High precision interferometric testing of transparent, thin plane-parallel parts

Leslie L. Deck, Peter J. de Groot, James A. Soobitsky
Zygo Corporation, Laurel Brook Road, Middlefield, CT. USA, 06455-0448

Laser Fizeau interferometric profilers utilizing phase-shifting interferometry (PSI)[1] techniques are routinely used for high precision surface measurements. Because of interference from the other parallel surface, these tools often have difficulty measuring transparent plane-parallel parts like the glass disks used in today's high density hard drives and the pellicles used for semiconductor lithography applications. To handle this multiple-cavity interference problem, metrologist's have turned to other techniques, including coherence-coupled Fizeau cavities,[2] wavelength tuned phase-shifting,[3,4] and low coherence Mach-Zehnder designs.[5,6]

To satisfy the precision and resolution requirements for today's hard disk and glass pellicle manufacturers, we describe a novel low coherence equal-path interferometer, here called the Flat Glass Tester (FGT).[7] This new instrument operates at 455nm for enhanced vertical resolution with respect to traditional 633nm Fizeau interferometers, and a 2K x 2K camera with matching optics for high lateral resolution. In addition to solving the problem of separating parallel semi-transparent reflecting surfaces, the FGT has extraordinarily low coherent noise and high overall performance with respect to alternative solutions, particularly for mid-spatial frequency measurements.

Figure 1 shows the optical design of the FGT. A spectrally broad-band, extended source illuminates the interferometric cavity consisting of high-quality flat reference and beam-splitter elements and the object to be measured. The first surface of the beamsplitter is coated to reflect 50%. The back surface of the reference has a 15% reflective coating to accommodate both bare glass and reflective parts. The object surface is normal to the optical axis and at a position such that the optical path between the reference and beamsplitter equals the optical path between the beamsplitter and object. A key feature of the geometry is that both the beam splitter and reference elements are tilted so that direct reflection of the illumination beam is stopped at the aperture. The result is a high-contrast fringe pattern with fully incoherent illumination, and without any background light from unwanted reflections.

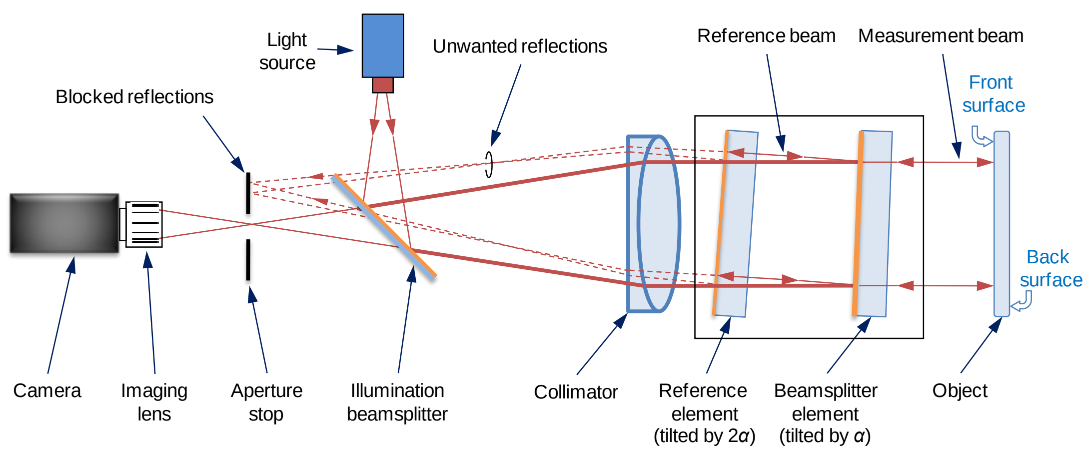

Figure 1: Basic optical layout. A broad-band extended source illuminates an interferometer cavity consisting of the 1st surfaces of the reference and beam-splitter elements and the object. The object surface is set to the equal-path location and focused onto the camera. Phase shifting is accomplished by moving the boxed elements as a whole.

The source is a high brightness LED with a mean wavelength of 455nm. A spectral filter provides a coherence range of ±50 microns around the equal path position. The LED source is spatially extended and is imaged to completely fill the aperture stop of the imaging system. This combined low spatial and temporal coherence eliminates coherent artifacts and significantly reduces the affects of dust and particulates in the optical system, allowing the tool to meet very low noise specifications. An indication of the measurement uncertainty can be derived from the uncertainty matrix[8] which reports the standard deviation of each pixel from an ensemble of measurements. Ideally the map of standard deviations should be uniform and Figure 2 shows this is indeed the case, predicting a 180pm single measurement rms repeatability.

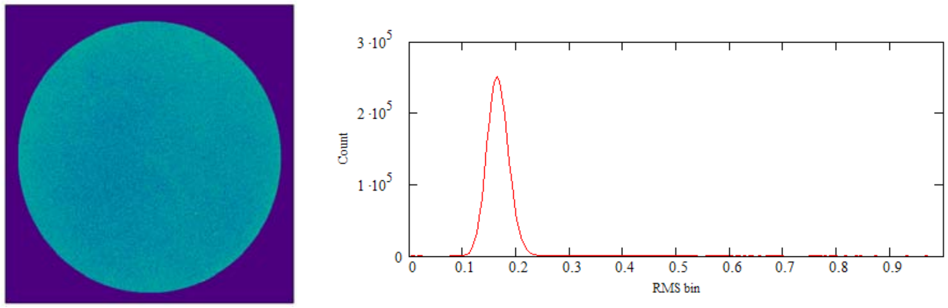

Figure 2: The uncertainty matrix calculated from an ensemble of 40 measurements.

An important goal for the FGT is accurate measurements of surface mid- to high-spatial frequencies. To that end, the collimator and imaging lens are custom broad-band fixed-focus designs that produce less than 0.1% distortion across the 100mm field. The instrument design goal is to reproduces surface structures with 200 micron periods (half Nyquist) with a phase transfer function of 70% and 100 micron periods (Nyquist) at 40%. Measurements of the instrument transfer function with a step artifact (Figure 3) show a transfer function very close to these design goals over most of the field.

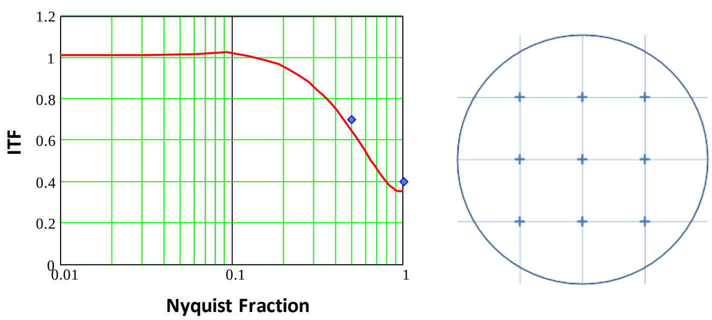

Figure 3: Measured system ITF (red line) as determined with a step artifact at the 9 field locations indicated on right. Each field location produced the same ITF. The blue diamonds represent the design goals for the half and full Nyquist frequencies.

An additional consideration for accurately reproducing mid- to high-frequency surface features is a low system coherent noise, which can be the dominant noise source in laser-based interferometers. Coherent noise can be isolated and quantified by observing speckle decorrelation as a function of surface tilt.[6] Figure 4 illustrates this decorrelation in the FGT by plotting the rms difference between a null measurement and measurements with various amounts of tilt. Each measurement in the plot represents 10 averages and is high pass filtered with a 1mm^{-1} spatial frequency to remove the affects of retrace and turbulence. The curve for a standard laser Fizeau instrument is included for comparison. Compared to the standard laser Fizeau, the FGT consistently measures 3 to 5 times lower rms error for all values of tilt.

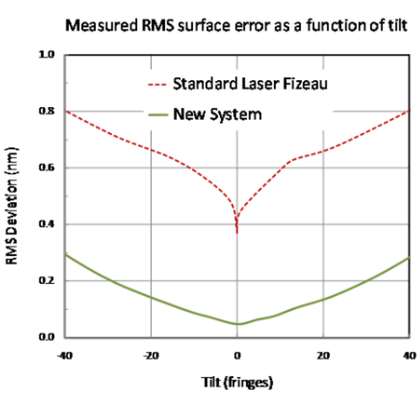

Figure 4: RMS residuals as a function of part tilt for the FGT compared to a standard laser Fizeau. The measurements have been high pass filtered with a 1mm cutoff to minimize turbulence affects.

The instrument has been applied to the measurement of a variety of plane-parallel objects. Figure 5 shows measurements of both glass (4% reflectivity) and aluminum (90% reflectivity) hard disk blanks. The interference contrast for both disk materials is better than 75% for both surface types in spite of the large difference in reflectivity.

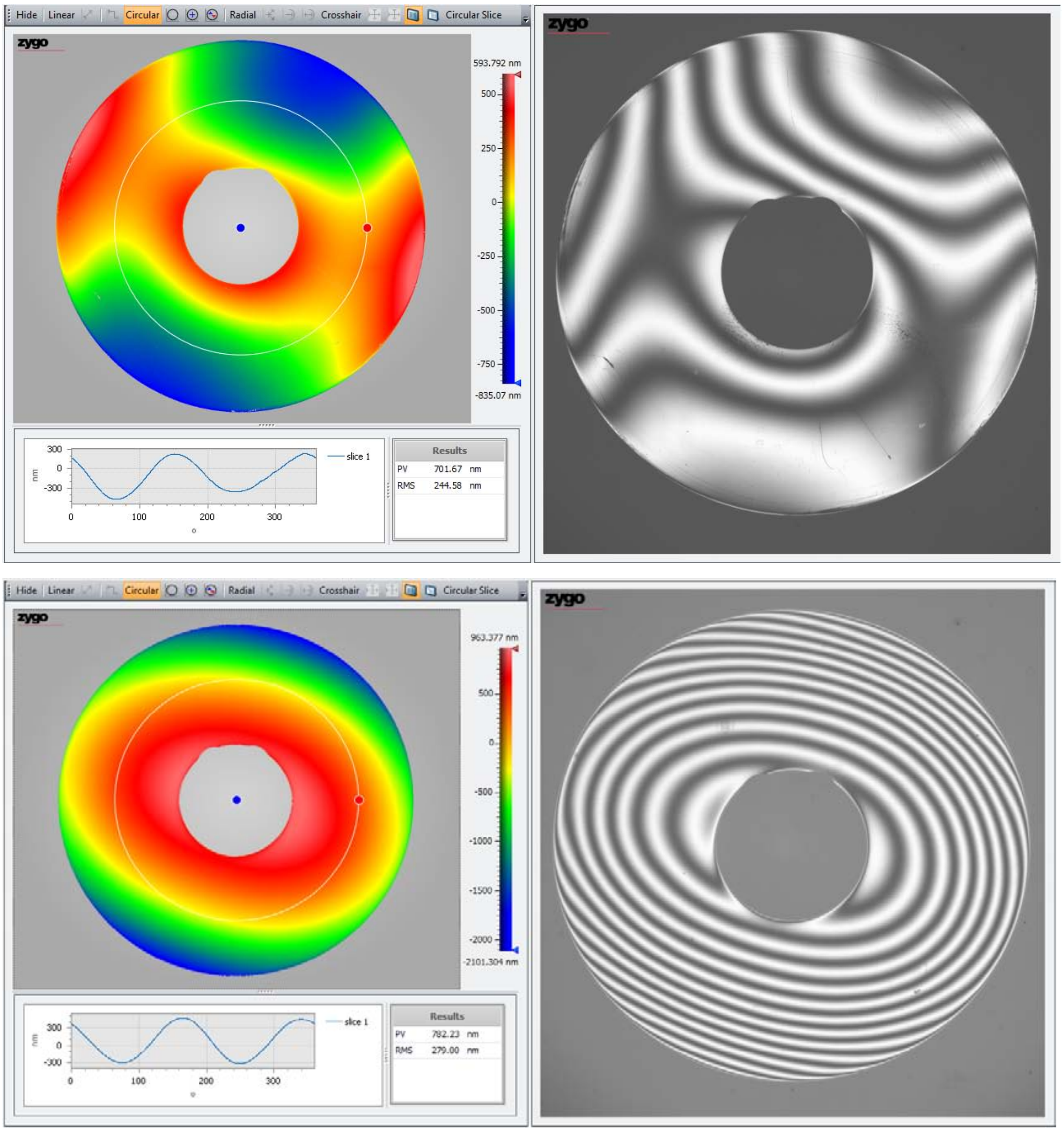

Figure 5: Measurements of 65mm hard disk blanks made of aluminum (top) and glass (bottom).

---

[1] J. Greivenkamp and J. Bruning, Chap. 14, of "Optical Shop Testing", D. Malacara, ed. (J. Wiley, 1992)
[2] B. Kimbrough et al, "Low-coherence vibration insensitive Fizeau interferometer," Proc. SPIE 6292 (2006)
[3] P. de Groot, U.S. Patent 6,359,692 (2002)
[4] L. Deck, U.S. Patent 6,882,432 (2005)
[5] K. Freischlad, "Large flat-panel profiler," Proc SPIE 2862, 163-171 (1996)
[6] K. Freischlad, "Interferometer for optical waviness and figure testing," Proc SPIE 3098, 53-61 (1997)
[7] P. de Groot, et al., published US Patent Application 20110007323 (2011). Additional U.S. and foreign patents pending.
[8] C. Evans, "Uncertainty evaluation for measurements of peak-to-valley surface form errors," CIRP Annals 57, 509-512 (2008)