Step height measurements using a combination of a laser displacement gage and a broadband interferometric surface profiler

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ABSTRACT

We describe techniques for measuring step heights between separated, nominally plane-parallel surface regions of a precision-engineered part. Our technique combines a broadband, 10-micron wavelength scanning interferometric profiler with a HeNe laser displacement gage. The infrared wavelength accommodates machined metal parts having a surface roughness in excess of what would be possible with a visible-wavelength interferometer. The combination of broadband interferometry, which removes fringe order ambiguity, with a laser displacement gage makes it possible to determine the relative heights of surfaces separated by several mm with a 2-σ uncertainty of 0.3 micron. We present the instrument theory, experimental implementation and results of instrument testing.

Keywords: interferometry, laser gage, coherence scanning, step height, gage block

INTRODUCTION

An important area of development for interferometric surface profiling is relational measurements, meaning the profiling of a first surface with respect to a second surface that may be widely separated. Examples include parallelism of opposing surfaces, orthogonality of adjacent surfaces, and size of a plane-parallel part.[1] Figure 1 illustrates two examples for which the relational measurement includes a step height parameter to characterize the overall separation in height between e.g. surfaces A and B. An accurate measurement of the step height requires full profiles of both surfaces.

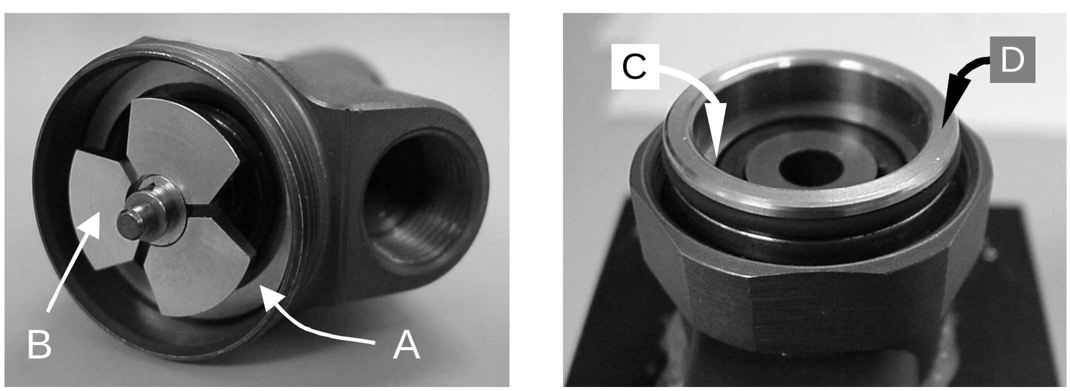

Figure 1: Example precision-engineered part requiring a step-height measurements between surfaces.

Part diameter=30 mm.

Presently, there are few options for optical measurement of step height such as those shown in Figure 1. There are two significant obstacles to overcome: (1) profiling technology for the non-optical surface textures, meaning ground, lapped or machined surfaces; and (2) method of representing two surface profiles in a common coordinate system so as to determine the relative orientation and spacing of the surfaces.

For microscopic samples, for example parts less than 5 mm in diameter, a viable profiling option is scanning white light interferometry or SWLI.[2] In SWLI, the broad spectral bandwidth facilitates determination of the interference fringe order, an essential task for relational measurements. Qualitatively, one can imagine scanning the optical path difference in an interferometer that includes the sample part in the measurement leg, and selecting for phase analysis the interference fringe having the highest contrast. For larger parts and rough surfaces, however, the speckle noise generated when visible white light reflects from rough surfaces complicates part alignment, light level adjustment and measurement repeatability to the point where it becomes attractive to consider alternatives. We have found it effective to move to infrared wavelengths—the 8 to 12 μm region—to overcome these speckle effects and improve measurement reliability. Our IR Scanning technique also relies on a broad spectral bandwidth to remove fringe order uncertainty, using a glowing filament as the light source.[3]

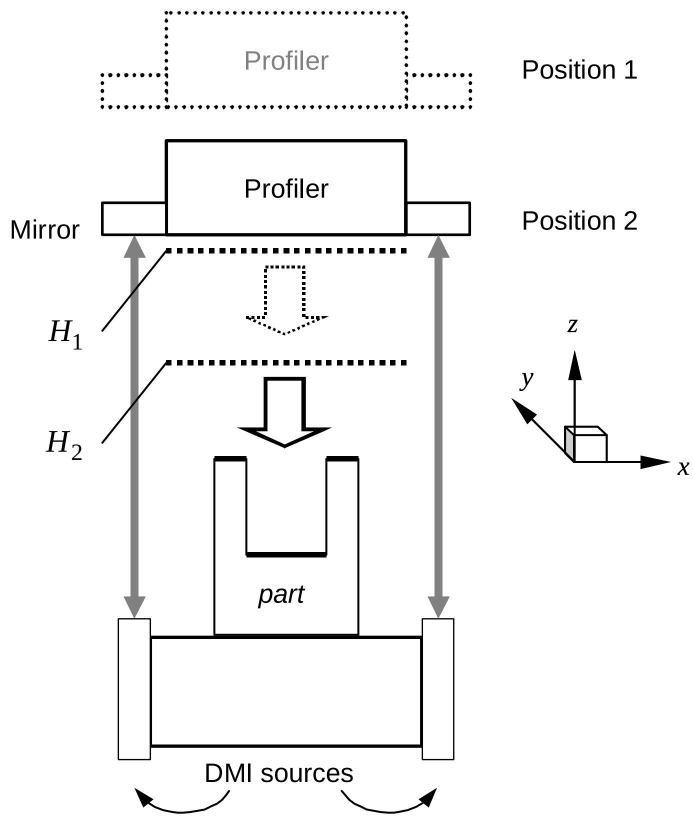

Figure 2: Basic measurement geometry for step height measurements using IR coherence scanning profilometry combined with displacement measuring interferometry.

Techniques such as SWLI and IR Scanning have a large but limited range of acceptance for surface profiles—on the order of 100 microns—because of difficulties in the smoothness and straightness of scan motions over longer travel ranges. Consequently, for parts such as those shown in Figure 1, one is compelled to measure the two surfaces of interest using two separate scans. The key metrology step then consists in relating the two scan geometries to a common coordinate system. Figure 2 shows in a highly simplified form a strategy for relating the results of the two scans by means of displacement measuring interferometry or DMI. Two DMI beams or axes of measurement, as shown in the figure, provide information on the changing separation and orientation of the profiler and the support surface of the sample part. The measurement sequence consist therefore of measuring a first profile in position 1 of the upper surface of the part with respect to a datum H_1, followed by a displacement of the profiler to position 2, at which a second profiler scan generates data for the lower surface of the part with respect to a datum H_2. The DMI pair records the difference in separation and orientation of the two profiler datums H_1, H_2.

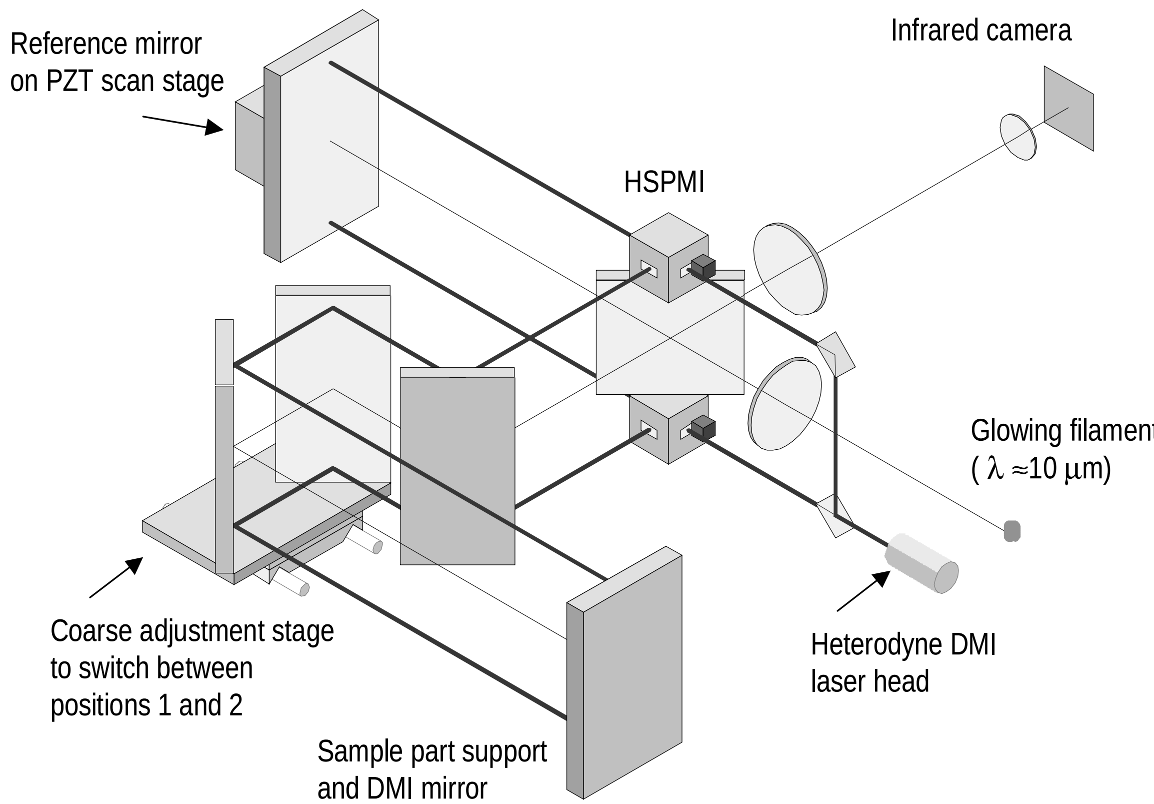

Figure 3: Example geometry for a step-height measurement system based on infrared scanning interferometry combined with a two-axis laser displacement gage and two high-stability plane mirror interferometers (HSPMI).

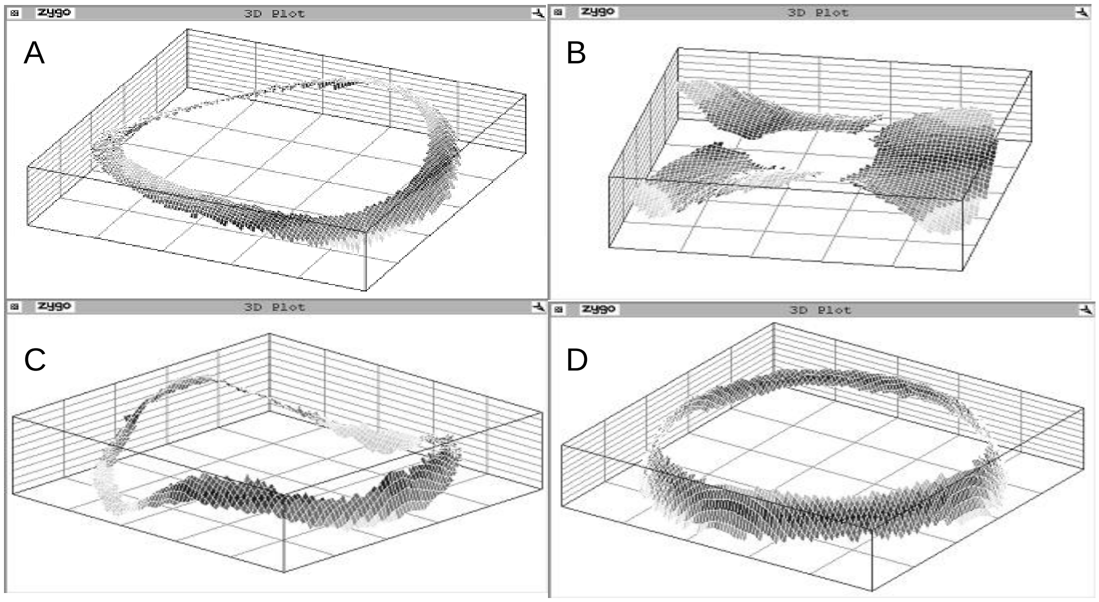

Figure 4: Height profiles of the four surfaces identified in Figure 1.

We have constructed an instrument following the basic design concepts of Figure 3 and have measured a wide variety of precision engineered parts for step height that were previously considered unsuitable for optical metrology. Figure 4 illustrates the IR Scanning profiler data corresponding to the surfaces shown in Figure 1. The surface roughness for these samples varies from 1 μm to 14 μm Rz, the latter being a very challenging level of roughness for interferometric metrology. Experimental work demonstrates that these IR Scanning profiles, combined with DMI data, provide field-averaged step-height measurements with a 2-σ expanded uncertainty of 0.3 μm, including part removal and replacement, the effects of surface roughness, calibration and combined instrument uncertainties. The same system simultaneously provides parallelism and flatness data to similar levels of uncertainty.

REFERENCES

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