Evaluation of the measurement performance of a coherence scanning microscope using roughness specimens

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INTERFEROMETERS FOR SURFACE ANALYSIS

Precision manufacturing has seen a steady increase in the use of high-speed, non-contact optical measurements of form and roughness. A dominant technology is coherence scanning interferometry (CSI), also known as scanning white light interferometry (SWLI), which provides quantitative maps of the surface topography for a million image points in a few seconds (Figure 1). CSI relies on interference fringe contrast, optionally combined with interference phase, to determine surface heights [1].

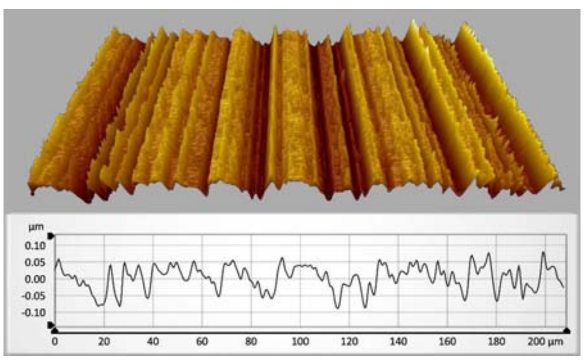

FIGURE 1. Areal surface topography map (above) and an extracted linear profile (below) of a Rubert 502 precision reference specimen as measured optically by CSI.

While recognizing the benefits of optical areal measurements, several groups have reported unexpected results from interference microscopes that compromise confidence in these tools [2]. In some cases, researchers have observed large differences in profile results depending on the data processing mode [3]. In other cases, average amplitude or *Ra* values measured with CSI have disagreed significantly with stylus measurements, in some cases by as much as a factor of two [4,5,6].

It has been shown that anomalous results for sub-micron *Ra* specimens can be overcome in many cases by switching to phase shifting interferometry (PSI) where feasible [3], or by using specialized CSI data analyses that make use of phase information to improve measurement results on optically smooth parts [7]. However, the need to select between two or more measurement modes is a complication that has slowed the adoption of optical tools for routine measurements of surface texture.

Here we evaluate the performance of a new instrument (Figure 2) specifically designed to simplify the transition from stylus to optical measurements for metrology of precision machined, ground or polished surfaces.

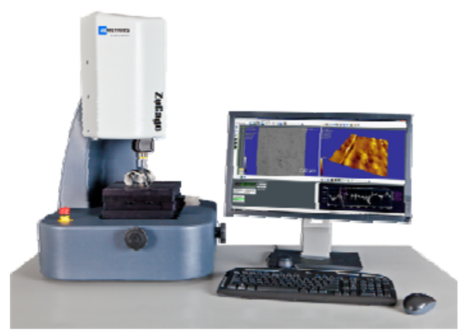

FIGURE 2. ZeGage™ coherence scanning interferometer.

This instrument has a *single* measurement mode with a 1nm surface height repeatability midway in performance between traditional fringe contrast and phase measurement methods. Proprietary hardware and software obviate the height distortions sometimes observed in traditional CSI, significantly improving the measurement consistency and ease of use of the instrument.

The evaluation relies on a comparison of *Ra* values as determined by contact stylus and optical measurements. The results for fourteen commercial roughness specimens demonstrate good agreement over a wide range of surface textures from smooth to rough, with the best results obtained for magnifications that balance optical resolution with sufficient field of view to capture the dominant surface features.

REFERENCE SPECIMENS

Roughness measurement reference specimens are standardized in ISO 5436 Part 1:2000, where they are referred to as material measures. Types C (sinusoidal) and D (random) are appropriate for evaluating instrument performance and in applications where the user may wish to quantify a statistical parameter such as the average amplitude or *Ra*.

Rubert & Co Ltd manufactures a series of precision reference specimens made from electroformed nickel. They are most often used with stylus-type contacting surface measuring instruments as standardized in ISO 3274, but are increasingly being used for qualifying optical and non-contacting instruments. The present study concerns twelve of these standards as described in Table 1.

TABLE 1. Rubert roughness specimens and their nominal Ra values.

Specimen number	Pitch (µm)	Type	*Ra* (µm)
501	♦	Random	0.02
502	♦	Random	0.03
503	♦	Random	0.10
504	♦	Random	0.15
543	2.5	Sinusoidal	0.04
542	8	Sinusoidal	0.06
529	10	Sinusoidal	0.10
531	100	Sinusoidal	0.30
528	50	Sinusoidal	0.50
530	100	Sinusoidal	1.00
527	100	Sinusoidal	3.00
525	135	Sinusoidal	6.25

We also evaluated two HALLE Präzisions-Kalibriernormale random roughness specimens, one fine (KNT 2070/03 .024 micron *Ra*) and one coarse (KNT 2058/01 0.216 micron *Ra*), both calibrated at PTB. These high-quality calibration standards conform to ISO 5436.

METHODOLOGY

We performed stylus measurements on the Rubert specimens at the Center for Precision Metrology at the University of North Carolina at Charlotte with a nominal stylus radius of 2µm. We applied a Gaussian filter with a low-pass spatial period cutoff of 2.5µm, per ISO 3274-1996. For stylus results on the Halle specimens, we rely on the certified *Ra* values from the manufacturer.

For the optical measurements, we employed Mirau objectives with 10X, 20X or 50X magnifications, according to the observed surface detail. The 1024 X 1024 camera provides field of view widths of 934µm, 417µm and 167µm, respectively. We applied an areal Gaussian filter with the 2.5µm-cutoff to the topography and calculated the *Ra* value from linear traces for direct comparison with the stylus results. For the random roughness specimens, the reported results represent an average of eight or more *Ra* measurements at different locations. There were no changes in the software configuration between the various samples.

RESULTS

TABLE 2. Measured Ra in µm for the Halle random roughness specimens.

	Stylus	Optical 10X	Optical 20X
Fine	0.0238	0.0237	0.0239
Coarse	0.2160	0.2370	0.2150

Table 2 compares the results for the Halle specimens, showing excellent agreement for the fine roughness specimen at both magnifications. The 10X measurement of the coarse specimen overestimates the *Ra*, possibly because of speckle noise from unresolved surface structures. The 20X magnification shows excellent agreement for both specimens.

Rubert random specimens 501, 502, 503 and 504 differ from the Halle specimens in that they contain more high-frequency roughness information; therefore, we chose 20X and 50X magnifications for the comparison. The results in Figure 3 and Table 3 again show good agreement between the stylus and optical *Ra* values. Figure 4 illustrates the agreement when using the 50X magnification compared to our 2µm radius stylus measurements.

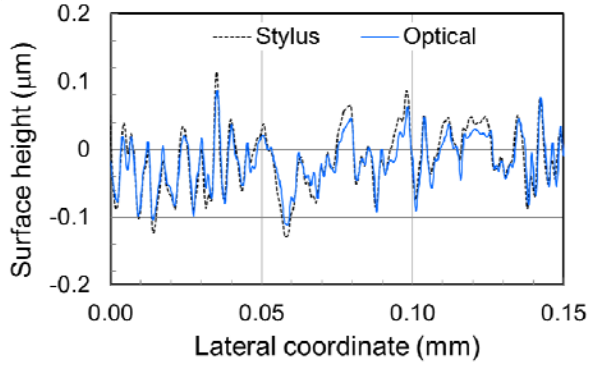

FIGURE 3. Comparison of stylus and optical profiles at 50X for the Rubert 502 specimen.

TABLE 3. Measured Ra in µm for the Rubert random roughness specimens.

	Stylus		Optical	
	2µm	0.25µm	50X	20X
501	0.015	0.019	0.012	0.016
502	0.035	0.038	0.031	0.036
503	0.067	0.099	0.076	0.095
504	0.119	0.150	0.130	0.150

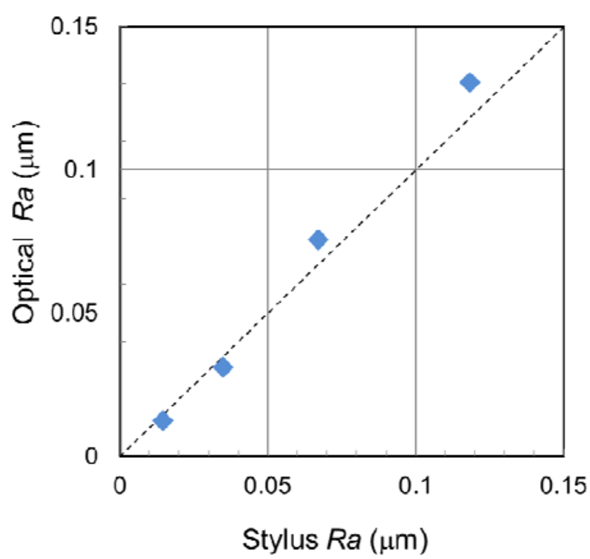

FIGURE 4. Graphical representation of the measurement results on Rubert random roughness specimens at 50X magnification. The diagonal line represents perfect correlation.

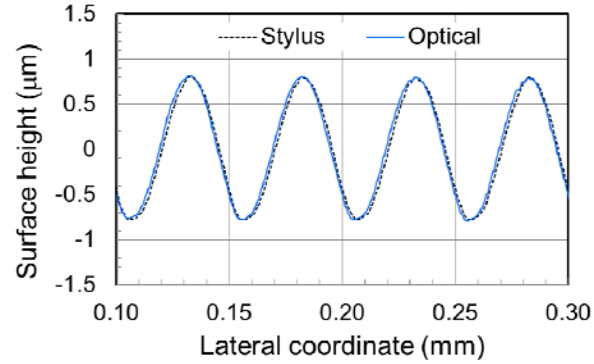

FIGURE 5. Comparison of stylus and optical profiles at 20X for the Rubert 528 specimen. A small phase shift has been added to more clearly separate the overlapping data plots.

TABLE 4. Measured Ra in µm for the Rubert sinusoidal specimens.

	Stylus	Optical	
	2µm	50X	20X
543	0.018	0.021	-
542	0.060	0.051	0.048
529	0.097	0.090	0.108
531	0.315	0.315	0.316
528	0.507	0.515	0.506
530	1.009	1.050	1.012
527	2.995	3.066	3.025
525	6.389	6.362	-

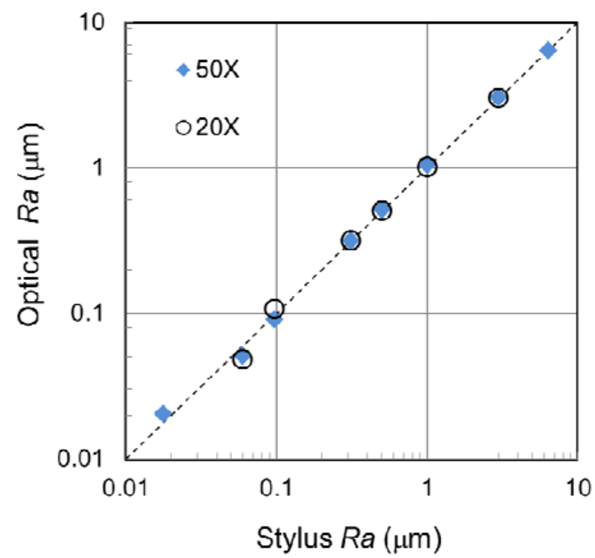

FIGURE 6. Graphical representation of the results on Rubert sinusoidal roughness specimens at 20X and 50X magnifications. The diagonal line represents perfect correlation.

Somewhat surprisingly, the 20X results are in better agreement with the stylus values provided by the manufacturer, which were obtained with a smaller, 0.25 μm radius tip. This is particularly evident for the 503 and 504 specimens. This phenomenon may relate to the sensitivity of CSI to optically unresolved surface roughness as described by Ettl et al. [8].

Figure 5 directly compares the stylus and optical profiles for the Rubert 528 specimen, and Table 4 summarizes the *Ra* values for all of the sinusoidal specimens. The 20X magnification has insufficient lateral resolution for the small-pitch 543 specimen and insufficient slope acceptance for the large-amplitude 525 specimen; while the 50X accommodates all eight specimens. The summary graph in Figure 6 plots the optical result as a function of the stylus measurement on a log-log scale, showing good agreement over a wide range of roughness amplitudes, for both the 20X and 50X magnifications.

CONCLUSIONS

As Paul Rubert has observed, "…many optical surface measuring instruments can be used in more than one mode of operation, each giving different results with certain surfaces, but with no obvious or a priori way for the operator to know which mode should be used in which case…" [9]. The evaluation here of a new coherence scanning interferometer shows progress towards overcoming this limitation. While the choice of objective does influence the result, the comparison of stylus and optical *Ra* measurements show good correlation across fourteen roughness specimens having highly varied surface texture using a single software mode.

We view the results as a significant step forward towards simplifying the desirable transition from traditional stylus instruments to high-speed, non-contact areal measurements for routine measurements of roughness and surface form in precision engineering.

REFERENCES

[1] de Groot P. Coherence scanning interferometry. Optical Measurement of Surface Topography, R. Leach, ed., 1st Edition. Springer Verlag Berlin, 2011: 187.

[2] Hillmann W. Surface profiles obtained by means of optical methods—are they true representations of the real surface. Ann. CIRP. 1990; 39: 581.

[3] Rhee H-G, Vorburger T V, Lee J W, Fu J. Discrepancies between roughness measurements obtained with phase-shifting and white-light interferometry. Appl. Opt. 2005; 44: 5919.

[4] Gao F, Leach R K, Petzing J, Coupland J M. Surface measurement errors using commercial scanning white light interferometers. Meas. Sci. Technol. 2008; 19: 015303.

[5] Powers B M, Cohen D K, O'Hearn J, Brown C A. Proc. Scale-based comparison of interferometric, confocal and stylus measurements and their ability to discriminate. ASPE Summer Topical Meeting on Precision Interferometry. 2010; 49: 86.

[6] Fujii A, Suzuki H, and Yanagi K. A study on response properties of surface texture measuring instruments in terms of surface wavelength. ASPE Summer Topical Meeting on Precision Interferometry. 2010; 49: 91.

[7] de Groot P, Colonna de Lega X, Kramer J, Turzhitsky M. Determination of fringe order in white light interference microscopy. Appl. Opt. 2002; 41: 4571.

[8] Ettl P, Schmidt B E, Schenk M, Laszlo I, Haeusler G. Roughness parameters and surface deformation measured by coherence radar. Proc. SPIE. 1998; 3407: 133.

[9] Rubert P. Report on the results of an intercomparison, using stylus-type and non-contacting surface measuring instruments. Proc. XII International Colloquium on Surfaces, Chemnitz. 2008; 135.