Dynamic Interferometry® provides early process feedback for faster, more aggressive polishing of large mirrors.

High-Throughput Measurement Speeds Production of Large Optics

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Introduction

Dynamic Laser Interferometry is an established technique for measuring optical grade surfaces in the presence of vibration and air turbulence. Unlike traditional laser interferometry, Dynamic Interferometry does not require expensive vibration isolation systems, extensive mechanical coupling between the instrument and test optic, or air flow abatement. The method provides a cost-effective means of assessing the quality of large optics, often one meter diameter or larger, even when the optic must be placed many meters from the interferometer to enable measurement.

While Dynamic Interferometry is useful for verifying an optic's final shape it is also capable of providing accurate data to guide polishing. This data, gathered early and throughout the process, allows more aggressive polishing that greatly shortens manufacturing time.

This article discusses the challenges of measuring large optics during polishing, how Dynamic Interferometry has been applied to overcome these challenges, and the benefits to optics manufacturers of employing the technique.

Challenges of Measuring Large Optics During Polishing

Measuring a large optic in a shop-floor environment presents multiple difficulties. Figure 1 shows a typical setup for measuring a large, aspheric optic. The size and curvature of the optic dictate that it must be located many meters from the measurement system.

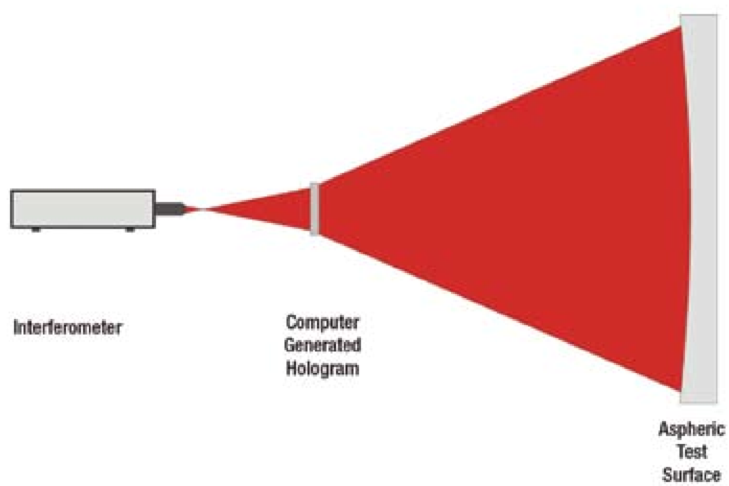

Figure 1. Setup for measuring a large, aspheric optic.

This measurement poses difficult challenges for a temporal phase-shifting laser interferometer. Because a temporal phase-shifting system acquires data over a sequence of frames, its acquisition time is long—on the order of hundreds of milliseconds. Over the duration of the measurement, vibration and air flow would hinder, or more likely prevent, the acquisition of data. Vibration and turbulence would therefore need to be tightly controlled, which would mean coupling the instrument and optic through a single, vibration-isolated pad or stand, as well as carefully controlling air flow and temperature differentials. All of these measures would be expensive and would require significant alterations to a facility.

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The polishing process presents additional metrology challenges. Maximizing polishing throughput requires that the measurement process, including setup, alignment, data acquisition and analysis, be as fast as possible.

Thirdly, the surface roughness of an optic in the initial stages of polishing will exceed the measurement capability of most systems. Early in the process a large optic may have local surface deviations exceeding 40 microns. Such high local slopes are difficult for measurement systems to resolve. Qualitative methods provide some degree of process feedback, but the sooner a manufacturer can acquire quantitative data the faster and more accurate the polishing process can be. This early, quantitative feedback becomes even more critical for guiding automated polishing equipment.

Dynamic Interferometry Provides Polishing Feedback

In an instantaneous interferometric measurement all data is acquired simultaneously in a single frame, rather than sequentially across several frames. Acquisition time is only tens of microseconds, making the systems virtually insensitive to vibration. This insensitivity enables measurements when the test optic is located far from the instrument, even on a separate concrete pad. The effects of air turbulence can be easily removed from the data by averaging multiple measurements. Where a traditional interferometric measurement will be compromised by even minor air perturbations, an instantaneous measuring system actually performs better with a degree of fast-moving turbulence.

Several methods have been developed and commercialized for instantaneous phase data acquisition:

1. In the software-based spatial carrier method, high frequency tilt fringes are applied by tilting the reference surface relative to the test beam. The tilt fringes are then filtered out by the software algorithms that determine the phase and thus the surface heights.
2. In an off-axis Fizeau interferometer the test and reference beams pass through separate internal apertures which select the correct polarization states from the test and reference optics. The apertures also filter the tilt fringes and high spatial frequencies.
3. In a stitching interferometer, multiple data sets covering small portions of an optic are stitched together to provide a full measurement of the total surface.
4. In Dynamic Interferometry, polarization elements separate the test beam into four or more phases. All phase data is recorded simultaneously and analyzed to determine surface heights.

Each of these instantaneous methods may be capable of providing final quality control for large optics. However, most methods are not capable of providing feedback for the early stages of polishing. In a spatial carrier system the filtering required to remove the tilt fringes limits the spatial resolution and thus the range of slopes that can be resolved. High spatial frequencies are also filtered out by the apertures used in Method 2, again resulting in a reduced range of measurable slopes. A stitching interferometer retains high spatial frequencies, but great care must be taken to preserve low frequency data during the stitching process. Only Dynamic Interferometry has proven capable of measuring the full range of spatial frequencies present during polishing, across a large aperture, in the environments typical of a polishing process.

Case Study: Measuring a Large Aspheric Optic

Optical Surface Technologies of Albuquerque, NM designs, manufactures and coats custom optical components for specialized applications. In a current project the company is polishing six 1.4-meter diameter, parabolic mirrors. Stringent requirements dictate that the final surface quality will need to be 29nm RMS, so both large-scale shape and small-scale structure are important to monitor during polishing.

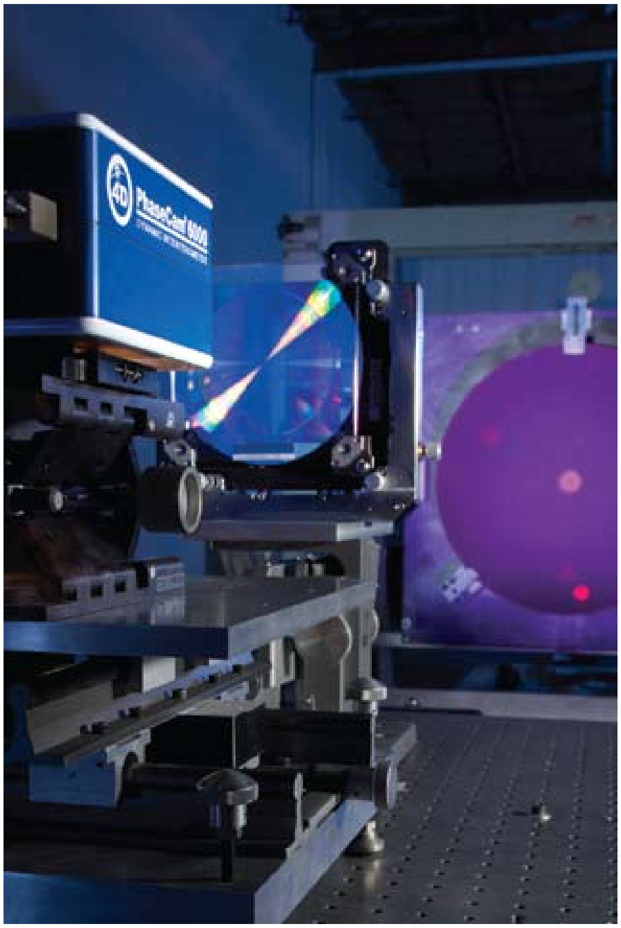

FIGURE 2: Measurement setup for 1.4-meter parabolic optic, with the interferometer in the foreground, CGH and optic. Courtesy Optical Surface Technologies.

The size and shape of the optic dictate that it be located approximately 3 meters from the interferometer, resulting in the optic being located on a separate concrete slab. As the facility is situated near the intersection of two interstate highways, the measurement environment is also subject to significant background noise and vibration.

The manual polishing process consists of two phases: first, polishing the blank to a sphere and then polishing in the final shape. Rod Schmell, Optical Fabrication Manager at Optical Surface Technologies, noted that acquiring reliable measurement data early in the process is critical for producing the mirrors on a tight schedule. “If we can see surface deviations when the surface quality is at 33 waves RMS, then we can polish more aggressively and converge on the final shape faster,” he said.

For these measurements the company first employed an off-axis Fizeau interferometer, but because of the extreme local slopes they were unable to obtain reliable data. A dynamic interferometer was then used and was found to measure accurately (Figure 3) even at the rough blank stage. “We had data we could believe, and we tracked it throughout the polishing run,” said Schmell. “The data gave us confidence to work the part more quickly,” he added.

Also important was the dynamic interferometer’s ease of use for in-process measurement. Setting up the off-axis Fizeau system required alignment of two spots per optical element; determining which spot was correct required significant time and effort. The Twyman-Green type dynamic interferometer did not have this limitation. This advantage, along with minimal system drift and other benefits, enabled the polishing team to reduce the entire measurement cycle to only 15 minutes.

FIGURE 3: Dynamic interferometric measurement of a large aspheric surface during the early stages of polishing.

Conclusion

Dynamic Interferometry provides quantitative feedback for manual and automatic polishing operations, from rough polishing to final shaping. Despite the difficult measurement environments of most polishing operations, dynamic interferometry enables aggressive polishing with less downtime, so manufacturers can deliver high-quality, finished optics in less time.