

Multiple Aperture Shear Interferometry (MArS) and the influence of the spatial light modulator and light sources on measurement errors

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Multiple Aperture Shear Interferometry enables flexible optical form measurement. In this paper, we present the measurement principle and show setups for transmission and reflection measurements. Possible sources of error are identified, which is essential for the establishment of an uncertainty budget.

1 Introduction

Classical shearing interferometry is a prevalent optical technique that is employed to measure wavefront distortions, e.g. laser beams or for testing the quality or form of optical surfaces. The principle is simple: In shearing interferometry, the wavefront under test is split and then slightly shifted or sheared before recombining. The resulting interference fringes show the gradient of the wavefront phase. The measured derivatives of the wavefront can be integrated to reconstruct the wavefront. No reference beam or reference surface compared to Fizeau interferometry, for example, is required.

Within the framework of the joint DFG project "Optical surface metrology with spatially and temporally partially coherent light wave fields" (OPaL, project No. 460789164) of BIAS and PTB an optical form measurement system based on Multiple Aperture Shear Interferometry (MArS) [1] is developed. In contrast to classical shearing interferometry, (i) partially coherent light sources are used, (ii) the shear is realized with a spatial light modulator and (iii) the surface form is determined using an optimization algorithm.

The purpose of the system developed in this project is the flexible, accurate and quick optical measurement of smooth surfaces at an affordable price. This goal satisfies a great need especially in the field of optical form measurement of aspheres. There are various metrological approaches for optical asphere metrology such as point-based or area-measuring systems. One prominent example is the tilted-wave interferometer developed by Mahr GmbH, which is currently being further developed and validated at the PTB [2]. However, traceable asphere metrology is still a major challenge. The MArS setup shown here may serve as a flexible and cost-effective alternative.

In the following, we show the MArS setup for transmission and reflection measurements and demonstrate a new flexible light source that can be

adapted to the surface geometry. In a previous contribution, we already investigated the influence of wave vector uncertainty on the reconstruction of the surface form in a MArS measurement [3].

2 Principle and setups of MARS

Within the projects, we initially started with a MARS set-up in transmission, see Fig. 1. The 4f-setup ensures that the test specimen is in focus of the image sensor. The specimen is illuminated with a partial coherent multi-light source. The polarizer in front of the SLM is set at 45° so that one obtains two reflections of the SLM, one reflection from the front and one reflection from the rear side. The shear can be adjusted using the inscribed blaze grating.

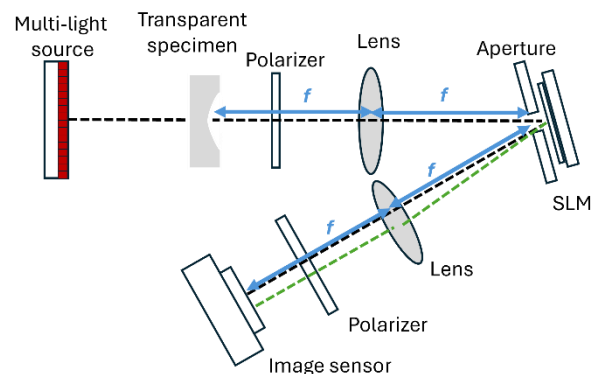


Fig. 1 Schematic of a setup of MARS in transmission.

We carried out measurements e.g. on a 4 μm depth mould, compared these with Fizeau interferometry and obtained an excellent agreement for the peak-to-valley (PV) value better than 100 nm [4].

Figure 2 shows an illustration of the set-up for optical form measurement in reflection. Here, a pellicle beam splitter illuminates the SLM vertically. For larger lens objects, an additional multi-light source is positioned directly in front of the test specimen and measures in a two-step process first the form of the inner aperture and then the form outside of the inner aperture.

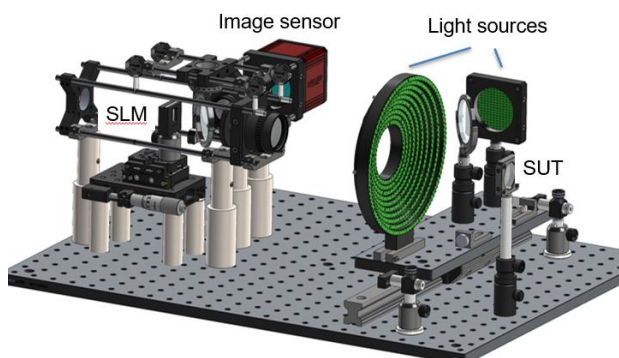


Fig. 2 Illustration of the MARs-setup in reflection.

Figure 3 shows the telescopic concept of the new flexible multi-light source. Ten rings of LEDs can be moved in relation to each other to adapt the illumination to the surface geometry. The required configuration is then fixed with clamps so that the light source positions do not change during the measurement. The multi-light source consists of approximately 1400 LEDs. If one wants to accurately determine the wavelengths of the LEDs, one can also integrate fibers into the multi-light source in order to supply light from a HeNe-Laser.

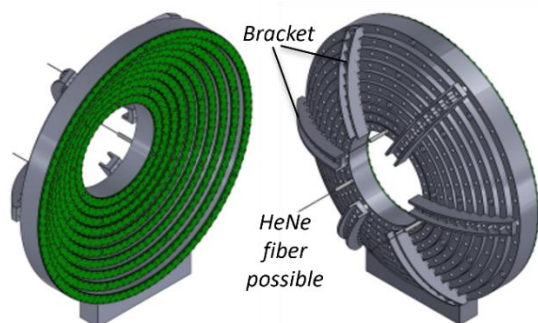


Fig. 3 Illustration of a new flexible multi-light source with an outer diameter of 18 cm. Optional fiber entrances for HeNe-Laser can be used.

With the MARs setup, the wave vectors \mathbf{k} are measured in the object plane. An inverse optimization algorithm determines the surface form. The surface form parameters e.g. Zernike coefficients are adjusted until the measured wave vectors match the surface geometry as closely as possible. To obtain the global minimum in the optimization problem, good initial values are necessary. The design surface form parameter can be used for this purpose, for example.

3 Error influences

Various errors input quantities, in particular from the LEDs and the SLM are currently being investigated to evaluate the measurement uncertainty of the form measurement.

LEDs are not point sources as assumed for the evaluation of the form. In addition, constant wavelengths and accurate positioning of the LEDs are required.

The LED positions can be measured both offline and inline.

The SLM itself is not homogeneous and has variations in phase response. Typical errors of the SLM are (i) phase nonlinearity in the phase response of the SLM to input gray levels, (ii) pixel crosstalk due e.g. modulation at one pixel affects neighboring pixels due to fringing fields or liquid crystal spreading and (iii) fill factor limitations due gaps between pixels that don't modulate light. Investigations on these SLM errors using a 45° blazed grating as an example can be found in [5]. The phase deviation of the SLM can be reduced by a 3D-calibration instead of a 1D-calibration. 3D-calibration means that each pixel of the SLM receives its own correction values, which can be stored in a look-up table.

4 Discussion and Outlook

Multiple Aperture Shear Interferometers (MARs) were set up at BIAS and PTB, which offers the possibility of measuring aspheres fast and cost effective. A flexible light source with LEDs was developed and set up. Important error influences of the MARs setups were identified. Future work includes optimizing the evaluation, improving the calibration of the system and providing a full measurement uncertainty budget. In addition, a measurement setup for 3-inch optics is under construction.

Acknowledgement

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