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NEW SHAPE MEASUREMENT METHOD OF CONCAVE MIRRORS ON DIGITAL PROCESSING OF HARTMANN TEST PRINCIPEL

NOVÁ MĚŘÍCÍ METODA TVARU KONKÁVNÍCH ZRCADEL NA PRINCIPU DIGITÁLNÍHO ZPRACOVÁNÍ HARTMANOVA TESTU

Abstract

The theory, optical, mechanical, and software design for a special Hartmann wavefront analyzer is presented. This method is applied for the non-contact method of concave mirrors shape measurements. The so-called Hartmann test is used with the digital image reading and the fast computer data evaluation. In this method a transparent spatial modulator is used instead of binary mask. Our institute Joint Laboratory of Optics produces segmented mirrors for the Pierre Auger observatory fluorescent detector [1]. We use this method as the qualitative measuring of this spherical mirror segments. These segments are unique because they are light and ultrathin. The production of mirrors is based on standard operations commonly used in the optical industry (cutting, drilling, milling, grinding and polishing), with the difference that they are extremely thin. This fact can cause segment shape instability in the production process. This method objectively defines the shape and specifies the difference of the segment shape from an ideal surface in micrometer accuracy.

Abstrakt

V tomto článku je prezentován princip speciálního Hartmannova testu, což je metoda, která je použitelná pro bezkontaktní měření tvaru vlnoploch a tedy i odrazných ploch. Popisovaná metoda je v zásadě klasický Hartmannův test, ale je zde použito digitální zpracování dat a navíc místo binární masky je zde použit transparentní prostorový modulátor. Metoda byla vyvinuta pro kontrolu reflexních ploch segmentů zrcadla, které se použijí na fluorescenčních teleskopech observatoře Pierre Auger [1]. Tyto segmenty jsou z důvodu redukce hmotnosti velmi tenké, tento fakt ovšem zapříčiňuje nestabilitu tvaru při výrobě. Tato metoda objektivně určí tvar zrcadla a odchylku od ideálního sférického tvaru a to s mikrometrovou přesností.

1 INTRODUCTION

The Hartmann test [2,3] was invented a century ago to perform optical metrology. Subsequently these sensors have been adapted to a wide variety of applications including adaptive optics, ophthalmology, and laser wavefront characterization. In this document we will explain the operation of the Hartmann Wavefront Analyzer and explicate application of the test in shape and

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shape stability measurement of concave mirrors, especially mirror segments which are used at the Pierre Auger Observatory in the fluorescent telescopes.

2 EXPERIMENTAL SETUP

In this measuring setup we use simple axis setup (fig. 1). In this setup we use a laser diode as high intensity point source. The light beam has sufficient intensity and very good homogeneity, speckl pattern is possible to subtract in final image. After the reflections from mirror and pellicle beamsplitter the beam goes through the transparent spatial modulator, which is between two crossed polarizers. The combination of the two crossed polarizers and phase modulator form amplitude modulator.

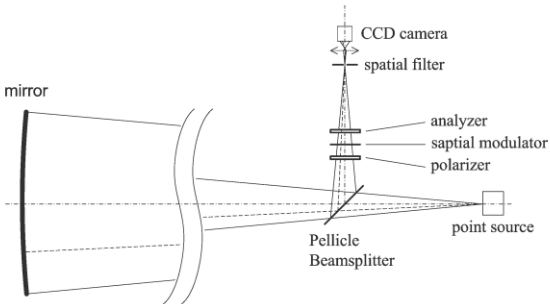

Fig. 1 Layout of the measuring setup, the dashed line is a traced beam that goes through the center of the mask hole.

3 DATA PROCESSING

There are four steps for analysis process: digital pattern processing, determination of the hole images positions, conversion to wavefront slopes, and wavefront reconstruction. Spatial modulator produces by steps whatever binary masks, in each step wavefront slopes are measured in several points. Example is on fig. 2, where is the surface tested in 30 radial symmetry pattern with 40 points. The spatial modulator creates "hole images" fig.2, which are detected with the CCD camera. In this setup we use patterns with dynamically changing radially distributed holes; these patterns are advantageous for its central symmetry and easy processing in polar coordinate system is possible and this mask will detect the most common flaws of the mirror surface, zonal errors, and concentric hills and valleys.

3.1 Digital pattern processing

The CCD camera creates an image of the holes; this image consists of diffracted spots and background (mask is a little translucent outside the holes and the CCD chip produces some noise). After some morphological operations, noise is filtrated and small areas are removed. The final result is a pattern with the intensity profile of the holes images with intermediate space value equal to zero.

3.2 Spot positions

The hole image positions is computed from the modified pattern. The location of the focal spots is determined from the light distribution on the detector array. For a sampled irradiance distribution with measured pixel intensities *Iij*, the spot positions $r_{c,k}$ and are commonly determined by the first moments:

$$r_{c,k} = \frac{\sum_{i,j \in AoIk} r_{i,j} I_{i,j}}{\sum_{i,j \in AoIk} I_{i,j}}, \tag{1}$$

where *k* is spot number and the summation is taken over the pixels assigned to the spot k in the Area-of-Interest *AoIk*. Then the given spot centers are sorted and assigned to the holes on the mask.

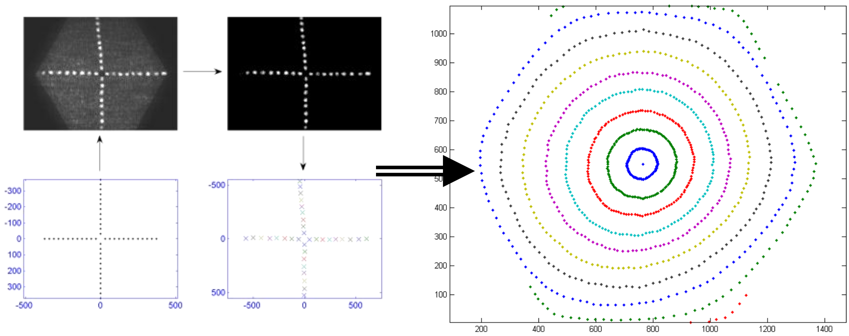

Fig. 2 Process of the mirror surface scanning

1) Pattern on the spatial modulator.
2) CCD Snapshot, “hole images”.
3) Picture after background subtraction and filtering.
4) Final spot centers.
5) All spots in one picture.

3.3 Conversion to mirror shape slopes

There is an easy way to find the wavefront gradient or mirror shape normal line orientation. If you know the point source position, the position of the incident point from where the beam is reflected to the given hole and the position of the given hole, it is just an easy geometric problem to find the normal of the mirror surface in the incident point. This way it is possible to find the wavefront or surface gradient in every incident points.

3.4 Wavefront reconstruction

Once the local wavefront slopes have been determined, the wavefront can be reconstructed by performing a type of integration on the gradient measurements. To perform any measurement, the Mirror Shape Analyzer is illuminated with a beam that is reflected from the mirror with reflective surface $\Phi(x,y)$ that is measured and the diffracted spot positions are determined from the CCD image using the centroid algorithm. For this discussion we limit to considering one radial part of the image, but the rest can be treated in the same fashion. The measured two-dimensional shape is designated by the variable $\Phi(x,y)$.

3.5 Linear Integration

In this simplest of surface reconstructors (it is possible to use much more complicated reconstructors, for example Southwell [4] or Modal Zernike Reconstructor [5]), the computer begins at the center of the pattern and defines the mirror shape height at this integration area as zero. The height of the mirror surface in the next adjacent integration area along the scan direction is calculated as the previous wavefront height plus the average slope of the current and the previous integration area times the aperture separation:

$$\Phi_n = \Phi_{n-1} + \left(\frac{\partial \Phi_{n-1}}{\partial r} + \frac{\partial \Phi_n}{\partial r} \right) . \frac{s}{2} . \qquad (2)$$

Mathematically, this is given for the *r* direction, where Φ is the mirror surface and *s* is the aperture separation.

4 RESULTS

In figure 3 there is one of the shape measurement results. This is the shape of the hexagonal mirror segment used in the fluorescent detector. As it is evident from this figure, the mirror has an astigmatic aberration. This deformation is caused by not optimal sticking of the ultrathin segment to the polishing base. The mirror segment is deformed this way after unstick from the base.

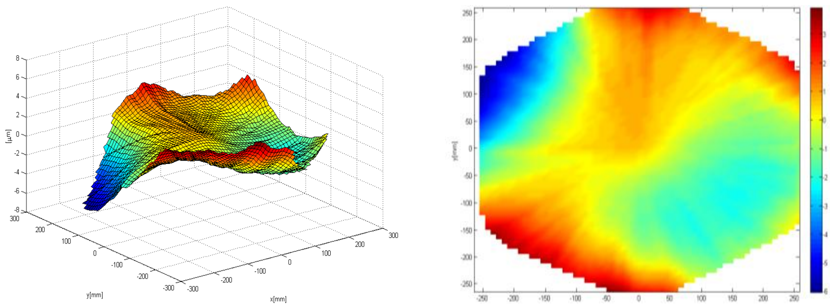

Fig. 3 Result of the segment shape measuring; difference between ideal spherical and real shape, the scale is in micrometers

This method is quantitative research of the concave mirror shape. This is straightforward technique for measuring large, even highly aberrated concave mirrors with µm accuracy. Using of the amplitude modulator is allowed flexibility: speed x resolution optimization. There is possible whatever scanning of the mirror surface or only problematic part of the surface.

5 CONCLUSIONS

In this paper is demonstrated a straightforward technique for measuring large, highly aberrated concave mirrors. We were able to make rapid measurements using the Hartmann mirror shape sensor. This method can be used as fast quality test in optics shops. In the next experiment we are going to test shape stability of the ultralight mirror segments used in PAO this way.

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