Form metrology of optical surfaces based on partial coherent shearing interferometry in reflection

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Abstract

The concept behind a new LED multispot illumination setup for reflective measurements with a shearing interferometer for the form metrology of optical surfaces is presented along with its first realization. The challenges and initial approaches are discussed while examining interferograms of different specimens in an early development phase. Resolvable interferograms from different light sources reflected by the surface under test are captured simultaneously. This enables data acquisition of the measurement area even for surface forms with high dynamics such as those that exist in aspheres and freeforms.

Keywords: Form metrology, shearing interferometry, aspheres, freeform surfaces

1. Introduction

In the first development phase within the framework of a joint project by the Bremer Institut für angewandte Strahltechnik (BIAS) and the Physikalisch-Technische Bundesanstalt (PTB), a shearing interferometer combined with an LED multispot illumination setup, called the Multiple Aperture Shear Interferometer (MArS), has been developed for measurements in transmission [1]. Based on partial coherent light sources, simultaneous illumination from different angles is used to ensure resolvable fringe densities of the interferogram all over the measurement area [2]. Thus, even shapes with large height dynamics and also without symmetry can be measured.

The challenges for measuring in transmission are firstly that distinguishing between the actual shape of the front and reverse surfaces is not possible, and secondly that the measurement is disturbed by a possible non-homogenous refractive index of the material used. To solve these problems, the concept behind a measurement setup for reflective usage comparable to other asphere measurement devices [3] is presented. This setup keeps the advantages of flexible illumination. Furthermore, the shearing interferometer remains the same as for measurements in transmission. The LED multispot illumination setup however has to be changed. Light sources in outer areas can be arranged in a direct way to be reflected to the interferometer aperture at the specimen. However, all parts of the specimen with a surface normal to the optical axis need to be illuminated from the inside of the interferometer aperture for appropriate reflection. To avoid shadowing by light sources placed in front of the interferometer, the specimen is illuminated with virtual spot lights (see Figure 2) inside the interferometer aperture. In addition, with the outer light sources, the gapless illumination of the specimen is created and yields a resolvable fringe pattern at the sensor plane.

2. The Multiple Aperture Shear Interferometer

For measuring freeform optical elements with areas containing steep slopes, an optical measurement technique based on a high precision shearing interferometer combined with multispot LED illumination [2] has been developed. Figure 1 shows the setup in transmission mode. As a shearing element, a spatial light modulator (SLM) is placed in a folded 4f lens configuration, which also provides a 1:1 image of the specimen on the camera. Both sheared wavefronts originate from the SLM which allows almost equal optical path lengths and thus makes the setup insensitive to vibrations. A flexible LED fibre arrangement provides multispot illumination which can be adapted to the specimen surface form. The low temporal coherence of the LED-based illumination suppresses unwanted interference, while the spatial coherence is sufficiently high to obtain clear interferograms. In addition, light emitted by different LED fibres does not cause interference and thus avoids disturbing interferograms in overlapping regions. The setup secures the optimal coverage of resolvable interferograms all over the measurement area.

Figure 1. Sketch of the shearing interferometer setup with a multispot light source for measuring in transmission. The LED positions can be adapted to the form of the surface under test (SUT).

2.1. Illumination setup for reflective measurements

For reflective measurements, the specimen needs to be illuminated from the interferometer side. Outer light sources
can be placed around the specimen for gapless illumination. Areas of the specimen with a surface normal towards the optical axis need to be illuminated in the direction of the optical axis to ensure that the reflected light is inside the interferometer aperture. Corresponding light sources would have to be placed in the interferometer aperture and would thus block the light from the interferometer. To overcome this, a beam splitter is used to illuminate the sample from the inside of the interferometer aperture as shown in Figures 2 and 3. The spot is focused in the plane of all other spot light sources to generate a central spot light source, as shown in Figure 2. With this technique, a homogeneous distributed field of spot light sources is created which can be adapted to the specimen surface form.

![Figure 2. Sketch of the concept of the illumination setup for form measurements in reflection. The image of the central light source is called the virtual light source. The size of lens 1 defines the interferogram aperture.](image1)

**Figure 2.** Sketch of the concept of the illumination setup for form measurements in reflection. The image of the central light source is called the virtual light source. The size of lens 1 defines the interferogram aperture.

**Figure 3.** Realization of the illumination setup for form measurements in reflection. The central light source is placed beside the interferometer and is reflected to the specimen by the beam splitter. Other light sources are placed around the specimen due to the black bowl.

### 3. Measurement examples

To test the new illumination setup, different specimens were used. Additionally to flat and spherical surface forms, a concave off-axis parabolic mirror is tested to investigate the possibilities of adapting the illumination to different dynamic and non-symmetric forms. Figure 4 shows the spherical convex mirror and the concave off-axis parabolic mirror. Figures 5 and 6 show interferograms provided by these two specimens.

![Figure 4. Left: spherical mirror with a radius of curvature of 25 mm and a diameter of 25 mm; Right: off-axis parabolic mirror.](image2)

**Figure 4.** Left: spherical mirror with a radius of curvature of 25 mm and a diameter of 25 mm; Right: off-axis parabolic mirror.

Due to the spot light sources employed, the specimen is illuminated by multiple spherical waves. The reflection of these wavefronts depends on the curvature of the specimen. This results in various patch sizes and fringe densities. Figures 5 and 6 represent roughly the same area of the image sensor. To cover the whole area of the convex spherical specimen, far more light sources need to be used compared to the convex off-axis parabolic mirror. However, it can be seen that by using multiple light sources, also light from the steep slopes of the mirror enters the interferometer. The measurement uncertainty of the measurement concept has not yet been determined but it is expected to be in a typical range for interferometric measurements [4].

![Figure 5. Interferogram patches created by six light sources. The specimen is a convex spherical mirror with a radius of curvature of 25 mm. The central light source is marked with a red box.](image3)

**Figure 5.** Interferogram patches created by six light sources. The specimen is a convex spherical mirror with a radius of curvature of 25 mm. The central light source is marked with a red box.

![Figure 6. Measured interferograms of an off-axis parabolic concave mirror illuminated by three light sources. The central light source yields to the upper interferogram. Additionally to the fringes representing the form, a rough structure on the surface becomes visible.](image4)

**Figure 6.** Measured interferograms of an off-axis parabolic concave mirror illuminated by three light sources. The central light source yields to the upper interferogram. Additionally to the fringes representing the form, a rough structure on the surface becomes visible.

### 4. Conclusion

A first version of the illumination setup for measurements using the MArS setup in reflection has been implemented. The interferogram quality has been shown for different surface forms and is sufficient enough for form evaluation. Moreover, the size of the illuminated areas has been investigated for the illumination setup. With this information, the amount of necessary light sources will be adapted for further measurements. In the ongoing research work, a comparison of the evaluated interferometers to other measurement techniques is planned. Additionally, the challenges of measuring glass surfaces instead of mirrors will be investigated.

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