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Scanning measurement of aspheres

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A B S T R A C T

The measurement of aspheres today is often done using computer generated holograms with interferometry. We show that this method holds some significant systematic errors caused by imperfect adjustment of the optical components. This gives rise to the question if a measurement is possible without utilization of computer generated holograms. Therefore we propose a new elliptical setup using a laser interferometer and a set of scanning mirrors. Our work shows that this setup is capable of form measurement for individual aspheres but still poses some adjustment challenges.

1. Introduction

The use of aspheric surfaces has extended the capabilities of optical components in the past decades and continues to contribute to the field of high performance optics. The production process for these surfaces is an iteration of fabrication and measurement processes where the fabricated surface is measured and referenced to its design data repeatedly. Usually the surface has to be adjusted in a subsequent production step which is followed by another measurement step. This procedure is repeated until the final surface meets the design specifications [1,2].

For the measurement part of this process different options can be considered. A traditional way for the measurement is the use of a stylus that scans the surface profile in a two-dimensional movement. This method is relatively slow and bears the risk of damaging the surface in the process. An alternative method is the use of a form testing interferometer in combination with a computer generated hologram (CGH) [3]. While spherical or planar surfaces can be tested by such an interferometer without additional components, the nature of aspherical surfaces demands a CGH that adapts the testing wave front of the interferometer to the expected surface. Thus the CGH is unique to the surface and cannot be used for a different asphere type. The cost of the CGH makes it uneconomic to test only a small series of aspheres or even single parts [4].

Latest developments of new measurement devices include interferometers that only cover a small part of the surface at a time and stitch multiple measurements together or optical sensors that are mounted on a small coordinate measurement system that can move the sensor over the aspheric surface and keep it perpendicular to the expected surface so that the measurement is possible. These concepts have a relatively complex composition of expensive components in common making the final measurement device very expensive [1,5,6].

Here we first show the limitations on the accuracy of a CGH-based measurement caused by slight misalignments that are hardly detectable by the operator without additional analysis algorithms. This further motivates the demonstration of a new approach for testing of aspheres with less possible systematic errors. The new

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measurement setup is based on a distance measurement interferometer that also allows for a scanning measurement of different types of aspheres within the same setup.

2. Comparison to systematic errors of hologram assisted optical testing

In order to motivate the new measurement method and draw a comparison to systematic errors of the standard interferometric measurement method of aspheres, we first give an overview of investigations on an experimental setup which has been realized for studying the misalignment error. This error cannot be totally eliminated since usually the operator minimizes the overall averaged fringe density which often corresponds to the minimum peak to valley value.

This indicator however is not valid when strong and highly dynamic aspheres are tested. Especially in case of freeformed optics, an operator is hardly capable of finding the optimized position by following the fringe pattern. To give a general impression of the systematic measurement error, in the following the parameter space with regard to the specimen's position in 5 axes has been varied with a hexapod system (PI, H-811, repeatability in position: <100 nm, see Fig. 1). The results showing the correlation of misalignment and measurement error is depicted in Fig. 2.

The results in Fig. 2 proof the positive correlations of tilt and the coma value in a Zernike decomposition. This basically reflects the impressions of experienced users. Therefore, without compensation methods which have not been proposed till now, this measurement method shows higher systematic errors with increased asphericity, motivating the benefits of the following new setup which has no need for holograms.

3. The setup for the new measurement device

The basis for the measurement device is an imaginary ellipse that is represented in the setup as a mirror that is a part of that ellipsis (see Fig. 3). The measurement device we use is a laser interferometer for length measurement, whose path is modified with the use of tilting mirrors within this ellipse.

The hardware as seen in Fig. 3 consists of a laser interferometer, two tilting mirrors, an ellipsoidal mirror (which represents a part of the underlying ellipse) made from aluminum and a rotary axis with a lens holder (see Fig. 4). Additionally a PC with a D/A-card is used for the control of the mirrors and the interferometer.

One defining property of an ellipsis is that every ray of light that is emitted in one of the two foci will be reflected at the ellipsis so that it will reach the other focal point. This means, that such a ray of light will always be perpendicular to the surface of a sphere which is centered at one focal point.

Therefore a tilting mirror will be placed in one of the focal points (the left focal point in Fig. 3) to allow for a scanning procedure. At the other focal point there is the mount for the lens under test which is an air bearing rotary axis to be able to measure the whole surface. This lens under test can now be scanned with the help of the first tilting mirror. To enable a measurement the laser light must take the same path on its way through the setup from the laser interferometer to the lens and back. To achieve this, the ray must be perpendicular to the surface of the lens. If the lens under test is a sphere this single mirror would suffice to completely scan the surface of the lens by variation of the tilting mirror.

But since we measure aspherical surfaces, a second mirror is needed to ensure that the laser light is locally perpendicular to the aspherical surface which leads to the back and forth path of the light being identical.

The measurement will be done by measuring the optical path length between the laser interferometer and the lens and the evaluation of this data will be discussed below.

4. Control, simulation and evaluation

As outlined before for every position on the surface of the lens one has to find the two positions for the tilting mirrors that will lead to a ray perpendicular to the surface of the lens and thus allow a measurement. This process replaces the custom CGH necessary for asphere testing with a classic interferometer and is done before the measurement itself.

4.1. Control data generation

This is done by using a ray tracing simulation developed in MATLAB that handles the light as a geometric beam with

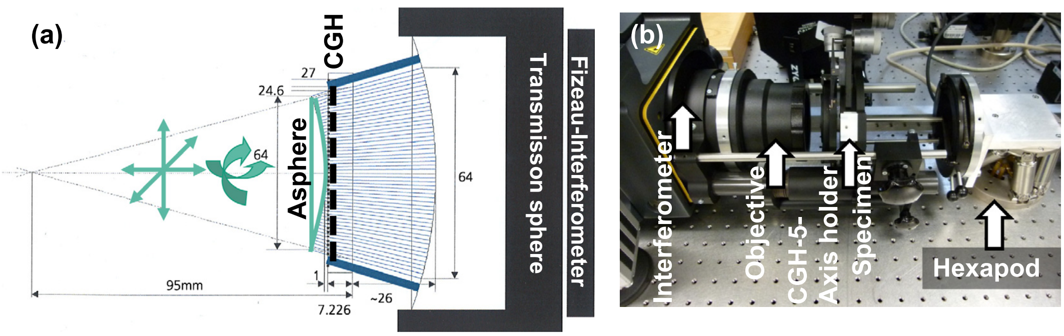

Fig. 1. (a) Basic setup shown schematically with asphere. (b) Experimental setup with special constructions for mounting of the asphere and the CGH.