Compensation for residual aberrations in the illuminating arm of an interferometer with an adaptive mirror

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To improve the efficiency of interference control through compensation for residual aberrations in the illuminating arm of an interferometer, it is proposed to use a flexible adaptive mirror based on a bimorph piezoelectric cell. Possibilities of modeling geometric and wave aberrations on an adaptive mirror have been studied in actual and computer experiments. The results obtained are discussed. A method is proposed for tuning interferometer using an adaptive mirror.

Introduction

Some problems in astronomy, as well as in optical sensing of the atmosphere require the use of high-quality optical antennas, since just the optics quality determines the error in the parameters measured. Testing the surface quality is an essential part of the technological process of fabricating optical parts.

Interferometry is one of the most accurate techniques for testing optics. The main difficulties in testing optical surfaces are connected with the necessity of compensating for natural aberrations of optical systems used to form the illuminating wave front on the surface of an optical part tested.[1] Aberrations in the object arm of an interferometer are transformed causing deformation of the interference fringes. Therefore, the optical system forming the illuminating wave front should have only limited residual aberrations.

Residual aberrations are caused by imperfections of the elements making up the illuminating arm, as well as by calculation and alignment errors. It cannot be completely compensated for due to more rigorous requirements to optical quality and alignment. Therefore, the optical system forming the illuminating wave front should have limited residual aberrations.

As a tool for correcting for residual aberrations in the illuminating arm of an interferometer, it is proposed to use a flexible adaptive mirror based on a bimorph piezoelectric cell. In order to decrease the residual aberrations, one can achieve, by selecting proper control voltages, quite good modeling of the geometric and wave aberrations thus increasing the accuracy of the interferometric control. In this paper, we present and discuss the results of computer and actual experiments with an interferometer.

1. Numerical simulation of the residual wave aberrations in the illuminating arm of an interferometer

The effect of residual aberrations on the error of interferometric measurements can be taken into account through reasonable selection of limits at the stage of the interferometer design. To determine the limits, we have conducted numerical simulation of residual aberrations in the illuminating arm of the interferometer W_r that led to the error in interferometric measurements ΔW (Ref. 2).

We have selected a classical optical arrangement of the Fizeau interferometer.[3] The advantages of this interferometer are its simplicity in manufacturing and alignment, versatility, and the absence of any optical elements between the reference surface and a surface under test. This considerably reduces the requirements to the quality of elements in the illuminating arm, that is, elements located between the source and the reference surface.

The optical layout of a Fizeau interferometer is depicted in Fig. 1. The beam from a laser source passes through a collimator and a beam splitter and then it is focused by an objective at the point F'. An aplanatic meniscus is set behind the objective so that its reference surface has the curvature center at the point F'. In such an arrangement, the aplanatic meniscus does not introduce distortions into the illuminating wave incident normally to the reference surface and forming the reference wave front.

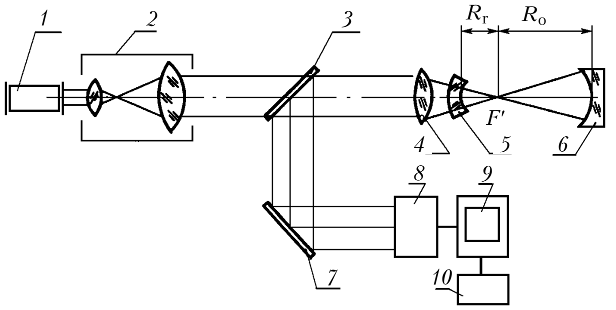

Fig. 1. Optical layout of the Fizeau interferometer: laser *1*, telescopic system *2*, beam splitter *3*, objective *4*, aplanatic meniscus with reference surface *5*, optical part to be tested *6*, beam-turning mirror *7*, TV camera *8*, video monitor *9*, interferogram processor *10*, interferometer focus *F'*.

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The surface to be tested is located at the distance R_0 from the point F', where R_0 is the radius of curvature of the part tested. Therefore, the illuminating wave is also normally incident on the tested part, and, reflecting from it, it passes the same way, forming, after refraction at the reference surface, the object wave front. The object and reference fronts interfere, forming the interference pattern, which is recorded with an observation device, for example, a TV camera with a monitor. To obtain the objective information, the video signal is processed on a personal computer.

Results of numerical simulation of the residual aberrations in the illuminating arm of the interferometer W_r leading to the error in the interferometric measurements ΔW are given in the Table. It can be seen that the residual aberrations present within the interferometer should be taken into account when processing the interferograms recorded.

Reference diameter D_r, mm	ΔW, in fractions of wavelength, λ	Interferometer residual aberration W_r, μm					
		D_r/R_r ratios					
		1:0.66	1:1.5	1:3	1:10	1:50	1:70
30	1/500	0.51/0.750	0.4/0.60	0.3/0.44	0.16/0.2	0.07/0.1	0.06/0.09
	1/100	1.141	0.898	0.658	0.362	0.158	0.132
100	1/500	0.94/1.38	0.74/1.1	0.54/0.8	0.3/0.44	0.13/0.2	0.2/0.3
	1/100	2.088	1.647	1.209	0.667	0.294	0.434
150	1/500	1.45/1.7	0.9/1.3	0.66/1.0	0.37/0.5	0.31/0.4	0.35/0.52
	1/100	2.559	2.018	1.482	0.818	0.684	0.789

2. Experimental modeling of the residual aberrations in the illuminating arm of an interferometer using an adaptive mirror

Residual aberrations are caused not only by the calculation error, but also by optics imperfections and the error of alignment. To check experimentally the results obtained, we have made a mock-up of an interferometer with a flexible adaptive mirror (Fig. 2).

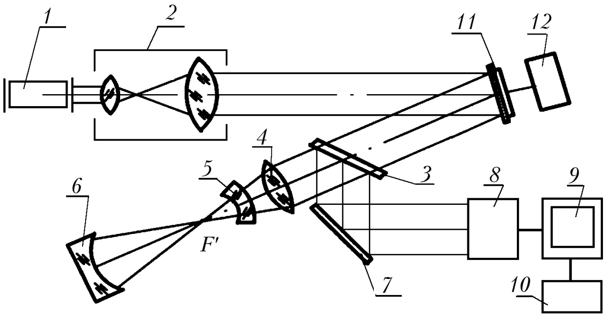


Fig. 2. Optical layout of the Fizeau interferometer with a flexible mirror: laser *1*, beam expander *2*, beam splitter *3*, illuminating objective *4*, aplanatic meniscus *5*, optical part tested *6*, beam-turning mirror *7*, TV camera *8*, video monitor *9*, interferogram processor *10*, flexible adaptive mirror *11*, mirror profile controller *12*.

The general view of an element of a flexible adaptive mirror is shown in Fig. 3. A piezoceramic plate with electrodes sputtered on both its sides is glued to a quartz substrate with a mirror coating 1.5 mm thick and 60 mm in diameter. The internal electrode of the plate is grounded. The external electrode is sectioned into 13 parts, as shown in Fig. 3.

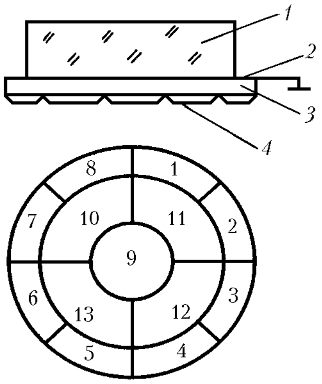
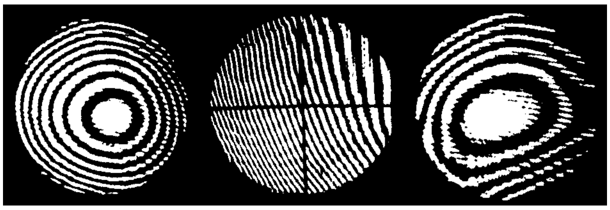


Fig. 3. Flexible adaptive mirror: quartz substrate with mirror coating *1*, grounded electrode *2*, piezoceramic plate *3*, control electrode consisting of 13 sections *4* (bottom view).

The operation principle of the flexible mirror is the following. As a dc voltage is applied to the electrode, the piezoceramic plate expands due to the inverse cross piezoeffect. The glued quartz substrate does not allow the plate to expand. This leads to appearance of the bending moment at the edges of the control electrode and, thus, to deformation of the mirror surface.

In Ref. 4 it was shown that optimizing the radii of internal segments with respect to the mirror diameter and selecting proper control voltages, it is possible to achieve quite good modeling of the geometric aberrations. Figure 4 depicts interferograms demonstrating the efficiency of the mirror operation.



a *b* *c*

Fig. 4. Interferograms of a flexible adaptive mirror modeling geometric aberrations: spherical aberration (*a*), coma (*b*), astigmatism (*c*).

To achieve the needed deformation of the adaptive mirror leading to compensation for W_r, control voltages were selected in a Fizeau interferometer with a plane reference surface. In this case, the adaptive mirror was used as a part to be tested. The wave front from the adaptive mirror was measured by counting the number of fringes in the interference pattern. After such a calibration, the mirror was set as shown in Fig. 2, and the control voltages were determined. The value of ΔW was determined after processing the interferograms. Comparison of the experimental results with the numerically simulated ones (Fig. 5) demonstrates a good agreement between them. Some discrepancy can be explained by the mirror arrangement at an angle to the incident wave front and by hysteresis phenomena in the adaptive mirror.

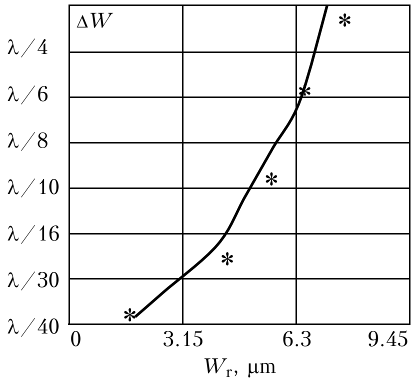


Fig. 5. Experiment (asterisks) and calculation (solid curve).

Conclusions

The experiment conducted showed that a flexible adaptive mirror can be used as a tool for correcting for the residual aberrations in the interferometer.

The considered algorithm for tuning the adaptive mirror solves the problem of checking the results of numerical simulation. However, in an actual interferometric experiment, it seems worth performing optimal adaptation of the mirror to the shape of the illuminating front. In this case the criterion of optimality may be the root-mean-square error of the wave front or the root-mean-square deformation of fringes. To use all the interferometer elements and manage without a new reference, it is possible to modify the interferometer so that the top point of a tested part coincides with the interferometer focus and to tune interferometer according to the minimum deformation of the fringes in the interference pattern. The optimization algorithm can be automated.

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