

## **Enhancing Measurement Accuracy with Subaperture Stitching Interferometry**

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Interferometry has long been the method of choice for measurement of optical surfaces. With proper environmental control, nanometer-level precision and beyond can be achieved. Systematic errors (biases), however, increase the measurement uncertainty beyond the precision. A major source of such error is the quality of the reference wavefront. In typical commercially available transmission spheres, the reference wavefront is imperfect by 50 nm or so PV (over its full aperture) – 1 to 2 orders of magnitude higher than the precision!

Several methods exist for calibrating this bias, and thereby narrowing the gap between uncertainty and precision. They employ the principles of error reversal and/or averaging to separate the surface measurement from errors in the reference wavefront. As a result, these methods all require multiple measurements under different orientations of the test and reference parts. Examples include the three-flat, two-sphere, N-position, and random-average tests. Subaperture stitching provides an alternative method of reference wave calibration. Most stitching methods rely on pre-calibration of the reference wavefront (using one of the aforementioned methods), but QED's technique (patent pending) allows the reference wave bias to be calibrated as part of the stitching computation. Reference wave bias causes a discrepancy in regions of subaperture overlap, which can be modeled and thus compensated by the algorithm. This eliminates issues of calibration "lifetime" or applicability, as the reference wave is computed in-line with the stitching.

In theory, any of these methods can capture the reference wave bias. Yet naturally all the methods have limitations in precision and lateral resolution that require certain trade-offs to be made. While the stitching algorithm can achieve any resolution in principle, the robustness of the calculation and the available computing power typically limit the practical use to a few hundred Zernike polynomials. The two-sphere method provides a full resolution estimate; but suffers from alignment sensitivity and a poor cat's eye measurement. Furthermore, the two-sphere test is not always possible, since the cat's eye can only be measured when the point focus of the transmission sphere is accessible to the stage travel. The random-average method requires a calibration artifact, can be quite time consuming, and suffers from low-order inaccuracy if the calibration artifact is not a complete sphere.

Stitching does, however, have one key advantage over all the others – it can be used in tandem with any other method. For example, a random average or two-sphere reference can be computed and subtracted from the subaperture data before it is stitched. The stitching algorithm can then optimize over any remaining systematic error (for example, originating from inaccuracies of the calibration method or time separation

between the calibration and the actual measurement). This provides the best of both worlds: a full resolution calibration (for removing mid-spatial frequencies of the reference wave) and an accurate low order calibration that is not time-separated from the data. We demonstrate results of various calibration methods on QED's subaperture stitching interferometer (SSI<sup>®</sup>), and show the advantages of using stitching in tandem with other methods.