillah@uaz.edu.mx (J. Villa).

https://doi.org/10.1016/j.optlaseng.2018.10.001
Received 30 May 2018; Received in revised form 4 September 2018; Accepted 3 October 2018