Using the instrument transfer function to evaluate Fizeau interferometer performance

Leslie L. Deck and Peter J. de Groot
Zygo Corporation, Middlefield, CT 06457
les.deck@ametek.com

Abstract: Advances in test procedures and analysis techniques now enable reliable instrument transfer function measurements to 1000 cycles per aperture independent of several traditional sources of uncertainty and operator error.
OCIS codes: (120.3180) Interferometry; (120.3930) Metrological instrumentation; (120.5050) Phase measurement; 110.4850 Optical transfer functions

The ITF

One of the performance characteristics of metrology instruments used when fabricating high precision optical components is the ability to detect and accurately measure mid- and high-spatial frequency surface form deviations from the ideal figure. These fine-feature surface errors can have a deleterious effect on optical imaging performance, from aberrations to light scattering. These considerations have driven camera formats from VGA to 1, 2, 4 million pixels and even larger. Optical designers have been challenged to keep up with this trend so that the optical resolution of the complete system implied by the dense sampling is consistent with expectations.

Limitations to the lateral resolving power of optical instruments for 3D measurements of surface form can be measured with the instrument transfer function or ITF. The ITF is a more complete and meaningful description of instrument response than a single lateral resolution number such as the Raleigh limit or the camera pixel size [1]. A simple linear ITF catalogs the response of the system to pure surface sine wave patterns as a function of frequency. In the limit of very low amplitude sine waves (<< λ), we can predict the instrument response to the overall surface structure by mapping the Fourier components of the surface, weighted by the ITF, to the reported topography [2]. The foundation for a rigorous understanding of the ITF is well documented in the literature [3].

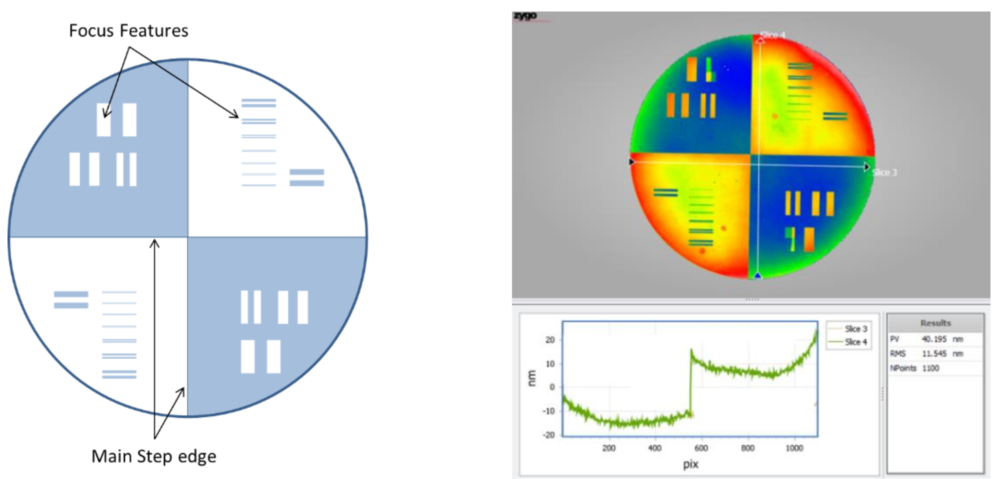

Figure 1: Left—ITF test sample design. Right—Measurement result.

Test specimens

Design and fabrication of test specimens for ITF rely on the fidelity of raised features on the scale of a few nm. One approach is fabricate an artifact with a variety of periodic patterns that are linearly chirped in frequency and oriented in different direction [4]. This type of test specimen is conceptually the most straightforward, but fabrication is difficult and the final product is not easily verified for quality across the full frequency range.

Our approach has been to use the 3D equivalent of the edge spread function test [5], relying on a sharp step features across the 100mm full aperture of a super-polished disk. These feature are fabricated using conventional lithography methods. The test sample shown in Figure 1 has two lines, one horizontal and the other vertical, and includes additional features to aid on properly focusing the instrument. The calculation of the ITF follows from comparing the frequency content of the measured step to an idealization of a perfect step. This approach is valid provided that the step height is small—in our case, about 25nm and sharp. If the step height or any other 3D feature approaches a quarter wavelength in height, we are no longer in the linear phase regime and the measurement results will not be an accurate indication of the true ITF. Confidence in the results follows from evaluating the quality of the step height using interference microscopy at a high magnification, at a lateral resolution limit on the scale of a single micron.

Robust measurements

Many factors can influence the fidelity of an ITF measurement. Environmental disturbances can degrade or accidentally exaggerate ITF results, motivating the use of vibration-robust data acquisition [6]. Instantaneous methods based on spatial phase shifting nearly eliminate vibration issues, but the ITF is understood to be lower for these methods [7]. Whether through data acquisition, processing or averaging strategy, the noise should be below 1nm rms [8]. Finally, the instrument should be properly focused to maximize the ITF, which is not always easy to achieve for the latest generation of large-format systems. When using a test sample as in Figure 1, a successful strategy is to optimize the ITF measurement in post processing by digitally propagating to the plane of best focus [9].

Results

Figure 2 shows an ITF measurement result, in this case for an instrument with a design 50% cutoff at a spatial frequency of 8 cycles per mm. Measurements at different field positions along the step height features in the test sample are important for verifying that the expected spatial frequency response is consistent over the full surface area. The steep slope at high frequencies is consistent with apertures in the optical system intended to prevent camera aliasing. With newer camera formats having larger pixel counts, realistic spatial frequency sensitivity can be 1600 cycles over the aperture.Figure 1

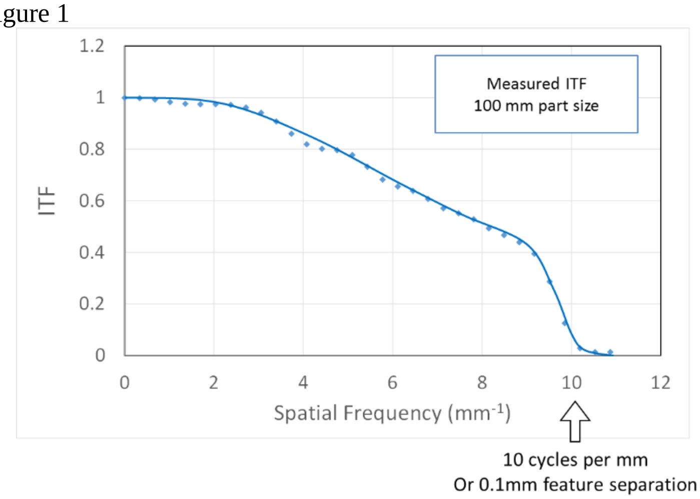

Figure 2: Example precision ITF measurement results showing a design resolution limit of 1000 cycles over a 100mm aperture.

References

[1] X. Colonna de Lega, and P. de Groot, "Lateral resolution and instrument transfer function as criteria for selecting surface metrology instruments," in *Optical Fabrication and Testing*, OSA Proc. Optical Fabrication and Testing OTu1D (2012).

[2] P. de Groot, X. Colonna de Lega, D. M. Sykora, and L. Deck, "The Meaning and Measure of Lateral Resolution for Surface Profiling Interferometers," Optics and Photonics News **23**, 10-13 (2012).

[3] J. W. Goodman, *Introduction to Fourier Optics*, (McGraw-Hill, New York, 1996).

[4] J. Chu, Q. Wang, J. P. Lehan, G. Gao, and U. Griesmann, "Spatially resolved height response of phase-shifting interferometers measured using a patterned mirror with varying spatial frequency," Optical Engineering **49**, 095601-095601-7 (2010).

[5] P. Z. Takacs, M. X. Li, K. Furenlid, and E. L. Church, "Step-height standard for surface-profiler calibration," in *Optical Scattering*, Proc. SPIE **1995** pp.235-244 (1993).

[6] L. L. Deck, "Model-based phase shifting interferometry," Applied Optics **53**, 4628-4636 (2014).

[7] D. M. Sykora, and P. de Groot, "Instantaneous measurement Fizeau interferometer with high spatial resolution," in *Optical Manufacturing and Testing IX*, edited by J. H. Burge, O. W. Fähnle and R. Williamson, Proc. SPIE **8126,** 812610-812610-10 (2011).

[8] *Verifire™ HD Interferometer System*, Product Specifications SS-0091 (2016).

[9] L. L. Deck, "Method and apparatus for optimizing the optical performance of interferometers," US Patent Application 15/383,019 (2016).