

1 Introduction

This work deals with an approach to the Ronchi deflectometry technique which will be shown to allow topographic measurements of both rotationally symmetrical and non-rotationally symmetrical surfaces. The radius of curvature values and complete topographies of both spherical and toroidal samples will be obtained by analyzing the shadows of a test consisting of equally spaced light and dark parallel stripes (a Ronchi test).

Before we go on to the main body of the work, some preliminary considerations on the setting in which this thesis was developed, the main innovations we believe this work contributes to the field of optical testing, and a short overview of the contents of the remaining sections of the work will be presented.

1.1 Development outline

When a work of the extension and length of a thesis is considered, we understand that a few details about the department within which the work was carried out may be of some interest to the reader.

The full thesis was undertaken at the Department of Optics and Optometrics (DOO) of the Technical University of Catalonia (UPC), located in Terrassa, Spain; the work was done as part of its research line in Optical Engineering and Laser Systems Technology. The thesis goes into a field of metrology close to other research projects being carried out at the DOO, such as the development of a profilometer based on confocal microscopy or a white-light interferometer without the need for a vibration-isolated environment. In a very close line of research, an outline for Real Optical Systems Analysis (R.O.S.A.) is being developed.

The author started the present work late in 1995, simultaneously with the final stages of an industry-oriented grant for the development of software to simulate the photometric properties of car tail lights and indicators in a CAD context. While at work on this thesis, the author was taken on by the UPC first as a part-time assistant lecturer and finally as a full-time assistant lecturer. The author now gives classes on Ophthalmic Lenses as part of the B.Sc. degree course in Optics and Optometry at the UPC. He is indebted to the group of persons who have helped him to carry out all these tasks simultaneously, and finally allowed him to spend his time writing this work over this last year.

1.2 Novelty of the proposal

We understand that the main innovation of our proposal is the development of an approach to Ronchi deflectometry which allows high-quality topographic measurements of both rotationally and non-rotationally symmetrical surfaces.

Ronchi deflectometry is a well-known technique commonly found in all optical testing-related bibliographies. However, surface topographies like the ones that will be presented in this work are not often seen in Ronchi deflectometry measurements, even in the case of rotationally symmetrical measurements. We believe this may be due to

the fact that Ronchi deflectometry has been used for a long time (the pioneering work in the field by Vasco Ronchi was started in 1921), but almost always applied to detecting manufacturing flaws in rotationally symmetrical telescope primary mirrors, usually through direct observation of the shadow pattern obtained. Research into the technique was never abandoned, although no computing possibilities could be applied to on-screen analysis of the shadows of the Ronchi ruling. The advent of powerful computing resources and CCD arrays has enabled us to propose an approach to the technique that is able to perform repetitive topographic measurements on surface areas of a few square centimeters with measured height ranges of about 0.5mm.

Nevertheless, this alone would have been merely an update of classic mid-seventies references, in which spherical and aspherical surface profiles were widely tested using null tests, though no topographies were obtained. We believe our main contribution is the development of a measurement tool based on the Ronchi deflectometry technique which, apart from the measuring capabilities mentioned above, for the first time can measure non-rotationally symmetrical surfaces repetitively and perform topographies and radii of curvature measurements of toroidal surfaces, regardless of the position and orientation of the sample.

1.3 Section summary

Before we start developing the main body of this thesis, a short overview of what the reader will find in its different sections is presented.

Section 2 reviews the current state of the art in optical profilometry techniques of reflective surfaces. The techniques most closely related to Ronchi deflectometry are developed at greater length, and confocal microscopy techniques, interferometric profilometry techniques and Moiré and Hartmann deflectometry, together with a very general description of Ronchi deflectometry, are presented in different subsections. Whenever possible, some commercial instruments using the measurement principles depicted in a given technique are named. The authors merely wish to mention these instruments as examples of commercial applications of a technique, and such statements should under no circumstances be considered an endorsement of the product. If numerical values for the quality of the instruments are provided, they have been obtained through available commercial information.

In Section 3 the theoretical framework of Ronchi deflectometry will be put forward. The Ronchi test will be analyzed from both diffraction theory and geometrical optics theory. Under experimental conditions of sufficiently low frequencies of the Ronchi ruling, the two theories will be shown to be equivalent, and the geometrical theory will be preferred due to its simplicity. This section will also show how to perform topographic measurements of a surface using the geometrical theory applied to analysis of the Ronchi test shadows.

This thesis should be considered to be an experimental work, and as such a specific section explaining both the experimental setup and the data processing steps which are performed on the acquired data is required. This will be given in Section 4, where the complete experimental setup will be presented and step-by-step data processing operations will be described, allowing the reader to see the complete set of intermediate steps from the acquired data pattern to the reconstructed topography of the sample.

Section 5 depicts our efforts to improve on some of the drawbacks of the classic Ronchi deflectometry technique. An attempt has been made to increase either its sampling or its accuracy by using certain methods which will be described here. Aspects ranging from the shortcomings of increasing the frequency of the ruling due to the increase in diffractive effects to our endeavors to implement phase-shifting schemes to Ronchi deflectometry will be introduced. This section includes a wide description of phase-shifting techniques, and a data processing operation allowing the application of phase-shifting schemes to non-sinusoidal signals, prior to showing how phase-shifting techniques cannot be applied to Ronchi deflectometry due to the unavoidable presence of diffractive terms in the registered intensity signal. We will put forward an alternative to phase-shifting (which we have termed microstepping of the Ronchi ruling), which will greatly improve surface sampling without disturbing increases in the diffractive effects.

Once all the enhancement techniques, the data processing operations and the experimental setup have been presented, we will then reach the stage of performing experimental measurements. Section 6 presents the potential of our approach to Ronchi deflectometry for measuring surface topographies of rotationally symmetrical surfaces. In order to illustrate the data processing steps from the measured pattern to the final measured topography, a complete series of intermediate results will be given for one spherical sample at a given distance from the Ronchi ruling. Next, six spherical samples are measured, giving repetitive measurements at three different distances

from the Ronchi test, showing our technique's ability to perform high quality topographic measurements of rotationally symmetrical surfaces. Radii of curvature measurements are compared with reference values, allowing us to ensure that our setup is properly calibrated.

Finally, in Section 7, we will perform surface topographies of non-rotationally symmetrical surfaces. As in Section 6, some intermediate results of the data processing procedures will be presented in order to reveal some of the important differences that toroidal samples involve. Six toroidal surfaces will be measured: their topographies will be presented and their radius of curvature will be measured at three different distances to the Ronchi ruling. As these samples are not rotationally symmetrical, the potential of our approach to Ronchi deflectometry for measuring regardless of the sample's orientation will be proved by measuring each sample in four different orientations. This means that each topographic measurement will be performed in twelve different situations, yielding consistent proof of the reliability and repeatability of the measurement technique put forward.

Section 8 gives the conclusions of the present work. Some of the future projects which have been planned in order to follow up the research field opened up with this work are also presented. The complete set of references cited throughout the work is also provided as an independent bibliography section.

We shall thus now start our presentation. We hope you will enjoy this work as much as we enjoyed making it possible.