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Subaperture stitching test of convex aspheres by using the reconfigurable optical null

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ABSTRACT

Subaperture stitching test in combination of the reconfigurable optical null we proposed recently provides flexible solutions to various surfaces including convex aspheres and even aspheres of large aperture. However it is challenging for the stitching optimization to get the real surface error because the surface error is strongly coupled with misalignment-induced aberrations in near-null subaperture measurements. Aiming at this challenge, we first figure out the property of aberrations induced by misalignment of optical null or test surface. It shows that identical misalignment of the optical null introduces nearly identical aberrations to subapertures with different off-axis distances, while misalignment of the test surface introduces little aberrations to the central subaperture. The stitching algorithm is then proposed with focus on decoupling surface error and induced aberrations. The major step is to calibrate out the effect of misaligned near-null optics before stitching optimization by using the central subaperture measurement. We also present the through-the-back null test for the purpose of cross test. The axial distance is precisely monitored by a low coherence interferometer, which enables accurate determination of the spherical aberration component of surface error. Final experimental results show consistent spherical aberration obtained by stitching test and by the through-the-back null test. It is a big step towards instrumentation of subaperture stitching test for aspheres with rather big amount of misalignments in surface metrology practice.

1. Introduction

Interferometric test of large convex surfaces is difficult and expensive because it requires interferometer optics and/or null optics of larger aperture [1]. A natural solution to this problem is subaperture stitching test which measures and then stitches a series of smaller subapertures. The subaperture with both reduced lateral size and vertical aspheric departure is much easier to be measured with a standard interferometer. However for large aspheres with large aspheric departure, too many subapertures are demanded to cover the full aperture since the size of subaperture has to be reduced significantly. Therefore null optics is recommended to compensate subaperture aberrations. In this case, the measured area is still limited by the aperture of null optics. We generally have to divide the full aperture into more than one ring of subapertures. That is, we have to measure subapertures located at different off-axis distances. As a result, null optics with different capability of aberration compensation is required. Considering the fact that astigmatism and coma dominate the subaperture aberration for general aspheres, we proposed a reconfigurable optical null based on the counter-rotating Zernike plates [2]. The optical null can be reconfigured as different null by simply counter-rotating the plates. Variable aberrations composed of astigmatism and coma are then generated to correct most of aberrations for subapertures located at different positions on surfaces of various aspheric shapes. It is also referred to as near-null test since the aberrations are partially, not completely instead, corrected for each subaperture. Similar near-null optics is the variable optical null [3,4] proposed by QED Technologies. The stitching result is comparable to the self-null test result but with some low order errors from prescription uncertainty removed [4].

Subaperture stitching test in combination of the reconfigurable optical null provides flexible solutions to various surfaces including convex aspheres and even aspheres of large aperture. However making subapertures measurable is merely the first step. Stitching all subaperture measurements effectively is more important and difficult for aspheres. Various aberrations are introduced to each subaperture due to uncertain misalignment of both the near-null optics and the test surface [5]. It is quite challenging for the stitching algorithm to get the real surface error including low orders because the surface error is

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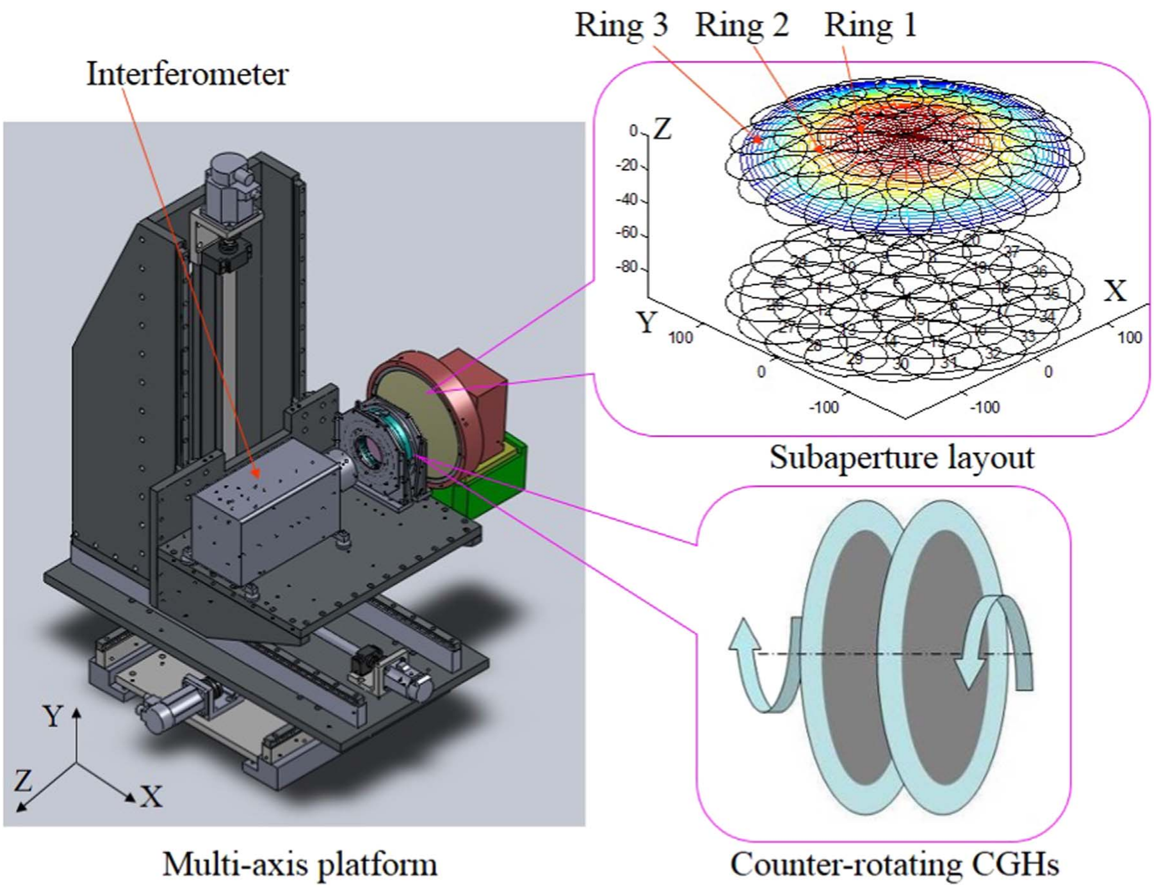

Fig. 1. Setup of the near-null subaperture test system.

strongly coupled with misalignment-induced aberrations in near-null subaperture measurements.

Since the beginning of this century, the research focus of subaperture stitching test has been shifted from large flat optics to curved optics including aspheres [5–13], cylinders [14] and even freeform wavefronts [15]. Most efforts were made to stitching of subapertures measured in the non-null test condition. No null optics is used and hence only the misalignment of test surface will introduce aberrations coupled with the surface error. Such induced aberrations can be well modeled by theoretical calculation of deviations of the misaligned surface from the nominal one, or directly by ray tracing the misaligned test system either for circular or annular subapertures [8–10]. Therefore it is not so difficult to decouple the aberrations from the surface error in non-null subaperture measurements. However, more aberrations are induced and coupled when null optics is introduced in subaperture test. Their contribution to the subaperture measurement can be identical with the surface error, though the misalignment-induced aberrations are still predictable through ray tracing [12] or analytical modeling [14]. Complete decoupling through stitching optimization is then naturally impossible [13]. Therefore we usually have to demand all subapertures be measured in well aligned null condition. As a result, aberrations such as coma and astigmatism induced by misaligned null optics are small enough to produce tolerable surface error, mainly spherical aberration (SA) of rotational symmetry. But such demand does not work for near-null subapertures. We do not know exactly whether the near-null optics is aligned because the subaperture is nominally not measured in null condition. Stitching optimization with focus on decoupling induced aberrations and surface error is quite challenging in this case. Currently the near-null stitching can not give reliable result with some low order terms, especially the SA. We address this problem detailedly in Section 2, taking a convex even asphere as an example. Then in Section 3, we describe a well controlled system for through-the-back null test of the same surface. Section 4 presents experimental results which show correct surface error is obtained from near-null subaperture stitching test.

2. Stitching test of near-null subapertures

2.1. Test system setup

The test surface is a 6-order even asphere (Roc=1023.76 mm, K=0, clear aperture is 320 mm) with about 34 μm in aspheric departure. It is the same part we tested in [2] but with subsequent polishing. The stitching results used as feedback to corrective machining have guided the polishing process successfully. But as the surface error got reduced, the SA component became doubtable. That is precisely the problem we discuss in this paper.

Three rings of subapertures are arranged with off-axis angles β=2.5°, 5° and 7.5°, respectively. Here the ring corresponds to a circle where the geometric center of subapertures lies, i.e., subapertures lying on the same ring have equal off-axis distances but different azimuthal angles. Accordingly they have identical aberrations due to the rotational symmetry. Therefore only aberrations of the three off-axis subapertures along x direction are analyzed nominally. Two computer generated holograms (CGHs) are mounted on a pair of center-through rotary tables with individual adjustment of lateral shift and tip-tilt, composing the reconfigurable near-null optics. The phase functions of two CGHs are composed of two terms Z5 (primary astigmatism at 45° and focus) and Z7 (primary y-coma and y-tilt) of Zernike polynomials, plus the power carrier. By counter-rotating the CGHs with 0.62°, 2.17° and 4.74°, respectively, aberrations of off-axis subapertures on the three rings are compensated with single-pass residuals less than 5 λ (λ=632.8 nm). Aberrations of the central subaperture are small enough to be resolved directly by the interferometer, and the CGHs do not need

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