Asphere metrology utilizing automated variable null optics

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Aspheric surfaces can provide significant benefits to optical systems, but manufacturing high-precision aspheric surfaces is often limited by the availability of surface metrology. Aspheres typically require dedicated null correction optics in addition to the interferometer itself. The cost, lead time, inflexibility, and calibration difficulty of such null optics, however, makes interferometric aspheric testing a far less attractive proposition than the relatively simple spherical test. As a result, testing remains a barrier to the widespread use of aspheres in optical systems.

Without null correcting optics, an interferometer can test mild aspheres with perhaps 10 waves of departure from best-fit sphere (~40 waves departure from vertex sphere). Few aspheres are this mild, and the calibration and processing of such "non-null" tests can be challenging. In 2006, QED Technologies introduced the SSI-A®, extending the interferometric capability to ~100 waves without dedicated null optics (or even 200 waves in some cases, 800 waves from vertex sphere) in an automated process [1]. Many aspheres fall within this capability range, but a significant number do not. Furthermore, aspheres on the edge of the SSI-A capability require a relatively large number of subapertures to test (~100 or so).

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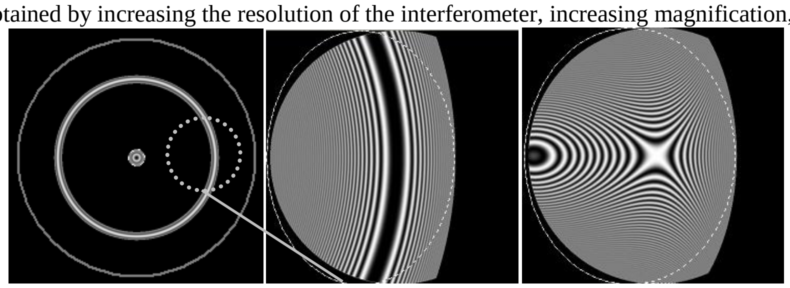
1. The non-null interference problem

Subaperture stitching alone can increase flexible interferometric aspheric capability by an order of magnitude. But additional aspheric capability and speed improvements are keenly sought. Figure 1a illustrates an attempt to measure an asphere with 80 waves of departure from best-fit sphere over its full aperture; only a small fraction of surface is resolved by the interferometer. Magnifying the data and looking only at a subaperture, increases the resolvable fringe density (Figure 1b), as does re-optimizing the local best-fit sphere (Figure 1c). Subdividing the aspheric surface reduces the amount of aspheric departure the interferometer must resolve at one time. It is readily apparent that more capability can be obtained by increasing the resolution of the interferometer, increasing magnification, or both.



(a) (b) (c)

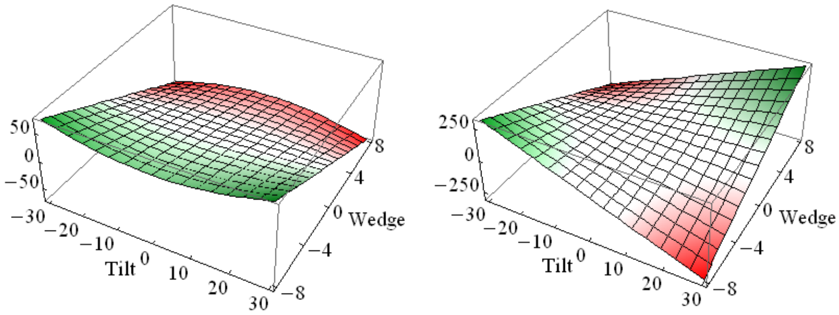
Figure 1: Simulated fringe patterns for an 80 wave asphere: (a) full aperture non-null test, (b) subaperture measurement, and (c) subaperture measurement with re-optimized local best-fit radius.

2. Variable optical null (VON™) via Rotating Prism Pair

Using subaperture stitching with a variable null has great synergy. First, magnification can be employed much as shown in Figure 1 to reduce the amount of asphericity in any one subaperture. The variable null thus needs correspondingly less wavefront generating capability. Second, the "order" (or complexity) of the wavefront is also reduced by only looking at a fraction of the surface at once. For example the subaperture wavefront in Figure 1c is primarily astigmatism (order 2) with a little bit of coma (order 3), while the original full aperture wavefront was higher order (primarily order 4 spherical with some of order 6). Third, QED's subaperture stitching technique employs "interlocked compensators" that enable calibration of systematic error through the stitching itself [2]. These are of considerable value when attempting to calibrate a variable nulling device.

A variable and tiltable optical wedge placed in a nominally spherical wavefront produces variable amounts of astigmatism and coma. The amounts of these aberrations depend on the numerical aperture of the spherical wave, the tilt of the wedge, and the amount of wedge.

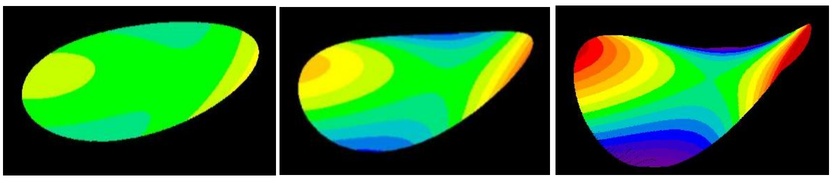
Figure 2 illustrates the amount of these aberrations produced in the case where the wedge is placed relatively close to a 6” f/2.2 transmission sphere.



(a) (b)

Figure 2: Aberration introduced by a variable wedge as a function of the wedge angle and tilt; (a) Zernike coma and (b) Zernike astigmatism. The units are microns (for aberrations) and degrees (for wedge angle and tilt).

This amount of aberration enables testing of some aspheres with 1000 waves of departure from best-fit sphere. For example, an ellipsoid with conic constant -0.471 and vertex radius 72 mm has ~650 μm departure from best-fit sphere over an aperture of 118 mm. Subapertures required to cover the part (using a 6” f/2.2 transmission sphere) would have surface profiles shown in Figure 3. Note that the vertical scale is ~500 μm, and thus the (b) and (c) have far too much departure for an interferometer to resolve unaided. But note that the profile is nearly all coma and astigmatism; case (c) has ~40 and 220 μm of Zernike coma and astigmatism, respectively. These aberrations fit entirely within the gamut shown in Figure 2.



(a) (b) (c)

Figure 3: Subaperture measurements of an asphere with an aperture of 118 mm and 1000 waves of departure from best-fit sphere. The subapertures are (a) 20 mm (b) 35 mm (c) 50 mm away from the axis of symmetry. The vertical scale is ~500 μm.

A variable wedge is relatively easy to achieve via a pair of prisms that can be rotated with respect to one another. Figure 4 illustrates a pair of 4 degree wedges in both the zero (a) and sum of wedges (b) configurations. Any net wedge angle between -8 and 8 degrees can be achieved with this configuration by rotating the prisms. Tilt of the prism pair is easily obtained by mounting the pair on a rotary stage (with an axis of rotation perpendicular to the prisms. This design is advantageous since all the surfaces are flat, and the motion is not especially complicated. Such simplicity makes calibration of the nulling element more tractable. QED has successfully integrated a rotating prism variable nulling system in its Aspheric Stitching Interferometer (ASI®), and has demonstrated measurement results on the 1000 wave asphere described in this section [3].

(a) (b)

Figure 4: example of paired optical wedges for creating a controllable aberrated wavefront in a converging beam.

3. Summary/conclusions

A Variable Optical Null employed in a subaperture stitching system enables flexible testing of aspheric surfaces. Aspheres with 1000 waves of aspheric departure from best-fit sphere have been measured with a rotating prism pair as the variable null – an order of magnitude more capability than stitching without the variable null.

4. References

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