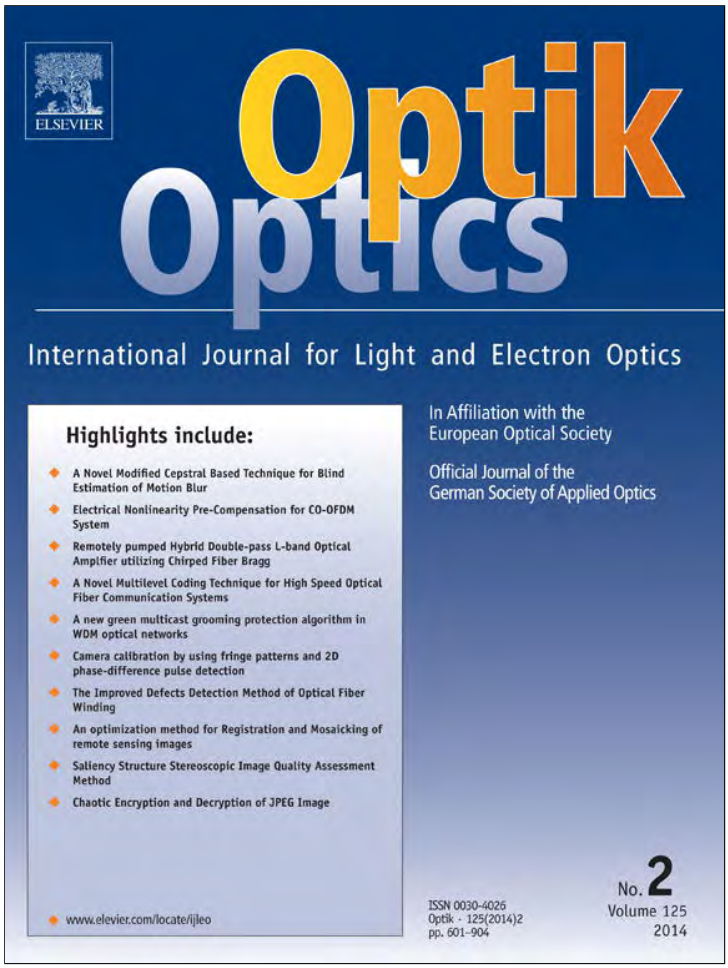

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Analysis of the common characteristics of the Hartmann, Ronchi, and Shack–Hartmann tests

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ABSTRACT

An overview of the settings of the planes for the filters and observed patterns in the Hartmann and Ronchi tests is presented. Also a new set of filters for both test were developed. In a similar way, it is easy to extend this analysis to the Shack–Hartmann test, and to propose a new Null Shack–Hartmann filter.

1. Introduction

In the field of optical testing of optical surfaces and systems, there is a profuse quantity of techniques (Malacara [1], Twymann [2], and Dyson [3]) and they are classified as interferometric, and non-interferometric (sometimes called geometrical or curvature slopes) measurements. Some of them, like the Hartmann [4] and Ronchi [5] tests in the past were classified in the second group. But later on, they were recognized as interferometric techniques also [6]; and one important advantage of the second group mentioned above, and among them the Hartmann and Ronchi tests, is that they do not need sophisticate equipment or reference optical components, only a kind of filter that could be a knife edge [7], wire [8], Hartmann screen, or Ronchi ruling. Hence a qualitative analysis can be carried out very easily; but on the other hand, if quantitative results are required, careful mathematical treatment of the information registered in a Hartmanngram or Ronchigram can also be realized; as it usual in all the testing interferometric and non-interferometric methods.

2. The Hartmann and Ronchi tests

The Hartmann and Ronchi tests were discovered at the beginning of XIX Century. For many years they were analyzed in different

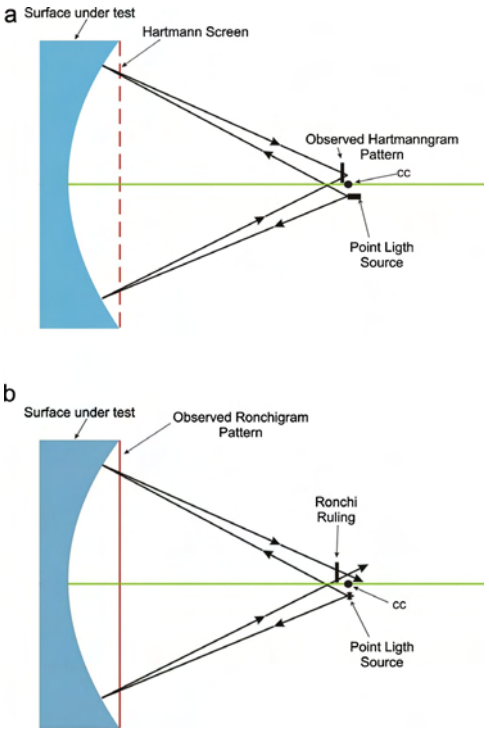

Fig. 1. Diagrams for the experimental schemes for: (a) the Hartmann test, and (b) the Ronchi test.

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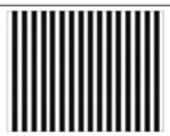
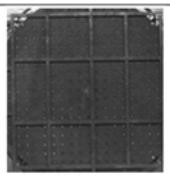
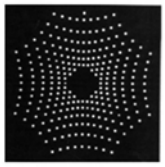
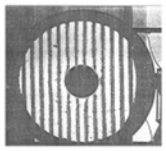
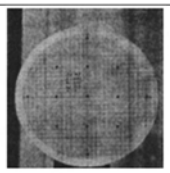
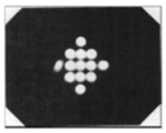
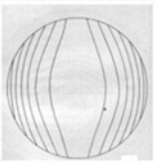
	Filter			Observed Pattern	
Type		*Size Position*	*Type*	*Tested Surface*	*Size Position*
Ronchi Ruling	 Figure 2a.	Small c.c.	Ronchigram	 Parabolic Figure 2b.	Big c.s.
Hartmann Screen	 Figure 2c.	Big c.s.	Hartmanngram	 Hyperbolic Figure 2d.	Small c.c.
Null Ronchi Grating	 Figure 2e.	Small c.c.	Null Ronchigram	 Hyperbolic Figure 2f.	Big c.s.
Null Hartmann Screen	 Figure 2g.	Big c.s.	Null Hartmanngram	 Parabolic Figure 2h.	Small c.c
Big Hartmann-Ronchi Screen	 Figure 2i.	Big c.s.	Hartmanngram	 Parabolic Figure 2j.	Small c.c.
Big Null Hartmann-Ronchi Screen	 Figure 2k.	Big c.s.	Null Hartmanngram	 Parabolic Figure 2l.	Small c.c.

Fig. 2. For the Hartmann and Ronchi tests; this figure contains two main columns called filter and observed pattern with surface tested. On each side of the columns there are written on the left hand side the filter used and the observed pattern; and on the right hand side the corresponding sizes and positions. For photographs g and h see Refs. [1] and [8].

ways, either in its theoretical and experimental concepts. In the work by Cordero et al. [9] both testing methods were studied considering the similarity between them. In another paper, by the same authors, Cordero et al. [10], a common mathematical analysis for both kinds of tests was developed, considering mainly ray tracing technique.

In Fig. 1a and b the common schemes for these Ronchi and Hartmann tests are shown. From the comparison and analysis of both tests the next common aspects were derived: (a) they measure the transverse aberration, that are used to obtain the wave front, W, of the optical surface or system under test, (b) normally white or other kind of light sources can be used, (c) a screen or filters are used, this means the Ronchi ruling or the Hartmann screen.

The main aim of this paper is to present the Table of Fig. 2, where some aspects of both tests are related: (i) the normal procedures of the tests, and the so called null methods; (ii) the size and position of

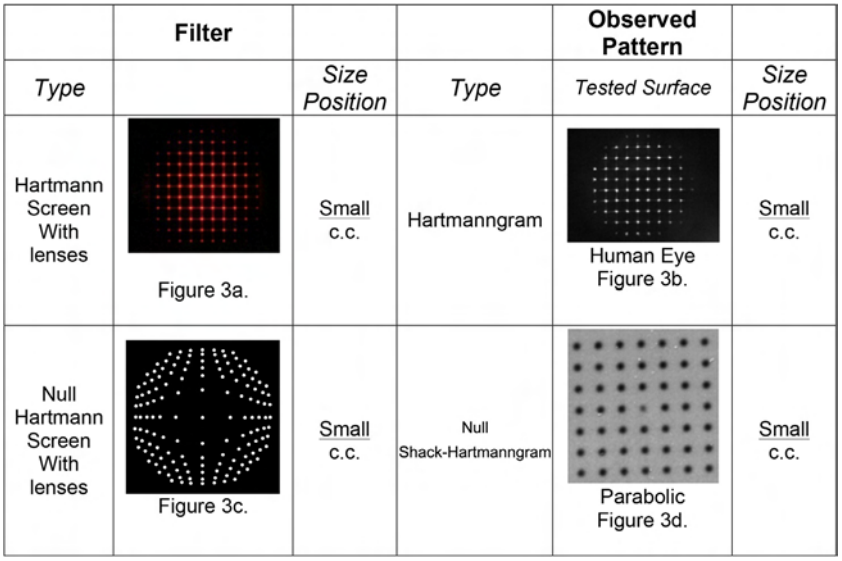


Fig. 3. In this figure we expose for the Shack–Hartmann test, the kind of filters used and observed pattern, according to the explanations given in the text and Fig. 2.

the Ronchi ruling and Hartmann screen; (iii) the size and position of the observed, of the so called, Ronchigram and Hartmanngram. A step forward from the analysis of Fig. 2 is to investigate the structure of Shack–Hartmann [11] test.

To understand Fig. 2, a brief explanation is necessary about the concepts involved besides the pictures. On the left side of the called Filter column, the kind of filters used are given. On the right side of the same Filter column the size and position of the filter are described; where c.c. means close to the center of curvature, and c.s. means close to the surface. For the right column labeled observed pattern, again the size and position are described for the corresponding Ronchigrams and Hartmanngrams; with the same meaning for the positions given for the filter column. In the next paragraph we describe different situations when an optical concave surface is being tested. We have included everything in the figure with the purpose of visualizing the whole scheme.

For the first row, Fig. 2a and b, the classical Ronchi ruling test is shown with a big Ronchigram observed over the surface under test. For the next row, Fig. 2c and d, the case of the typical Hartmann test is illustrated, using a big screen in front of the surface; the observed small Hartmanngram is recorded close to the center of curvature of the surface, but outside of the caustic of the source image. In the third row, Fig. 2e and f, this is the case when a null Ronchi ruling is used, developed by Malacara and Cornejo [12], where straight fringes can be observed at the Ronchigram. This kind of arrangement is useful for testing aspheric surfaces, because a lens design program can be used to obtain the Null Ronchi ruling, see Hopkins [13].

Fig. 2g and h describe a kind of Null Hartmann Test [9], where the classical Hartmann screen is modified, changing the structure of the well aligned holes into another distribution; to produce at the end a Hartmanngram with well aligned spots, see Cordero et al. [9]. This kind of modification of the Hartmann screen is probably difficult to do for big surfaces, but can be used for smaller surfaces under 1 m in diameter. On the other hand, an interesting aspect is that the Null Hartmann can be produced by overlapping two equal theoretical Ronchigrams, rotated 90° with respect to each other. In the intersections of the fringes of the Ronchigrams are the locations of the holes of the Null Hartmann screen.

The last two rows of Fig. 2 are interesting for better understanding the close relation between the Hartmann and Ronchi procedures; because they are the results of combining both the Ronchi and Hartmann test for the design of new filters. In Fig. 2i the classical Hartmann screen with holes is replaced by a big size Ronchi ruling, that is located now in front of the surface under test. The observed pattern, Fig. 2j, becomes now a kind of Hartmanngram with continuous fringes, instead of spots. But actually, in this case of Fig. 2i and j, what is finally produced is the inverse of the test of Fig. 2e and f. Because from the third row, Fig. 2e and f, instead of the big Ronchigram pattern of Fig. 2f, what it is observed is a small Hartmann–Ronchigram with the structure of the Null Ronchi ruling, Fig. 2e. In other words, if one desires to build a Null Ronchi ruling, relocating and putting a big Ronchi ruling in front of the surface (Fig. 2i), a Null Ronchi ruling will be produced and observed as in Fig. 2j.

The last case shown in Fig. 2k and l is a modification of the so called Ronchi–Hartmann screen, located in front of the surface; the bands are modified in a way that instead of being straight ones, they have certain curvature that depend upon the surface under test. Therefore, at the pattern observation plane, a small Hartmann–Ronchigram with straight fringes will be observed. This means that the inverse test of this last row becomes the first row of Fig. 2; in other words, because an exchange of the filters and patterns planes was realized, the last row test is the "inverse" of the first row, or vice versa.

3. The Null Shack–Hartmann test

From another point of view, it is possible, along this line of relations between the Ronchi and Hartmann tests, to obtain and clearly understand the well known Shack–Hartmann test (1971). Because instead of following along the second row and last two rows of Fig. 2, where the Hartmann screen is located in front of the surface, with holes or bands emulating a big Ronchi grating; in the Shack–Hartmann set up, the big Hartmann screen, Fig. 2c, has been shifted back to the observation plane now with smaller size, similar to the Ronchi ruling of Fig. 2a and e. But a set of lenses, with short focal distances should be located just behind the screen, for proper observation of the Hartmanngram, at the focal distance plane of the lenses; this is illustrated in Fig. 3a and b.

A forward step related with the Shack–Hartmann method, is our proposal, in this paper, to modify the structure of the small Shack–Hartmann screen, in order to obtain a Null Shack–Hartmann test. If the holes of the small Shack–Hartmann screen are positioned along the curves shown, Fig. 3c, as it is done and calculated in the Null Ronchi ruling (Fig. 2e); using for example a lens design

program [13]. The Null Shack–Hartmann screen is shown in Fig. 3c, and the Hartmanngram that contains spots perfectly aligned in a square mesh is observed in Fig. 3d. This kind of pattern of Fig. 3d is equivalent to the straight fringes, Fig. 2f, of the Null Ronchi test.

4. Conclusions

For many years an extensive literature can be found about the Ronchi and Hartmann tests (see Cornejo [6], Ghozeil [14], Malacara and Ghozeil [15]). In this paper we have presented how with a series of simple pictures, and the analysis of the locations planes for the filters and observed patterns, both tests are intimately related. Following these relations, it is possible to find the affinity, at the end, with the well known Shack–Hartmann method; and the possibility to produce a Null Shack–Hartmann test, equivalent to the Null Ronchi test.

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