overcoming the fringe jitters

High-speed testing can provide the necessary isolation for accurate nanometer-scale measurements.

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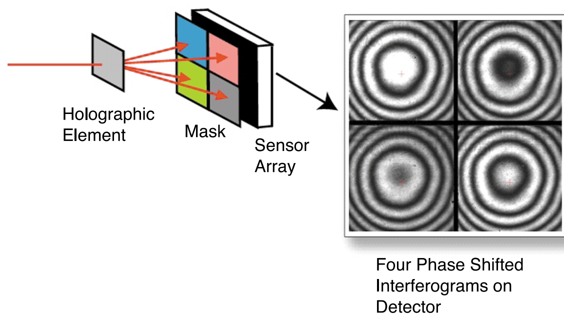
Precision manufacturing requires robust metrology. Optical manufacturers rely on the resolution, accuracy, and precision of commercial phase-shifting interferometers, which can operate with nanometer resolution and precision—assuming a stable test environment.

Unfortunately, the typical laboratory or production environment is not stable on the nanometer scale. At frequencies from 1 to 100 Hz, relative rigid body motions between the interferometer and an optic under test can easily be hundreds of nanometers if not tens of micrometers. Architectural structures vibrate and resonate as a result of the movement of people, elevators, reciprocating pumps, fluid flow, heating and air conditioning, noise, and external traffic. Further, air movement and thermal sources can trigger index-of-refraction variations.

Although commercial vibration isolation tables can provide a stable environment for many applications, they are not without pitfalls and limitations. For example, they are not amenable to testing large light-weighted or thin composite mirror structures, or meter-scale and larger optical elements with long radii of curvature. Such problems require another approach.



This dynamic interferometer with a holographic optical element produces four phase-shifted interferograms imaged on a single detector.

speed it up

The solution can be found by thinking about the amplitude-frequency vibration spectrum of the perturbing environment. Data acquisition using commercial temporal phase-shifting interferometer systems typically requires from four to 13 frames of video-rate data. This data rate necessitates that the amplitude and frequency of mechanical perturbations to the test setup be less than $\lambda/100$ at 1 Hz. Isolation tables can provide this level of performance. For cases in which vibration isolation is not practical, however, a solution is to dramatically shorten the data acquisition time. In the absence of resonances, the amplitude of the vibration spectrum monotonically decreases with increasing frequency. Decreasing the data-acquisition time can effectively freeze the fringe image during the measurement.

A number of interferometric methods have been used to achieve rapid data acquisition: high-speed static fringe, single-frame spatial carrier, and dynamic interferometry. The most basic is high-speed static interferogram capture. Despite the low spatial resolution, low accuracy, and the need for time-consuming data post-processing, this method continues to be used.

The single-frame phase measurement technique requires the introduction of significant tilt (greater than 150 fringes) between the test and reference arms of the interferometer. This approach requires well-corrected internal interferometer optics to minimize off-axis aberrations. The spatial carrier method treats the surface under test as a mosaic of very small windows with tilted flat wavefronts. The tilt fringes introduce systematic phase shifts between adjacent pixels. This method permits accurate data acquisition at camera frame rates, but with reduced spatial sampling and local slope limitations on the optical surface.

Dynamic interferometry incorporates a polarization Twyman-Green configuration with a 2-D grating at the exit pupil and a phase mask in the imaging path (see figure). The grating/mask combination produces four phase-shifted interferograms imaged in parallel on a single high-resolution detector. A single frame of intensity data therefore provides the four frames necessary to compute phase. In essence, the phase shifts occur spatially, not temporally.

Commercially available mega-pixel cameras can acquire high spatial sampling data arrays in as little as 30 µs. With sufficient laser power, it is possible to shutter the source for data rates 100 times faster. Data can be acquired to allow the generation of phase movies to study the dynamic motion of surfaces. The presence of air turbulence over long path lengths can still degrade a single measurement, but each interferogram reflects the same perturbation, and averaging can quickly reduce this error contribution. The dynamic interferometry method preserves measurement accuracy and spatial sampling of the wavefront while overcoming the degradation of environmental perturbations. **oe**

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