

# WIDE-FIELD INTERFERENCE MICROSCOPY FOR AREAL TOPOGRAPHY OF PRECISION ENGINEERED SURFACE

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## INTERFEROMETERS FOR SURFACE ANALYSIS

Interference microscopy is a well-established optical method for areal surface topography and characterization. Of the available techniques, the dominant method for general applications in precision engineering is coherence scanning interferometry or CSI, because of its ability to measure a wide variety of surface textures. CSI microscopy relies on interference fringe contrast, optionally combined with interference phase, to determine surface heights [1-3].

## MEASUREMENTS OVER A WIDE FIELD OF VIEW

Although the range of part sizes encompassed by “microscopy” is subject to interpretation, most often the field of view of microscopes is limited to low magnifications (e.g. 2X) and a 10 mm field of view. Many precision-engineered parts are much larger than this while still requiring the precision of interferometric metrology.

For fast and convenient measurements of surface form and waviness, there is an interest in extending the basic field of view beyond the usual limits of microscope objectives. Some solutions rely on a change in technology to grazing incidence [4], geometrically desensitized interferometry [5], or infrared interferometry [6]. These solutions trade some of the attractive performance benefits of CSI for a larger field of view, and also restrict functionality to form only, whereas detailed surface texture is accessible with CSI using higher magnifications.

There is therefore an interest in extending CSI to larger fields of view. In a previous ASPE paper, we discussed several of the obstacles to this extension, including the optical configuration, the ease of use and the acquisition and processing of interference signals that may be weak and difficult to interpret at the low numerical aperture (NA) values typical of low magnification objectives [7]. Here we report significant new progress in hardware and software for wide field of view areal surface topography metrology for precision engineering.

## NEW INTERFEROMETER DESIGN

Researchers and manufacturers have developed a number of configurations based on dedicated systems for wide field of view CSI systems. Most of these systems are of the Twyman-Green or Michelson geometry [6, 8] and are dedicated to low magnification measurements of form.

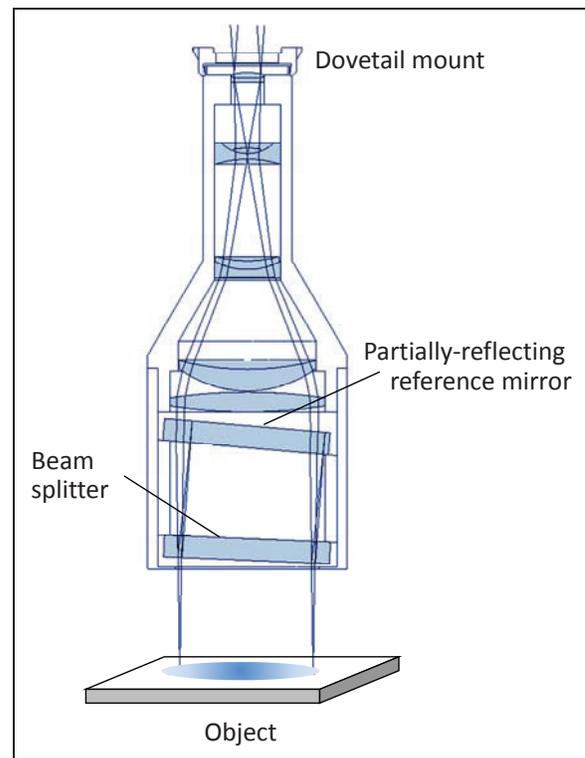


FIGURE 1. Wide-field of view 0.5x objective [9].

We propose an approach based on new, compact and removable low-magnification 0.5X, 1X and 1.4X objectives. This approach allows for form and fine-scale texture measurements up to 100X with a single, multi-purpose platform. FIGURE 1 illustrates the new design for wide-field objectives using a plate beamsplitter and partially-reflecting plate reference mirror [9, 10]. This interferometer realizes an equal-path geometry without the large cube beamsplitter

and reference arm of the more familiar Michelson configuration. The partially transparent surfaces obviate the need for the central obscuration of the Mirau type objective, while retaining the advantages afforded by placing all of the optical components along the same axis. The beam splitter and reference surfaces are oriented so as to reject unwanted reflections, resulting in high fringe contrast with minimal scattered light. Although the imaging is through tilted plates, the optical design achieves well-controlled lateral chromatic aberration and distortion  $< 0.1\%$  over the full field at 0.015 NA. The complete objective is significantly lighter and more compact than traditional wide field objectives.

A dovetail mount allows for installing the new objective interchangeably with objectives of other magnifications on a complete CSI system for both form and texture measurements (FIGURE 2). The 0.5X wide-field objective is matched to appropriate tube lenses and camera formats to maximize the field of view. A megapixel camera provides lateral sampling of  $32\mu\text{m}$  over a  $32 \times 32\text{mm}$  area.



**FIGURE 2.** Multi-functional interference microscope system with interchangeable objectives, here configured with the 0.5X objective.

#### DATA ACQUISITION AND PROCESSING

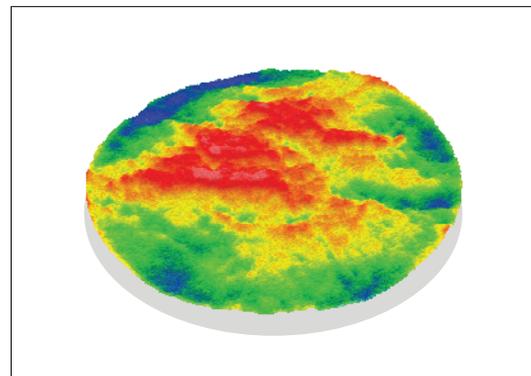
At low magnifications, the range of random surface heights present within the point spread function of the optical system can be comparable to the wavelength of light when measuring rough parts, resulting in lost fringe contrast [11]. This effect combines with the large variations in surface texture and effective reflectivity of common precision-engineered

parts to create significant challenges in signal detection.

Advances in data collection and processing since our last report have dramatically improved the data density on difficult surfaces [12-14]. The result has been an improvement in the number of useable height values when compared to conventional CSI in some cases from 30% to 99%. In many cases, the system reports full 3D topography maps for parts that are not discernable in the intensity images because the surface texture scatters most of the incident light.

The platform of FIGURE 2 offers user-selectable measurement modes, depending on the desired speed, surface height range and measurement precision. These modes include CSI with frequency-domain data processing [15], sub-Nyquist sampling for 3X higher data acquisition speed, and a mode that combines CSI with sinusoidal phase shifting interferometry (PSI) for low noise on smooth parts[14, 16].

Measurement precision depends on part texture, with best results for optically smooth surfaces. The surface topography repeatability [16] for a single image field on a polished reference artefact is 2 nm for individual CSI measurements and  $0.1\text{nm}/\sqrt{\text{Hz}}$  for continuous averaging using sinusoidal PSI [14]. This low noise level enables measurements of fine detail even on reference specimens such as the SiC flat, as shown in FIGURE 3.



**FIGURE 3.** 3D surface topography image of a 30-mm diameter SiC standard flatness artefact. The measured  $S_q$  is 3.9nm.

#### PRECISION MACHINING EXAMPLES

Principal uses of large field of view CSI include flatness and waviness measurement of automotive, aerospace, semiconductor and, most recently, 3D additive manufacturing

components [17]. CSI also provides the required data for relational metrology such as parallelism or height between separated surfaces. Here we provide examples of measurements on machined metal parts and assemblies.

A first example in FIGURE 4 is a CSI measurement of a fuel injector component having a ground, unpolished surface finish. The surface roughness is such that there are no continuous fringes visible in the instrument. The full 3D image of FIGURE 5 is readily acquired in a few seconds using CSI and the new objective.



FIGURE 4. Photograph of a 29-mm diameter machined fuel injector component.

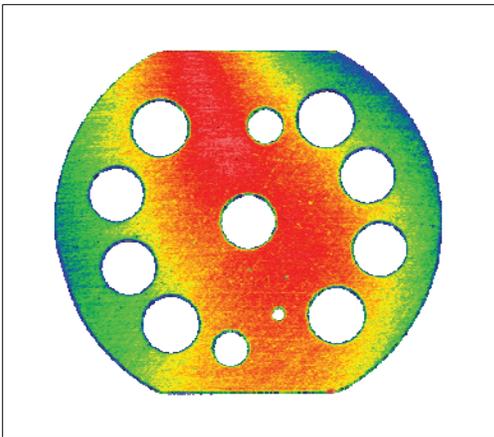


FIGURE 5. 3D CSI image of the part shown in the previous figure. Parameter results:  $S_q = 1.106\mu\text{m}$ ,  $S_z = 6.615\mu\text{m}$ .

For larger objects, an established technique is the automated stitching of multiple acquisitions with lateral displacements [11]. For stitching measurements, the benefits of the wide field

objective include significantly reduced data acquisition time and improved form metrology as a consequence of fewer stitched fields. As a first example, the pump part of FIGURE 6 is slightly too large for a single data acquisition, but is readily measured with four overlapping fields. The result in FIGURE 7 reveals the top surface form, and the recess of the impeller blades. As a final example, FIGURE 8 shows an assembly of gears in a housing with variable surface textures and reflectivities, successfully measured using stitching of 29 sub-Nyquist CSI image fields into the complete 3D topography shown in FIGURE 9.

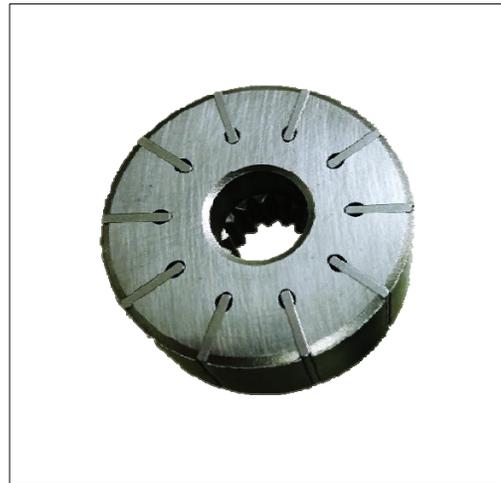


FIGURE 6. Photograph of a 36-mm diameter pump impeller component.

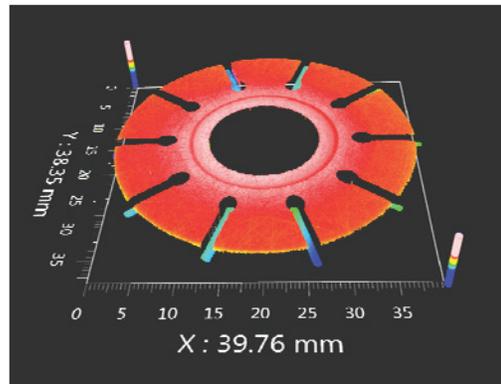


FIGURE 7. 3D CSI image of the part shown in the previous figure.



FIGURE 8. Photograph of a 150-mm diameter transmission pump assembly.



FIGURE 9. 3D image of the part shown in the previous figure.  $Sq = 26.7\mu m$ ,  $Sz = 119.8\mu m$ .

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